CHAD IS OUR MOST IMPORTANT PRODUCT

An Engineer's Memoir of Teletype Corporation

Jim Haynes

The author operating W5YM in 1957

I. How it all started

When I was growing up in a small town I thought it was an awfully boring place. Now I realize that I had some opportunities that probably would not have been available in a larger city. For one thing, it was possible for a kid to hang out at the newspaper office, telephone office, telegraph office, or radio station and watch a Teletype machine in operation. Things were slow enough that the people who worked there usually had time to answer questions. When I wanted to understand how a Teletype machine worked the wire chief at the telephone office let me borrow the "green book"[1]. After reading all about selector cams and swords and code bars and pull bars I could drop in to the Western Union office where the manager, a friend of the family, let me play with a little-used printer and see in action all the parts I had read about.

Another advantage to living out in the sticks was that television arrived very late. This allowed a pretty good news stand to remain in full operation through most of my teen years. Jack's News Stand carried several magazines of interest: *Radio-Electronics*, *Radio & Television News*, and the amateur radio magazines *QST* and *CQ*. Hugo Gernsback's *Radio-Electronics* ran a series of articles by Edmund C. Berkeley about digital computers, which gave me an early introduction to binary arithmetic, Boolean algebra, and logic circuits. Jack's also subscribed for a while to a Western Union service that brought baseball scores on a ticker. This was one of the old-fashioned tickers with the mechanism under a glass bell jar. They made a lot of noise even when not printing anything, as the principle involved sending polarity reversals at about 20Hz that operated a ratchet to drive the print wheel. These tickers had long been retired from stock market service as too slow; but they were still fast enough to keep ahead of the baseball games. Western Union hated to throw anything away.

In those days (circa 1953) Wayne Green had an occasional column in *CQ* magazine on the subject of amateur radioteletype; and I happened to see one of them[2]. Until then I had never imagined that a teleprinter was something an individual could possess and use to communicate via amateur radio. Although I didn't have an amateur license at the time I had an uncle who was a ham. He kept me supplied with old copies of *The Radio Amateur's Handbook* which I devoured. Ham radio looked like a lot of fun; getting a license was something I always intended to do

[1] Principles of Electricity Applied to Telephone and Telegraph Work, A.T.&T. Long Lines, 1938 edition

[2] June, 1953, page 35

someday.[3]

Now I started combing the classified ads in *QST* hoping to find a machine for sale at a price I could afford. Soon I saw a 21-A printer advertised for something like $25 by Paul Lemon, W6DOU, of Hayward, California. In due time the machine arrived on our front porch along with a letter from Paul explaining what had to be done to get it working. This was about the time that hams were starting to get pretty good machines, especially Model 26s, and were getting rid of the stuff they had previously struggled with, Model 12s and 21-As.

The 21-A was a small parallel-input tape strip printer used by Western Union to receive from their archaic[4] time-division multiplex. The mechanism was powered by a big solenoid. Paul's letter explained that a ham, Cecil Crafts W6ZBV of Southern California, had designed an electronic receiving distributor for the 21-A. The design had been published in *RTTY,* a little magazine put out by Merrill Swan, W6AEE, in Pasadena, CA. Wayne Green's article in *CQ* had also mentioned Merrill's magazine. I wrote to Merrill explaining the situation and asking for a copy of the issue containing the electronic distributor article. I also subscribed to *RTTY.* Merrill sent me the issue containing the distributor article; and we began a friendship carried on by mail for years until we were able to meet face to face. I can't think of anyone who did more than Merrill to befriend and help anyone who wanted to get into radioteletype. All the while he held a full time job, and with the help of his wife Margaret put out the magazine every month. A number of regional amateur RTTY groups published newsletters and bulletins; the Southern California one under Merrill's editorship rose above mere regional interest and became the *de facto* national RTTY publication.

The Western Union friend supplied a roll of printer tape, so while I was waiting to get started on the distributor I could exercise the machine by hand, first tripping the code magnets and then slamming down the solenoid. There was also a receiving converter to be built - a circuit to convert frequency-shift-keyed audio from the radio receiver into signals to operate the printer. I found the W2PAT design which had been published in *QST* . The original version of this design required a polar relay, which a telephone company friend supplied. The electronic receiving distributor was quite an ambitious project, involving something like 20 vacuum tubes. The principle was a trigger circuit to detect the start pulse, fol-

[3] The Western Union friend I'm sure would gladly have taught me Morse code, except that his was American Morse, not the International Morse used in radio. He sometimes remarked that he didn't understand how anybody could copy that gibberish on the radio, not having a sounder to click it out.

[4] Pre-electronic, using motor-driven faceplate distributors.

lowed by a string of one-shots. A pulse at the end of each one-shot time was gated with the incoming signal to a tube that drove the corresponding code magnet. The last one-shot drove a tube that controlled the print solenoid. One of my telephone company friends did the maintenance on the mobile telephones of the day, so he saved for me some tubes that were not really good enough to put back into the radio sets but were still usable. I wish I could say the thing worked as soon as I had it built; but in fact I never got it to print anything but gibberish. Over a period of several years I played with it on and off, but never got anywhere. Part of the problem was lack of any kind of equipment to adjust the one-shots. The designer's instructions were to transmit single characters while adjusting them: first Es, then As, and so on so that each bit was successively brought into time. I didn't have a keyboard to generate those characters. Another problem was an error in the published schematic, which did not come to my attention for several years. Nor did I have access to a modern oscilloscope, which would have allowed me to see where the pulses were falling. I'm sure it didn't help that lots of the parts I used had been salvaged from old radio sets, and thus were of poor quality. My knowledge of pulse and digital circuits was very limited too. If I had been a lot smarter I could have devised an unsymmetrical multivibrator that would generate a single character repeatedly, such as LTRS or V with the proper timing to make a start pulse and repeat at the character rate.

I must also give a lot of credit for my early engineering education to Paul Klipsch, the engineer and loudspeaker inventor. He had come to town with an Army ordnance proving ground at the start of World War II. He was in charge of instrumentation there and worked on his loudspeaker design in his spare time. After the war he decided to stay there and start a business manufacturing the loudspeakers. He had quite a reputation in the town, both as a brilliant engineer and as an eccentric. Mrs. Klipsch was my junior high school English teacher. A future engineer could hardly have a better mentor than Major Klipsch. The loudspeaker business in those days was often slow; Paul would have me sit down beside him while he took out some "talking paper" and started making sketches and explaining things. At one point he learned to fly and bought a used Stinson airplane. I wangled a job with him one winter washing the airplane and patching holes in the fabric. From time to time he would try to get the airplane to perform better than it was designed to do. In one experiment he cut wedges of styrofoam and we taped them on to the wing struts and took the airplane up to see if it would fly any faster. (It didn't; the masking tape we used to hold the styrofoam on probably added more drag than the wider struts eliminated.) In time Paul not only gave me a job but allowed me the run of his shop for building my own projects and doing my own experiments. It was there that I built the electronic distributor and attempted to get it working.

In 1955 I graduated from high school and that fall started at the University of Arkansas, studying electrical engineering. Under the influence of Paul Klipsch I immediately sought out the faculty member who was in charge of the student chapter of the Institute of Radio Engineers and joined. It was just something that I had absorbed from him that if you are an engineer you should participate in the appropriate professional society. Dr. Walt Cannon was also the trustee of the university amateur radio club station and the overseer of the electronics laboratory. A large corner of the electronics laboratory was devoted to the amateur radio club station, which included a huge and most impressive transmitter, an ex-military BC-325 with knobs and meters all over it. There was also a Morse code practice machine, which added to my determination to get my amateur radio license and get the club station W5YM on the air with radioteletype.

I never took a course under Walt Cannon; but I had a job under his supervision working in the electronics laboratory. He was always one of my favorite professors. He didn't have much of a reputation as a classroom teacher; but his office was a feast. His office door was open all the time, unless he was in class. There was a constant stream of faculty and students dropping in, participating in the running conversation, and leaving to be replaced by others. Anyone willing to sit for a while in Walt's office was sure to learn some interesting things about serious electronics.

On one occasion he took a group of us to an I.R.E. conference in Oklahoma City. That was quite an experience for a small-town kid. I was the kind of person the exhibitors love to hate, a mere student gathering up every brochure and catalog in sight. In later months and years I went through that material over and over; one of my later bosses said I was a "walking catalog" of the industry. That seemingly wasted literature probably generated a lot of sales. While on the Oklahoma City trip we visited the F.A.A. Aeronautical Center. One of the things I remember seeing there was a Model 15 running experimentally at 100 WPM. Wisely, they abandoned that particular effort and bought Model 28s.[5] We also visited a large telephone office,and a power generating plant, and International Crystal Mfg. Co., a second-floor business much beloved by radio amateurs.

The next development was a decision by Teletype Corp. to build a manu-

[5] I have since learned from an article in *Bell Laboratories Record* that Model 14 and 15 equipment was operated at 100 WPM during World War II as a war emergency measure. The need to move lots of traffic justified the considerably increased maintenance effort.

facturing plant in Little Rock. In connection with this company officials visited the University and its engineering school, and left a catalog of Teletype products, inviting us to select some to be given to the school.[6] They suggested a Model 19 would be most appropriate. Prof. Cannon invited me to go through the catalog with him and decide what to ask for. We decided to push our luck and ask for a Model 28, because we wanted to get into electronic computers and the higher speed of the Model 28 would be advantageous for that purpose. We also asked for punched tape equipment, again with the idea of preparing input for a computer. Teletype agreed to our requests. I was away for the summer when the equipment arrived. It consisted of a 28KSR, a 14 typing reperforator, and a table with an XD and a perforator of the kind used in a Model 19 (DPE). There was also a loop power supply to make it all go. The stock name plates on the equipment had been modified, no doubt at some expense, so that instead of “Chicago USA” they said “Chicago-Little Rock USA”.

The catalog, as I recall these many years later, contained Model 28 KSR and RO, Model 14 typing and nontyping reperforators and XD, Model 19, possibly Model 15, the lightweight printer Model 31, and various tables with perforator and XD combinations. (I’m not sure about Model 15, because Model 28 had replaced it functionally, yet Model 19 was still available and used Model 15 components. The Model 28 ASR set had not yet been produced, which is why the Model 19 was still in the catalog.)

It wasn’t long after I got back to school in the fall that I had W5YM on the air with radioteletype. At last I could communicate by radio with some of those people I had been reading about in the pages of *RTTY.* One of these was Bob Weitbrecht, W6NRM/W9TCJ, who was then at Yerkes Observatory in Wisconsin. Bob was one of the great technical contributors to amateur RTTY, and one who traveled many miles to promote the mode and to help others get started. In those days it was popular to have round table discussions among several stations. Almost every night I would get into a round table while doing my studying. They would ring the printer bell when it was time for me to transmit; and then I could quickly scan the copy and make my comments and turn the session over to the next station and get back to my homework. There was also a lot of clear-text non-amateur radioteletype on the air in those days. We regularly copied press, government and commercial traffic.

[6] In another article I suggested that it was the sight of my forlorn 21-A printer in a corner of the lab that prompted the offer of new Teletype equipment. I don’t know whether this actually had anything to do with it, or whether they even saw the 21-A.

On October 4, 1957 the Russians put up Sputnik, the first artificial satellite of Earth. The next morning, Saturday, Walt Cannon picked me up in his car and we went to a lumber yard for some 2x4s to use as antenna masts. We put up a pair of dipole antennas, arranged as an interferometer.[7] We would tape record the satellite signal and give the tapes to a professor in Physics, where they had a frequency counter. (Electrical Engineering was too poor to have one.) He would study the Doppler shift in the frequency of the satellite signal. During this time the press traffic on the air was voluminous. We would copy the latest bulletins on our Teletype machine and hang the copy on the lab door for all to read. One of the news stories read,"Teams of scientists are busy calculating the orbit of the new satellite. People who do this kind of work are called celestial mechanics."

Sometime during those school years I acquired a Western Union 401 printer from a New York ham. This was a compact receive-only tape strip printer. The character selection mechanism was very similar to that of the Teletype stock ticker (circa 1930), modified to receive 5-unit code. Teletype used a very similar mechanism to make the Model 26 page printer.

Our contact at Teletype was Dennis Bobka in Sales. I would write to him from time to time asking for parts, or suggesting ways to improve the equipment. I remember being fascinated with the selective calling Model 28 at the local F.A.A. flight service station and installing that set of parts in our Model 28. I assume it was because of my contacts with Dennis that Teletype offered me a summer job in 1958. I had not planned to get a job that summer because ROTC summer camp would take half the summer. Teletype was willing to take me for the six weeks that were left after camp, so I accepted. When I told Merrill Swan about the summer job he gave me a list of friends to contact at Teletype, one of them being Bob Reek. He and Bob had shared a room at a summer course on transistors a year or two earlier. As it turned out I was to work under Bob that summer, and also the following summer.

[7]Connecting two closely-spaced dipole antennas together gives a radiation pattern with lots of peaks and nulls, making it possible to determine the angle of arrival of signals.

II. In the good ole summer time

Someone at Teletype suggested I stay at the Lawson YMCA in Chicago. That proved to be a fine suggestion. It was in the same block as a subway station where I could take a train to work every morning. For variety I could walk a few blocks west and take an El train. The stop nearest Teletype, at Fullerton Ave., was served by both subway and El trains from the Loop. Lawson had an amateur radio club, so I made some friends right away. One of these was Jim Dolvin, an FCC field engineer who resided there; and there were at any time usually a few men from Western Electric attending W.E. training at a center in the city. Later there was Bob Weesner, who worked for W.E. Hawthorne Works in cable measurements.

I showed up bright and early at 1400 Wrightwood and told the guard why I was there. Pretty soon Alma Cade[8] came to escort me to the new work place, Bob Reek's department. There I met Frank Biggam, Roy Ogasawara, another engineer whose name I don't remember, draftsman Gerry Marbach, and technician Marvin Gaudette. I'm probably going to mix up some of the things that happened that summer with things that happened the next summer, when I was again employed at Teletype, as I was not graduating until January 1960. Bob's department was devoted to time division multiplex. Teletype's first multiplex product, the AN/FGC-5, was there in two tall cabinets - this was a vacuum tube (and thyratron) multiplex system. Development was being completed on AN/UGC-1, a compact solid state four-channel mux (compatible with the FCG-5); and work was under way on the AN/UGC-3 sixteen-channel mux. The sixteen-channel mux may have been the first Teletype product to use the standard-size printed circuit cards. These were quite an empowering concept, allowing us to design at the level of logical blocks rather than of circuit design and individual parts.

It was an interesting time. Transistors were still too slow to be of much use in the computer business; but they were plenty fast enough for the kinds of things Teletype did. I got a quick introduction to transistor logic circuits. I came to the conclusion that transistors made excellent switches and lousy linear amplifiers, an observation that set the whole direction of my life's work.

All the multiplex systems used ring counters in the start-stop and multiplex distributors. The ring counter circuit used in the transistor mux employed point-contact transistors, taking advantage of their unique properties. These allowed use of a single transistor per counter stage. The disadvantages were that these devices were available only from Western Electric, and were expensive, delicate,

[8] later, Jordan

unreliable, and quite non-uniform. Frank Biggam had worked out a circuit using two junction transistors per stage. My first assignment was to build and test that circuit. It worked fine; and Gerry Marbach was able to get all the parts onto the same size etched circuit board that was used for the point-contact counters, so we had a direct replacement for the earlier circuit. I don't know what happened after that, because I remember the next summer the 16-channel multiplex was in production with point-contact ring counters.[9] I don't believe there was any further use of ring counters after the multiplex projects, because someone had discovered how to build distributors using shift registers.

I could imagine basing some products on the code converters of the mux system. Two of them back to back would be a regenerative repeater. It could also serve as a speed converter (lower to higher speed only). I guess there was no corporate interest in these applications because the mux was designed for the military; it would have been too costly to use parts of it for civilian applications. Now that I think of it there are other things we could have done with our mux technology had we wanted to develop other products. I was dimly aware at the time that Western Union had something called *Varioplex*, which served a number of customers over a smaller number of trunks. At the time we didn't have the term for it; now we would call it virtual circuits.[10] The concept reappeared in "statistical" multiplexers in computer installations in the 1970s, and then reached full fruit with the development of packet switching. It did occur to me at the time that we could do a limited sort of switching if we had something like a patch board to allow us to direct any channel in the mux to any code converter. Years later, in the era of computer time sharing, there was a market for port selectors, which allowed terminal users to select a computer to be connected to. These were essentially data PBXs using time-division multiplexing.

There was an ancient Hammarlund Super-Pro radio receiver in the lab (the same model in use at W5YM) and a Navy-furnished FSK converter. We sometimes used these to pick up multiplex signals off the air and print them. Thus I learned the meaning of some of those signals I had previously heard on the radio but could not get to print on an ordinary printer.

The military liked polar circuits. Kleinschmidt had a polar selector, which

[9] Bob Reek believes all the production mux systems used the bipolar transistor counters; so the 16-channel mux I saw at Fullerton with point-contact counters may have been a special case. We know that Western Electric was eager to cease production of the 2N110 point-contact transistors.

[10] One could argue that Varioplex was the ancestor of packet switching, as it allocated a channel among users by allowing them to send at most a fixed-size packet at a time. I doubt that the inventors of packet switching were even aware of Varioplex.

pleased the military as it made it unnecessary to use a polar relay to receive polar signals. Bob Reek handed me a memo from E. J. Cook in Sales suggesting how Teletype could meet the competition. His idea was to put a diode in series with the selector magnet so that mark polarity would pass through the magnet. Then he had a dummy selector magnet in series with a diode to pass current in the opposite direction. Hence the circuit impedance would be about the same for current in either direction, and the neutral selector would operate. Bob asked me to write a report on this, which I did, saying it probably wasn't a very good idea. Many years later I realized that my analysis was as bad as the original idea, as I had failed to consider what happened to the energy stored in the dummy selector magnet when line current reversed polarity. Still it probably wasn't a very good idea, as the advantage of a true polar selector would be lost when using what was actually a neutral selector.

Bob seemed to have a drawer full of little short-term projects like this. I don't remember if it was my first or second summer there that he suggested I think about a solid state replacement for the polar relay. He had some company's solid state relay that had been taken apart and sketched out. It was fairly awful. In those days the only high voltage transistor we could get was the 2N398; and they were not very reliable. Handling 120 volts and 60 ma. looked like it would require putting transistors in series to handle the voltage, and hence complicated driving circuits. It seemed to me that transistors were a lot better suited to low voltage, high current applications. Delco was producing power transistors for use as audio power amplifiers in their auto radios. I figured the best way to replace the polar relay would be to rewind the selector coils with 1/10 the usual number of turns, use heavier gauge wire, and run them at 12 volts and 600 ma. I got a set of coils made up, put them on a 28 typing unit, and tested it with a transistor driver. All went well until the transistor burned up - I was at the time too naive to realize the need to reverse bias the base when the transistor was turned off. After I left someone else[11] took this idea and ran with it, resulting in the low voltage selector magnet driver used in the Model 32, 33 and 35 equipment. I never did understand why the circuit got so much more complicated than I had envisioned it; but then I never claimed to be much of a circuit designer. Perhaps it had to do with operation at 110 baud, where my testing of the simple circuit had been limited to 75 baud.

I had some other ideas in connection with the low voltage selector magnet

[11]Chuck Winston received several patents relating to constant-current selector magnet drivers; but the circuit embodied in the 182630 circuit card and used in the 32/33/35 models of equipment was patented by R. J. Miller, patent No. 3,293,505, Dec. 20, 1966.

driver that did not come to fruition at the time. Traditionally telegraph circuits were operated on a closed-circuit current loop basis. This makes switching awkward because it is necessary to keep the circuit closed at all times, and to break into it to insert a piece of apparatus. Consider, for example, the simple matter of a printer station with a typing reperforator that is sometimes to copy what the printer prints and sometimes not. A way to do this with current loop operation is to have separate line relays for the printer and reperforator, and to short the marking contacts of the reperforator line relay when it is not to copy. Without the separate line relays it is necessary to have a complicated switch that keeps the reperforator marking in a local loop when it is not copying, and that breaks the printer loop and inserts the reperforator into it when reperforation is desired. It seemed to me that with a transistor-controlled selector magnet we should think about operating the internals of a teletypewriter set with, say, six-volt signals, and have an interface to a current loop at the point where we connected to a transmission line. We could do our switching inside a set with our solid state logic circuits, make a low-voltage solid state regenerative repeater (Harold Cook had designed one), do speed conversion electronically, etc. For the reperforator example a simple single-pole switch would suffice to connect its selector magnet driver input to the printer voltage signal. For some reason this idea didn't take hold, so that even when Teletype started using low-voltage selector magnet drivers they were operated in current loops. The early dial TWX modems all used current loop interfaces for the TTY signals, albeit low voltage ones. I guess I didn't present the low-voltage set internals ideas forcefully enough to get the attention of people who had the power to take the company in that direction.[12]

The second summer (1959) I was assigned to repair and complete the instruction manual for the 16-channel multiplex. The engineer who had done most of the work on the system had started on the manual and then left the company and gone to work for Hughes in Southern California. I wound up starting almost completely over, as the text the engineer had left behind was fairly incomprehensible. He was a very capable engineer; he just couldn't write. As evidence of this, there was a postcard he sent to the department some time after assuming his new job. It read, "Hi, I'm having an enlightening affair at Hughes." And there was the specification stating, "...these parts will not be supplied by the supplier."

I went to work, sometimes hand writing, sometimes talking into a tape recorder, sending everything down to a typist in K. Jean Phelps' department. Most of the

[12] Bob Reek had already thought of the low-voltage selector idea; he recently showed me a page from his notebook.

diagrams were logic diagrams. The text covered the system at the logic level. Then another section of the book devoted a page to each circuit card, showing the parts layout, the circuit schematic, and an explanation of how the circuit worked.

There was another set of equipment, the AN/UGA-1, associated with the AN/UGC-3. Although it was not classified equipment I was never told what it did, not having a need to know. Bob Reek recently explained that the Navy had a high-speed crypto machine that could encrypt the 16-channel mux signal; then they translated the encrypted signal back down to 16 separate synchronous low speed channels that were transmitted over a frequency-division link. Even the four-channel mux had a connector that provided access to some internal signals for some unstated purpose. The Navy wanted a sine wave locked to a square wave we were providing. I proposed using a low-pass filter to remove the harmonics from the square wave. I had a filter company bring in a breadboard filter, which seemed to me to work fine. For some reason Bob didn't think that was the right approach to the problem. (He tells me now that he was taken aback by the size and weight of the filter; but ultimately this method was used in the product. I am sure the production filter was smaller and lighter than the filter company's thrown-together prototype.)

There was no time-division multiplex work at Teletype after the UGC-3. The military standardized on independent sideband radio and frequency division multiplexing for telegraph signals. One reason might be just the flexibility of being able to use a circuit interchangeably as a voice circuit or as a 16-channel telegraph circuit. Another reason might be the effects of multipath propagation in HF radio, which really tears up short signal pulses.

The big project in Bob's department that summer, and in fact in several departments, was the F.A.A. Automatic Data Interchange System, ADIS. This was to be a major improvement in the way aviation weather data was collected and disseminated. It was of some urgency because jet airliners were just coming into operation, making it necessary to get weather data transmitted farther and faster than before. The architecture (not a term we would have used at the time) of the system was a set of 100 wpm area circuits connected through reperforator-transmitter sets to a high speed nationwide backbone circuit, initially operating at 600 wpm. The stations on the area circuits were polled for traffic by a unit being made by some other contractor (Stelma?). All traffic collected on the area circuits was retransmitted on the backbone at switching centers. High speed punches (BRPE) copied selected traffic from the backbone for retransmission on area circuits other than those from which it originated. For example, New York weather would be collected on the area circuit serving New York, and then retransmitted on the high speed backbone. The switching center for the area circuit serving Los Angeles would copy New York weather from the backbone and retransmit it on the area circuit, making it available in Los Angeles.

Selection of traffic to be copied from the backbone to area circuits (and to certain other circuits served by the switching centers) involved a magnetic core-rope decoder developed by Sylvan Silberg. Each weather message began with a location identifier of two, three, or four characters, according to the station where it originated. Traffic coming off the high speed circuit passed through a shift register made of flipflops. Outputs of the flipflops were amplified and sent through a bundle of wires which were threaded through toroidal ferrite cores in various combinations. The current in any one wire was enough to inhibit a core from switching when a sampling pulse was sent through another wire that threaded all the cores. The pattern of threading the cores was such that for any valid location identifier in the shift register one core in the rope would switch while all others were inhibited. Outputs from the cores went to the rows of big plugboards.[13] Columns of the plugboards represented BRPE punches on R-T stands which fed traffic into the area circuits and other 100 wpm circuits. A plug containing a diode could be inserted at any intersection of a plugboard to cause a particular BRPE to copy a message from the originator associated with that row of the plugboard. There were several hundred location identifiers in use; so the core ropes were an elegant way to decode all of them at once. The only trouble would be if a location identifier had to be added or changed; the wires in the bundle would have to be traced and restrung correctly to detect the new identifier.

Physically ADIS was built in tall cabinets of the kind that had been used for the AN/FGC-5 and for some earlier FAA station equipment. The electronics were built of standard size circuit cards, like those of the AN/UGC-3, mounted in modules about the size of shoe boxes.[14] These shoe box modules became a standard packaging scheme for Teletype electronic and some electromechanical assemblies. A cabinet could hold two reperforator- transmitter stands side by side, plus all the electronics and relays needed to operate them. The R-T stands were also called High-to-Low (H/L) and Low-to-High (L/H) converters.

