Radio Relay - In The Beginnings

From a Historical and Personal Viewpoint
With an Emphasis on Microwave Radio Relay

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Relay -

The dictionary definition speaks generally of carrying on a race of successive runners, of traveling a long distance on horseback using successive teams of (or single) horses, or of conveying messages from runner to runner. In terms of ***communications*** that has been going on since early Greek times, that of conveying news or messages; indeed, cryptography is said to been used back then as well as in the Roman Legions that followed. France and England has systems of semaphore signaling to send messages for hundreds of miles since the late 1600s. Mail service can be said to be a relay of written communications, albeit slow and going through many different *couriers*. Maritime semaphores and signal flags could send the same message throughout a large fleet...provided all were in visual range along the relay path.

Electrical Relay -

Several forms of *telegraphy* were devised and tried before 1844.[1] Samuel F. B. Morse was not the first but, under the financial backing of Alfred Vail and the Vail family, innovated a very useful feature into their patent (granted in 1849) called a ***relay***. In a single *loop* of connection, key and battery at the transmitting end, an electromagnet moved an ink pen whenever the key was *closed* and sent electrical current into the wires. The Morse-Vail Telegraph allowed the electromagnet to operate *another key* which controlled a *second, separate* loop. The effective range of the telegraph was thus *doubled.* Due to the technology of the time, no more than three *relays* could be installed before the cumulative distortion of all those relay mechanisms forbade any further range increase.[2] What is important to consider here is that the Morse-Vail Telegraph System may have been the first ***real-time relay*** method in communications.

A single operator could have his dots and dashes reproduced as far away as 80 miles through the Morse-Vail Telegraph relay, delayed only in terms of fractions of a second. It may be that this little relay innovation was the real motivator behind the worldwide spread of the Morse-Vail Telegraph System. It wasn't the code itself since other countries, especially those with different alphabets, devised their own codes for their languages.

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[1] The Morse-Vail Telegraph was first demonstrated in 1844 between Baltimore, MD, and Washington, DC, although Morse devised/innovated/invented his first system in 1837. *Tele* stands for distance and *graph* stands for a visual means of output. The first Morse-Vail Telegraph system had an ink pen marking on paper tape, hence the *graph* in *telegraph.* The acoustic receiver or *sounder* was not implemented until a decade and more had passed and with radio using tone beeps to indicate the code elements both make the word *telegraph* improper. The teleprinter is still referred to as a telegraph system since it began and continues (on a lesser scale) to output a graphical output of characters on paper.

[2] Each combination of electromagnetic and insulated contact has a finite time delay referred to *pick-up* (contact operated) and *drop-out* (contact released). Given the 1840s, there was ***no*** real electrical industry with an established set of components and specifications from which to choose. However, the simple innovation called the *relay* may have been the origin for modern electromagnetic relays used in virtually all of electrical and electronic systems in various forms.

Relaying by Other Electrical Systems

Prior to about 1912, there was little success in early attempts at increasing the range of the telephone.[3] That needed a reasonably good ***active amplification*** system. The first vacuum tubes (invented in 1906) became good enough in production in that year to allow the landline telephone system to extend beyond the limitations of a single loop. It took a much longer time (till 1927) before *negative feedback* and the *linearization* of amplification allowed the telephone connection to extend thousands of miles using many *repeater* amplifiers along the route.

Radio as a communications medium fared perhaps worse. Long distance radio communications required very long wavelengths and tens of kilowatts of transmitter power...all to be received by an efficient *crystal set* receiver that was little more than a simple RF-input rectifier feeding headphones. The vacuum tube was sorely needed there. Not just that, a host of other things about basic theory of radio waves and radio circuitry.

There was some considerable advance in knowledge in the form of the ***carrier system***. John R. Carson of AT&T devised the mathematical form of modulations for AM, FM, and PM in 1915. It was from those basic formulas that ***single-sideband suppressed carrier*** signals could be made to work.[4] With a renewed interest in passive-component *wave filters* (as they were quaintly called then and for a long while after) of the bandpass variety, lots of differing theory started to come together. AT&T claims a first in 1918 for getting a trial system of *carrier* underway that could carry four voice-frequency telephone circuits on a single pair of wires. Put another way, such a system could quadruple the number of telephone circuits along a wire route and thus increase AT&T revenue without laying an extra mile of wire.