One topic I found particularly interesting was the message protocol, the set of character combinations used to signal the start of a message, the end of a message,

[13] Silberg patent No. 3,147,339, Sept. 1, 1964

[14] In the mux system the cards were mounted in pull-out drawers fitted into a standard military rack cabinet. The card sockets were wired with formed cables of stranded wire and soldered connections. In the shoe box modules solid conductor wire and wire wrapping were used to interconnect the card sockets.

the end of a collection of messages, etc. ADIS was a Baudot system, so there were no single control characters set aside for these purposes. To design a protocol one had to find combinations of Baudot characters that would not occur by chance in message text and would not destroy the appearance of the printed copy. ADIS used combinations such as CR-CR-LTRS and FIGS-CR-LTRS. I was getting interested in message switching systems and the different choices of protocols they employed. Teletype's involvement in switching systems was restricted both by the 1956 AT&T consent decree and by the position of Teletype in the Bell System. Any system likely to be offered to Bell System customers would be designed by Bell Labs, who regarded Teletype as merely a component supplier. Teletype was allowed to design systems that appeared to have no future with Bell System customers; and because of the consent decree the government was the only customer whose systems business Teletype was allowed to pursue.

I was faced with a two-week involuntary layoff during the annual plant vacation shutdown. Somehow I was able to display my prowess as a perforator operator (developed during many hours on the air operating radioteletype at W5YM); and the people involved decided it might be useful to have me around to prepare tapes for ADIS testing, which was urgent enough to continue during the shutdown. So I got to work continuously through the summer. As the plant cafeteria was closed I would go out to lunch, often to a little burger joint on the corner of Southport and something. The owner was Italian. He had a juke box that seemed to contain nothing but Mario Lanza records.

One of the problems we discovered when we started putting ADIS all together was the result of mixing relay and transistor circuits. Phil Barry had designed an LBXD control using relays. It turned out to be an awful source of noise spikes that found their way into the transistor logic and caused mischief. We wound up putting diodes across just about every relay winding in the system before we got it to behave as intended.

In 1959, unlike 1958, there was a rather large group of summer students at Teletype. One I remember from ADIS was John Eisenbies. He later went to work for IBM in North Carolina and wrote a nice article about data communications protocols that was published in IBM Systems Journal.[15] Toward the end of the summer there was a meeting held for all the summer students. Jim Wack told us about the difference between engineering school and the real world. In engineering school we were given lots of problems to solve. In the real world we would spend more of our time figuring out what the problems are. The customer will

[15] IBM Systems Journal vol. 6 issue 4, 1967, p. 267.

come to you and say, “This is my problem,” and when you get to working with it you will discover that the real problem is something altogether different.

It was that summer that Chuck Winston demonstrated ink jet printing. He had a single nozzle printing “TELETYPE” on a fast-moving strip of paper tape. There was also off in one corner of a lab a high speed drum printer. I think it was a Signal Corps prototype AN/FGC-36, and as I recall there were a lot of thyratrons in the electronics[16]. My understanding is that Teletype had built the machine for the Signal Corps but was not interested in pursuing the drum printer technology. Kleinschmidt went ahead to produce a product using that technology for the military and later in a civilian version. Then there was a military drum printer supposedly designed by Kleinschmidt but manufactured by another company.

I’m pretty sure it was that same summer that the tuned-reed tape punch was being worked on by Dr. Carlson. This led to the DRPE punch a few years later.[17] The concept was that a steel reed would be held up by an electromagnet. When current was cut off the reed would swing down, driving a punch pin, and then swing back up, at which time the electromagnet would grab it again. A by-product was a lot of audible noise. Being in the lab with the punch (and at the time there was just a single reed in operation) was like being in the same room with a power lawnmower or a chainsaw.

Now and then some of us would go to 4100 Fullerton Ave. where the time-division multiplex equipment was being manufactured. I always liked to visit Fullerton. The Sales organization was in that building; so I would sometimes run into Dennis Bobka or another friend. The cafeteria at Fullerton was a particularly cheerful place. And Fullerton was where the interesting odd products were made. Someone told me about the Model 15s made for an Arabic country. The type basket traveled from right to left; this was accomplished rather simply by running the carriage return strap around a pulley, and a few things like that. An Illinois Bell switching system called Bellfast was in production there. I saw a two-headed XD; and someone explained that these were used for two applications. One was a low-budget time-division multiplex in which one message was sent in the first half of each bit time and the second message was sent in the latter half. Receivers for this were simply ordinary printers with the range finders adjusted to sample at the proper early or late places. The second application was a version of the Vernam cipher, in which a one-time key tape ran in one of the XD heads and the message

[16] Byrnes patent No. 2,927,960, March 8, 1960

[17] Zenner patent 3,056,546 issued Oct. 2, 1962. As the patent for the entire machine was filed for in May of 1959 I assume Dr. Carlson was working on some specific problem for which a one-reed punch was sufficient. It may be that I am mistaken and saw this work in 1958.

tape in the other. Relays formed the exclusive-OR of the key and message bits, and that was transmitted. The receiving end used the same hardware and an identical copy of the key tape, so that a second exclusive-OR restored the clear text. And I remember seeing the unclassified portion of some Navy cryptographic equipment that used relays to mix key and message bits.

A favorite Saturday morning activity was to walk from the Lawson Y to posh Michigan Ave., then across the river to the Loop, mingle with the crowds, and take the El or subway back. On one of these walks I passed a building where there was an announcement that a new Univac solid state computer would be demonstrated one night soon. I went to the demo and took it all in. What they meant by "solid state" turned out not to be transistors, but rather tape-wound magnetic cores. This was one of those nobody-but-Univac-would-ever-do-it-this-way products. What was not revealed was that in the heart of the machine was a multi-kilowatt vacuum tube clock generator running at 2 MHz. Still, I suppose it was cooler and more reliable than the other contemporary computers employing hundreds or thousands of tubes. Teletype had one of these, an IBM 650, which sat in a glassed-in air-conditioned area at Wrightwood. Both the Univac Solid State and the IBM 650 computers used magnetic drums as main memory and thus were awfully slow (but still faster than a roomful of people with desk calculators).

One of the delights of downtown was Kroch's and Brentano's book store. I picked up a book there on information theory and discovered Huffman coding. I kept trying to think of a way to apply it to Teletype systems; but there just wasn't any practical way to implement it at that time. Another book acquisition was Shannon's Mathematical Theory of Communication. This was my introduction to the idea that band-limited signals could be sampled at merely twice the bandwidth and reconstituted exactly from the samples. I gave some thought to this in connection with our time-division multiplexing. The theory seemed to say that if we sampled teleprinter signals a little faster than the bit rate we could dispense with the serial-to-parallel-to-serial conversion. There didn't seem to be any opportunity to develop the idea at that time.

Another favorite Saturday activity was to take the bus or subway/elevated to the South Michigan Avenue radio surplus joints. The only trouble with this pastime was the temptation to buy stuff; and the trouble with buying stuff was that I would have to get it back to Arkansas at the end of the summer.

The best weekend activity was a visit to Ray Morrison. Ray was an engineer for Illinois Bell, a ham (W9GRW), and a friend of Merrill Swan. He also had a side business refurbishing junk Teletype equipment and selling it. His basement and garage had to be seen to be believed. A visit to Ray started with a ride on the subway/elevated all the way to the end of the line at Howard St. Ray would meet me there with his car and take me to his home in Skokie.[18] We would visit for a few hours while he showed me whatever he was working on. One of his projects was connected with Telephone Pioneers and involved printing Braille with a Teletype printer. On one occasion Ray had a bunch of old Model 14 tape strip printers that had apparently been used by the Weather Bureau, as they had the weather type arrangement. I believe he was going to buy parts from Teletype to convert these into typing reperforators, which some foreign government wanted to buy.

On another occasion Ray handed me a big cardboard box and started putting parts into it. Before I realized what was happening he had given me a do-it-yourself kit to build a Model 15 out of parts. He drove me all the way back to the Lawson Y, as it would have been too hard to handle the box on the train. The radio club at Lawson had two rooms: one kept clean for radio operating and one that was more of a work shop. I spread out all the parts on a table in the shop room and went to work with Gunk and rust remover obtained from a nearby hardware store. Bob Reek got me a set of Model 15 manuals from the Sales organization. He may have also liberated a paper crank from the stash of parts that was kept in the test lab. Ray said a paper crank was the one thing he couldn't give me, as they were always missing from the machines he got as junk. It took most of my spare time for the rest of the summer to do it; but by the time I was ready to leave Chicago I had the machine working. Just down the hall from the radio rooms there was a piano practice room. Someone – I never saw him – practiced incessantly, playing nothing but "Home on the Range" over and over and invariably messing up the rhythm at the very end. So I was forced to listen to the nightly recital as I worked. The reward for an evening's work was always a dash to the snack bar to get a chocolate sundae just before they closed.

Ray also gave me a rack cabinet which he was going to throw away, having removed the contents for his purposes. I kept it in the radio room and gradually filled it with acquisitions from the surplus stores and ultimately with the Model 15. I prevailed upon one of the friends in the radio club to wait a couple of weeks after I had left and then have a truck freight company pick it up and ship it to me in Arkansas.

Ray liked to tell about how he wanted a DXD. Teletype gave him a delivery

[18]This was several years before the beginning of service on the Skokie Swift extension of the elevated. The tracks later used for the Skokie Swift were at that time used by the old North Shore Line railroad.

date far into the future, so he bought all the parts and put the machine together himself.

At the time I was a member of Civil Air Patrol. The Illinois Wing headquarters was in a downtown office building. I would go there one night a week after work and help out with the office work. It was a nice opportunity to do something useful and to be among a group of friendly people.

William Shirer in his autobiography tells how he went to Paris in the 1920s and got a job with the Paris edition of the Chicago Tribune. He recounts his delight at living in Paris with all its culture, the contrast with his boring home town of Cedar Rapids, Iowa. I'm sure I was just as delighted to be living in Chicago as he was to be in Paris, experiencing life in a big city and doing interesting work with leading-edge technology among a great group of people. (I enjoy hearing Gershwin's *An American in Paris*. It works just as well for an Arkansan in Chicago.)

III. From the halls of ivy to the wild blue yonder

Back at the University I had spent a certain amount of time studying teletypewriter switching systems. Western Union sent me some literature on one of their systems; and the telephone company got me some material about the 81-systems. We had tons of parts lying around the lab, so I had started building some things...a circuit to route messages to machines in a certain priority order, and a circuit to control the XD, skipping over the blank or LTRS feedout between messages and pausing for a go-ahead at the start of a message. I wrote a very hand-waving paper about a planned switching system and presented it at an IEEE student paper competition. In retrospect I should have taken all this stuff out when I graduated, as nobody who came along later could make any sense of it and the Teletype equipment fell into disuse.

Sometime while I was in school we had a visit from the Telecruiser. I presume Fayetteville just happened to be along the route it was going anyway and the crew decided to stop for a day's rest. It was nice to see the latest products nicely displayed, and to show friends the kinds of things that were being done at the company where I spent my summers.

For some reason I didn't do a senior project related to Teletype; instead I wanted to build a radar. We had a lot of pieces of World War II surplus stuff lying around, so many of the necessary parts were there. The power lab supplied a pole transformer that run backwards would produce about 15kV. I never got very much of the machine built. Then Walt Cannon got the Army to donate a couple of surplus SCR-584 radars. One of these was straight out of WW-II; the other had been extensively modified by some aerospace company. I got the older radar to work from time to time. We were afraid to leave it turned on for more than a few minutes at a time because we had no FCC license to put a radar on the air. The only thing we ever detected with it was a water tank on a nearby mountain. I guess there was some educational value in going through this truck trailer full of electronics and more or less learning what it all did. It certainly was fun.

There was a psychological benefit to working at Teletype (or, I suppose, at any real-world industry). Our lab at the university was piled high with leftovers from World War II. Even though this stuff was fifteen years old it was something of a damper on our creativity. The war had been a time of such rapid technological progress that it was as if we were living in the shadow of a past golden age. One could spend all his time just trying to understand what a previous generation of engineers had already accomplished, rather than learning to invent new things. The work we were doing at Teletype involved entirely recent technology: transistors, logic design, printed circuits, magnetic cores, and using modern oscilloscopes. It invited one to put the past behind and get to work on the future.

I graduated in January, 1960, and having gone through ROTC entered the Air Force a couple of months later. Those were the days when men who didn't take ROTC were liable to be drafted immediately upon graduation. I was assigned to Edwards AFB in the Mojave Desert of California. I had very mixed feelings. On the one hand it would be nice to see California, and to be fairly near my friend Merrill Swan and all the other activity there. On the other hand Edwards was an airplane test base and had nothing to do with the communication systems engineering that I really wanted to do. What I didn't know until I got there was that Edwards also had a facility for testing rocket engines, and that was to be my assigned work for the next year and a half. Well, maybe that would be fun. Some of us[19] had played with rockets in college, and now I could get into the real thing.

It turned out to be a stereotypical government project. There were twice as many people on the job as were needed. The electrical engineering was entirely trivial. In any case it wasn't needed until the mechanical work on the test stand had been done, and that kept falling behind schedule. Eventually the project got so far behind schedule that even the people running it admitted it should be cancelled. (We would have been testing a rocket engine that was no longer in production.) During the eighteen months that I was on this project I had many stimulating discussions with my office-mate; we found a lot of interesting reports and other matter to read; and I got a lot of ham radio equipment designed. I continued thinking about switching systems and designed and built some equipment to be used in one. Because they were cheap, and also because I was being whimsical, most of these designs used vacuum tubes. I started out with a timing generator that produced pulses for each of the elements of start-stop characters. This was based on a transmitting distributor designed by Bob Weitbrecht and used a matrix of neon lamps for decoding the states of a binary counter. Another design using neon lamps as switching devices generated all 32 characters of the Baudot code by gating the timing pulses appropriately. That is, there were 32 outputs, each providing one character repeated continuously. Then I built a sequence generator, using a thyratron ring counter design taken from the Teletype AN/FGC-5 multiplex, which transmitted a sequence of characters by selecting them from the character generator. And I built radioteletype converters, a controller for an FRXD, and

[19]Led by the late Mike Dertouzos, who went on to head the Laboratory for Computer Science at MIT.

various other equipment. I worked out a hubbing scheme as I had envisioned for the low voltage selector magnet driver project, but using power vacuum tubes and ordinary 60ma selectors. It worked very satisfactorily. I wrote up a description of it for Merrill's *RTTY* magazine. I don't know if somebody at Teletype saw that article or if it was a case of independent invention; but several years later at Teletype I saw a factory test fixture that used vacuum tubes to drive a lot of selector magnets from a single test message source.

My office mate, Wes Sherman, had a brother-in-law living in Los Angeles who had a one-man business designing and building electronic equipment for the movie industry. One of the items he was called upon to design was a film footage counter. Wes helped with the design. I suggested using something like the bipolar ring counter we had worked on at Teletype. He implemented it with power transistors so that it was able to drive indicator lamps directly.

Wes was married and thus had a house on base. When I first got to Edwards I had a lot of my equipment shipped out there, but had very limited space in the bachelor officer quarters. Wes invited me to set up my RTTY station in his garage. We operated it from there for a year or so until I was given additional space in the BOQ and was able to move the station there. This station consisted of the Model 15 that I had built in Chicago, plus an old military surplus transmitter and receiver.

After the rocket engine project was cancelled Wes was able to get an assignment to an instrumentation group on the main base, where the focus was airplane testing. I obtained an assignment to a communications-electronics staff office, which promised a variety of work. One man in the office worked full time on a sort of inventory of electronic equipment on the base. Another man was the frequency coordinator. At a place like Edwards there is a constant need to assign frequencies for radio communication and telemetry to various test programs, and to try to insure that the various operations do not interfere with one another. There is also an attempt to insure that new electronic systems arriving at the facility do not cause interference to ongoing work and are not disabled by interference from existing systems. One of our activities was to draw up specifications and begin procurement of a mobile van that could be used to track down sources of radio interference. This work entailed some interesting trips to Atlantic and Pacific Missile Ranges, to learn how they did interference problem solving, and additional trips to Florida where the contractor selected to build the equipment was located.

Some organization on the base had a requirement for HF communication with aircraft from a vehicle on the ground. They were using a World War II-era Navy TCS radio set with many shortcomings. Almost invariably they would lose communication with the aircraft and have to curtail or repeat some tests, at great expense. About this time the Collins KWM-2 single sideband amateur transceiver came on the market, including a configuration that fit into a Samsonite suitcase. My boss saw the ads for this and figured it could meet the needs of the test program and would be a great improvement over the TCS. The colonels upstairs who had to approve the purchase were not sure. This was ham radio equipment he was proposing, not a military-spec set; and the name Collins didn't mean much to them. (Among radio amateurs Collins had a top-notch reputation; Collins was also a leading supplier of avionics and military radios. Art Collins and Air Force Chief of Staff General Curtis LeMay were personal friends, as well. It was probably their friendship that was instrumental in converting the Air Force from AM to SSB for long-range voice communication.)

I went to the Base Exchange one morning and bought a copy of *CQ* magazine and brought it back to my desk. On the front cover of that particular issue was a photo of Gen. LeMay (who was a ham), in uniform, and some youngster using some radio set of the day. My boss saw that picture and asked to borrow the magazine for a few minutes. He took it upstairs and showed it to the colonels, saying, "Now this is the equipment I am proposing we buy to meet our needs." It didn't matter that the radio in the picture was not a Collins at all; they didn't know one radio from another. He came back a few minutes later with all the signatures needed to buy the KWM-2. When the equipment came in I got to take it home for a couple of days to try it out on the ham bands. Later this same kind of equipment was used in large quantities in Vietnam. It was available in quantity and it met the needs of certain units in the field.

It was during this time that I first got up close to a digital computer.[20] Edwards had an IBM 704, a vacuum tube machine which by then was fairly obsolete. The computer was kept busy with scheduled work during the day and evening. On graveyard shift engineers with problems to solve were allowed to use it hands-on. One of my friends from the rocket site was an aeronautical engineer who was doing some work in FORTRAN, so I asked him if I could tag along the next time he was going to do a computer session. He told me to dress warmly, because they kept the temperature in the computer room around 60 degrees to improve machine reliability. We got to the machine room just before midnight and met several other engineers who had signed up to use the machine that night. The idea was that one

[20]I had taken the one computer course offered in Electrical Engineering at the U of A; but we didn't have a computer there at the time. During my last semester there the Agriculture school acquired a Bendix G-15 computer, which was to be used to breed bulls. I never got to see it.

would run his program, and while he was figuring out how to correct the inevitable errors another would be using the machine.

The lone computer operator turned the machine over to us and retired to a warm office. The process was to read some cards that started the FORTRAN compiler, then to read a deck of cards containing the program. A horrid old 100 lines-per-minute printer would produce a listing; and if the program wasn't too bad the machine would eventually punch out a deck of cards containing the executable program. Then you put those cards in the reader and started the machine again. All this was accompanied by much spinning of reels of tape. One of the engineers was quite knowledgeable about the computer. He would sit at the console and now and then stop the machine and examine something in the big panel of lights; or maybe he would manipulate the switches to alter the value of a variable or part of the program. The rest had to make do with what the printouts told them. After a few hours of this, during which I closely examined a lot of the hardware to see how it was built, one of the engineers concluded that the machine was malfunctioning. He called in the operator, who ran a test program that confirmed something was wrong. The operator said he would notify the IBM field engineer when he came in in the morning, and we all went home to bed. "Some nights you get your work done, some you don't," was what they told me.

A little later the 704 was replaced by a more modern IBM 7090 transistorized computer. I mentioned earlier that in those days transistors were fast enough for use in Teletype equipment but were too slow for computers. In the 7090 IBM had got around the problem by using some special kind of "drift" transistors and emitter-coupled logic. The transistors were fast (well, 60 MHz was fast in those days) only if the collector-to-base voltage was about 6 volts. To get around the voltage offset from input to output there were circuits with NPN transistors and one set of logic voltage levels, and others with PNP transistors and a different set of levels. Logic designers had to alternate stages of circuits of the two kinds. It took quite some time for IBM to get the 7090 all installed and working, perhaps a couple of months, so I got a good look at the innards of the machine before it was closed up and the machine room was closed to visitors. It was built out of the IBM SMS circuit cards, slightly larger than those used by Teletype and having thinner lines and more edge connector fingers. These cards were assembled by automatic machinery. The backpanels were all wire-wrapped automatically by Gardner-Denver machines. I later learned of something really weird about the 7090. It used an eight-phase clock. A cable carrying the clock signals between two cabinets had as much time delay as one phase of the clock. The wire labelled "phase 1" at the sending end of the cable was labelled "phase 2" at the other end because by the time the phase 1 pulse got through the cable the time was phase 2 at the sending end. This could have driven someone batty, a cable with different names at the ends of a piece of wire.

For some reason the 7090 systems employed the same lousy card machines and line printers that were supplied with the 704. These were never used in normal operation. Instead every 7090 site had at least one 1401, a small computer which was used as a card-to-tape and tape-to-printer converter. Card decks were fed into the 1401 and written to tape; then the tape was manually moved to the 7090. A small monitor program in the 7090 read the tape and ran the jobs one after another. Output went to another tape drive. When the output tape filled up it would be carried to the 1401 for printing. The 1401 had really nice peripherals, especially the 1403 printer. This ran at 600 lines per minute and used a print chain rather than a drum. It was very impressive to watch; and it made an impressive amount of noise. It was really a new generation of printing technology. In drum printers the same character is present at all print hammer positions at a given time. In chain printers there is a different character at each hammer position. Hence it was necessary to scan all the characters in the chain and compare with all the characters to be printed before each hammer strike time. For the end users the big improvements were in print quality and in the possibility of having changeable print chains with different fonts. With drum printers any timing errors in the print hammers cause characters to be printed above and below the print line, which is highly noticeable. With chain printers the timing errors affect the horizontal spacing between characters and are much less noticeable. Chain printer technology was later adopted by General Electric for the Terminet terminals and by Teletype for the Model 40[21].

The 1401 was a fairly slow small computer, built with complementary saturated transistor logic. Texas Instruments had developed the 2N130x family of transistors, pretty slow by later standards but faster than what had been normal[22]. The circuits used NPN and PNP transistors in alternating logic stages, as in the 7090, but for a different reason. The transistors were operated in saturated mode, so the two different voltage levels were just a matter of providing turnoff bias to the transistor bases. The NPN stages might have emitters at ground and collector pullup resistors going to +12 volts. The PNP stages then would have emitters at +6 volts and collector resistors going to -6 volts. This seems to save some parts

[21] Brodrueck patent No. 3,845,710, Nov. 5, 1974

[22] In fact, IBM had developed automatic machinery for making the transistors. Then IBM management decided they did not want to tie up capital in component manufacturing and sold the whole works to T.I.

count because the collector pullup resistor of one stage is also the base pulldown resistor for the following stage. Each transistor stage was a voltage inverter but was not considered to invert the signal logically. A logic inverter was an emitter follower, so it didn't invert voltage.

For their transistor machines IBM had developed an elaborate design automation software system. Engineers drew logic diagrams on special sheets, which were then keypunched by clerks. The software worked out the wiring of the machine. It had a data base of all the different circuit cards so it could check for things like overloaded signals and incompatible connections. When all the errors were got out it would generate a card deck of instructions for a Gardner-Denver wiring machine and print logic diagrams on a line printer using a special font that included vertical and horizontal lines and corners of boxes. Aside from the saving in drafting labor this practically guaranteed that the logic diagram agreed with the way the machine was actually wired. Logic signals could have fairly long names, enough to make the logic diagrams largely self-explanatory and reduce the amount of written explanation of how the logic worked. It was quite an impressive accomplishment, particularly in an era when a large computer had 4096 36-bit words of memory.

My engineer friends complained about the IBM 7090 operation; they were no longer allowed to come in late at night and have hands-on access to the machine. They had to leave a card deck in the evening and pick up the results the next morning. The slightest mistake in the cards meant waiting another day for results. One group of engineers on the base had their own IBM 1620 computer. This was a small slow machine. On this particular one the only printer was an IBM electric typewriter, so they had to learn to write programs that solved their problems without producing much output. Edwards AFB at that time also had a large punched card accounting operation using electromechanical card machinery.

Another facility on the base was Central Timing. There were several racks full of vacuum tube logic modules which encoded the time of day into a high speed bit stream. The signal was broadcast all over the base by a powerful VHF transmitter. Every measurement site on the range – radars, phototheodolites, and telemetry recievers – had a receiver for the time signal and recorded the bit stream along with measurement data. Thus it was possible to time-correlate measurements taken at many different places. Mostly measurements were recorded as analog signals on one-inch magnetic tape. At the conclusion of a test the data had to be digitized and run through the computer, first to convert raw numbers into known physical quantities, and then to time-correlate the measurements and do things like triangulation from tracking sites to find the actual path of an aircraft. One of the engineers in the instrumentation group undertook a very large project, designing and building a special-purpose digital system to pre-process the data tapes and greatly reduce the amount of work the computer had to do. The design made extensive use of ready-made digital logic modules. In this case they were solid state. At the time there was quite a market for digital logic modules with several companies being in the business of producing them. Digital Equipment Corp. got started by manufacturing such modules.[23]

A colleague and I were sent to work on the radio system at Central Timing. One problem was simply a need to change the radio frequency of the system. A more serious problem was that the contractor who had originally designed the system had given no thought to bandwidth. The transmitter was modulated with fast-rise-time pulses, so that the signal occupied many megahertz of bandwidth. This had been tolerable at one time; but now there was more demand for frequency space and the timing system was seen as very wasteful. Also the contractor who built the transmitters was apparently not well versed in VHF RF design; they were full of parasitic oscillations and tended to transmit on frequencies of their own choosing. The system was completely duplicated for availability, so we were able to tear one transmitter apart while hoping that the other one didn't break. As it was, we had to do our work late at night so as not to get in the way of the people who used the equipment in the daytime. Maybe that is why I don't remember how our project turned out.

At one point the base was told to appoint a cryptographic officer; and I was chosen. After some time the necessary security clearance came through. I never had occasion to use it beyond having a sergeant point to the cryptographic machine and tell me that was what it was. Another of my occasional duties was MARS (Military Affiliate Radio System) director. I collected some equipment to get the MARS radio station on radioteletype, but never managed to get it in operation on that mode. Maybe it was because I already had a RTTY station in my quarters, so there was no particular urgency to get another station going when nobody else wanted to use it.

I was also put in charge of AUTODIN installation. This didn't involve much real work, as all the planning was being done elsewhere. I just had to know what was going on and answer people's questions as they arose.

AUTODIN was one of those military projects that started out small and simple

[23]Only after achieving a profitable business producing modules were the company founders allowed by their financiers to build computers. At the time I first wrote this Digital Equipment was a major computer manufacturer. The company did not succeed in transitioning to personal computers, was acquired by Compaq, and then Compaq was acquired by Hewlett-Packard.

and grew like a tornado until it had everything swirling around inside and had the power to do a lot of damage. It started out as a simple upgrade to COMLOGNET (COMbat LOGistics NETwork). The original COMLOGNET consisted of IBM card transceiver machines located in base supply offices, all connected by private lines to a hub at Tinker AFB, Oklahoma. Message switching was the equivalent of torn tape, card decks being carried from receiving machines to transmitting machines at Tinker. I suppose the Army and Navy at that time had their own similar arrangements for processing supplies information. Private lines were necessary because in those days there were no modems available from the telephone companies and connecting foreign equipment to the switched network was strictly prohibited. The IBM card transceivers came in two versions. One used telegraph signaling and telegraph private lines. The other had built-in modems to work over voice-grade lines. I believe there were several modem frequencies so that several transceiver pairs could share a voice-grade line.

In that same time frame each of the three services had its own administrative message system; and as might be expected each service did it differently. The Air Force had Plan 55, a Western Union system using mostly Teletype equipment. The Navy had an 82B1 system from the Bell System, also using Teletype machinery. The Army had a military-nomenclatured system (AN/FGC-30) built for them by Automatic Electric and Kleinschmidt.[24] There were standards for message format so that messages could be gatewayed from one sytem to another. All of these systems were based on paper tape store-and-forward technology. Plan 55 made some use of vacuum tube electronics within the switching centers; I believe the others were almost entirely electromechanical, perhaps using some electronic timers. All used Baudot code. All the services had other communications systems as well: e.g. the Air Force needed aviation weather and flight plan data interoperating with the FAA air traffic control system. The Army's A.E./Kleinschmidt system was depicted in a civilian version in the Kleinschmidt catalog; I don't know if any were ever sold. A feature of Plan 55 was 200 wpm cross-office transmission, using electronic sending and receiving distributors and LARP parallel-input punches. It also used Western Union's loop-gate transmitter. A requirement of the system was that message routing codes appear in the final copies of all messages. In some earlier systems the routing codes were used to set up connections and then were lost, having already gone through the tape readers. The loop-gate transmitter held the tape, forming a loop, as the routing codes were read the first time. Then it could shift the loop of tape for a second reading to transmit the routing codes

[24]It is not clear to me whether the Army system was ever actually deployed.

cross-office ahead of the message.

The original COMLOGNET had a number of shortcomings, making the Air Force interested in a replacement. The card transceivers, based on the standard keypunch machine, were slow. They were not designed with switching in mind; there was nothing to separate messages, nor to signal when a message was complete and ready to be switched. The many private lines, all terminating at one base in Oklahoma, were expensive. There was no encryption. Outside of COMLOGNET there were other card transceiver systems. Edwards AFB had two of these. One ran to an office building in Pasadena, where there was an operation that had a very strange early computer, and a few scientists and programmers. The other ran to a Navy base at El Centro, where the Air Force did parachute testing under supervision from Edwards.

The replacement system was first called COMLOGNET, then AFDATACOM, then AUTODIN (Automatic Digital Network), and eventually DCS AUTODIN when it became the one message switching system for all the military sevices under the Defense Communications System. The idea was to use computer technology for switching centers and a common code something like Fieldata throughout the system. Western Union was the prime contractor, selecting RCA to supply the switching computer equipment and IBM to make some of the terminal equipment. The most common terminal was the Compound Terminal, accomodating both punched card and Baudot Teletype message origination and reception. IBM made a refrigerator-sized box of electronics that did code conversion, error detection and correction, and synchronous transmit and receive. This connected to a modified keypunch machine and a Teletype Model 28 ASR set. All traffic was to be encrypted, so the terminals had to be located in secure facilities. This was not pleasing to the former COMLOGNET users who were used to having the card transceivers in their own office areas.

There were also magnetic tape terminals. The intention was to read and write tape in the native mode and code of whatever computer was used at a base, transmit in the common system code, and connect to a tape drive at the other end that might be for a different kind of computer and use a different size, mode, and code on the tape. Tape terminals would use circuit switching rather than message switching so that the possibly very long messages on tape would not have to be stored for forwarding by the switching centers. Circuit switching was also to be available as an option with teleprinter terminals, allowing secure conversations to be held.

Later there were other kind of terminals. In particular the Univac 1004, a programmable card and printer remote job entry terminal, came into wide use as an AUTODIN terminal. There was also a terminal based on a Kleinschmidt ASR set for situations not requiring cards or high-speed printing.

My involvement with all this was quite limited. I visited Pasadena and El Centro to see where the equipment was to be installed and explain what facilities work had to be done. It was fairly disconcerting to the users, particularly at Pasadena, because they didn't have a lot of space, had never dealt with a crypto-secure facility before, and the exisiting card transceiver setup worked fine for them. But there were to be no exceptions to the policy that AUTODIN would replace all existing card transceiver installations. I don't know whether AUTODIN was ever installed there; it was such a small outfit with such a strange and obsolete computer that it was never clear to me that what they were doing was necessary or useful. I got to see an AUTODIN switching center as it was under construction in San Bernardino.

During my assignment to the staff office I got the AF to send me to a communications conference in Chicago. I was able to get in a visit to Teletype in connection with that trip, which was in the winter, probably of 1961-1962. R&D by then had moved to Touhy Ave. I remember being told about the low voltage selector magnet driver in the 32, 33, and 35 line. I also remember being shown a room containing a large amount of relay equipment in cabinets, all in operation and making a very busy sound. If I remember correctly this was part of the Delta system.[25] I don't know what a room full of relays had to do with the Delta system - I bellieve it was for interchanging traffic with other airlines having store-and-forward switching systems. Of course it was exciting to view the new R&D building which was such a contrast to 1400 Wrightwood.

I believe it was at this conference that I saw a high speed printer made by Motorola for the military. This used a dot matrix principle, recording on Teledeltos paper[26] with a moving print head. The paper moved continuously; and the print head traveled on a slant so that it kept up with the paper motion. By the time the print head had moved off the right edge of the paper and another print head had taken its place on the left the paper had moved just enough to start printing on the next line. Hence there was no need for a line feed mechanism. This kind of stunt was never acceptable to Teletype because it required that all print lines take as much time as if they were full of characters. Teletype people insisted that a printer given a short line should print that line and immediately be ready to start

[25] It was always called the Delta system because it was designed for Delta Airlines. Later United Airlines got a similar system. The Delta installation was soon replaced by a computer-based switching system. The United system was removed after the WADS tariff was disapproved.

[26] a dry electrosensitive recording paper developed by Western Union. More about this later.

the next line.

Although I had nothing to do with it, I will record what I have heard about the Delta system for the sake of documenting it. I guess what the customer wanted was a conventional store-and-forward message switching system with mnemonic routing codes. What AT&T proposed was to simulate such a system using the voice switched network.

There were a lot of good reasons for doing it this way.

- The marginal cost of carrying message traffic on the switched network is practically insignificant.
- There is no need to build and install special switching equipment for a particular customer, who may decide to adopt some other switching system long before the equipment is amortized.
- There is no need to build a dedicated network of telegraph circuits.
- The customer doesn't have to provide floor space and personnel for switching centers.

On the other hand

- The switched network is controlled by dial pulses, not by mnemonic codes.
- The switched network provides no storage; so any storage has to be at the originating station.
- The switched network was designed for hearing callers. Callers may encounter various call-progress tones, recorded voice announcements, intercept operators, and ordinary telephone subscribers in the case of a wrong number. There are various kinds of switching offices with somewhat different user interfaces.
- The switched network has no capability for multiple-address messages.
- The way it was implemented required a horribly complicated ASR set to be installed at each customer site, rather than concentrating the complexity in a central office where maintenance personnel are always available.

The problem of various kinds of switching offices was avoided by connecting all the customer stations to a particular kind of crossbar office, using foreign exchange lines as necessary. The problem of mnemonic routing codes was met by the Codomat[27]. This was a sort of rotary card file attached to the side of the message preparation ASR set. Tabs on the cards were printed with mnemonic codes. The cards were punched with telephone numbers. The operator would select the card for the desired message destination and move it next to a slot at the top of the machine. Swinging the card into the slot would actuate a crawling-head reader to read the Baudot codes, which got copied into the message tape being prepared. I remember a discussion of the problem of punching all those cards; but I don't know how it was solved. The problem was further complicated by the fact that the destination might be in the same area code or in a different one from the originating station. Hence some code cards had to have seven-digit numbers while others had to have ten-digit numbers. Then after the initial batch of cards was manufactured there would be small-lot production needed at random times because of number changes. The ASR set allowed the operators to key in the telephone numbers manually in case the required numbers were not in the Codomat. Built into the case of the Codomat was a time-of-day clock that generated Baudot output by means of cam-operated switches connected to the rotating parts.

Messages were received on RO machines. There was only a single character answerback. (i.e., it was an "Are you ___ ?" answerback rather than a "Who are you?" answerback.) To provide some circuit assurance there was a pulse signal sent from the receiving machine back to the sending machine; failure of this signal would bring up an alarm.

A most wondrous part of the machinery was the tape reader, LFXD. The system used Baudot code punched into the middle of one-inch tape. Other rows in the tape were used for control purposes, such as indicating the beginning of a telephone number and indicating a successful delivery. A message could have several addressees. The machine would attempt to call the first number, and if successful would send the message. Then the reader would punch a hole next to that number, indicating successful transmission. The reader would then run in reverse to the beginning of the message and look for the next unused number to call. If a number was busy or got no answer the machine could skip on to the next number. Only after all the numbers had been used and the message delivered to all addressees would the reader move it beyond the place where it could be pulled back. I am not clear on whether entire messages could be skipped because of busy line or no-answer to allow other messages further down the tape to be transmitted. There was something about sending an undeliverable message to an intercept number if

[27] Zenner patent No. 3,014,093, Dec. 19, 1961

it was undeliverable to the intended addressee after some number of attempts.

Messages had to be in a specified format adopted by the airline industry. This required header and trailer sequences typical of a real store-and-forward message switching system. There were stepping switches in the bottom of the ASR set to generate these character sequences. Part of this was custom-wired for each station, to generate its own address code. In addition to the complex ASR set - the bottom compartment was completely filled with relays and stepping switches - there was a big box of telephone equipment, consisting of a modem and an autodialer.

Meanwhile, back at Edwards AFB, after a while I was assigned out of the staff office and into a group that did analog computer simulations of aircraft and spacecraft. That seemed like a bad end for an engineer who was brought up on digital technology; but it turned out more or less all right. I had the opportunity to design some hardware for a change; and some of it was somewhat digital. I built a circuit to time-share an oscilloscope display, using a thyratron ring counter circuit once again taken from the AN/FGC-5 multiplex.[28] The unit had asked for some engineers with analog computer experience; what they got were mathematicians with digital computer experience. One of my duties was teaching them the basics of analog computers, after which they went off to do wonderful mathematical things I never could have done with that or any other kind of computer.

Then there was the Packard-Bell 250 digital computer. I had seen it somewhere on the base earlier, perhaps at Central Timing. Later it turned up in the instrument building where another engineer was trying to repair it and showed me what he was doing. After a while he got too busy to deal with it. We in the analog computing branch managed to get our hands on it, as we were thinking at the time about hybrid analog-digital computing and thought it might be worth our while to play with. This Packard-Bell company, no relation to the present company that acquired the name, was I believe the offspring of Bendix Computers and an ancestor of Scientific Data Systems. The PB250 computer was a little thing, occupying about a third of a desk top, not counting the Flexowriter used for input/output. It used wire delay lines for memory and serial-by-bit arithmetic. I worked on it every day for some time, searching out bad transistors and diodes, and in the process became very familiar with the principles of operation. After a while I noticed that near the end of the day I would have it fairly close to being operable; and then the next morning it would be in much worse shape. It was some time before I realized that the sergeant in charge of the shop was having the men run a floor

[28] In this case the reason for using tubes rather than transistors was to get a large voltage swing to apply to gates controlling the analog signals.

polisher every afternoon just before quitting time. The floor polisher was plugged into the same outlet as the computer. When it was turned on it made a big dip in line voltage. When the voltage came back to normal the output voltage of the computer power supply would overshoot, usually taking out a few semiconductors in the process. After that I made sure the computer was unplugged when the floor polisher came out; and I made steady progress until the computer was more or less working. We were able to load a long paper tape that gave the machine some kind of programming system a little less awkward than pure binary machine code. It took a long time to load the paper tape; and then of course the memory contents vanished when we turned power off. So far as I know the machine never did any useful work at Edwards. I don't know if they did any useful work elsewhere. We were talking to the manufacturer of the analog computer, Electronic Associates, about hybrid computing. They said there was an interesting new machine on the market, the PDP-1 from a new company called Digital Equipment.

Spare time activities at Edwards included frequent visits to Merrill Swan in Arcadia, about a two-hour drive from the base. Many Sunday afternoons were spent in Merrill's amateur radio room, discussing the fine points of radioteletype and the latest news about Teletype equipment. Merrill's brother Everett worked for a Bell company and kept him informed. A visit to Merrill almost always included a stop at C&H Surplus in Pasadena to look at the latest detritus of the computer and aerospace industries. Over a period of time I acquired a collection of samples of digital circuits packaged in quite a variety of ways. I also picked up a bunch of surplus delay lines, with the idea that I might someday make a computer along the lines of the PB250.

I had a few visits with Bob Weitbrecht as well, either driving to his home far to the north near San Francisco, or at his mother's home in Sierra Madre. When I got out of the Air Force I spent about a week at Bob's home before heading back to the midwest. Bob worked for what was then Stanford Research Institute, now SRI International. He gave me a tour of part of the place. One thing I remember seeing was a read-only memory constructed with U-shaped ferrite cores through which wires could be threaded. Ferrite caps were placed over the open ends of the U-s to close the magnetic circuit.

Before I went into the Air Force I had given some thought to making it a career. Not long into the actual experience it seemed that I had to choose between being an officer and being an engineer. I was too design oriented to be happy working in a situation where all the design was done outside. Perhaps there was some place in the military where I would have been happy to work; but finding it and getting into it seemed an unlikely possibility. As my tour of duty neared its end I had a job offer from Teletype and an interview with a company in Virginia, where Walt Cannon was then working in addition to teaching at a university there. The Virginia company did antenna work, mostly for the military. I hated to disappoint Dr. Cannon, but it didn't seem like the kind of work that I would want to do, comnpared with what I had done at Teletype.

IV. From the winding up to the winding down

Having been hired back by Teletype, I made my way to Chicago in the spring of 1963. The entire operation was now in Skokie. I found that I was to work under Frank Biggam, whose department had at the time DART and the Dataspeed Type 2 line of high speed paper tape transmission equipment used over the switched network. While I was looking for a place to live Frank suggested I look in Deerfield, where he was living at the time. I was able to rent an old house with a big yard and a basement, allowing plenty of room for my antennas and collection of radio equipment and junk. The main drawback was that the house was just across the street from a commuter railroad, so there was the noise from trains screaming through at all hours.

DART (Data Analysis of Reorder Traps) was a project for some Bell operating companies. Their electromechanical switching systems were able to detect certain kinds of internal errors. They punched a special card with information about the state of the machine when an error occurred. I don't believe these cards were meant to be read by machine; so they wanted the same information punched into paper tape for data transmission and analysis by computer. Lou Costello had charge of this project. Warren Foxwell worked on Type 2 Dataspeed. This used CX readers and BRPE punches and Bell Dataphone 202 modems. I was given Type 5 Dataspeed, which some other engineer had already started. This was to use Bell 402 modems, a design that gave a low-cost transmitter and an expensive receiver. This made a nice combination for data collection systems in which there are many senders and one receiver. The transmitter circuit was a lot like a Touch Tone dial. It used only two transistors to generate 9 tones. The operation was 8-level parallel, plus a timing channel. The system was to use the CX reader and the DRPE tuned-reed punch, with a new punch driver being designed by Gene Sullivan.

My understanding is that there were three generations of DRPE drivers. The first, used only in a demonstration model, simply used high voltage and series resistance to operate the punch magnets. Thus it consumed a lot of power and generated a lot of heat. The second had something to do with storing energy in inductors, and was used in some delivered products.[29] The third driver, Gene's design, applied a high voltage to get the reeds moving and a lower voltage to hold them against the magnets.

I remember spending a day or two at Fullerton, where the only activity still

[29] Reszka patent No. 3,191,101, June 22, 1965.

in the building was putting together the engineering model of a system for FAA Service B, which carries flight plan data. The system was called BDIS, sort of a pun on ADIS.[30] There were also pieces of CODIS lying around. Teletype had started on a system for FAA Services C and O. Then FAA had cancelled the effort and gone with a computer-technology switching system. BDIS used DRPE punches with the inductor driver design. A problem I was looking at involved an electronic differential message counter, which kept a count of the unsent messages in a reperforator-transmitter stand, counting up for each message punched and down for each message sent. One input to the counter came from a contact closure. There was a lot of contact bounce, causing extra counts sometimes.

BDIS was about the last switching system job that Teletype did. There was a similar system called AIDS for internal use by New York Telephone Co. There was MAPS, a multi-address processing system for NSA. Then there was a small selective-calling system with a polling controller. Practically all switching systems after BDIS were based on computer technology and thus were outside the scope of what Teletype was allowed to do under the terms of the 1956 consent decree.

There was a fairly new concept circa 1963 of making coded sets. In the past a customer wanting, say, a KSR set had to order a cabinet and a keyboard base and a typing unit and an electrical service unit and perhaps some other items and modification kits and then put them all together when the separate parts arrived. The coded set concept assigned a codes to popular complete sets, so that the customer could order one item and get a complete set ready to use.

The Type 5 Dataspeed transmitter used reed relays to store the tape reader signals, as the modem had a contact-closure interface. The engineer who had started the project had built a prototype transmitter as a box containing the CX reader and its motor, the reed relays, and a power supply. I was concerned about the lack of space for optional features in the box; yet making the box big enough to accomodate them would make it too large to fit on a desk. (Type 2 Dataspeed, and the Type 5 receiver, used large floor-standing cabinets. The Type 5 sender was supposed to be available in both floor model and desk-top cabinets.) One day as I was walking around the plant I happened to see a box on the wall containing the relays for the key telephone system in someone's office. That gave me the idea to put most of the works of the Type 5 sender into a wall box, with just the

[30] ADIS was an acronym for Automatic Data Interchange System, which just happened to be used for what FAA called Service A. Hence Service A:ADIS = Service B:BDIS = Services C and O:CODIS; but BDIS and CODIS are not acronyms.

tape reader and the modem taking up space on a desk. I used the off-the-shelf key telephone wall box, which was big enough to hold all the accessories we ever designed, and then some.

This required a multiconductor cable running from the tape reader box to the wall box. I was unhappy with the size and stiffness of the cable stock we were using. The cords on key telephones on our desks were a lot better in this respect. A few telephone calls to Western Electric plants turned up enough information to enable us to use the parent company's cordage in our products.

About this time we made an interesting discovery. R&D was always required to produce a schematic diagram and an actual wiring diagram for any wired assembly. When we were releasing something to production there was a man who would compare these two documents to be sure that they were in exact agreement. We had always assumed that the factory used the actual wiring diagram to develop the instructions for the people doing the wiring; that is why we went to the trouble to produce it. We learned that in most cases the factory was ignoring our actual wiring diagram and developing their instructions from the schematic. The drawing that was so much work to produce was not being used except for checking against the schematic used to produce it. (Perhaps it was considered useful to the customer for maintenance purposes. Most Teletype equipment was shipped with a schematic diagram and an actual wiring diagram.)

Gerry Marbach had a collection of sayings, e.g. "For gluing use glue." I believe this one originated because there was some guy in the factory who would call up from time to time to complain about vital information missing from one of our drawings. Maybe Gerry had released a drawing showing a pad glued inside a cabinet but had not specified what substance to use for adhesive.

Occasionally an engineer would find it necessary to redesign some mechanical part. Sometimes the older parts could be reworked into the new design, and sometimes the supply of old parts could be used up and the new ones phased in. Sometimes the old parts were totally unsatisfactory and had to be scrapped. I heard about one of these changes which hit the factory just as a batch of the old parts were in production. The factory asked permission to finish making the batch of old parts before they scrapped them. This made no sense at all to R&D. It turned out that the factory workers' pay was partly based on the number of pieces completed; they would lose money if the parts were scrapped before they were finished.

There were little rooms in R&D called "drug stores" because the walls were lined with shelves of glass bottles. The bottles held all of the common screws and washers and springs and things, so that experimenters would not have to requisition them or keep their own stocks. It seems now like it would have been a good idea to have a similar system for the commonly used electronic parts.

When I had too much of sitting at my desk I liked to take a stroll through the plant, usually through the factory. One impression this made on me was that with all that activity going on out there, if I screwed up in the design end and caused that activity to stop it would be a Very Bad Thing. It was also gratifying to the ego to see something I had designed being manufactured. It also gratified the factory workers to know that the design engineer cared enough to come out and see them at work and listen to any suggestions they had about making the product easier to manufacture. Most of the time I just wanted to learn more about what the factory machines did, and to see things others had designed that might suggest ways to improve my own designs.

We used unijunction transistor R-C oscillators as bit timers in electronic receiving and transmitting distributors. These had to be adjusted to frequency and were subject to drift. It occurred to me that we might use tuning fork controlled oscillators for much greater frequency stability; they were available ready-made in a little plug-in package. For receiving we needed the oscillator to start and stop, and to generate the first pulse in about half the normal bit repetition rate. Well, maybe (was this suggested by the tuned-reed punch?) there could be a circuit to clamp the tuning fork in a stationary position and then release it at the beginning of a character. I talked to Stevens-Arnold, the maker of these oscillators and was told that it could probably be done. A little later Mr. Stevens, or maybe it was Mr. Arnold, came to visit us with samples of free-running and start-stop tuning fork oscillators. As I recall they worked pretty well; but apparently a bit timer that didn't need adjusting was not such a high priority as I had thought it to be, as we didn't pursue this any farther.

The use of Dataspeed equipment in the field often meant using Model 35 equipment to punch tape that was then transmitted by Dataspeed.[31] Hence the information was in 7-bit ASCII. (1961 upper-case-only ASCII at the time) Warren Foxwell realized it would be easy to do a vertical parity generation and check in Type 2 Dataspeed; it was just a matter of adding a single flipflop to toggle for each marking bit in the serial data stream and transmitting the parity bit in the unused 8th bit channel. I remember there was a lot of political difficulty with this concept. Somebody didn't think we should call it an error detector, because

[31]This shows the separation between data processing and data communication, as required by the 1956 consent decree, starting to get fuzzy. Customers were renting private-line Model 35 ASR sets from the telephone companies to use entirely offline as keypunch machines.

we didn't want to give the customer the idea that the system might occasionally make errors. It seemed to me the customer would be a lot angrier when errors did happen undetected than if we admitted they were a fact of life and we could often detect when one had happened. For a while "data quality indicator" was a euphemism for the device; then somebody decided that "vertical parity check" was the right thing to call it. I don't believe it was ever offered to customers.

There was a story circulating about the significance of single-bit errors. One customer was a truck parts distributor. A truck dealer had placed an order for seven dipsticks. In the order form the quantity was at least a four-digit field. A single-bit error in transmission had changed 0007 to 1007. The computer at the parts warehouse apparently was not programmed to check for reasonableness of data and accepted the order as it stood. Supposedly the computer generated a form letter to the dealer saying that only 253 dipsticks were in stock and they were being sent right out, the rest of the order to follow as soon as the dipsticks could be made. Fortunately a shipping clerk had the common sense to wonder what that dealer wanted with all those dipsticks, started asking questions, and brought the mistake to light.

Those were the days before Model 33 and Model 35 keyboards were generating parity in the 8th bit. They simply made the 8th bit always marking. There was an interim Model 35 keyboard that generated correct parity on some characters and wrong parity on others; and then there was at last a keyboard that generated correct parity for all characters. If we had had parity keyboards there would have been no need for parity checking in Dataspeed; we would have simply transmitted the parity read from the tape and the customer's computer could check what it got, passing all 8 bits through Dataspeed.

There was another story about parity. When Model 35 equipment with parity keyboards did get into the field in quantity there were reports of occasional errors from a certain model of tape reader, always in the 8th bit. When these reports got back to the designers they replied that there were some problems with getting the mechanism to read the 8th bit reliably. Since they 8th bit was always marking (before parity keyboards) they had deliberately biased the mechanism to favor reading the 8th bit as marking.

John Auwaerter spoke to me one time about parity. It seems that in some standards activity IBM was campaigning for odd parity transmission. I guess they wanted to distinguish between a real character and a "hit" that would have all bits marking, hence even parity, or a break that would have all bits spacing. Teletype wanted the standard to be even parity. Otherwise it would not be possible to have rubout be a legitimate character. I suppose if forced to we could have made equipment that would automatically invert the 8th bit, so that we would read even parity from tape and transmit odd parity. This didn't occur to me at the time.