Carrier systems could be carried on radio by 1928 now that the *shortwave bands* (the HF or 3 to 30 MHz frequency range) had been shown to bounce around half the globe through ionospheric reflections. That and higher-power vacuum tubes to make AM transmitters with some muscle and receivers with sensitivity, selectivity, and stability to pull in very weak signals with good clarity. A 12 KHz bandwidth wire *carrier system* would carry four separate voice channels (3 KHz BW each) or two voice channels and eight teleprinter circuits. Teleprinter signals, normally in a *bipolar loop*, could be conveyed by audio tones, one frequency for the teleprinter *mark* and another for the teleprinter *space*. A Dutch radio circuit between Holland and the Netherlands Antilles began in 1928 using such a SSB format. By convention the *commercial* 12 KHz BW SSB form became standard and persists to this day.[5]

Real-time *relaying* did occur in commercial SSB but in a hybrid, composite fashion. SSB signals would go by carrier system to a transmitter over wires and that repeated in reverse from the SSB receiver. There doesn't seem to be any evidence that this was done by one or more SSB links in a path.

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[3] The best anyone could do was to make the microphone and receiver of the telephone as efficient as possible. That led to any number of quackery in electronic gizmos, few of them actually working well.

[4] Of course it took a **lot** of new, radical, different circuitry to accomplish that but recall that vacuum tubes were only 9 years old in 1915 and everyone had to learn what they were about.

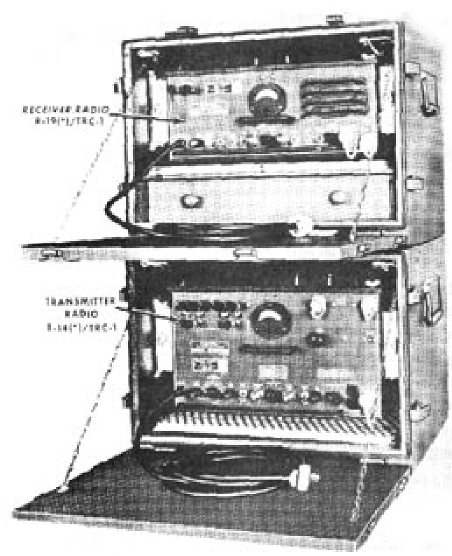
[5] *Single-channel SSB* radio did not become popular (or practical) for radio amateurs and others until about 1950. A half century later SSB voice has nearly eclipsed AM voice on HF bands for all but broadcasters. A private boat owner can now have an HF SSB transceiver (for deep water sailing safety) that costs the same as one for a radio amateur.

Enter FM Radio

In the late 1930s the Fred Link Company had some trials of mobile FM radios for various police forces. FM has several advantages on the receiving end: *Limiter* stages can effectively suppress radio noise such that the FM signal has the same received amplitude and with more clarity (reduction in noise, particularly impulse noise) than can be said for AM systems. FM could do so with a wider modulation bandwidth than was common in early AM.[6] FM adapted well to quartz crystal control and the *channelized* (fixed frequency on specific frequencies) tuning did not require much operating skill. This was ideally suited for military use.[7]

By early 1941 a number of high-HF, low-VHF range FM radios had been planned for U.S. Army forces on land, most of them intended for wheeled or tracked vehicles. Those needed quartz crystal units to hold their frequencies (or channels) steady and a nationwide U.S. effort was undertaken to supply those crystal units.[8]

The *Tracs* Roll Along



Among the first of these ***AN/TRC*** radio sets devoted to radio relay use was the **AN/TRC-1** family.[9] Pictured at right is a receiver (top) in its transit case with accessories and crystal unit box in drawer below, the transmitter (bottom). The operated at 70 to 90 MHz, FM, about 40 W RF output from the transmitter and double conversion in the receiver. Power supplies were internal to each, operating from 115 VAC power (note line cords and plugs). Both receiver and transmitter had built-in diagnostics, checking both RF and AF (modulation input) circuits.

A part of that family was a 50-foot mast (with gin pole) and a truly adjustable 3-element Yagi antenna with coaxial cable. The Yagi's adjustments were clearly marked in frequency for the director element, director-to-dipole spacing, dipole length, dipole-to-reflector spacing, and reflector element length. Locking-sleeve nuts allowed setting to the correct frequency in the field without special tools. Noteworthy is the audio line connections using spring-loaded turret terminals for quick

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[6] Yes, there are penalties there, chiefly *Carson's Rule* (of the original 1915 formulas) but this concerns moderate bandwidth increases as will be shown.

[7] This cannot possibly be mistaken for any intent to say military personnel are *stupid* but rather to say that their need to communicate reliably and without fuss is an absolute necessity when an enemy is trying to destroy them through many deadly and very loud means.

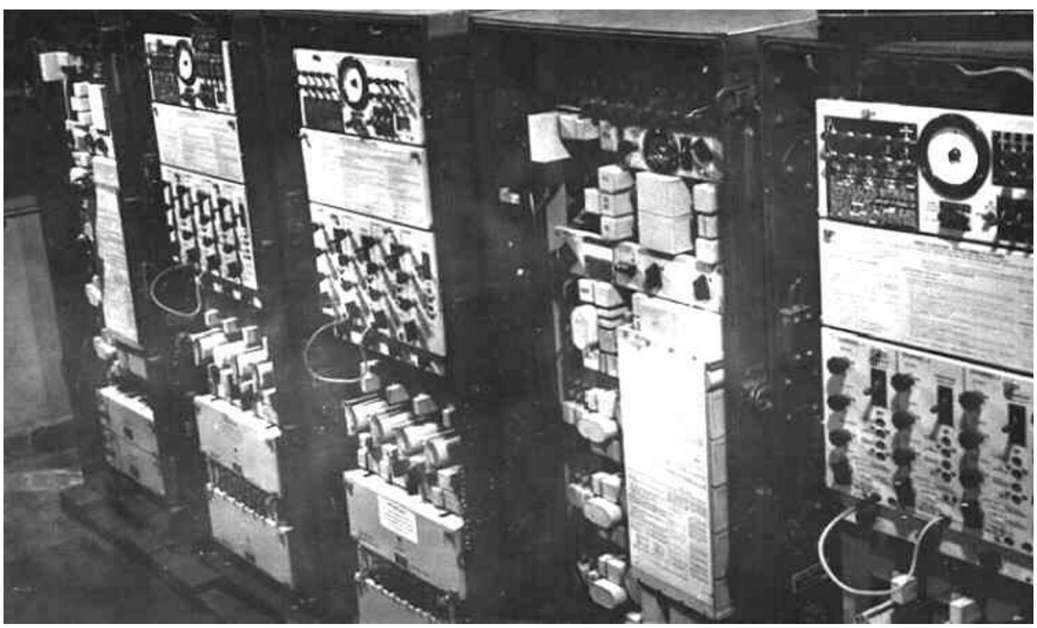
[8] This is a whole other story and it is told by an insider on several websites, particularly that of Professor Virgil I. Bottom as reproduced on www.corningfrequency.com. Suffice to say that quartz crystal unit production during WW2 had the second-highest priority, topped only by the Manhattan Project (the atomic bomb). In the last three years of WW2 about 5 dozen U.S. companies produced a million crystal units a month!

[9] The *AN* stands for *Army-Navy*, useable by both service branches while *TRC* meant *Transportable Radio, Communications.* The *TRC-1 family* refers to the -1, -3, and -4, all using the same receiver and transmitter and differing only in the quantity of each and whether or not those dash numbers included antennas and mast structures. The concept of a *package* of equipment for specific uses had already entered the scene.

attachment (or disconnect). The radio set was designed for rapid deployment: battlefield locations are fluid.[10] Changing to another frequency (or *channel*) was quite easy. Change one crystal unit in the transmitter, one in the receiver. The transmitter tuned circuits following the oscillator could be tuned via the front panel selector switch and meter, up to and including the final amplifier; just a matter of peaking the meter indication. The receiver had a simple three-tube signal source accessory that accepted a transmitter channel crystal and provided a frequency-correct, but uncalibrated low amplitude signal for trim-peaking the front end (IF strip did not need retuning). The equivalent of a modern *S-Meter* on the receiver front panel allowed the antenna and mast to be rotated to the proper azimuth for best signal with the other link's radio set.