There was also a controversy over the order in which bits were transmitted. In five-level code there was no particular meaning to any of the bit positions, so it was rather arbitrary which way we numbered them and transmitted them. With ASCII the digits were mapped to binary number codes, so that the various bits could be considered to have binary weights. The way we built things resulted in sending the least-significant bit first. IBM argued that the proper thing was to send the most significant bit first. (No doubt because that was what they were already doing with their own codes.)

Aside from transmission errors there was another problem that occasionally vexed the users of Dataspeed equipment. Sometimes the tape reader would rip the feed holes of the tape. With an unattended transmitter this meant that it would send the same character over and over forever. If the receiver was a paper tape machine this would use up all the tape supply; if the receiver was an online computer it would generate a terribly long, worthless message, unless the machine was smart enough to realize that something was wrong and disconnect. I don't know if we didn't protect against this problem because we didn't know how at the time, or if it was a matter of cost. Later on another group developed a low-speed polling system and did include protection against this problem. It consisted of a one-character storage register and a circuit to compare the current received character with the previous received character. A timer measured how long they compared the same. If they stayed the same for too long the timer would run out. This was assumed to mean torn feed holes. Then the system would send a break to stop the errant transmitter.

While working on Type 5 Dataspeed there was something I knew intuitively and could only later state as a principle. That was to start a design by thinking about how the user will use it, and then design to make the user's actions as clear and simple as possible. (The term "user-friendly" had not been invented yet.) I don't remember the particulars, but in Type 2 Dataspeed there were some controls on the front of the machine which were suggested by the engineering logic of the machine but which made the user's job more complicated than necessary. I found a way to eliminate them from the Type 5 equipment.

We did a field trial of a Type 5 prototype at a customer site in the city. The customer's operation had many trays of IBM punched cards. Clerks would pull cards from the trays and run them through an IBM machine that read the cards, added some information from a keyboard, and punched a tape that was transmitted somewhere. I suppose this was an inventory maintenance type of activity.

I was surprised that a popular accessory for Type 2 Dataspeed was a shoebox-sized oscilloscope that fitted into an extra module space in the cabinet. I couldn't understand why a telephone company would pay for an oscilloscope and leave it at the customer's premises when it was used so rarely. The explanation was that in New York and other large cities the maintenance people get around on foot and by taxicab, so there is a severe limit to the weight of tools and test equipment they can carry with them.

Warren and I worked together on a Dataspeed accessory we called the identifier/recognizer. One concept behind the Dataphone modems was that they would be used for voice-coordinated transmission. One station would call the other; the operators would discuss what they were going to do; then they would push the DATA buttons and transmit the data. In fact a lot of customers didn't want to use voice coordination at all. They wanted to load a tape on the transmitter at the end of the work day. At night the receiver would call the transmitter and collect the data, taking advantage of lower night telephone rates. Hence we were concerned that a wrong-number caller, not to mention an industrial spy, would call a loaded transmitter and it would spill its data before the intended caller got to it.

The high-speed modems didn't have much in the way of handshaking, and they transmitted in one direction at a time. There was an optional accessory called a reverse channel that transmitted a signal in the direction opposite to data. The Bell System never was very forthcoming about what baud rate could be used on the reverse channel; but allowed as how you could turn it on and off at some slow rate and that keying would be received at the other end. Warren designed a code wheel, simply a circular printed circuit board turned by a clock motor. This would transmit a start-stop character containing 14 bits of information at a speed slow enough for the reverse channel. A similar wheel in the Dataspeed sender at the other end would compare characters bit-by-bit and allow transmission from tape only if they were the same. The wheels could be coded in the field by cutting through the etched traces, so that different customers would have different codes. The unit in the Dataspeed receiver was called the identifier; that at the Dataspeed sender was called the recognizer.

My main contribution was the bit comparator of the recognizer. IBM at the time had surplus manufacturing capacity for relays, as the market for electromechanical punched card accounting machines was winding down. They started advertising their relays for sale to industry. I had always admired IBM relays as examples of beautiful design. They were making one that had two equal operating windings plus a mechanical latch to hold the relay operated. This single part was the heart of the recognizer. One operate winding was powered from the reverse channel signal. The other was powered, in reverse polarity, from the local recognizer disk. Another brush on the recognizer disk completed the circuit only in the middle of each segment. As each segment went by, if both local and distant bits were spacing the relay windings were un-energized. If both segments were marking both windings were energized, and being of opposite polarity cancelled each other. But if the local and distant bits were different only one winding would be energized. That would operate the relay; and then the latch would keep it operated. Hence if the relay was operated at the end of the character there had been a mismatch in at least one bit and the sender would not transmit its tape.

In the course of getting the IBM relay and its socket released as Teletype parts I discovered that Teletype had used IBM relays many years earlier. The product was apparently something of a cryptographic nature, so I was not able to learn any more about it.

We found that some customers wanted to use Type 5 Dataspeed senders but no receiver; they would connect the receive modem directly to a computer. The computer would have an autodialer so that it could call a number of transmitters without any human help. We visited Univac in Minneapolis to discuss this kind of operation. Later our technician spent several days or weeks at Univac helping them test and integrate the Teletype equipment into their system. Some problem arose - I don't remember the details anymore - I had thought that the computer should wait a while and time out if nothing happened. The Univac people said that was not acceptable; they wanted the computer to get a definite signal one way or the other and not have to do any timing. So I designed something involving a thermal time-delay relay for the sender that would satisfy their requirement. This experience confirmed the need for plenty of space in the transmitter wall box for unanticipated accessories. It also illustrates the value of design engineers talking directly with the customer, and not having to go through several layers of bureaucracy. Type 5 Dataspeed senders turned out to be very popular for use in this kind of central-data-collection system because of their relatively low cost. I believe several thousand were sold.

While working on Dataspeed I undertook a bootleg project investigating higher speed logic. In the early 60s there had been a breakthrough in transistor fabrication, first the epitaxial technology and then the planar technology that eventually made integrated circuits practical. These technologies made very fast transistors available very cheaply. I bought a handful of these transistors and built them into the usual Teletype logic circuits, tacking on speedup capacitors across the base resistors. Risetimes were at least as fast as our oscilloscopes could display; so I was confident that if we needed faster circuits we would have no trouble building them. One potential problem was that the new transistors had a limited reverse base-emitter voltage rating. A few of our usual circuits depended on a higher reverse voltage than these transistors would have allowed.

I also thought briefly about an electronic stuntbox, and ordered some printed circuit card edge connectors with taper pin terminals for the purpose. Taper pins would allow reprogramming in the field without soldering or wire wrapping. I had in mind supplying all the bits of a charater in normal and inverted forms and having the technician in the field select among these signals to feed into an AND gate to recognize a particular character. Hence the need for easily changeable connections. I didn't pursue this any farther since nobody seemed to be interested in that kind of product; and it seemed likely that programming would be too complex for technicians in the field to undertake. I've heard that several years later the need for an electronic stuntbox was appreciated and a product was developed.

From time to time there was discussion of programmable ASR sets. I never got involved in one of these projects except for discussing them. I believe one of the Bell operating companies had made up some sets for a customer, using Model 28 or Model 35 equipment. The concept was to have preprinted forms in the machine, and something that would use horizontal and vertical tabs to lead the operator from one data field to the next in filling out the form. There was the Model 29,[32] which was a modified Model 28 that used IBM BCD code and I am told was made for Western Electric internal use only. There would have been a ready market for these sets outside the Bell System; but the System did not want to appear to be promoting IBM over other computer makers by accomodating IBM code. Also the System did not want to offer the public anything that would compete with or delay ASCII as a successor to all these computer companies' varieties of BCD codes. The Model 29 ASR set had two tape readers, one for a program tape and one for a message tape. I don't know much else about the Model 29, so I don't know if the program tape did the forms positioning operation described above or something else. I am not sure whether all the Model 29 equipment that was made stayed within the Bell companies for internal use. After I left Teletype I encountered some Model 29 equipment at General Electric, where a technician was converting the typing units to Model 35 by changing a few parts. Still later a bunch of Model 29 RO machines turned up at a surplus dealer in Oakland, California in connection

[32]In Ran Slayton's museum tour document the Model 29 is identified with an up/low printer intended as a replacement for the Model 20. Such a machine did not sell. It is reasonable to use the same model number for the BCD code machine, since in both cases a six-level code is involved. The machine which many of us knew as the Model 29 was sometimes called the "Model 28 IDP ASR Set".

with a junked RCA computer. One of my friends made a little money by buying some of these machines and converting the typing units to Model 35 and selling them to a man in Los Angeles who dealt in used Model 35 equipment.

The problem of IBM BCD code came up again as Teletype dabbled with magnetic tape. Computer manufacturers had gone through a variety of tape sizes and formats, eventually adopting 1/2-inch 7-track tape as used by IBM as a *de facto* standard. Each computer company had its own version of something like the IBM BCD code (even within IBM there were several different versions). Toward the end of my time at Teletype I worked on a project, under Harold Cook, that produced a punched card to magnetic tape product for internal use by a Bell company. I designed the transmitter, which used a little tabletop card reader made by NCR. Roger Biros designed the receiver. I don't know whether any significant number of these were produced.

In 1964 IBM announced System/360, a new computer architecture with 8-bit characters and a new 8-bit code (different from ASCII). This eventually made 7-track magnetic tape obsolete, replacing it with 9-track tape. But there was a lot of 7-track equipment in the field. so it was several years before 9-track tape was in the majority. To meet government demands for use of ASCII there was a bit in the computer that put it into "ASCII Mode" and didn't do anything of much significance. The ASCII bit was eliminated from the following generation of IBM computers in the 1970s.

ASCII went through a lot of growing pains. At the outset there was a conflict between what a code ought to be and what all the existing codes were. A code ought to have all the characters of the alphabet mapped into an increasing sequence of binary numbers, with no gaps. This facilitates use of the code for sorting. All the existing BCD codes were based on punched card coding, which has two gaps in the alphabet. IBM lobbied hard for a code that would be easily convertible to punched card code, as the BCD codes were. Unable to prevail, IBM withdrew its objections and designed its own code, called EBCDIC. All this agony seems so pointless today, because arbitrary code conversions are trivial with a computer. It seems to me it was equally pointless even at the time. Even later IBM brought out a line of equipment with a 6-bit code, and a new card and card reader/punch using this code. The card, although smaller than the standard data processing card, held 96 columns of data.

Then there were all the control characters, intended to facilitate message processing and block error checking. These also turned out to be fairly pointless, because people want the ability to transmit arbitrary binary data. Someone invented a protocol to make this possible. Designate one character as Data Link

Escape, DLE. If DLE occurs in binary data transmit DLE DLE and remove the added DLE at the receiver. DLE followed by any other character is a control character; and all the characters except DLE are available. Still I suppose there was some merit in trying to standardize control sequences so that different manufacturers could produce equipment that would interoperate. But again practically all systems that got to the field included computers that could be programmed to handle any protocol. IBM's Binary Synchronous Communications protocol became very popular.

The shoebox packaging of printed circuit cards was turning out to be too small. There were new modules 2 and 3 times the size of the shoebox, and a new logic card a little more than twice as big as the previous standard one. The same kind of socket was used, so that a wide socket could accomodate one of the new cards or two of the old ones with a spacer between. I believe Teletype pioneered the use of card sockets with the card guides molded in. I had some misgivings about the new packaging because it perpetuated the low packing density of the previous design, which by then was several years old. I would like to have seen finer circuit traces, more dense component placement, and closer spacing of the edge connector fingers. Further, if we had been able to use the same card sockets that IBM or some other computer company was using there should have been considerable savings because the parts were being made in such large volumes.

I was recruited to work on writing the manual for MAPS (Multiple Address Processing System). This was a product for the NSA and involved high speed readers and punches. The customer insisted that we use some hardware they had standardized for logic. The modules were molded in epoxy and had leads coming out one side; so we mounted them on Teletype standard printed circuit cards.

Claude Kagan of Western Electric Princeton Research Center was an occasional visitor to Teletype. I gather he was considered something of a pest by many people there; but I got along fine with him and enjoyed his visits. Claude and I were both enthusiasts for using small computers as components of systems. We would talk about all the neat things that could be done using Teletype equipment and minicomputers. He got to do some of them for manufacturing applications at W.E. Teletype apparently couldn't do anything with computers in systems for customers because of a strict interpretation of the 1956 AT&T consent decree. I don't remember if he had already started R.E.S.I.S.T.O.R.S. (a computer activity for youngsters) or if that came later. He was notable for having an old Burroughs vacuum-tube computer installed in a barn on his property, with magnetic tape drives occupying the former cow-milking stalls.

Our lab was located in the northeast wing of the building. From our windows one could look out toward the Edens Expressway and see the big rotating sign at Allstate Insurance. It was depressing on cold winter days to see the temperature on that sign, especially when it was negative all day.

The R&D building at Touhy Avenue had been designed with movable interior walls, so that lab space could be easily reconfigured as needed. A typical R&D department had maybe ten people: a project supervisor, a secretary, and the rest engineers, technicians, modelmakers and a draftsman or two. Each engineer and technician had a desk and a workbench, called an MTS bench (Member of Technical Staff), behind the desk. There were other workbenches as needed away from the desks. I heard this arrangement was copied from some Bell Laboratories location.

Once a year there was a lab cleanup day. Wire baskets from the factory were set in the halls outside each engineering department. They were to be filled with whatever equipment was no longer useful and would be hauled away the next day. For some of us this became more of a "junk exchange" day, as we would prowl the halls looking for interesting *objets d'arte* that other departments had thrown out.

During this time the RS-232 modem interface standard was being worked out. The Dataphone modems were a step along the way from the old Bell System to the new regime brought on by Carterfone. Until the early 1960s the official doctrine was "no foreign attachments" to the switched network. If a customer wanted to connect his own equipment to Bell facilities he had to use leased private lines. Around 1960 the switched network had reached a state of being nearly all customer-dialed for long distance and the management began looking at using it for data transmission. The Delta system had been a prototype of this, using the switched network and modems and autodialers to simulate a message-switched system. The Dial TWX conversion followed, getting TWX off dedicated telegraph circuits and manual switchboards and on to the voice switched network. Enough bandwidth had become available that it was no longer sensible to use narrowband circuits for telegraphy and a separate plant for voice.[33] With on-line computing coming into the picture the management realized that there was money to be made in allowing data over the voice network, and that it would be necessary to allow customer-provided equipment to be connected. Some executive stated that by such-and-such a year half of all the traffic on the network would be data. RS-232 was an industry standardized interface between Bell-furnished modems and

[33]However, there were special data-only interoffice trunks. The flexibility of #5 crossbar made it possible to route TWX calls over data trunks and voice calls over voice trunks.

customer provided equipment. In the case of Dataspeed the equipment might be partially or entirely furnished by the telephone company; but we used the same modems that were available to customers generally. These were called Dataphone modems and always included a telephone for placing calls manually. There was also an auto-dialer accessory so that a computer could initiate calls. Then there were a variety of card-operated and memory-operated dialers.

It is hard for us today to realize just how bad the switched network was in the 1960s. The Bell modems were, by today's standards, over-elaborate and under-performing. This was necessary at the time to get more or less reliable modem operation over random connections to random places on the network. The 103-series modems provided full-duplex operation at 150 baud or less. With two pairs of frequencies for the originating/answering station and the possibility of inverting mark/space on either or both there were strap options allowing eight mutually-incompatible services using the same modems. I'm not sure how many of these were ever used in service. One was for TWX, in which case there would not be a voice telephone as part of the setup because voice was not to be used on TWX calls. One was for Dataphone, which did allow voice. And there was something called WADS (Wide Area Data Service) and something else called WADS-prime that were at least envisioned, whether or not they ever happened.

Then there were the 201 modems, providing one-way-at-a-time operation using synchronous transmission, 2000 baud on the switched network and 2400 baud on private lines. The 202 modems provided one-way-at-a-time asynchronous operation at 1200 baud. There was a 300 series for use on special high speed lines and operating at 56K baud. The 400 series included those used with Dataspeed 5, and one that could decode TouchTone signals. Then there was one for fax. RS-232 could not be used for the 400 series modems because they were parallel input and output and the standard did not provide for enough channels. It was applicable to all the serial modems.

There are arguments over who "first" did computer time sharing. The development that had the most effect on Teletype was no doubt the system developed by Dartmouth College, initially using relatively inexpensive General Electric computers. This system introduced the popular BASIC programming language. G.E. gave Teletype and other potential customers free use of one of these systems in Phoenix on a trial basis before turning it into a business. This service affected Teletype because it took advantage of cheap Model 33 equipment and could use the telephone network for access. Minicomputers came along about the same time and took advantage of Model 33 ASR sets for inexpensive input/output. Both of these applications were misuses of the Model 33 line, which had been designed for low volume TWX installations where they would be used 2 hours per day or less. In computer applications they ran constantly. In my opinion the Model 33 had a lot more to do with the success of minicomputers and time sharing than is usually acknowledged. We can't really complain about misusing the machine in these applications where low cost made the difference between having or not having any market at all. Big computer makers, e.g. Burroughs, should have had more sense though and not used 33s as console devices on their expensive computers. (Univac used 35s, as did Scientific Data Systems.)

There was a demonstration of G.E. time sharing at some electonics conference in the city. I was recruited to man a joint Teletype/G.E. booth where we were showing it off. Computer games existed even in that dim past; a popular part of the demonstration was a computer-simulated horse racing game. I particularly remember one person who visited the booth, an optical engineer. It didn't take long for him to satisfy himself that the time sharing system was good for doing the routine calculations of his line of work at a price he was quite willing to pay. He wanted to sign up for the service on the spot.

I read in some publication an argument between two famous computer scientists. One said, "When I compute I want many pages of output, so computing with a 10 character per second terminal is worthless." The other rejoined, "When I compute all I want the computer to tell me is 'yes' or 'no'."

Computer time sharing illustrated some of the conceptual problems with tariffs for TTY services. TWX was a no-foreign-attachments service. People who wanted to use their own equipment were supposed to use Dataphone. But time sharing services wanted to allow TWX stations to connect, since they had no use for voice coordinated transmission and TWX was cheaper than Dataphone. All this wrangling over different tariffs for essentially the same equipment reminds me to remark that Teletype R&D seemed to be split philosophically along a line of low-speed (called "standard-speed") and high-speed equipment and services. It appeared that at low speed some old geezers at Bell Labs, who had been around since the beginning of TWX, had control of all the product and service planning. At high speed they were out of the picture and Teletype was much more on its own to design products. These had to meet needs as perceived by AT&T or the Bell operating companies; but they didn't have to pass through the Bell Labs filter.

Frank Biggam and I made a trip to AT&T headquarters, then at 195 Broadway, New York City, to confer with some people about Dataspeed and related products. It was about the worst travel experience I ever had. Teletype had its own travel agency in the plant. When traveling on business we were allowed to change the tickets to include personal travel and pay just the difference. I had arranged to fly to Arkansas from New York for a visit with my family before returning to Chicago. But that is getting ahead of the story. We flew into one of the airports and started looking for a taxi to take us into the city. There were lots of people waiting and few cabs, so Frank said we should take the bus to a Manhattan airline terminal and we could get a cab from there. Again there were lots of people and few cabs. Frank was sure that if we walked the short distance to Penn Station we could get a cab from there. Once again, no cabs. Fortunately our hotel was only about six blocks from Penn Station, so we hoofed it with our baggage to the hotel. I had a rather heavy bag since I was making a longer trip before returning to Chicago. The hotel rooms were expensive; the beds were small. This was a new hotel, with a computerized checkout system. A computerized checkout system in those days meant an IBM 1401 and punched cards; so when we were ready to check out we had to wait while somebody punched cards and the computer ran a job and produced our bills on the 1403 printer before we could leave.

When we had finished our business the man we were visiting told me where to stand outside the building to catch a cab to La Guardia. It was snowing. I stood there yelling and waving at cabs for about 45 minutes; but all those that went by were either taken or out of service. I went back to the office where we had visited. The man went down into the subway with me, made sure I got on the right train and told me where to get off. He said there would be cabs there to take me to the airport. I got off at the designated place and as before found a long line of people waiting for cabs that rarely came by. Somebody told me where to go to catch a bus to the airport. I got to the airport long after my flight had left. The airline people were very helpful, but all they could do for me was get me on a flight to Washington, and from there to Memphis that night. I got to Memphis and sat in the airport all night until the first plane for Little Rock came in the morning. My parents were supposed to meet me in Little Rock; but there had been an ice storm and all the roads were closed. I was able to get a cab to the railroad station. This was before AMTRAK but a few railroads were still running their own passenger trains. The train finally arrived about 6 hours late and I got to the home town a few hours later.

While I was at La Guardia I got to see the American Airlines reservation system (that preceded Sabre). The system was made by Teleregister, a wired-program computer with magnetic drum memory designed for inventory control purposes. The airline treated a seat in a certain class on a certain flight as a part number in the inventory. The agent had a little keyboard/display terminal that made it possible to inquire of the inventory status of a part and to sell a part, removing it from inventory. There was an arrangement of coded metal plates fitting into a reader on the terminal that related the flight numbers and classes to the part numbers used internally by the system. It worked well enough for what it did; but it was far too small to handle the entire business of the airline. It lacked features of a modern reservations system, such as the ability to look up passengers by name. [34]

We were excited about the Bell System introduction of electronic telephone switching. The #1 Electronic Switching System for central offices and the #101 ESS for PBXs were announced about the same time. #1 ESS used diode-transistor logic and a space-division switching network made of dry reed switches. The #101 ESS used resistor-transistor logic and time-division switching. I gather that the #101 ESS turned out to be a dog and was soon discontinued. #1 ESS was interesting because of its high reliability architecture. There were two of nearly everything, operating in parallel, and if either part failed some internal checks or failed to agree with its twin the software would split the system in two and then attempt to reconfigure a working system out of what was left. The whole computer industry sat up and took notice. The computer portion of the system was marked by some typical Bell System weirdness. It was a Harvard architecture, with completely separate memories for program and data. The program store was read-only in normal operation and used some kind of magnetic wire technology. The data store used perforated ferrite sheets rather than the magnetic cores that were the industry standard for writable main memory. I believe the intent was to make some use of plated wiring rather than having to thread wires through cores as everybody else in the industry was doing. (IBM, with its superb manufacturing engineering, was threading cores by machine; everybody else did it by hand.) Even the transistors were strange, with two leads coming out one end and one lead out the other.

The big project at Teletype was Long Lines Project 176, for the government. Teletype was assigned several tasks. One was called a high speed ASR set and contained two Inktronic printers and a high speed tape reader and punch. Sylvan Silberg's department was doing most of the work on this. They were using a purchased magnetic core memory to hold the character patterns for the printer. The whole thing was to be encrypted, so there were stringent requirements on electrical and acoustic emissions from the set. This may have been before TEMPEST came into use as a code word for that kind of secure equipment. There was also a requirement for two kinds of fax machines. I was moved to Ran Slayton's department to work on fax. This was not an assignment I wanted; I had always

[34]This system was ancient even then; it is described in the November, 1951 issue of Western Union Technical Review.

looked down on fax as a medium that wasted a lot of bandwidth and produced signals that were not machine-readable. There was supposed to be one machine for letter-size photo quality transmissions and another for large format black and white documents such as weather maps. We were supposed to be able to operate with analog transmission facilities for good quality reproduction or with a binary channel for encryption. Gene Sullivan came to this project too, so I guess we had Type 5 Dataspeed released to production by then. We hired as a technician Paul Mitchell, Jr. who was just out of the army. Yoshi Nishimoto was the secretary for the department; Fred Mocking and Bill Lill worked there as well. (This was about 1965.) I think Fred was working on the high voltage power supply for the Inktronic printer, which was being made by a Western Electric activity in Greensboro, NC.

I don't remember doing any work on the photo quality equipment. There was an analog-to-digital converter in the lab that had been built for us by somebody like Airborne Instruments Lab (division of Cutler-Hammer). Maybe it was to permit encryption of the photo-quality fax. I remember some mention of the English company Muirhead. All our work that I remember was with the large-format fax. We had a machine in the lab made by Alden Facsimile, a Massachusetts company. Some people from Teletype had visited the Alden factory and the owner John Alden. I'm told he was very proud of being a descendant of The John Alden of the Mayflower. Teletype was not impressed with the ruggedness of his product, although I guess the Air Force or the Weather Bureau were using them. Fax recorders of that generation used a rotating spiral wire on one side of the paper and a blade on the other. The intersection of the wire with the blade was the scanning spot where recording took place. Western Union had developed Teledeltos paper. This had a black center and a white coating. Applying a high voltage across the recording spot burned off the wite coating to leave a black mark. We didn't want to use Teledeltos because the high voltage seemed to invite problems with RF emissions from the machine. Also someone said that the result of the sparking was toxic fumes, though I don't know that anyone ever got a toxicology report on it. The other recording technology was electrolytic, using a paper wet with electrolyte. Passing a current through the recording spot moved metal ions from the blade into the electrolyte where they reacted with something to make a rather faint mark. As this etched away part of the blade it was necessary to keep the blade moving so that it would not be eaten away unevenly. The paper had to be kept in a humidor in the machine. At the start of a recording some paper had to be fed out to be sure that there was wet paper under the blade. The paper shrank quite a bit as it dried. The moving spiral wire tended to pull the paper to one side, so there had to be a mechanism to pull it back. Nobody in his right mind would want to use such a technology, but it was all we had at the time. We had a letter-size Stewart-Warner fax recorder in the lab in addition to the Alden. The Bell System had produced a Dataphone modem for fax. Stewart-Warner was hoping to make a business in fax equipment based on businesses faxing documents over the switched network. There were also to be service bureaus where the public could send and receive fax messages. The concept was pretty close to the way fax is used today; but the technology was so miserable and the cost of equipment was so high that it never achieved a market at the time.

There were two varieties of wet fax paper. Hogan Faximile of New York City supplied "catechol" paper which gave a gray mark. Alden supplied paper which gave a sepia mark. Alden made lots of dubious claims about the sepia being easier to read, and catechol being a hazardous substance. Fortunately the same kind of current and blade material would work with either. The paper was sealed in plastic bags for shipment and storage. It had a limited life in the humidor, as the water would tend to wick out and evaporate from the exposed edge.

My second trip to New York City included a visit to the Hogan plant, which was located on an upper floor of a nondescript manufacturing bulding in a nondescript neighborhood. Mr. Hogan was, I believe, the son of a man who had been a distinguished member of Institute of Radio Engineers, perhaps one of the founders. I don't remember much about the plant except for a machine which made the fax paper. There was a wide roll of paper stock; and the machine would cut it to the width the customer wanted and roll it up. I was surprised to see how many different widths were being made for various customers, varying from narrow tape up to wide paper for weather maps. This trip to New York was much more pleasant than the previous one. I was with Ran Slayton and Gene Sullivan. We arrived in the late afternoon before our meetings the next day. Ran had worked for Western Union in NYC before coming to Teletype and knew his way around the city. He asked Gene and me what we would like to do that evening. We decided we would like to have dinner in a nice restaurant, ride the subway, and go to the top of the Empire State building. Ran proved to be a fine tour guide to the big city and took us to do all of those things.

It is embarrassing to remember how naive we were to be working on fax machinery. Western Union and Alden and Hogan had years of experience and lots of money invested in the technology, which we set out to teach ourselves from scratch. For some reason Teletype decided to have the machines developed for us by Dixon Automatic Tool in Rockford, a machine tool company that had done some work for the Teletype factory and knew even less about fax than we did.

Their chief engineer was named Burns Darsie. At our periodic meetings he entertained us at lunch with stories of building torpedo boats in World War II. I don't remember much about the fax recorder they built for us. It was probably basically a ruggedized copy of the Alden machine. I do remember the scanner they were building for us, as it was quite a contraption. There was a lead screw to move a scanning head across the paper. At the same time it carried another scanning head, moved out of position, across the paper in the opposite direction. At the end of travel there was a mechanism to switch the just-used scanning head out of position and the just-returned one into position for scanning. It was fun to watch the two scanning heads moving in opposite directions, then hear a loud click at the end of travel, and then see them crossing again. [35]

Meanwhile we were working on the optical part of the scanner. We had some company in town make us a portable darkroom, essentially a pipe framework covered by a leatherette sort of fabric, the whole thing large enough to get a workbench inside. This allowed us to work on the light-sensitive parts of the system without disturbance from the normal office lighting. We frequently went to the nearby American Science Center to obtain lenses and other optical items. This was a store that catered mostly to amateur scientists and to students doing science fair projects. One of the problems we had to solve was producing a tiny spot of light for scanning. Paul Mitchell came up with the idea of using a microscope backwards; putting a light bulb at the viewing end and getting a tiny spot out the other end. I remember we also engaged an optical consultant to help us. In analog mode we got to where we were getting pretty good pictures. Digital mode was a problem because we were producing only one bit per pixel, so we needed a threshold circuit to decide whether a given pixel was black or white. We should have learned something about half-tone screens as used in the printing industry to handle grayscale pictures. As it was our digital pictures were pretty bad. One morning I came in and Paul had relabeled a switch on the control panel from "analog/digital" to "good/bad". The first time we sent a colored item, a magazine cover, through the scanner what came out didn't look anything like what went in. It was then that we realized our photo detector was more sensitive to infrared light than to visible light, and that the inks used in printing the magazine cover have very different reflection properties in the infrared range. We needed to filter the infrared out of our light source. American Science Center had something called "heat absorbing glass", used in slide projectors to keep heat from the projection lamp from burning the slides. That worked pretty well; but I also called around to

[35] Patents 3,546,707 3,553,359 3,555,266 and 3,688,032

some photographic equipment makers who offered real infrared filters of various kinds.

I have no idea why we didn't go to Western Union for a fax machine, or even invest some time in reading Western Union Technical Review. Perhaps the aversion to Teledeltos paper and recording technology were part of it; but still W.U. had a lot of experience with fax scanners as well as with recorders.

Ran Slayton was editor of the IEEE Transactions on Communications at the time. Since I was an IEEE member he would ask me from time to time to help out. We were developing a table of "descriptor terms." There was some notion that every article should be tagged with a few words from a standardized list so that an information retrieval system could search for relevant papers easily. One of my jobs was to skim through the submitted papers and select the appropriate descriptors, or to invent new ones if none of the existing ones seemed to be appropriate.

At Wrightwood our environmental testing facilities had been fairly primitive. There was a pretty good industrial oven that was big enough to hold one of the drawers of the 16-channel multiplex. For cold tests we used a household chest-type freezer. Then there was some process that required putting an oven into the freezer, and propping the lid open a calibrated amount. At Touhy Avenue we had first-rate facilities: a sound chamber, a screen room for RF testing, a temperature chamber, and a shake table. The shake table was a transducer, like a loudspeaker, that was several feet across. It was driven by a huge kilowatt size amplifier fed from an audio oscillator. There was a story about a Model 32/33 being bolted to the shake table; then someone plugged into the amplifier input without turning down the gain first. The transient was enough to make the machine fly all to pieces. Another story concerned a Model 32/33 that had been in the temperature chamber when the thermostat broke or was accidentally set too high. The plastic parts melted right around the mechanism, giving it a shrink-wrapped appearance.

Some other funny stories concern the plant cafeteria. Just about everybody who didn't bring in a lunch from home ate in the cafeteria; it was cheap and the food was good. An item on the menu was raw hamburger. One of the engineers in our group ate it from time to time. I never saw anybody else ask for it. There was a group of six or eight young men and women who always ate together in the cafeteria at one of the round tables. They always seemed to be enjoying themselves, talking and laughing a lot. Paul Mitchell called them "the gay group" at a time before that word acquired its present meaning. We had names for some of the cafeteria specialties. "Hockey puck" was quite good, a round piece of Italian sausage. (That name came from a line in a Tom Lehrer song, "She's My

Girl.” About her cooking, “...and if I’m in luck I’ll get broiled hockey puck.”) I was pretty thin in those days, though already worrying about a growing spare tire around the middle. One of the cafeteria workers, an older Irish woman, would see me in line and mutter something about “got to fatten you up” and pile extra potatoes and gravy on my plate. There was no choice of salad dressings; the green salad came already oiled. One time some of us noticed a group of people coming through the line, one of whom was obviously a visitor. We saw him go to the condiment stand and pour hot sauce all over a green salad; he must have thought it was a red French dressing. We watched to see what would happen when he took the first bite. It was quite suspenseful; he talked for a while, then picked up a big forkful and brought it near his mouth, then put it back down and talked some more, finally taking a bite of the salad. Immediately he turned red, started gasping, grabbed for a glass of water, drank it all down. We felt guilty afterwards for laughing at his predicament, but at the time it was pretty funny. I will mention later the importance of the company cafeteria as a medium of engineering communication.

While working on fax I undertook a bootleg project, with the blessing of John Auwaerter, to study a small computer that could be used for our systems business. It was clear that the era of switching systems based on paper tape storage and wired logic was over, as evidenced by the cancellation of CODIS and the emergence of switching computers such as the G.E. Datanet 30, the Collins C-8400, the IBM 7740 and others. I had a notion that we could build a much cheaper computer that would be useful for some things. I thought maybe we could use delay line memory because in our business characters came in and went out at regular intervals that were fairly long by computer standards. Perhaps the cyclic nature of the delay line would not be such a disadvantage if we could process characters from a number of lines during one cycle. To get an idea of cost I took basically the Packard-Bell 250 design and packaged it in Teletype standard cards. I came up with a cost of a few thousand dollars, as I recall. The idea was taken to some higher-ups for consideration of whether we should move on with it. It was turned down on the grounds that the 1956 consent decree prohibited the Bell System from doing any data processing; and this was perilously close to data processing. I never did any actual programming to see whether the cyclic concept was feasible. I learned much later that some company did use such a computer in a telephone switch; so I guess it was feasible, with enough ingenuity. In retrospect, it is a good thing we didn’t go any further with this because delay line memory had absolutely no future in the mainstream computer business. One thing the study did show was that we could have made a computer for a lot less money than it would have cost to buy one. Computer companies must have been extremely high overhead businesses. Yet even at those inflated prices customers were choosing computers in preference to paper tape and wired logic for message switching.

Al Reszka was also working on some ideas about computer-based switching. His concepts were quite different from mine; but we agreed that Teletype would have to do something like that if the company was to get back into the systems business. Al was also doing some studies on the proposed commercial Inktronic product. At one point he had concluded that it never would achieve reliable printing. I guess he either found a way out of the difficulty or was overruled, since a commercial Inktronic was produced for a while (and never did achieve reliable printing). At one time Al's department was working on the read-only memory for the commercial Inktronic. This was considered a highly proprietary concept, so his offices were closed to anyone not connected with the project. At least I assume that is what the closure was about; I don't know for sure since I wasn't allowed in there anymore. If so, this is amusing since the memory was basically what I had seen at Stanford Research Institute some years earlier; and a better design than Teletype's was already being produced by IBM to store the microcode in their System/360 Model 40 computer and in some peripheral controllers. [36]

About the time the Inktronic was getting into production for Project 176 I read in a trade magazine that Hewlett-Packard was making a plotter or strip chart recorder using electrostatic deflection of ink droplets. They were deflecting in one axis only, using the paper motion to cover the other axis. It was noted that they used an ultrasonic pulser on the ink supply. I mentioned this to Chuck Winston; but I suppose by then it was too late to go back into research to see if ultrasonic pulsing would result in more uniform size ink droplets.

Teletype always celebrated National Engineers' Week with a day or two of sessions in the auditorium and a banquet. There were speakers from within the company and also outside speakers brought in. One of the latter was a professor of business at Northwestern who talked about perception. He started off with a little rotating optical illusion. The nature of the demonstration was that those sitting near the front would infer one kind of reality from what they saw, while those sitting near the back would preceive something entirely different. Another of his illustrations was, "what do you say to a misbehaving child?" In the English-speaking countries you say "be good" because behavior is seen as a moral issue. In

[36] Published as "The Design of Transformer (Diamond Ring) Read-only Stores" in *IBM Journal of Research and Development*, September 1964, p. 443. This refers to earlier work done at Bell Laboratories.

France the corresponding saying is “be wise.” The child’s behavior is contrary to his own good. In Scandanavian countries you would say, “be kind;” misbehavior is discomfiting to other people. And in the German-speaking countries you would say, “get back in step!” because conformity to acceptable social behavior is being violated. Another speaker was a psychologist with a business of making tests for employment aptitude and that sort of thing. He was less convincing. One of the in-plant speakers was from the Engineer of Manufacture organization. He had a huge board displaying all the kinds of connectors currently in use in products. He didn’t need to say anything; the point was well made that before releasing yet another connector we should see if there wasn’t one already in use that would be suitable.

Speaking of connectors, the Warwick Electronics plant that made TV sets for Sears was nearby. I was told that Molex connectors were first developed for Warwick. Teletype adopted them in a big way.

Some of us got to go to a Bell System-wide engineering conference at Holmdel. I remember an interesting historical talk about the problems of early telephone offices. There was a talk about the new single-slot paystation telephone; how it had been designed to make it difficult to pry or break open, and how the coin chute discriminated between genuine coins and slugs. There was a talk by an engineer who designed shipping cartons. There was a talk by a couple of Teletype engineers about the Model 32/33 line, “a new product for a new market,” saying that for the intended light duty there was no need for the machine to be extremely durable they way the 28/35 products were made. It was further designed for ease of assembly and use of power screwdrivers. Reference was made to the German V-2 rocket and how the engine nozzle could be made of ordinary steel because it only had to last for three minutes.

John Edgren and I went to an IEEE conference held in Cedar Rapids. We got to visit Collins Radio as part of the conference. Collins at the time was making a message-switching computer. We got to see a lot of the Collins facility and how they used Teletype equipment and what they were doing in on-line computing. They were experimenting with making their own integrated circuits. I believe they said they didn’t intend to manufacture their own ICs, but wanted to have a good understanding of the processing technology. John soon went to work for Illinois Bell.

There were other auditorium presentations from time to time - I don’t remember which ones were connected with Engineers’ Week and which ones were held at other times. There was a talk by a man who did an annual(?) article for IEEE on advances in printing telegraphy[37]. He talked about all kinds of technologies in use worldwide: things like Hellschreiber and something with electrolytic paper and a tellurium electrode. He also talked about A. B. Dick down the street having developed a “cathode ray tube with a beard” meaning a CRT with an array of wires passing through the glass faceplate. This was used to print by depositing an electrostatic charge on paper passing the wires. Charged spots on the paper would then attract charged particles of dry ink. There was also a presentation about the Culler-Fried online computer system at University of California at Santa Barbara. This system used two keyboards; one for alphanumerics and one for mathematical functions. A mathematical function was represented as an array of values. Thus the sum or product of two functions could be computed by a term-by-term sum or product of the array values. The result was displayed on a video screen.

I remember walking through the sales area one time and noting that Teletype was hosting a meeting of the “Reactive Typewriter Society”. At the time I didn’t know what this group was about. Later I learned that it had some connection with the TRAC computer language developed by Calvin Mooers. Claude Kagan was quite an enthusiast for TRAC and used it in his work and also with a group of youngsters he was leading to study electronics and computers.

There were often interesting things to be seen in the Sales display areas, which were on two floors. There was a small switching system called TASP that was sold to urban police departments[38].

Teletype did some dabbling in edge-punched cards. Friden had tried to promote this medium as well. Teletype may have brought it to a product stage; but I don’t think there was any significant market for it. Now if we had made a machine to read IBM punched cards there probably would have been a lot of demand for that product.

Reperforator-transmitter sets in the Model 28 line were tall, narrow and deep, so that two of them could go side-by-side in a cabinet and so that large tape reels would fit underneath. I remember seeing an unusual R-T set, coded LRXD, which was built to the same form factor as the older FRXD, the backbone R-T set of the older store-and-forward message switching systems. The LRXD provided a 28-line plug-compatible replacement for the FRXD.

Teletype page printers from at least the Model 15 had been available in friction-feed and sprocket-feed versions. A machine could be converted from one to the

[37]I believe this is W. Y. Lang, author of “Advances in Printing Telegraphy in 1964”, IEEE International Convention Record, Vol. 13 part 1, 1965, and “Advances in Printing Telegraphy in 1965”, IEEE International Convention Record, Vol. 14 part 1, 1966.

[38]Probably the same as, or derived from, Halvorsen patent No. 2,625,601, Jan 13, 1953

other; but it took a non-trivial amount of work. Either way the paper was 8-1/2 inches wide. (There were some other, narrower widths available as well, requiring different platens.) With sprocket feed the paper would be 7-1/2 inches wide after the strips containing the sprocket holes were removed. Now in the mid 1960s there was a customer requirement for sprocket feed using wider paper. I don't know whether the reason was a need to print 80 columns, corresponding to the columns of a punched card, or whether there was a desire to have 8-1/2 inch wide paper after tearing off the sprocket hole strips. The designers were able to get a slightly wider platen into the typing unit. In hindsight one wonders why the desire for 8-1/2 inch paper between sprocket hole strips was not obvious all along. It would have been easy enough to make the Model 28 an inch wider when it was first being planned. Competing products, such as those based on the IBM Selectric, had wider platens as most typewriters do. In some of these it was a simple matter to remove the platen entirely, allowing friction feed and sprocket feed platens to be interchanged in a moment.

I had an opportunity to take an in-plant class in computer programming in FORTRAN. Teletype at the time had a couple of IBM 1401 computers and a 1410 computer in the business end of the business. When I first got there the old 650 was either still in use or had just been retired; and there was an IBM RAMAC 305 system in use. RAMAC (Random Access Method of Accounting) was a wired-program machine capable of things like inventory control. I guess it was rather like the Teleregister system I saw at La Guardia; it used a magnetic disk system for storage and had electric typewriters connected to it as terminals. IBM had invented magnetic disk storage over the opposition of some old product planners who believed punched cards were the only way to run a business. Punched card accounting was a well developed technology; but it didn't work very well in applications like inventory control where fast access to random data elements is a requirement. The 1401s had a FORTRAN compiler, which was of very interesting design because the 1401 was such a small machine. As a project for the class I wrote a program to calculate the sideband amplitudes of frequency shift keyed data signals.

Walt Zenner's retirement party in 1964 was a major bash, held in the plant with a banquet and what would now be called a roast. All the managers participated in skits. The new Model 37 stock ticker project having been completed, a representative of the NYSE was there to present Walt one of the old glass bell jar stock tickers as a keepsake. (Those tickers were already collectors' items at the time, having been replaced with a better Teletype ticker about 1930.)

Roger Klich was promoted into the position vacated by Walt Zenner. It seems to me there was a vacuum of leadership after Walt's retirement: not that Roger was not a capable leader, but that the company had run for so many years with Walt having all the answers. Now that he was gone there was nobody so authoritative. Part of the problem was external and coincidental. Under the old Bell System rules Walt's instincts couldn't be wrong. The ordinary customers had to take whatever they were given. Large, important customers could have something designed specifically to their wants. Teletype Sales was just beginning to consider that large groups of ordinary customers, e.g. insurance agents, could aggregate to a large important customer. With the advent of Dataphone service the rules were suddenly changed. Customers could shop around for data terminal equipment suited to their needs. At the same time there came a big increase in online computing. It was no longer a reasonable assumption that one of our machines was talking to a basically similar machine at the other end of a wire. Dataphone modems allowed speeds up to 2000 baud on dialup connections; and customers wanted to take advantage of those speeds since the charge for a call was the same regardless of speed. Computers, unlike people, tended to put out a lot more data than would be typed on a keyboard. Hence customers wanted faster terminals than were needed in the era of strictly people-to-people keyboarding.

Somehow I got moved off the fax project and into Joe Murglin's department. Alma Jordan was our secretary; Phil Barry worked in there on Model 37 planning; there were Detlev Brodrueck and Paul Shih and some other engineers and techs I don't remember. One of the assignments Joe and I worked on together was an attempt to create a vision for the future product line and present this in a meeting chaired by Roger Klich. It seemed like we would work all week on a presentation, make it at the meeting, and then Roger would say that was not quite what he wanted and ask us to come back again the next week. I remember at one point saying, "It looks like we'll be stuck with paper tape for a while." and he responded with something like, "You'd better hope we stick with paper tape for a while; it's the mainstay of our business." I found this disappointing, knowing that we needed to move into some other storage technologies. Neither diskettes nor magnetic tape cassettes had been invented yet. A forerunner to the cassette was a tape cartridge that RCA was promoting for entertainment. It was basically the same as today's cassettes but twice as large and used 1/4-inch tape. Scientific Data Systems had adapted this medium to computer use under the name Magpak. I remember talking to someone at SDS about tape formats and whether we could use the technology; but this never led anywhere. Nor did the RCA cartridge last very long in the audio market; it's just as well we didn't do anything with it.

Phil Barry and I decided we could measure how well the company was doing by watching the turnover of mail boys. The entry level job was delivering mail around the plant. If we got a new mail boy (or girl) at frequent intervals the business must be doing well, as they were being promoted and new ones hired.

Some time earlier John Auwaerter had showed me a product description for the IBM 1050 equipment. This was something like an ASR set; but the printer, keyboard, tape punch, and tape reader were separate boxes connected to an electronics box. There was also a punched card reader that could be attached. Because the parts were all separate modules a 1050 could be configured as a receive-only printer, or as a paper tape only transceiver, or as a KSR, or any other reasonable combination of capabilities just by plugging in the appropriate modules. John seemed to think this was an important concept; and I agreed. We also paid some attention to the IBM 2740 and 2741 terminals which had just come out. These were basically KSR sets built from Selectric typewriters. In fact they could be used offline as typewriters. They appeared to cost a lot more to make than an equivalent Teletype product, yet they rented for about the same monthly rate. There really wasn't an equivalent Teletype product at the time, as the 2741s offered upper and lower case printing. They might not have cost as much to make as we thought. IBM had some of the best manufacturing engineering talent in the world and probably could make things more cheaply than anyone outside that secretive company would have imagined. IBM was also free to manipulate rental rates and selling prices as they pleased. The IBM terminals, being based on an office typewriter design, lacked the durability of Teletype products. But they were sleek looking, didn't drip oil, were good for typing on letterheads, offered a variety of fonts, had great keyboard feel, and in general were quite appealing. [39]

I mentioned earlier that standard-speed products were subject to considerable interference by Bell Labs in their design. The Model 37 was the first product I worked on where this was an important factor. The Model 33 and Model 35 sets for dial TWX service used the 101 modems. These were big and costly and mounted in the pedestals of the machines out of sight. There was a 99-wire cable running between the modem and the Teletype product. Since the modem was out of sight there had to be most of a telephone built into the operator portion of the cabinet, allowing the operator to place and receive calls. Every one of the 99 wires was negotiated in long dreary meetings between Bell Labs and Teletype. For the Model 37 the interface had been cut down to 50 wires, but there was still a lot

[39] I recently heard an anecdote about a different company and a different product; but it involved a marketing man and an engineering-oriented executive. They argued whether their company needed a good product with excellent marketing or an excellent product with good marketing. This seems applicable to the situation with competing IBM and Teletype products.

of negotiation. Bell Labs insisted that a box of theirs, called a station controller, sit between the Model 37 set and the telephone line. They envisioned different kinds of station controllers for TWX, some other dialup services, selective calling private-line systems, etc.

We had learned that some of the Bell operating companies were avoiding the expensive dial TWX sets and simplifying their inventories by buying private line Teletype sets and connecting them to modems of the 103 family, which were relatively compact and included the telephone. This supported our thinking that in contrast to the Bell Labs vision we should have a product that stood on its own and was usable without any special station controller supplied by a telephone company. I started looking at the various applications of our equipment in relation to the RS-232 interface. This was a very interesting project. Even though RS-232 was intended strictly for modems it could be creatively interpreted to suit other kinds of systems. For example, the Request to Send lead was normally wired ON at all times with the full-duplex modems. In a polled private line system it could be used to indicate that the station had a message tape in the reader waiting to be sent. Hence if we provided a number of strapping options in our set it could be connected directly to a modem at the RS-232 interface, connected to a computer having that interface, or connected to a private line station controller in a polled or other kind of system. The basic Teletype product could connect to their station controller using RS-232. Then there could be a separate cable from the station controller to a key and lamp assembly to handle the conditions that RS-232 could not handle, such as a priority key or a telephone dial. I don't believe anything ever came of this idea. If I had had a better understanding of what Bell Labs was trying to accomplish I could have made a more convincing argument.

The Henry Dreyfuss industrial design firm did work for both Bell Labs and Teletype. This no doubt explains the similar profiles of the 500-type telephone set and the Model 32/33/35 machines. There is also a resemblance between the Dataphone sets and the Model 37 cabinet. For some reason there was no uniformity of color: the Data Phone sets were blue and gray and the Teletype 32/33/35 were beige and ivory. It is unfortunate that the industrial design did not extend to allow a Dataphone set to be neatly fitted to a Teletype machine. In the Type 2 DataSpeed machines we did have a special panel to accomodate the 202 data set in the cabinet. In Type 5 DataSpeed the receiving modem was a large box, and then there was a ”data auxiliary set” that sat on a shelf in the cabinet with another special panel to surround it. The data auxiliary set was nothing more than a key telephone but designed to resemble the 202 data sets. I don't know where you would put a Dataphone set in a Model 33/35 machine; but that combination would have eliminated a lot of the complexity and variability of the call control units and the earlier 101 data set in the base of the cabinet. I suppose the later Dataphone products were not forseen when the Model 32/33/35 machines were originally being designed for Dial TWX.

I picked a fight with the mechanical designers of the Model 37 typing unit. They had decided it should have online settable tabs. Previous products had had vertical and horizontal tabs settable only by a maintenance technician. It seemed to me, considering the machine as a computer terminal, that online settable tabs were fairly worthless. For one thing, a programmer would not go to the trouble to figure out all the tab stops that might be needed in an application and then write the program to generate the correct number of tab characters for every use of them. The other problem was that after sending a tab character the sender had to wait to allow the receiving machine to get positioned. In teleprinter-to-teleprinter operations we had used contacts on the printer at the sending end to interrupt tape transmission, on the assumption that sending and receiving machines would need about the same length of time to get positioned. With a computer program it would be necessary to calculate estimated time delays; they would probably be generated by sending fill characters rather than by actually delaying transmission for a time interval. I argued that a much more useful feature would be a horizontal jump of three spaces (the speed of tabbing was three spaces per character time). The computer could calculate the number of jump characters needed to position the print head to the nearest position, and then if necessary add one or two spaces. The mechanical designers would have none of it; they had figured out how to design online settable tabs and that was what they were going to do. As things later turned out in the computer timesharing business there was a *de facto* standard that tabs were set every eight character positions. The computer would be told whether the terminal had tabs. If it didn't, the computer would send the correct number of spaces to get to the next tab position when a horizontal tab character came along.

The Model 37 keyboard was another source of distress. It was similar to the Model 33 design, already famous for really awful touch, and promised to be even worse with its greater number of keys. John Auwaerter told me that the keyboard designers knew how to design a keyboard with rotary code bars - presumably similar to the IBM keyboard design with its superb feel - but that there wasn't time to develop such a keyboard given the schedule for the Model 37. As it turned out other aspects of the Model 37 delayed the schedule; there would have been enough time to develop a good keyboard, but the decision not to had already been taken.