The operating bandwidth was 12 KHz minimum, that designed to work directly with ***CF-1*** and ***CF-2*** carrier terminals. A CF-1 carrier terminal multiplexed four separate voice telephone circuits to/from a TRC-1, including a ringer supply known familiarly as a *thousand-twenty ringer.* Since the radio circuit could not include the low-frequency 20 Hz telephone ring current, the ring signal was converted to a 1 KHz (one thousand cycles, hence the *thousand*) tone for transmission and a 1 KHz narrow bandpass filter on the incoming side operated a relay to connect the 20 Hz ring supply onto the telephone circuit.

The CF-2 terminal frequency-multiplexed four teleprinter circuits onto a single voice circuit and included the constant-current (± 62 mA) supplies for the local teleprinter loops and even a built-in test set for setting proper operation of the high-speed polar relays that coupled the incoming frequency-selective detectors to the local loop. A single TRC-1 radio set plus one CF-1 and two CF-2 carrier terminals could then handle two separate voice telephone circuits and eight teleprinter circuits.

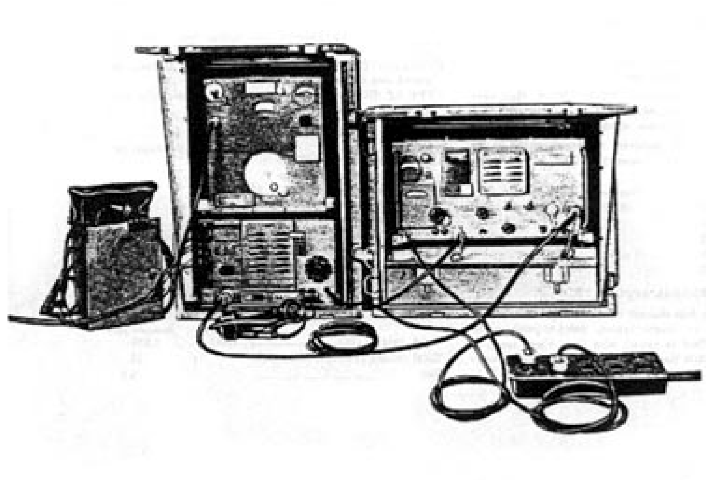


At left-to-right, a CF-1, two CF-2s, a CF-1, and a CF-2 used at Army station ADA in Tokyo in 1953 for emergency back-up through VHF/UHF radio relay sets in case the normal wire lines are cut. The transit cases served as cabinets. One carrier *bay* weighed nearly 300 pounds, had handles for a four-man human transport. The top panel of each CF-2 terminal is the polar relay test set, including a test socket.

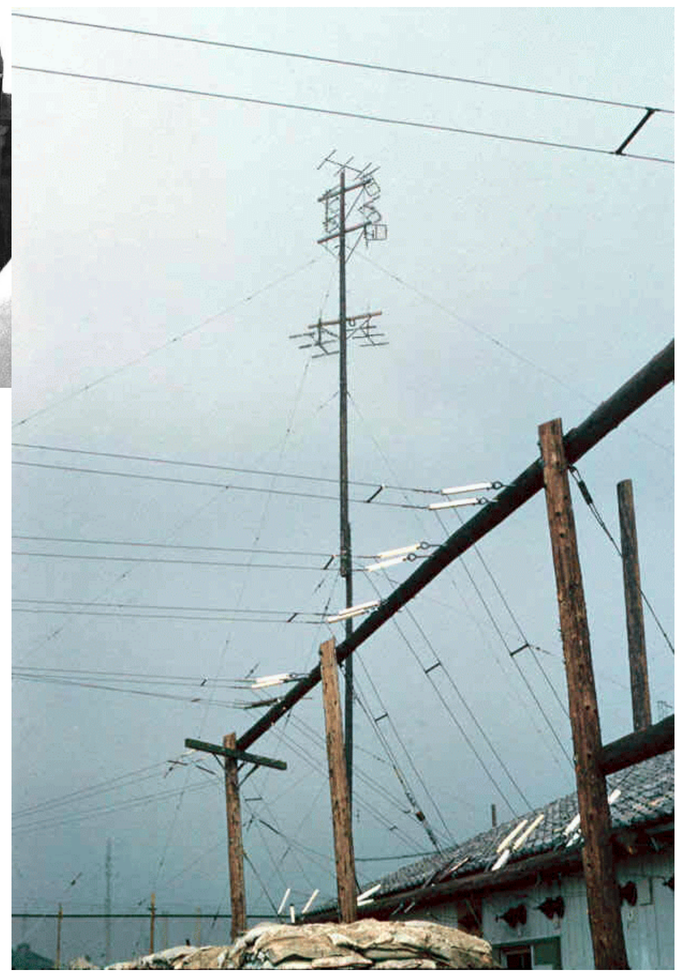
Carrier terminal equipment was of the telephone infrastructure style and recognizably made by Western Electric Company, the manufacturing arm of AT&T in the Bell System.