One of those delaying factors was the selector. It's hard enough to get a mechanical selector to work at 110 baud; at 150 baud it was seriously hard. At the same time Bell Labs said they couldn't guarantee a low-distortion signal from their modem at 150 baud. Detlev Brodrueck was doing some experiments with integrated circuits. Somebody else in the company was talking with semiconductor companies about a future product along the lines of what we now call a UART - an electronic sending and receiving distributor on a single chip. We figured we could make, at acceptable cost, a regenerative repeater out of integrated circuits. This would clean up the signal from the modem and allow the selector mechanism to get by with poor distortion tolerance. Personally I favored making the printer parallel input; this might let us run it well about the targeted 150 WPM. As it turned out the mechanical people worked and worked until they had a satisfactory 150 baud selector. This was one of the factors that delayed the product; but at least it satisfied Mr. Krum's dictum of 1925 that as much as possible should be done mechanically rather than electrically. This is a case of something that had become so much a part of the corporate culture that it was hard to accept the fact that the world had changed. I certainly did not forsee the rapidity with which microelectronics would render Teletype's prowess in things mechanical worthless; but it was clear that in some areas we were up against the limitations of mechanical technology. Another lesson which can be drawn from this is that a project which is challenging, which motivates the engineers to exert their best efforts, is not necessarily a project which should be done.[40]

I don't believe the Model 37 would have had much of a service life even if it had come to market on schedule, which is to say in the late 1960s. As noted earlier there were Dataphone modems substantially faster than 150 baud, soon followed by faster third-party modems. For use as computer terminals customers wanted the fastest possible printing or CRT display because computers put out lots of data in response to a little keyboard input. The daisywheel printer was soon to appear on the scene[41]; and after that the second-generation dot matrix machines able to produce a variety of good quality fonts. The Model 37 represented practically the last instance of intricate mechanical technology. The later printers all used the simplest possible mechanisms and relied on electronic logic for the complex operations. Another problem for the 37 was that it was only 50% faster than its predecessor. I don't consider this a hard and fast rule, but sometimes it's not worth

[40] From looking at a Model 37 parts book recently, it appears that some sort of integrated circuit regenerator was part of the product. I don't know whether this was used for receiving or for transmitting.

[41] Teletype had patented a daisywheel printer in 1938, but without electronics it was not a very promising product. See Reiber patent 2,146,380.

developing a new product unless it outperforms its predecessor by at least 2:1. It's interesting to speculate what might have been done if Teletype had set a goal for itself of a 300 wpm printer.

Joe and I made some more enemies as we argued that product development should be guided by marketing sense. We found someone developing an R-T stand at the request of Pacific Bell. We asked how many of them Pac Bell was going to buy. "Three," was the answer. Someone else was developing an eight-level keyboard perforator. We asked who the customer was. "We don't have one yet, but there is a five-level perforator in our product line, so we figured there should be an eight-level one too."

The Model 19 had a switch on the front: Keyboard, Keyboard-Tape, Tape. The tape punch and the signal generator were both connected to the same set of keyboard code bars. In Keyboard position the punch was deactivated. In Keyboard-Tape position both punch and signal generator operated. In Tape position the signal generator was disconnected. Thus in Keyboard position one could transmit without using tape. In Tape position one could punch tape "blind", perhaps while receiving a message on the printer. In Keyboard-Tape position one could transmit and punch a tape copy at the same time. More likely one would put the keyboard and printer on a local circuit to get printer copy while punching a tape for later transmission. (Which implies there is also a Line-Local switch, or at least some way to run the machine on a local loop without sending anything off-site.)

This was carried over into the Model 28 ASR, which also had a punch mechanically connected to the keyboard code bars in most versions. There was a big knob on the front of the machine marked K K-T T. The same idea was carried over into the Model 35 ASR. I don't remember a purely-mechanical punch in the 35 line; I believe the punch was run by putting the keyboard and a reperforator into a local loop in the T and K-T positions.

Meanwhile the Model 32 and 33 ASR sets were similar to a design popular in Europe but not previously used by Teletype. The tape punch was connected to the printer code bars. This made it possible to punch tape from a received message, something that required an auxiliary reperforator in Model 19 and Model 28. However it precluded blind punching while receiving traffic. The tape reader was connected to the keyboard contacts, so it was not possible to transmit from tape while using the keyboard and printer to punch tape locally. There was usually a Line-Local switch.

A further complexity was that in some models the tape reader or punch or both could be commanded on or off by characters received on the printer and decoded in the stunt box, at least on ASCII models. It began to bother me that we had such a variety of controls, making it hard to explain to an operator how to do what needed to be done and what could not be done on some models in some cases. The expression “user friendly” was not to be invented for a long time to come; but what we had was definitely not it. I sketched up a design for what seemed a more rational set of controls: Line-Local toggle switches for the printer and keyboard and Line-Local-Off pushbuttons for the reader and reperforator. This design was never tested on naive users or otherwise, so I have no idea whether it was actually any better than the traditional one. Someone at Bell Labs had worked on this problem a long time previously. Tape preparation stations for the 81D1 switching system had a key labelled “copy while perforating/copy while transmitting.”

Related to the above, but hidden from the users, was the issue of how to get local copy of transmitted signals. With half-duplex circuits you get local copy as a side effect of transmitting. With full-duplex circuits, such as were provided by the Bell 100-series modems, we had to make an internal connection to get local copy, since the incoming signal was separate from the outgoing. Some of the computer time-sharing companies were operating half-duplex to simplify their equipment. Others used a mode they called echoplex, in which the full-duplex transmission is used and the characters received at the computer are echoed back to the terminal. This has the advantage that in case of poor transmission the operator can see that the computer is getting garbage. It also allows the computer to control local copy, e.g. turning off echoing when the user is typing a password. Half-duplex systems had to print a black blotch to hide the password by sending some characters, carriage return without line feed, send some more characters, etc. and then let the user type the password. Obviously this works only with hard copy terminals, not with video terminals that cannot overstrike. With half-duplex operation there must be a Break key, as there is no other way to interrupt a computer that is sending unwanted output. With full-duplex operation any convenient character can be designated an interrupt character, as the computer can detect incoming characters while it is sending.

That reminds me of another issue that came up while ASCII was being revised. With hard copy terminals we assumed the ability to backspace and strike over a character. This might be used to add diacritical marks, for example. With video terminals as usually implemented there was no strikeover capability; backspace followed by a character replaces the previous character rather than adding to it. Apparently the designers of computer timesharing systems were not paying any attention to the people working on ASCII, and vice versa, because we got some practices in the computer industry that were misuses of ASCII characters. It became popular to use rubout to mean “discard the previous character” and a string of *n* rubouts to mean "discard the previous *n* characters." Hence if a computer received characters from a punched tape that had been corrected with rubouts it would discard unintended characters. It became equally popular to use backspace as an eraser, analogous to a manual typist backspacing and striking over for correction. On video terminals backspace usually just moved the cursor backwards, so it was necessary to transmit backspace space backspace to erase the unwanted character from the screen and position the cursor to enter its replacement. Hardcopy terminals often did not have a backspace capability, so whichever character was used for erasure it was useful to print some character such as a slash to remind the user how many characters had been erased. For some reason it became popular to use ETX to mean "interrupt the currently running program and kill it." EOT came to be used to mean "end of file" even though ASCII had the character FS assigned for that purpose. (Some Teletype equipment was arranged to put the modem on-hook on receipt of EOT.) No doubt some of these choices were made to get single-keystroke or CTRL plus single-keystroke commands on early Model 33s and 35s that could not produce all the characters in the ASCII set.

Then there was the issue of bit-paired versus typewriter-paired keyboard arrangements. Mechanical keyboards could not have arbitrary assignments of characters to upper and lower case; the characters on upper and lower case positions of a key had to differ by only a bit or two, in some systematic way for all keys. Often this led to a keyboard arrangement that was not the same as conventional typewriter keyboards, where the character assignment was completely arbitrary. Now that we have electronic keyboards and translation software this all seems very quaint; but at the time it was a major headache in code design.

I have already mentioned Teletype's generally under-recognized role in fostering computer time sharing by producing the Model 33. I began to get the notion that perhaps *APL* would be the next big thing in the time sharing business. *APL* is a programming language based on the work of Kenneth Iverson in his book, "A Programming Language." It makes use of an elaborate character set, including Greek and Roman characters and some unique symbols. To make it a practical programming language IBM had reduced the character set to something that would fit on the ball of a Selectric typewriter, and hence on a 2741 terminal. This was 88 characters, if I remember correctly. Teletype had two upper/lower case machines in development, Models 37 and 38, the latter derived from the 33. I also felt there was a future for what we now call word processing, which would require an upper/lower case terminal. Perhaps a low-print-quality terminal would be fine for input and for draft printing, using a more expensive machine for producing final copy. For these reasons I felt there was some urgency to get the Model 38 into production. Claude Kagan insisted that it was easy, that he had made a few parts and converted a Model 33 to print upper and lower case. As things turned out the Model 38 didn't get into production for several years. When it did it was not just an up/low Model 33; it had been widened to handle 14-inch computer forms. This introduced some reliability problems. *APL* is still around today, but it remains a small niche language with probably a dwindling number of afficianados. Word processing is of course a major application of computers, unconstrained by any need for a hard copy terminal; but in those days we had no idea there would ever be microcomputers. We can only guess what might have happened if the Model 38 had come on the market a lot sooner.

While the upper/lower case projects were under way someone (Walt Zenner, I guess) got the idea that maybe we could fake it with a specially designed type font. The Henry Dreyfuss firm was asked to design a new font that would look like lower-case but would not offend people by having proper names uncapitalized. A font was designed, a Model 35 typebox was produced, and a monograph was written and circulated explaining the project and giving illustrations. And that was the end of the "monocase" font, which was hard to read and didn't fool anybody.

From time to time there were rumors that Teletype would be spun off from the Bell System or perhaps sold to Western Union. Maury Goetz, the president of Teletype, remarked that the rumors were not new, and that whenever he would visit Western Union headquarters on business they would show him a little desk in a dark corner and say, "See here, Goats, we have a place for you when we take over Teletype."

In the late 1950s Western Union introduced Telex into the U.S. Telex had been in use in Europe since the 1930s. It was a circuit switched teletypewriter service similar to TWX, but with dialup connections rather than manually operated switchboards, and was international. In my opinion this was a major mistake for W.U.[42] First, it put W.U. into head-to-head competition with AT&T's TWX service; and AT&T owned nearly all of the local loops that were necessary to provide the service. Second it required W.U. to spend lots of money on electromechanical switching equipment and on new customer teleprinters. Electromechanical switching was about to be obsoleted by electronic switching. It probably annoyed customers as well by making it necessary for them to subscribe to both TWX and Telex. Telex operated at the European standard speed of 50 baud. W.U. was the major customer for Model 32 equipment.

It was always an article of faith with Western Union people that Bell's TWX

[42] However, I have been told that Telex was a big money-maker for Western Union.

service violated an agreement reached many years ago that Bell would "stay out of the telegraph business" and W.U. would abandon the telephone business. W.U. made repeated attempts to get the government to force AT&T to sell TWX to them. Their campaign was "one national carrier for voice, and one for record communications" as if the wires cared what kind of signal was passing over them. AT&T always countered that TWX was considerably entangled with the voice telephone business, sharing most of the same plant, so that separating the two would be almost impossibly difficult. Eventually W.U. prevailed and purchased TWX from the Bell System in January 1969.[43] I wonder if the executives of either company realized at the time that the best days of this kind of service were already past. A few years into the future it would be obsoleted by cheap customer-owned fax machines, the combined result of Japanese electronics, the Carterfone decision, and cheap long-distance telephone service. We wondered at the time what effect the sale would have on Teletype, since so much of our product went to TWX.

I never stopped thinking about how to make the product line modular *a la* IBM 1050, but I never came up with anything practical. In Model 32/33 the keyboard and tape reader were simply wired in parallel; each was arranged to open its contacts when not in use so as not to interfere with the other. It was hard to beat that for simplicity, even though it lacked generality. Perhaps the later Standard Serial Interface was someone else's take on making a modular set.

There was a project to make a block error correcting high speed tape set. I remember something like this being worked on in the late 1950s. It involved a reader that could back up and re-read, and a punch that could pull the tape backward and punch rubouts over a block of tape found to contain an error. By the mid 60s Walt McClellan had charge of this project, which was to be Type 4 Dataspeed. I have heard this did actually get into production. One major thing wrong with the concept is the time it takes to read a block of rubbed out tape. To me at the time it illustrated that Teletype needed to have some other technologies to employ: in this case small magnetic core or disk memory buffers that could hold a block for error checking and retransmission.

AT&T started talking about a system to be called #1ESS-ADF, something that was to use the computer of #1 ESS for data switching. I never understood exactly what the system was proposed to do; but it seemed to me that anything along those lines would be getting awfully close to the area of data processing prohibited by

[43]Government policy over many years seems to have been to keep W.U. with exactly one foot in the grave at all times.

the 1956 consent decree. I never heard much more about it. (I later learned that it was built, and used for TWX switching and also for some Bell System internal store-and-forward services. The literature [44] suggests that a single #1 ESS ADF could perform message switching for several customers at the same time, keeping their respective traffic segregated. After TWX was sold to Western Union further development of #1ESS ADF ceased.)

In any case the product was probably too late for the market; the days of pure message switching systems were over. Customers were using computer-based switching; and they wanted to do data processing, not just pass messages between people. The data switching computers that some companies were making wound up being adjuncts to data processing systems rather than standalone switching nodes. However I can imagine there would have been a good market for a service that would let a computer time sharing company give its customers a local telephone number to call, while the computer might be located far away.

There was the Great Model 35 Regenerator Crisis of 1965. Model 35 machines had as an optional feature a regenerator intended to clean up signals from keyboards and tape transmitters. I don't remember how the circuit worked, but it involved a circuit card with an SCR, and a timing contact operated by a cam in the transmitter[45]. The timing contact was supposed to deliver more accurately timed pulses than were available from the main transmitting contacts. Although this circuit had been designed in as an option, nobody had ordered any sets with it installed. Then AT&T decreed that as of a certain date all their Model 35 sets were to be furnished with the regenerators installed. Trouble was, the circuit didn't work at all reliably, delivering incorrect bits instead of sloppy-timed pulses without the regenerator. There was a period of several weeks when finished sets were being stacked in every available place in the factory as they couldn't be shipped. I believe the trouble was traced to a well-known phenomenon of an insulating film forming on contacts when the circuit voltage and current were not sufficient to keep the film burned off.

During this time Bob Weitbrecht was working on telephony for the deaf, which ultimately turned into the TDD machines of the present day[46]. Bob had a great ability to do things simply. He had done some experiments with transmitting TTY signals around the San Francisco Bay Area over dialed-up phone connections (ignoring the no-foreign-attachments rule). He used both frequency shift keying

[44] Bell System Technical Journal, December, 1970.

[45] Probably Scott patent No. 3,217,182.

[46] The full story of this work is told in a book, "A Phone of Our Own," by Harry Lang of Rochester Institute of Technology, published by Gallaudet University Press.

and make-and-break using the space tone only. The advantage of space tone only transmission was that no send-receive switch was needed. When he undertook to transmit longer distances, between the Bay Area and Pasadena, there was a problem with echoes causing garbled copy. Bob found a solution in transmitting FSK, turning on the carrier at the beginning of a start pulse and turning it off after a few hundred milliseconds of no typing. The detector operated on space tone only; the mark tone served only to overpower the echoes and desensitize the detector to them. He got a patent on this scheme.[47] Bob and some friends started a company to manufacture modems, to be used with second-hand 45 baud 5-level teleprinters. Some of the more affluent users bought new Model 32 machines from Teletype. The deaf people appealed to both the Bell System and the U.S. government for support and got none. The Bell System wasn't interested in a service that depended on the uncertain supply of used teleprinters, that used a modem incompatible with their own, that used an acoustic coupler, and basically duplicated the existing TWX service. The government wouldn't support anything that didn't use ASCII. Several years went by, during which computer companies flooded the country with acoustic-coupled modems. The political climate changed in favor of much greater commitment to aiding the handicapped. Eventually the technology was there to produce compact inexpensive terminals, typically using dot-matrix printing on thermosensitive paper. Today the service called TDD is available subsidized to deaf people everywhere in the U.S. It still uses 45 baud Baudot and the Weitbrecht modem.

I had thought that a Model 33 with a built-in originate-only acoustic coupler modem would be a nice product as a computer terminal. Of course the Bell System would have nothing of it; so there was a market opportunity for some third party to buy Model 33 machines from Teletype and add modems and sell them. Some of us used to say that it would be fun to start a business right across the street from Teletype, buying machines and parts from Teletype and configuring them into what customers really wanted.

Fred Mocking was interested in educational projects; he was an adviser to a junior engineering group. We gave some thought to designing a computer that would be built with relays, obtaining the relays from Bell System scrap. (At the time Western Electric had a program of giving away surplus parts and equipment to educational institutions.) I don't think this went any further than talk and a few sketches.

In amateur radio there was a Chicago area RTTY organization, but for some

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[47] Weitbrecht patent No. 3,507,997, April 21, 1970

reason I never went to any of their meeetings. I did attend a couple of the annual Chi-RTTY gatherings, where were held at McCormick Place in connection with some big conference, maybe IEEE or maybe NEC. People came to these from all over - Merrill Swan attended some of them, as did other well-known ham operators. There was a genuine colonel from Kentucky; he was commander of the state police and the proud owner of a new Model 32 ASR set.

One of those things that seems obvious now 35 years later but never crossed my mind at the time - Teletype should have undertaken to develop a teleprinter having no adjustments or lubrication. Not with the idea of producing such a machine in the short term, but with the idea of learning how to do it for some future product. Just looking at the adjustments and lubrication book for any Teletype product must have been scary to any prospective purchasers. Such a study might have produced something along the lines of the later Diablo and Qume daisywheel machines[48].

When I returned to Teletype from the Air Force I guess I had never given much thought to the role of Teletype within the Bell System. I assumed that systems like multiplex and ADIS were a normal part of the mix of ongoing projects in the company. After becoming familiar with AUTODIN and playing with the little Packard Bell computer I expected to have a lot to do with getting Teletype into the newer technologies for its systems work. I never thought about applying to Bell Labs or Western Union because I had been so happy at Teletype in my two summers there. Thus I was disappointed when I realized that Teletype had no future in systems work, and that Bell Labs was jealous of its own turf and regarded Teletype as merely a component supplier. Much as I enjoyed working at Teletype I started to feel that it was time to move on. I certainly was not prescient enough to realize that microelectronics would soon wash away the underpinnings of Teletype's entire business. I just didn't want to spend the rest of my life doing communication terminals for other people's systems. So I started interviewing companies that seemed likely prospects.

One was Collins Radio in Cedar Rapids. Collins had a reputation as the top of the line in avionics, broadcasting equipment, amateur radio, and military radio. They had a message switching computer product and were planning to do more along those lines; the man I interviewed specifically mentioned airline reservations systems. Collins made me an offer; but I decided Cedar Rapids was not where I wanted to live. As things turned out Collins soon faltered badly, lost tons

[48] Ran Slayton's museum tour document mentions a daisywheel printer that Teletype had started to develop.

of money without gaining a toehold in computing, and was eventually swallowed up by aerospace giant Rockwell.[49]

Another company I interviewed was Scientific Data Systems in Santa Monica. At the time they were in the minicomputer business, sort of a West Coast version of Digital Equipment Corp. I don't remember if they made me an offer. Before I left Teletype they had introduced a new computer line somewhat resembling the IBM System/360 but not compatible with it. They later produced a highly-regarded timesharing system running on these machines. Then they were acquired by Xerox, the first of several misadventures of that company outside the copier field.

I interviewed a couple of times with General Electric in Phoenix, getting an offer the second time, which I accepted. Coincidentally Teletype had plans to replace its IBM computing installation with a G.E. machine. When I mentioned my new job prospect to a friend who worked for IBM he confided that G.E. was the one competitor IBM was really scared of. I assume that was because G.E. was the only competitor rich enough to mount a serious challenge to the industry leader. IBM need not have worried; G.E. was highly decentralized and unwilling to bring enough resources to bear on one market segment to mount a serious challenge to a one-industry company like IBM. Further, G.E. had almost no high-level management that understood how to run a computer business; but that is getting ahead of the story.

G.E. had, however, caused IBM a serious loss of face by winning the contract to produce the computer for MULTICS at MIT. The goal of MULTICS was to make the time sharing system to end all time sharing systems, and was a DARPA-funded joint effort of MIT, Bell Labs, and the computer vendor. IBM had a cozy relationship with MIT, expected to win the machine contract easily, and was stunned when that did not happen.[50] [51]

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[49]As documented in the book, "Arthur Collins - Radio Wizard" by Ben W. Stearns. It seems tragic that Art Collins had an excellent vision of the future of computers and communication, but pursued it obsessively at a time when the technology was just not there yet. After reading the book I am really glad I didn't take the offer of employment at Collins.

[50]IBM rushed to produce a similar machine, System/360 Model 67, and promised a MULTICS-like operating system to run on it. The latter was never delivered. Customers ran the machines as Model 65s; or in the case of University of Michigan with an operating system written in-house.

[51]MULTICS had a lot of influence on operating system design, but proved to be an evolutionary dead end as a product. It was married to a large, costly mainframe computer. Time sharing systems running on minicomputers soon proved to be more appealing. They were relatively inexpensive to begin with; and a facility could be expanded simply by buying more of them. The UNIX operating system from Bell Labs was practically given away to educational institutions, ran on

It's a little odd that I had not given any thought to working in the computer field at the time I graduated from college. At that time I had thought that computers involved some interesting technology; but I wasn't interested in working on things that sat in glass-enclosed rooms and received all their input from punched cards. It was only when computers began to be used in online applications that they attracted my interest. I also was well aware that stored-program logic and magnetic storage were going to displace wired logic and punched paper tape in all kinds of systems applications.

I remember seeing at Teletype a Model 33 printer with a cash drawer underneath. It might have had a 10-key keyboard. There was talk of getting into the point-of-sale terminal market. In view of the consent decree restrictions I suppose the concept was for the telephone company to offer point-of-sale terminals and communication with the customer's computer somewhere else.

I hit the road for Phoenix two weeks later, in the early summer of 1966, leaving behind one unfinished project. Teletype was getting interested in numerically-controlled machining. There was a desire to connect a DRPE punch to one of the 1401 computers so that we could generate our own tapes to control the machines. I was asked to do the connection. IBM offered a customer-hardware interface to their machine as an option. They charged something like $150 a month for this feature. Perhaps in retrospect that would have been the most reasonable way to go; but I decided the price was too high and that I would instead make the DRPE connection emulate a magnetic tape drive. The tape drive interface was available at no extra cost, as tape drives were simply daisy-chained off the machine. This was not a totally harebrained scheme; some other company produced a successful time-of-day clock for IBM products that connected to the tape drive chain. Most of the tape drive logic was done inside the computer. The drives themselves were pretty simple, having only read and write amplifiers and the tape motion signals. One complexity of writing to a tape was that the drives had read-after-write heads and sent read signals back to the computer during writing. I don't think these had to be the same characters that were written; I think they had only to have correct vertical parity. I was going to use the logic circuits I had experimented with earlier: high speed transistors on standard Teletype circuit cards. I don't know whether the project ever got completed. About the time I was leaving Teletype had taken delivery of a Honeywell 200 computer, a machine that was directly targeted at IBMs installed base of 1401s. Perhaps by the time the DRPE project

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popular minicomputers, and was considered by many to be superior to computer manufacturers' own offerings. Then microcomputers took over.

had been completed there would not have been a 1401 to connect it to.

From this point on I will leave out a lot of personal history, confining the account mostly to things that involve Teletype.

Phoenix was quite different from Chicago. The climate is fairly pleasant for 8 or 9 months of the year and unbearably hot the other 3 or 4 months. For that reason most of the growth of the city had taken place in recent years, after the large-scale deployment of air conditioning. Hence it was mostly a low-rise city, very spread out, suburban-looking, automobile friendly, and new. The G.E. plant was near the northwestern edge. I rented a house on a large lot a few miles from the plant. There were cotton fields nearby; and in one field was a weatherbeaten sign saying a big shopping center would be coming soon[52]. In my yard were several grapefruit trees with fruit all over them. At first I assumed the fruit grew year round; later I learned it all got ripe all at once but you could just leave the fruit on the tree and pick it when you wanted to eat it. At the supermarket down the street the grapefruit was all from Florida.

In Ran Slayton's department at Teletype we had hired Jim Eller as a technician. He showed up in Phoenix working for Motorola and stayed with me for a little while until he found a place of his own. Jim was responsible for introducing a couple of neologisms into our pre-lunchtime vocabulary. "Djeet?" (Did you eat?) and if you replied, "No" then the response was "Squeet" (Let's go eat). I took the responsibility to carry these into G.E.

I saw Ray Morrison one more time. He had retired and moved to Sun City, next to Phoenix.

The corporate culture and working environment at G.E. were quite different from anything I had experienced at Teletype. The general manager of the department was a Dr. so-and-so. Teletype people had seemed fairly disdainful of PhDs. There seemed to be a belief that the experienced mechanical designers and the experienced people on the shop floor had a knowledge base far more useful than anything represented by the academic distinction of a doctoral degree.[53] G.E. seemed to have considerable pride in and reverence for its doctors. I suppose in the Bell System as a whole Teletype was somewhat an anomaly in this respect, considering how PhD-heavy Bell Laboratories was. At G.E. managers were called managers; that title carried a certain reverence. I was to learn over a period of

[52]I guess there had been a downturn in the local economy that had temporarily derailed some big development plans. When I passed through Phoenix several years later the shopping center had been built; and it was indeed big.

[53]However there was a Dr. Potts who had a long inventive career at Teletype; and there had been a Dr. Carlson in Teletype R&D when I worked there in the summer. There seems to be some question whether either of these gentlemen contributed anything worthwhile to the product line.

time that there was a sort of cult of management that pervaded the company. The first-level managers of engineers tended to be engineers themselves; but at higher levels it seemed as if management was considered a science in itself, and that a a G.E. manager could manage anything, from light bulbs to locomotives to computers[54]. Another G.E. doctrine, quite a good one I thought, was that engineers should be able to remain engineers if they wished, and not be forced into management to advance in their careers. There were a few engineers in the plant with the title of "consulting engineer." They were top technical experts who could be consulted on problems that were beyond the ability of the rest of us.

The engineers' offices were cubicles, most holding three or four people. Labs were out in the plant, quite a distance away. Perhaps the circuits people had labs in their office areas. In those days a computer was so big that I guess it wasn't considered practical to have the designers' offices in the midst of their labs. Also computers were awfully noisy with all the fans and blowers, so it would be hard to work around one. The circuit designers, logic designers, and power supply designers were all separate groups and didn't have much mutual communication. Unlike Teletype, G.E. didn't like to make mechanical things. Cabinets and logic frames and front panels were necessities; but otherwise we were told as much as possible to use parts that could be bought ready-made. Drafting was done in a central department. Control panels were made using numerically-controlled milling machines. Tapes to control the machines were prepared in the drafting department. It was a tedious and error-prone process. An engineer told me the story of the control panel for his project. When the machine had finished there was an unintentional extra hole. The draftsman reworked the machine control tape several times, each time getting the unwanted hole to move but not eliminating it. Eventually one of his changes moved the hole near the edge of the sheet, where the metal would be bent down and the hole would be out of sight. They decided that was time to leave well enough alone.

What I came to consider most significant, although it dawned on me gradually, was the coffee system. Teletype, perhaps through wisdom, perhaps through ignorance, kept the cafeteria open all morning. The different engineering groups would go for coffee at staggered times; but almost all the people in R&D passed through the cafeteria every morning. There was a lot of overlap in groups coming and going. The result was a high level of informal communication among the

[54]Scott Adams reports that many people see in his Dilbert comic strip a caricature of the companies they work for. For me the pointy-haired manager character seems to have G.E. written all over him.

entire technical staff. A new idea or interesting observation, mentioned casually during the morning coffee break, would be known throughout the R&D organization by noon. At G.E. the cafeterias operated only at meal times. There were coffee and soda vending machines throughout the plant and office areas. The engineers got their refreshments from the machines and returned to their desks to consume them silently. There was practically no inter-cubicle conversation. No doubt the vending machines were a great dollars-and-cents saving over keeping the cafeteria open; but I am convinced that any savings were far outweighed by the loss in informal communication. Another problem with the cubicles was that a talkative co-worker had a captive audience to distract from their work.

Soon after I went to work for G.E. I ran into Dennis Bobka, who had also left Teletype. G.E. at the time had an aging but highly regarded data communications processor, the Datanet-30. Dennis worked in a data communications group, where his expertise with Teletype's customer applications was quite valuable. Later I think he went across town to work for Motorola.

G.E. at the time seemed to have the best knowledge in the industry of data communication and data flow in the enterprise. Perhaps this was one area where the high status of management was a help rather than a hindrance; professional managers knew what they wanted from a data system. IBM, it seemed to me, had a much too computer-centric view of the world. They regarded a terminal keyboard as a particularly unruly species of card reader.

Labor relations at G.E. were strange. The computer department in Phoenix was a non-union plant. Phoenix natives tended to be anti-union. Arizona is one of the sparsely-populated not-very-industrial states. The natives tended to think of unions as those things they have back East in the steel mills, and in New York City where graft and corruption are endemic, and in California where the union workers are all communists. They preferred for themselves the Western lone cowboy ethos, and voted for Barry Goldwater. Other G.E. workers had come to Phoenix from G.E. plants elsewhere in the country, and were generally fed up with all of the petty nonsense that the unions there habitually engaged in. One of my fellow workers, a technician from Canada who was something of a conservative provocateur anyway, told of a trip he had made to see about something at a G.E. plant in Syracuse. Within fifteen minutes of his arrival he had been the cause of a union grievance. Whatever he was going to do required an oscilloscope. As there was not one in the room he walked across the hall and found one not in use and rolled it to where he needed it. The union contract required that only union technicians move test equipment between rooms.

Still it seemed that the G.E. management in Phoenix did not appreciate the anti-union sentiment in the plant, nor attempt to foster good labor-management relations. Perhaps the management training was geared toward dealing with the militant unions militantly, and didn't allow for the possibility of a labor force willing to cooperate with management. Or perhaps it was that in the absence of a union management couldn't figure out a mechanism for two-way communication with the labor force, there being no persons formally designated to represent the workers in dealing with management. Whatever the reason, time after time management made arbitrary, unilateral decisions with no apparent concern for the feelings of the workers. Each time I was surprised that the workers did not flock to the representatives of the big electrical unions, who were always hovering around, and demand union representation.

Another personnel phenomenon at G.E. was that the first-level managers of engineers were extremely retentive of their employees. If some other manager wanted you to work for his unit, and if you wanted to do so, it was practically impossible to get your own manager to let you go. It was said, and perhaps not jokingly, that it was easier to quit and get rehired than to get a transfer from one unit to another. I didn't try it.

My first engineering assignment at G.E. sounds like a half-day Teletype project: design a transmitting distributor to send several characters of ASCII to a Model 35. It took several months to complete. First I had to learn the G.E. logic circuit set. This was a bit strange. There were logic-level circuits like NANDs and flipflops. Then there were pulse circuits using blocking oscillators and pulse transformers. To trigger flipflops one had to use these pulse circuits; it was not permitted to use the edge of a level pulse to trigger flipflops. So my initial design was turned down by the more senior engineer in the cubicle, although it probably would have worked just fine. After getting a satisfactory logic design I had to go through design automation. Everything possible was wired by automatic Gardner-Denver machines; so it was necessary to put logic diagram information into a form that could be processed through several stages and eventually produce a deck of cards for the wiring machine. I was somewhat familiar with IBMs design automation, which allowed for logic signal names long enough to be self-explanatory. The G.E. system then in use allowed only ten characters for the logic name, and then required a four-character suffix composed according to some arcane rules that I never fully understood. I screamed that this was intolerable. It turned out that there was a new system then under development that would allow considerably longer logic names. Our cubicle had the opportunity to be the first to use the new system, so we decided to do it.

My circuit was to be a part of a larger item; and G.E. didn't have the ability to make small assemblies. So all three of us in the cubicle had to complete the design of the entire item before we could send our design through design automation and get something wired. That is what took several months, as other sections of the assembly needed special parts that had to be built to order. Then we had to figure out how to mount them and wire them and get them connected to the logic chassis. It made me a bit nervous, since at Teletype we designed things and had them wired up and then expected to do a certain amount of design revision in the lab before arriving at the final design. It wouldn't be impossible to revise my design under the G.E. system; but it was an awfully long time between design and the first test. G.E. had a unit called QRM, for Quick Reaction Manufacturing[55] which built the first model of anything new. Whereas Teletype would specify every screw and lockwasher by part number, G.E. had a general specification for mechanical assembly. QRM would choose all the bolts and nuts accordingly. Also it fell to QRM to design wire and cable routing; logic design engineers never concerned themselves with such matters.

I ran into the TRAC computer language again at G.E. There was a man who had programmed a TRAC interpreter on the Datanet-30. Later he quit to form a company that was going to do business data processing using software written in TRAC. I never heard any more about him.

Also running on the Datanet-30 was a text editing and formatting system, what we would later call word processing. I used this quite a bit, both for my writing for work and for a project I was doing at home, building a computer with the involvement of some high school students. There was an IBM 1050 set used as a terminal, and later some IBM 2741 terminals. For the high school project I would have the machine type on Ditto masters so I could run off copies for all the students. At Teletype we had talked about some needs for single sheet insertion; the IBM terminals made that easy since they were basically Selectric typewriters. Their reliability left much to be desired.

The Datanet 30 by this time was quite an old machine built with the old slow transistors. We had a joke about that. There was one backpanel wire in the machine something like 15 feet long. We joked that we would soon have to quit making the machines because we could no longer get transistors bad enough (slow enough) to tolerate that kind of backpanel wire length.

An interesting feature of the Datanet 30 was that the software was loaded from paper tape. The entire program was short enough to fit on a loop of tape that ran

[55] This always amused me, because in amateur radio QRM is the Morse code abbreviation for "I am being interfered with."

around on some rollers inside the front door of the machine. The machine had a watchdog timer that would expire unless the software frequently executed an instruction to restart it. If the watchdog timer expired the machine would automatically reload its software from the paper tape.

I'll include a story about G.E. magnetic tape drives, just because it is funny. IBM and everybody else in the industry made tape drives with vacuum column buffers so the tape could be accelerated very rapidly at the heads in spite of the inertia of the reels. G.E. had bought the rights to a patent for a different buffer technology, using scramble bins rather similar to the bins Teletype used on R-T stands to store paper tape. The amount of tape in a bin could be measured approximately by shining lights at the edges and measuring the light striking solar cells at the back of the bins. I'm not sure why G.E. did this; perhaps to get around IBMs patent on the vacuum columns. The scramble bins were much smaller than vacuum columns, but the tape drives as a whole were as large as vacuum column drives. This worked just fine mechanically; the tape could be accelerated rapidly and the servo system usually kept the right amount of tape in the bins. What nobody had thought of was that the tape in the bins rubs against itself, surface to surface. This continual rubbing tends to demagnetize the tape; so we had the phenomenon that a freshly written tape could be read easily, but as the tape was read repeatedly the recording would deteriorate until it could no longer be read successfully. G.E. eventually had to replace all of those tape drives in the field, at great expense.

I remember a visit by Ernie Kettnich and somebody else from Teletype. Maybe they were trying to sell G.E. on the Model 37. G.E. used IBM Selectric typewriters as console terminals on the computers and had reliability problems with them. I guess with the fairly low volume of computer sales, and only needing one console terminal per computer, it was considered too expensive to redesign the console to accomodate a different kind of terminal. I'm pretty sure I remember seeing a G.E. video terminal with a Model 33 keyboard; but I don't know if it was a production item or a laboratory prototype.

Although I had seen integrated circuits before leaving Teletype, the G.E. equipment I worked on was still discrete component technology. We did build a couple of integrated circuit modification kits for one of the computer models. It was fortunate that the machines in question used NPN silicon transistors, so we could connect directly to integrated circuits and intermix them with the rest of the logic. G.E. went through a tortuous process of evaluating competing integrated circuits and managed to standardize on the wrong family: the SUHL line made by Sylvania and Raytheon. Soon those companies dropped out of the I.C. business while

Texas Instruments dominated.

At the time there were some fairly cheap plastic cased Motorola RTL integrated circuits on the market. I could afford enough of these to undertake a project I had been wanting to do for some time. Back in the '50s I realized that synchronous transmission offered advantages over start-stop for radioteletype operation. The worst thing about start-stop on the radio is that with a mechanical selector a mutilated stop pulse allows the receiving shaft to keep going around, without latching up the clutch. Typically several characters are printed in error before the shaft gets back to where it is ready to stop for the stop pulse. I have seen a figure that this problem costs something like 15db of signal/noise ratio in character error rate versus bit error rate. With synchronous transmission there is the problem of remaining in synchronism, but not this problem that one bad bit causes several character errors. The second advantage of synchronous operation is that the detector knows where the bit boundaries are. Hence it can accumulate all the energy in a signal pulse, rather than point selecting in the middle of the pulse as a Teletype selector does. Frank Biggam and I had talked about this in connection with the multiplex equipment, it being synchronous. We couldn't do anything about it because we were being handed a signal that had already gone through a detector; to take advantage of it we would have had to build the FSK or PSK demodulator into the multiplex equipment. Collins Radio had a frequency division multiplex product, Kineplex, which did take advantage of synchronous detection. Teletype had made, in AN/FGC-5 days, a thing called a monoplex. It used multiplex parts to achieve a single-channel synchronous transmission. I never found any detailed information about how well it had worked in comparison with start-stop. At the time I didn't realize it had become a product; but Bob Reek tells me it was used for DEW Line communication over scatter circuits. I believe he said it was sufficiently promising that a synchronous two-channel multiplex was also operable over those circuits.

Thus I had long wanted to try synchronous radioteletype transmission in ham radio, but could not before then because I would have had to build a lot of equipment and the FCC rules required start-stop transmission anyway. After a while (OK, I admit I can be pretty slow sometimes) I realized that it would be possible to transmit a synchronous signal compatible with a start-stop receiver. It was just a matter of sending 7.0 unit or 7.5 unit code at an absolutely regular rate, putting in an idle character if there was no message character available for transmission. 7.0 unit code at 45 baud can be received without difficulty on a mechanical teleprinter and is easy to send synchronously and is fast enough to stay ahead of the keyboard or tape reader. Now with cheap integrated circuits I could easily build a start-stop receiving distributor feeding into a synchronous transmitting distributor. I could use blank as an idle character, or LTRS or FIGS as appropriate. At the receiving end a similar circuit could delete the idle characters, just to keep the machine a little quieter. I built the transmitting circuit and it worked fine, except that in those days we didn't have much in the way of I.C. breadboarding equipment so it was hard to keep wires from falling off. Then when I tried to transmit on the air with it the RF ran all through the circuit and paralyzed the logic. These problems could have been solved, but I put the project aside as I was doing other things at the time.

I learned a lot about computers at G.E. but I was never very happy working there. I just didn't have any confidence that the management was leading us in a direction that would be successful. A good telling of the misadventures of G.E. in the computer business is now available in a book, "King of the Seven Dwarfs" by Homer Oldfield, published by IEEE Computer Society. I decided that if I worked there for two years I would feel that I had paid my dues to the company for hiring me and moving me there and could leave in good conscience. I was also starting to think about a non-industry job where I could perhaps pursue some of my own ideas about computer design without the constraints of an existing product line. I made an interview trip to the San Francisco Bay Area, getting in a visit with Bob Weitbrecht in the process. I decided to call someone at Stanford University to see if there was any work there. Whomever I wanted to talk to wasn't in, so I decided to try Harry Huskey at Berkeley. I knew Huskey only by reputation; he had been in the computer industry since ENIAC, had worked in England for a time, had built the SWAC computer at UCLA, and then headed Project Genie at Berkeley, which was sort of a West Coast version of Project Mac at MIT. He was also editor of the IEEE Computer Group publications.

My call to Berkeley revealed that Dr. Huskey was no longer there; he had moved to a new U.C. campus in Santa Cruz. I didn't know such a campus existed; but it sounded like a nicer environment than Berkeley for all the latter's eminence. I reached him by phone at Santa Cruz; he told me that they were just getting started there and didn't have any work for an engineer right then, but to call him back in a few months to see how things were coming along. I returned to Phoenix and waited a few months. One day I had a particularly disgusting morning at G.E. and went home at lunch time and called Dr. Huskey. He said he was ready to hire someone, and that he had to make a trip to San Diego and could go by way of Phoenix and meet me at the airport for an interview. This must have gone well, as he offered me a job a few days later and I accepted. This was in the fall of 1968.

During the last week I worked at G.E. I was shown a prototype of a new product, the Termi-Net 300 terminal. This was not a Phoenix production; it came out of a communication products department in Virginia. It was a beautiful machine, a little larger and lower than a typewriter. The printing principle was a rubber belt carrying metal type fingers, each with a piece of type on the free end. There was a hammer for each print position. Thus it was the same in principle as the IBM 1403 line printer. No doubt there was a lot of electronics to make it work. They told me the production models would be made with CMOS and that it would all go onto a surprisingly small number of chips. The keyboard used some magnetic principle and had a very light touch. The speed was 30 characters per second. Mentally comparing this with the Model 37 I had thoughts similar to the infamous proclamation of Lincoln Steffens: "I have seen the future, and it works." A few years later there would be a 120 character-per-second version. It was pretty amazing to me that a company like G.E. could and would produce such an innovative product. There was nothing else in the entire company's product line quite like it, so far as I know. The company had no presence at all in office machines. I'm not aware that in Phoenix there had been any discussion of CMOS and the ability to make large custom integrated circuits. After the Termi-Net 1200 G.E. apparently lost interest in making terminals. By then there were several companies making daisywheel printers for formed-character printing and others making dot-matrix printers.

VI. Back to the halls of ivy (a little) and concrete (a lot)

I arrived in Santa Cruz near the end of September 1968. Dr. Huskey had a couple of barns on his property, so I had a place to store all my stuff while looking for a place to live. I moved in temporarily with Bob Weitbrecht; his home was about an hour's drive from the Santa Cruz campus.

The faculty of Information and Computer Science (I & CS) was headed by David Huffman, of Huffman coding and sequential circuit synthesis fame, who had come from MIT. The other faculty members were Dr. Huskey, who worked half time for the computer center and half time as a faculty member; and Bill McKeeman, who had just come from Stanford. Bill had given a talk at a recent joint computer conference which impressed us mightily at G.E. when we read it in the proceedings. I&CS was to have been the first board of studies in a new school of engineering at UCSC. Then a high-level committee declared there were already enough engineering schools in that part of the state and that it was not a good time to start a new one. This was something of a disappointment for me, as I had wanted to pursue graduate study in engineering. I&CS remained as a viable program under the Division of Natural Sciences. I met the man who had been hired to head the engineering school shortly before he left.

I will have to leave out most of what happened in the next 30 years to confine the story to matters relevant to Teletype. When I got there the computer center had just moved into its new building. There was an IBM System/360 Model 40 computer and an IBM 1130 minicomputer. Attached to the 1130 was a box made by Western Telematic to provide data communication facilities. There were five Model 33 machines. The business manager was about to contract with Western Union for maintenance on the Model 33s. I told him we didn't need a contract at that time, that the machines wouldn't need any maintenance until they were being used, and that I could probably fix most problems as they arose. There were some administrators who wanted to develop remote terminal applications using the 1130 and the Model 33s. They were not working with the 360-40 machine because data communication products for the 360 line were very much more costly than the Western Telematic box. Also our 360-40 had far too little memory to do more than basic things. The state of IBMs operating system technology was far behind what I had seen at G.E.

Nothing ever came of this because Western Telematic considered their design proprietary and would not release programming details. Instead they supplied decks of cards with Fortran-callable routines for use with their box. Fortran was hardly a suitable language for writing an administrative system; but then the 1130 was hardly a suitable machine for running it either. We sent the Western Telematic box back to the vendor and put the Model 33s aside for future use. The 1130 came with a connection for customer-added devices. I and some students designed a number of things to use with it. One of these, several years down the road, was a synchronous communications port, allowing the 1130 to be used as a remote job entry terminal. The astronomers in particular needed a lot of computing power, and would send their work through the 360/91 at UCLA. The 1130 had a line printer, the same clunky mechanism that IBM had supplied with the 704. Upon opening the modern cabinet you could see the 50s style 407 accounting machine parts which made up the printer mechanism.

When I arrived there was also the wreckage of a Univac Solid State computer that some company had donated. I found that it had been cannibalized of enough expensive parts to be beyond economical repair. Also the punched card peripherals used the Univac 90-column punching rather than the IBM 80-column format. We sent some parts of the Univac to a computer club at the Berkeley campus, where they had one of the machines and eventually got it to run.

Allstate Insurance donated a totally obsolete vacuum-tube Burroughs computer. I guess our main motivation for accepting it was to have it occupy floor space that we wanted to get while the getting was good. I did put it together and we could run it for a little while at a time before it got too hot. The building air conditioning was inadequate for such a computer. When we eventually scrapped the Burroughs I saved the console printer, which was a Model 28 RO. It had a screwy typebox arrangement such that data from the computer did not have to be converted to Baudot code.

There was also a Model 35 KSR and an acoustic coupler modem that had been designed by a Berkeley student and beautifully made on that campus. We could use it to connect to the Project Genie time sharing system at Berkeley.

The Social Sciences people had a statistical lab, containing various mechanical desk calculators and IBM punched card equipment. There was also a Mathatron, one of the early programmable electronic desk calculators. It was about the size of a desk, and had a Model 33 ASR in the middle. The users had written various statistical analysis programs, which were stored in pieces of paper tape. At one point they were about to buy a second Mathatron. About that time Digital Equipment Corp. came to us with a five-terminal timesharing system running on a PDP-8 minicomputer. Dr. Huskey persuaded the Social Sciences people to contribute their Mathatron money and he put in some computer center money to buy the DEC system. We would put two terminals in the statistical lab, two in the computer center, and then there was the console terminal that would also be in the computer center. We used four of the 33 KSRs in this service. The machine had a tiny disk; so we promised some sort of tape storage for users' programs. By this time we had hired Larry Laitinen, who had just got out of the Army and was a friend of Bob Weitbrecht, as our technician. Larry designed and built a 1200 baud modem, which we used with a cassette tape recorder so that users could record their programs and data. I don't remember the details anymore, but there was something to do with telephone repeating coils and a simplex circuit. This might have had to do with switching the DEC terminal hardware between 110 and 1200 baud. For some reason the computer didn't store its own software on the disk. Whenever the power went off, which was pretty often, we had to reload the software from paper tape at the 33ASR console. This took about two hours.

A couple of years later we replaced the PDP-8 system with one using a PDP-11 and software called RSTS. This would serve something like 32 terminals. At first we used DEC hardware to connect the terminals. This took three printed circuit cards per line with only a current loop interface available. We converted some to use RS-232 signals so we could attach video terminals instead of Teletype 33s. We had bought some Hazeltine 2000 terminals, an early video terminal that used magnetic core memory. Later on I designed some multi-port communication interfaces to replace the DEC hardware, getting 8 ports on one large wire-wrapped circuit board. A problem with the DEC hardware had been frequency drift in the bit rate timers. With the new hardware we used a crystal clock oscillator and simply wired each UART to the clock rate we wanted it to have.

A student had designed a program to work out wire routing so that we could use pre-cut and stripped wire with our wire wrapped boards. His input language, used to get from schematic diagram to computer input, was excellent. His program left much to be desired, taking far too much running time on the slow 360/40 computer. I wrote a new set of programs, using his input language and doing the process as a series of logical steps, that ran much faster. We built quite a bit of equpment of our own design using integrated circuits and wire-wrapped connections.

One office on the campus had an IBM Magnetic Tape Selectric typewriter with a communication port. This used some odd code and baud rate, but it was eventually supported by RSTS. I was still thinking of word processing on a computer, using this machine as a terminal. The Hazeltine 2000 terminals were typical of video terminals of the period. They offered a block mode, in which the operator could fill in a form on the screen and then transmit the whole screen at once. This was used in some transaction processing systems; but we had no use for it and ran the terminals in ordinary full duplex. It was several years later that Lear-Siegler made their famous “dumb” terminal that did nothing but send and receive, letting the computer do all the hard work.

We ran RS-232 signal levels for long distances, perhaps a couple of miles, without modems or line drivers, at speeds of 2400 baud. I also built a multiple current loop to RS-232 converter box to drive a bunch of Model 33s using current loop. This was simpler than putting an RS-232 converter into each machine, as it needed only one power supply.

We had a couple of modems on the PDP-11, used by the local junior college to dial in. Also I used a Model 35 and acoustic coupler modem so I could work on things from my home, about 10 miles from the campus. Quite often when there was a problem I could deal with it remotely and not have to make a special trip to the campus. I had a dog, a malamute. Something about the tones from the acoustic coupler got into her head and motivated her to “talk” quite loudly, which made a mess of the data going to the computer.

There was the change from 1961 ASCII to 1968 ASCII. Some computer languages used characters in ’61 ASCII such as up arrow and left arrow. These characters disappeared from ’68 ASCII. We worked with Fred Mocking, who by now was in Sales at Teletype, on a type cylinder that would compromise the changing characters so that the meanings of ’61 ASCII were not totally lost. The underscore character was made rather wedge-shaped so it could also serve as a left arrow. I no longer remember the other changes.

Beginning while I was still in Phoenix I got involved in Air Force Reserve work, including a summer training assignment. I was assigned to the rocket sled track at Holloman AFB, New Mexico. When I got there they said they didn’t have anything for me to do, and sent me over to the computer center. They didn’t have much for me to do either; so I basically watched the operation and found out what people did and wrote some recommendations, somewhat as a management consultant would do. There was a good group of people, some experienced civilians and some less experienced but quite sharp service men. The computer was a Control Data 3600, which by then was obsolescent. Working in the same building were some German engineers who had been brought to New Mexico along with captured V-2 rockets at the end of WW-II and for some reason had stayed on there.

Another summer I requested and got an assignment to the Air Force Communications Computer Programming Center at Tinker AFB, Oklahoma. This is where the programming for AUTODIN was done, as well as programming for some other computer-based communication systems. There were some Univac 494 (?) machines that I believe were used in a weather data switching system.

They had a project for me to do. Honeywell had lent them a 316 minicomputer with an attached magnetic tape drive, suggesting that they could find some use for it as an AUTODIN terminal or something similar. The tape drive held a few programming utilities, such as an assembler; and there was a Model 33 ASR for I/O. I obtained manuals for a couple of competing machines, Data General's Nova and Digital's PDP-11, and wrote some short pieces of program for all three machines. These program pieces did things I assumed would be useful in a communications application, things like moving a string of characters from one place in memory to another possibly overlapping place, and translating from one code to another. The PDP-11 turned out to be superior to the other machines in these operations, requiring substantially fewer instruction executions to accomplish a given task. I got to visit the AUTODIN switching center. The original RCA computers had been replaced by more modern ones, also made by RCA. I believe by this time the stations were using Univac 1004 machines with drum printers rather than Teletype equipment for printing messages.

After that summer the Air Force had no further use for me and discharged me.