[10] This was extremely valuable in the *Battle of the Bulge (Ardennes Forest)* in 1944 when German forces came within visual distance of one TRC-1 relay node. Signalmen kept the node operating until near capture, escaping with most of the masts lowered and disassembled, equipment dismantled, loaded on vehicles.

Following the TRC-1 families by about a year, the ***TRC-8*** family, apparently not designed by the Bell System, debuted during WW2. In the photo at right the transmitter (power supply bottom, RF section on top) is in the tallest transit case with the receiver on the right behind the rugged extension cord.



Surprisingly, considering technology of the time, both transmitter and receiver were continuously tunable over their 230 to 250 MHz operating range. Transmitter power output was about 12 Watts and, if kept in an approximate room-temperature environment, would remain in-tune for weeks and months of continuous operation.[11] Modulation bandwidth was also 12 KHz and would work with CF-1 carrier terminals.



Above, one of two radio relay benches at station ADA's old site. Top row has a TRC-1 transmitter, two TRC-8 receivers, TRC-1 receiver. Middle row has all TRC-8 receivers. Bottom row is all TRC-1, receiver on left, three transmitters on the right. Each TRC-1 set had a rather cheap shaded-pole fan in each hinged top cover, adequate but seemed out-of-place among the industrial-strength components inside.

At right, the old ADA transmitter site Radio Relay pole with 3-element Yagis for TRC-1 and the *Square-Corner Reflector* type for TRC-8. The TRC-8 antenna was broadband enough that no adjustments for operating frequency were needed. The 600 Ohm open-wire transmission lines (and white insulators) are for the high-power HF transmitters at ADA.

[11] *Approximate room temperature* is about 60 F to 100 F in the station ADA environment in the 1950s.

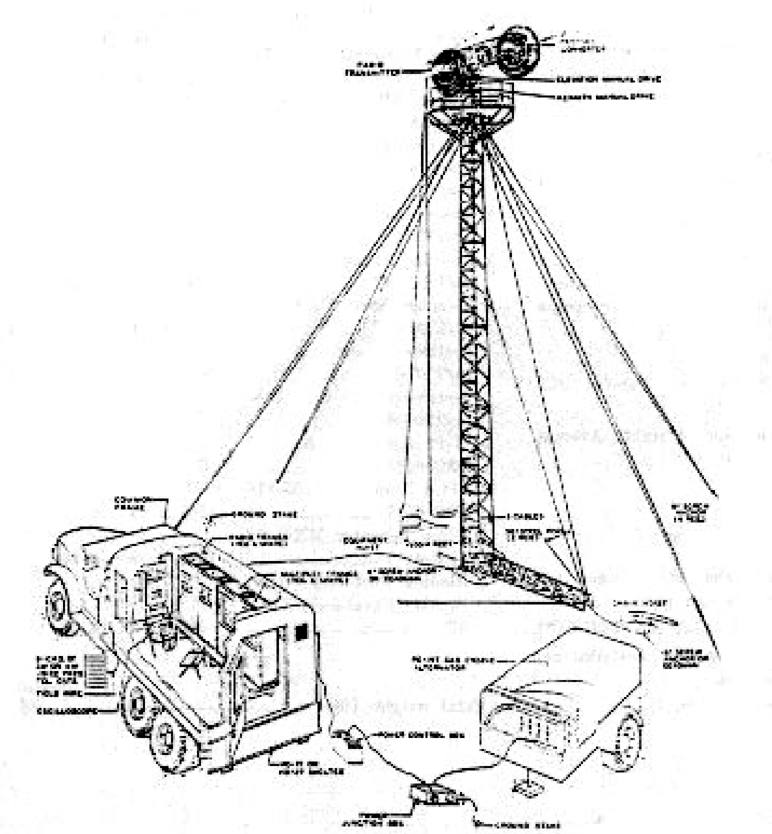
Above left, the TRC-1 receiver signal source for front end alignment during a frequency change. A transmitter crystal plugs in at right. Single marked peaking knob (black disk) and two toggle switches for modulation on-off, signal on-off. Octal sockets were used on all tubes except for the 829 transmitter final amplifier.