In the early days at UCSC there was an elaborate system for distributing audio lesson material, called Chester Dialog. Students at remote stations could dial up particular lesson material, which was then copied to a reel-to-reel tape deck which was under the student's control. There was a lot of wired logic and a Siemens T-100 teleprinter for logging its operations. When this system was dismantled a number of years later[56] I acquired the Siemens machine through the campus surplus store. It is one of the European-style Telex ASR sets.

Dr. Huskey got funding from National Science Foundation to work on a minicomputer time sharing system with graphics. There was a company named Data Disc producing a head-per-track disk that could store on each track enough dots to make up a television image. The plan was to use such a disk to store all the bits for a video display. At the time this was about the cheapest way to store that many bits; semiconductor memory was just coming into use and was not yet large enough to store a whole screen of pixels. The disk store could operate either in a character mode, where it generated dot matrix characters, or in a bit mapped mode where it generated arbitrary bit patterns. We acquired a Varian minicomputer for the project. I sketched out, and Richard Cutts designed, a multi-terminal controller for this machine. I still think it was rather clever. This was before UARTs became available. We used separate Teletype-size circuit cards for input and output. The

[56]The replacement system was simply to make multiple copies of tape cassettes for the students to play on their own machines.

main idea was that you could get an 8-bit shift register chip, serial-in, serial-out, in a 14 pin package. So we used these things to send and receive serial signals in both directions; slowly to/from the terminals and fast to/from the computer. A board in the computer scanned the line cards looking for an input card with a new character or an output card ready for a new character. When it found one it would interrupt the computer to have the situation handled.

The Varian minicomputer came with a Model 33 ASR as the console device. This ASR had form feed. I had been told that Model 33 by design was never to have had such an optional feature; I guess somebody powerful wanted it.

We bought a G.E. Termi-Net 300 for use as a hardcopy terminal for upper and lower case ASCII. Later we bought a Teletype Inktronic KSR for the same purpose at higher speed. We sent Larry Laitinen to Teletype maintenance school to learn how to maintain the beast. He had to modify the Inktronic, as it was designed for a particular Bell modem that did 1200 baud in one direction and 150 baud in the other; we wanted to keep the baud speed the same in both directions. Later we bought a Model 38, in search of a cheap up/low terminal. Somebody gave us some Univac character-serial printers. These were like a single column slice of a drum printer, having a print wheel and a hammer that were pulled across the paper by a stepping motor. There was a logic board underneath, filled with DTL ICs that were all marked with Univac part numbers rather than the manufacturer's numbers. When I had to work on these it was rarely much trouble to figure out which commercial DTL chip was actually being used.

Eventually our project was stopped because of a federal budget crunch. I think we were all relieved, because the Data Disc machine was giving us a lot of trouble, as were other aspects of the project. There was a period when Dr. Huskey was in India for a year. He did return to the U.S. briefly to testify in the Sperry vs. Honeywell trial which resulted in Sperry's patent on ENIAC being invalidated. In his absence the rest of us had carved out a much more ambitious design than we probably ever could have implemented. We made a presentation of our ideas at the 1972 Fall Joint Computer Conference.[57]

One of Dr. Huskey's creations was what he called a Polish assembler. This wasn't a particularly apt name for it; but it was an assembly program using single characters as operators, and operands preceding the operators. Other assembler programs of the day were designed along the lines of their mainframe card-oriented counterparts; they had columns for labels and operators and operands and comments, and mnemonic multi-character abbreviations for the operators. The

[57] "An Eclectic Information Processing System", proc. FJCC, 1972, Part I, p. 473.

advantage of Polish assembler was the very compact notation. A program written in this notation would load much faster from a Model 33 paper tape reader than would a more conventional program; and of course printing was correspondingly faster. A program written in Polish assembler looked like complete gibberish at first glance, just a page packed with a seemingly random ASCII characters; but once you learned to read it, it was quite clear.

Claude Kagan visited with us for a few days as he was attending some computer conference in the area. He insisted we could put a TRAC interpreter on our minicomputer in a matter of days; and in fact he sat there writing code for a day or two to get us started. We added some functions to it, getting it closer to a complete implementation; but I don't believe we ever really finished it or got it to do anything useful. I don't remember now if what we implemented was TRAC or something that Claude called A String Language. The latter was actually TRAC but with the names of the functions all changed. The reason for this was that Calvin Mooers had tradmarked the name TRAC, so nobody could have a TRAC interpreter without paying him a royalty and in return his certifying that what you had was a genuine TRAC interpreter. Changing all the function names resulted in a language that was really TRAC, but presumably did not infringe the trademark and could have fewer or more functions than genuine TRAC possessed. Later on Claude and his group of youngsters, R.E.S.I.S.T.O.R.S., produced a language they called SAM-76, which had all the features of TRAC and a lot more.

Another visitor was Fred Brooks, now most famous as author of "The Mythical Man-Month". At the time he was a professor of computer science in North Carolina. Previously he had worked for IBM and was a principal architect of System/360. It was hard to imagine that this soft-spoken professor was the man who sat across the desk from Thomas J. Watson, Jr. and told him they were ready to bet the company's future on a new architecture[58].

At one point Computer Science got a new permanent home in a new building. I was in charge of ordering lab equipment and arranging the space. I asked for movable interior walls such as we had had at Teletype. The construction people turned this down, saying it was much too costly and they could build metal stud and sheetrock walls anytime we wanted them for less money. I wished later I had been more persistent, or had got some powerful faculty members in favor of the movable walls. It turned out to take an act of the state legislature to get money to rearrange the interior of a building; and the process literally took years.

[58] Fortune magazine, September and October 1966 issues, tells the story of System/360 and the various personalities involved.

On the Computer Center side of the street, we eventually switched from RSTS to Unix, and grew from one PDP-11 to about fourteen VAX machines. With Unix we had to quit using Model 33s and our old CRT terminals, as Unix demands up/low case capability. We bought CRT terminals from a variety of vendors. The first one from Teletype that we looked at had a rather bad keyboard. It was an electronic keyboard, not the horrid Model 37/38 thing, but keys tended to jam if they were not hit right in the centers. There was a later Teletype effort that was a pretty satisfactory terminal; but we didn't buy any. By then there were so many manufacturers of video terminals that Teletype didn't get anyone's attention. On a visit to Berkeley I saw one of the AT&T-style graphics terminals. Bell Labs seemed to be pushing the concept of a time-shared computer driving a graphics-capable terminal, ignoring the more likely future of graphic computing workstations.

We did buy a few Model 43s as hardcopy terminals. We also bought a number of Model 40 printers, the OEM models with the not-exactly-RS-232 interface. We ran these at 2400 baud. The printer had a ready-for-next-character signal. This would have worked fine with a microcomputer that could stall until the printer was ready to proceed. It didn't work so well with the timesharing system; but I was able to write a Unix driver that would send idle characters when the printer was not ready. We ran the Model 40 printers for as long as we could get maintenance on them. However they were used less and less as laser printers with PostScript came into wide use. With all these printers the concept was to have a single printer serving a room full of video terminals. The time sharing users simply had the computer direct their print jobs to the nearest printer. Because there were several separate time-shared minicomputers I designed a printer-sharer circuit that let the computers compete for access to a printer and granted access to only one at a time. Later there was networking software that allowed a single computer to drive all the printers and any other computer to send jobs through it.

The mainframe IBM-style computer had a big Xerox high-capacity laser printer. Time-sharing users could also send print jobs through this printer. During this same time period a number of offices on the campus acquired what were then modern character printers: Diablo and Qume daisy wheels and NEC Spinwriters. Soon after the introduction of daisy wheel printers the typewriter industry switched to this technology. I bought a wheel typewriter at Sears that had a computer printer interface built into it.

At one time we requested information from a number of computer vendors about their offerings for large-capacity time sharing systems. We asked for some of the things we were already getting from our PDP-11s: terminal ports at 2400 baud and automatic restart following power failures, among others. I got a call from a supposed data communications expert at IBM who couldn't understand how we operated async terminals at 2400 baud - he seemed to be mentally blinded by the modems available at the time, which were limited to 1200 baud async and 2400 baud synchronous. Univac told us that each async port would cost $11,000. Most of the large computers required a card reader to get started up, even if we didn't plan to use any card input in normal operation. Most of the vendors could not imagine automatic restart following power failure. We decided to stick with multiple minicomputers, even though those were more difficult to administer than a single large machine would have been.

As the number of computers grew and as the number of terminals grew into the hundreds we acquired a port selector. This was essentially a time-division circuit-switching exchange allowing users to say at the terminal which computer they wished a connection to. At 1200 baud and below it simply sampled the signal several times per bit with no synchronism to the characters; so distortion was high but tolerable. It did however cause havoc with some of our longer RS-232 connections. At 2400 baud and above it used UARTs and switched characters in parallel.

Electrical storms are quite rare in Santa Cruz, so we didn't often have trouble with the RS-232 connections run in underground cable. On the rare occasions when we did have an electrical storm it would sometimes damage RS-232 drivers and receivers. I remember going to several of the Hazeltine terminals and replacing transistors blown by lightning. Several years later when we had lots of connections and the port selector, a lightning storm caused fires in the port selector. Lightning blew the RS-232 driver chips. The manufacturer had not provided fuses on the 12-volt supplies, so the blown chips shorted positive and negative 12 volts together, causing the chips to burn and burning the circuit board underneath. After that we tried to shut down the port selector whenever there was likely to be a lightning storm, and to ask the users to unplug their terminals. I was surprised that lightning did so much damage to underground cables. We learned later that when the cables were installed the shields had not been bonded together and grounded, so they provided no protection to the circuits inside.

During this period Digital Equipment decided to quit using Model 33 ASR sets and to build their own terminal-type printers. There was the DECWriter I, which was not around for long, and the DECWriter II made in large quantities. These were all dot-matrix machines. Starting with a 30 char/sec floor model they went to a 120 char/sec model, and also a typewriter-like desk model. These machines lacked paper tape capability; but by then most customers were buying some faster kind of I/O medium anyway. Data General may have also made a hardcopy terminal of their own, following the lead of Digital.

After building up to hundreds of mostly CRT terminals and expanding the port selector to a large size we started switching to microcomputers and Ethernet. By the time I retired we had got rid of the port selector and operated the modems and a few RS-232 terminals using Ethernet terminal servers. There seemed to be no limit to the demand for modems. Students and faculty have personal computers at home, but they want to send and receive e-mail through the campus server and do other things that require connection to the campus network. We got into a relationship with Metricom, an early maker of wireless network modems and provider of Internet service through their network. Then we got a service in which Pacific Bell provided modems and connected to our network. Students had to pay a fee for using these instead of the free ones we continued to provide; but they could usually get connected via Pac Bell when all of our modems were busy, which was most of the time. The nature of using modems has shifted over the years, from terminals to microcomputers emulating terminals to microcomputers running Internet TCP/IP protocols. This of course correlates with the increasing speeds of modems. It would be practically unthinkable to run Internet Protocol over a 300 baud connection; but at 14 K baud or higher it becomes quite reasonable.

There was a communication satellite out over the Pacific which NASA had quit using and made available to Pacific Rim nations for educational purposes. UCSC had one of the terminals. I was asked to advise how they might transmit Teletype signals using this satellite. I recommended basic amateur radio technology, using audio tones into the voice channel. Some other people in the operation felt they should be using Model 33 equipment and ASCII; maybe they wanted to be able to exchange computer programs. I was inclined to suggest they look for Baudot equipment. There must have been a lot of it scattered over the Pacific after World War II and Korea; and I had a hard time imagining how Model 33s would get the maintenance they needed out in the Pacific island nations. I don't know if anything was ever done one way or another.

During my early years at Santa Cruz there came to be more Model 28 equipment in the hands of radio amateurs. I suppose this resulted from conversion of TWX from Baudot to ASCII and from similar conversions in other teletypewriter services. There was a project among some of us to optimize a Model 28 printer for amateur radio. Amateur radioteletype is characterized by a frequently high error rate; the emphasis is on carrying on a conversation with a friend, or contacting a rare station in some distant part of the world, rather than on getting perfect copy. One part of the optimization was to install the automatic carriage return and line feed set of parts, so that a missed carriage return would not result in a black square at the right margin of the paper. Then we had the carriage return actuate the line feed function, to prevent a missed line feed from causing an overstruck line. There was at the time some problem with pranksters who would start up an unattended printer and send it nothing but line feeds, so that all the paper supply was unrolled. This was foiled by making linefeed a once-only function.

In those years TTL integrated circuits dropped steeply in price. I was able to build a speed converter out of TTL, and then a re-creation of the compatible synchronous transmitter I had experimented with in Phoenix. Another ham was going to build a receiver to take advantage of the synchronous signals. I don't remember that he ever completed it, but he told me recently that he had done so and was able to lock to the bit and character rates. Independent of that effort, some other types of frequency shift converters benefited from simply having transitions going on all the time, rather than sometimes long pauses between hand-sent characters. The concept became known as "diddle" and was built in to many of the later generation all-electronic radioteletype terminals.

Amateur radioteletype and other digital amateur modes of course have changed greatly along with the changes in commercial communication equipment and techniques. An early design was an integrated circuit speed converter and first-in, first-out buffer. This allowed one to run the teleprinter at 100 wpm while transmitting and receiving 60 wpm. The FCC rules were relaxed to allow speeds up to 100 wpm and ASCII in addition to 60 wpm Baudot. There was very little use of these expanded privileges in practice. At 100 wpm the signal pulses are shorter than at 60; and using ASCII they are shorter yet. Shorter pulses imply wider receiver bandwidth, and hence poorer signal to noise ratio. Shorter pulses are also more adversely affected by multipath radio propagation, which is often a problem even at 60 wpm. So 60 wpm Baudot continues in use to this day, to the practical exclusion of higher speed Baudot or ASCII.

A few Baudot-only or Baudot plus ASCII video terminals were produced. The small demand made for small production and high prices. With the coming of microprocessors there came to be a new class of amateur products for connection to an ordinary ASCII terminal. These provided for several modes of operation such as Baudot, ASCII, packet, and AMTOR. AMTOR is an ARQ system for amateur use, similar to SITOR used in the marine services. It transmits short blocks of characters in a four-out-of-seven code and then listens for an acknowledgment character before proceeding. Packet operation uses a protocol similar to the X.25 standard, or the Internet Protocol. These microcomputer products are relatively inexpensive as most of the program is stored in read-only memory and there are no moving parts.

With the coming of personal computers (and even prior to the IBM personal computer) there came to be software to run on these machines for amateur radio use. Some programs simply provide a Baudot terminal, perhaps with extra features such as selective calling and the ability to send canned messages and store sent and received text on disk. Other programs are a replacement for the ASCII terminal in connection with one of the specialized microcomputer boxes. These provide an easier to use operator display and add features such as messages storage and log keeping.

There also came to be boards designed to plug in to popular personal computers. Some of these perform functions similar to the stand-alone microprocessor boxes at reduced cost by using the computer for power supply and for storing the software. Others are digital signal processing engines. One class of these does FSK demodulation for Baudot, ASCII, AMTOR, and Pactor (a protocol similar to AMTOR) as well as a more complex modem for Clover, a four-tone modulation scheme that adapts to changing channel conditions.

The latest development came with the arrival of the 486 and then the Pentium processors. These processors are fast enough to do digital signal processing right in the computer itself. The widely-used computer sound cards provide the analog-to-digital and digital-to-analog conversion. Thus the PC has become a modem and user interface all in one, requiring only a connection to a radio set to become a communication terminal. The currently available modes include

- Baudot, at many different speeds and frequency shifts
- Phase shift keying at 31 baud, translating the ASCII character set into something like Huffman code so the more frequently used characters require fewer bits to transmit. Also phase shift keying at higher rates
- Hellschreiber, using on/off, frequency shift, or phase shift keying. This is an electronic simulation of the 1930s-era teleprinter system invented by Rudolf Hell (and duplicated by Teletype with the Model 17).
- Multi-tone frequency shift keying, using 4-32 tones and approximately one tone per character transmitted. This allows the signal pulses to be much longer than in regular Baudot, and hence has great immunity to multipath distortion.
- A very robust modulation scheme involving 63 simultaneous carriers and elaborate forward error correction

- An automatic link establishment system compatible to some extent with those used by the military and civil government agencies. These systems hop around among several frequency bands, sending test packets and choosing the best frequency for traffic.

In addition to these a ham has developed a digital FSK modem that accomplishes compatible synchronous transmission and reception of Baudot. Although the improvement over asynchronous DSP Baudot is slight, it tickles me that now somebody has accomplished rather easily the thing I wanted to do so many years ago when it was so hard to accomplish. At my request he added a cleaned-up Baudot signal output to the RS-232 port so I can drive a mechanical teleprinter.

A few years ago I was promoting an amateur radio annual event, "Green Key Night." This took place on February 20, the anniversary of the first FSK contacts on amateur radio on the HF bands in 1953[59]. On that day amateurs were encouraged to get on the air using mechanical teleprinters if they can, using wide (850-Hz) shift if they can, using vacuum tube radio equipment if they can, but in any case to remember the pioneers and wallow in nostalgia and have fun. AFter a few years with hardly any participation I gave up on it. There does seem to be a small resurgence of interest in operating mechanical teleprinters. One still sees advertisements, "Model 19 going to the dump, unless someone takes it", but there are starting to be advertisements offering homes for the old machines.[60]

I retired from the University early in 1998 and moved back to Arkansas.

[59] Prior to that date audio tone FSK was permitted and used on the VHF bands. FSK was permitted only on the former 11-meter band. There was some radioteletype operation on HF using make-and-break keying. Amateurs petitioned the FCC for permission to use FSK on the HF bands. FSK was the norm already for commercial and government HF radioteletype. After about two years of rumination the FCC announced that amateurs could use FSK on the HF bands, with certain restrictions, starting Feb. 20, 1953.

[60] An interesting topic for a future paper is that Frequency-Shift Keying seems to have been invented by an engineer at Teletype, Lawrence Schmitt. Experimental radioteletype work was done by Morkrum in the 1920s.

VII. Some afterthoughts

I do not blame Teletype management for the demise of the company. Many other old and well-managed companies have fallen by the wayside in recent years; and even mighty IBM has seen some very painful times. As a subsidiary of a subsidiary of a drastically restructured AT&T, Teletype could have had the plug pulled at any time by one of the parent companies in spite of what its own management could do. After the Bell System breakup AT&T seems to have had a lot of trouble deciding what business it wanted to be in, and the same can be said for Lucent, the former Western Electric.

It seems to me that the downfall of Teletype resulted from a combination of several factors.

- Unprecedented progress in microelectronics caused Teletype's store of knowledge and its manufacturing capability to depreciate to no value practically overnight. New companies sprang up like weeds as it became possible to create a variety of new products just by putting together parts bought from the semiconductor makers.

- Teletype's great factory may have bred a certain weakness; when you can make anything at all you may make too many different things. (Consider the number of part numbers dedicated to screws and springs, for instance.)

- A whole series of changes, some technological and some political and legal, rocked the familiar business environment. This began with Dataphone and the use of the switched voice network for data transmission. It continued through the CarterFone decision, the Bell System breakup, and further deregulation of the communications industry. The historic scarcity of telecommunication bandwidth gave way to a glut as competing long distance carriers entered the field and as optical fibers replaced copper cable and microwaves. Western Union, which had seemed in the early 1960s to have a rosy future, totally collapsed. Microcomputers largely replaced simpler equipment used as communication terminals.

- A lack of competition for so many years led to a certain amount of stodginess and complacency, and retarded development of a market-driven corporate culture.

- The 1956 consent decree seems to have marginalized Bell System participation in the world of business data communication, as communication became subsidiary to data processing.

- Increased participation in the market by foreign companies, and increased use of offshore production by domestic firms were probably factors as well.

I have learned that Teletype developed a remarkable capability in-house to produce large-scale integrated circuits.[61] Such a capability gives a company an advantage over competitors who have to work with off-the-shelf parts; yet it is tremendously costly to maintain and perhaps was not in the company's strategic best interest.

I like to use the demolition of the Touhy Avenue complex and its replacement by a shopping center as a metaphor for what is happening to our society as a whole: Where once we made things, now we buy things that others have made.

In 1960 the U.S. teleprinter business belonged to Teletype, Kleinschmidt, and Teleprinter Corp. (MITE), the latter two doing business mostly with the military. Western Union had occasionally dabbled with making its own teleprinters and paper tape equpment, and had imported a few European teleprinters to get Telex service started. The telephone companies' doctrine of "no foreign attachments" was firmly in place. Communication switching, both voice and teleprinter, was almost entirely electromechanical. Teleprinter switching systems used lots of paper tape for intermediate storage. ASCII was still on the horizon. TWX was still manual and Baudot; Telex was just getting started in major U.S. cities. Western Union seemed to have a bright future. Computers were well established in the business world, but there were very few instances of teleprinters (or terminals of any kind) connected to remote computers. Information transmission was via voice-grade lines or telegraph-grade lines limited to about 75 bits per second. There was still a lot of open-wire line in the telephone toll plant.

Although Teletype equipment had improved tremendously over the previous 50 years, in another sense the technology had not changed at all. Products continued to be intricate mechanical assemblies of parts made mostly on punch presses and screw machines. The world was about to turn upside down.

Just when it appeared that telegraphy was on the brink of a steep decline along came on-line computing to create a new need for it. Computer systems needed the

[61] Book, "Teletype, We Made That Data Move!" by Herbert A. Waggener.

kind of input that keyboards could produce and produced the kind of output that teleprinters could easily display. Whether the terminal to computer wiring was local or telegraphic or derived via modems from telephone circuits was immaterial. The boundary between communication and data processing, which had seemed so firm and clear at the time of the 1956 consent decree, began to disappear in the manner of the Cheshire Cat. Electronics came to be the principal underlying technology of both, and began to progress at a rate never before seen.

The voice telephone network approached ever closer to its mature state in which all calls are customer-diallable. Transistors made it possible to offer customer-premises modems and autodialers for use on the voice network. The Dataphone offerings dramatically modified the doctrine of no foreign attachments. Later the Carterfone decision blew it completely away. Customers were free to obtain their data terminal equipment on the open market. It became possible to implement business data systems using the switched voice network. Previously these would have had to use private line service at much greater cost. Because the switched voice network allowed considerably higher bit rates than were possible with telegraph circuits, customers had an incentive to want high-speed data equipment in preference to slow teleprinters. The Bell System breakup and the demise of Western Union meant that nationwide business firms no longer had a single company to deal with for communication facilities. The mere fact that the voice switched network kept on working was another reason to use it for business data communication.

Cheap fast transistors led to a generation of computer equipment that was cost-effective in replacing electromechanical communication switching systems. For message switching purposes computers also had the advantage of being adaptable to customer protocols rather than requiring customers to adapt themselves to the protocols wired into the switching systems. Computer switching in fact arrived just in time to cope with network complexities that were practically beyond the capabilities of electromechanical systems. Computer technology further offered higher reliability and lower maintenance as compared with the electromechanical equipment it replaced. Computers used solely for message switching had a short market life as the business world moved on to systems integrating communication and computer applications.

Following cheap fast transistors came even cheaper and faster integrated circuits, and then microprocessors. Products based on intricate mechanisms became obsolete practically overnight. The aggregate motion stock ticker was Teletype's last successful product of the old kind; and it had an unusually short product life. Integrated circuits lowered the barriers to entry into the industry. Video data terminals could be home built by hobbyists. Companies producing terminals popped up like mushrooms. Mechanical simplicity was bought at the price of electronic complexity. That complexity ultimately came down to a matter of program instructions, not trivial to produce but not requiring any significant investment in factory machinery. Over and above what it could do offline, the personal computer became the ultimate communication terminal, programmable to meet any imaginable customization.

Printers, magnetic card readers, and other special devices became computer peripherals. Printer technology went through dot matrix and daisywheels to laser and an ink-jet technology having nothing in common with Inktronic. Powerful electronics made facsimile at long last a cheap and practical means of record communication. The new cheapness allowed fax to enter markets that had been closed to TWX and Telex. Personal computers can also function as fax machines and can generate fax images from computer text. The packet-switched Internet became an alternative to modem communication over the voice switched network. As the Internet spread from a few research sites to the whole world personal computers became communication devices in other ways; first electronic mail and news, then pictorial, voice, music, and motion picture communication for the general public. Fiber optic technology turned the scarcity of bandwidth into a glut.

Electronics has always been an unusually flexible technology. Anything from a radio to a computer to a metronome to an aircraft control system could be built up out of more or less off-the-shelf parts put together in almost any convenient physical arrangement. Unlike mechanical technology there was rarely a need for a lot of custom-made parts fitted together precisely in a manner requiring great ingenuity to design.[62] The electronics of 1946 was not so different from the electronics of 1936 except for microwaves and miniaturization. The electronics of 1956 was not so much different either, except that we were pretty sure transistors were going to be important sometime soon. Even by 1966 it was hard to imagine that parts produced in semiconductor furnaces could ever compete with those produced on punch presses. How could we then have imagined a 104-key electronic keyboard selling at retail for ten dollars?

It's hard for me to imagine what Teletype might be today if it had survived. A maker of printers, competing with Hewlett-Packard, Epson, Canon, and Lexmark? Enlarge that group to include the makers of office copiers, since today's models

[62]This point is well illustrated by Teletype's first electronic multiplex, manufactured by an outside contractor without drawing upon Teletype's great knowledge bases of mechanisms and metalworking.

seem to be based on scanning and electronic printing, rather than direct copying. A maker of personal computers, competing with Hewlett-Packard, Dell, Apple, and a few others? A maker of handheld terminals with many capabilities, competing with Apple, RIM, Nokia, Motorola, and others? A maker of point-of-sale equipment and other non-consumer goods? Perhaps a maker of specialized equipment completely out of the public eye; or perhaps a maker of something totally unrelated to its former products, as with the GPS navigation company currently using the Teletype name.

J.H. 24 September 2010