Above right, the polar relay (SPDT contacts with center position off) used in the CF-2 teleprinter loops and in all the RF exciters in the station ADA main room for all teleprinter radio circuits. Black plastic cover has been removed and at right. The funny alignment tool in center is needed to reach the adjustment holes at the polar relay top contacts. Ordinary small screwdriver at the bottom. These polar relays required routine checking and re-alignment using one of the many CF-2 bay test sets. Pick-up and drop-out times were very quick, in small-unit milliseconds and adequate for 5-level, 60 WPM teleprinter service. Those could ***not*** be used on the few special multiplexed 4-channel teleprinter circuits due to an equivalent near-300-WPM data rate. Instead, a single octal based vacuum tube replaced the relay inside the cover to maintain the higher rate.

At left, the author as a rather young PFC caught by another (with the author's camera) while using the VHF order-wire (*O/W* on the sign above, channel 1) to actual perform some useful (but routine) task with ADA Control at the other end of the link. Note the old-style baggy *fatigues* utility uniform. This gives an approximate scale to the heights of the CF-1 and CF-2 bays, each heavy enough to withstand toppling in a few mild earthquakes.

ADA in Tokyo of the late 1940s and early 1950s depended on the VHF/UHF radio relay to back-up all the wireline circuits to Control and Teleprinter Relay. Post-WW2 rebuilding in Tokyo would occasionally cut through a main wire trunk.

Post-WW2 Microwave Radio Relay in the Army



The first two efforts to develop a true microwave radio relay system in the military resulted in the AN/TRC-5 and AN/TRC-6 (system drawing at right). Both used pulse modulation and time-division multiplexing and both were really inadequate for anyone's land forces.

The TRC-5 was contained in a bunch of transit cases, operated on a single frequency of about 1.5 GHz and suffered nearly 20 db coaxial cable loss from transmitter to a single small antenna on a mast. As of the summer of 1952, the Army had given up on that system and one terminal was used *for familiarization purposes* at the Signal School then in Fort Monmouth, NJ. Seven voice channels (the 8th or order-wire channel was never made outside of the system) could be connected...if a signal could be received.[12]

The TRC-6 was different. It offered 8 voice channels using *pulse position modulation* of a separate short channel pulse within a time slot of a repetition *frame* of about 8 KHz. It *sampled* each incoming voice-frequency signal at nearly 3 times the maximum voice channel frequency, then reconstructed it on the outgoing end back to an approximation of the original waveform. This wasn't just different, it was *revolutionary* in terms of 1945 technology. The chief developer of the system, AT&T, could have done more systems engineering but there just wasn't enough time to do the job right.

The RF end relied on klystrons for both the transmitter (into its parabolic reflector antenna) output and as local oscillator for the receiver (using a second, separate parabolic *dish*). The frequency range was 4.35 to 4.8 GHz and the transmitter output was (approximately) 100 mW (on a good day). Judging from the antenna reflector size and that frequency, each antenna gain was roughly 18 db in actual practice. The RF ends were at the ***top*** of the tower and thus it avoided any feedline losses coming or going.

The drawing shows a straight-sided triangular tower, apparently the original version. As of 1952 this had been changed to an un-guyed, wide base, tapering width rectangular form that supported a small top platform for the antenna dishes and RF boxes. Tower sections tapered in width so that they could nest for transport. Still,

[12] Those of us in Signal School for the 1419 MOS classification (Military Occupation Specialty) got perhaps 2 days to play with the single TRC-5 in the lab building. Memory of its details are fuzzy, perhaps as a result of the instructor telling us it was not used anymore. Without another set to complete the relay link, we had no chance to experience any other foibles it had.

the stability at the top was questionable and, as a signalman who has stood on that platform, normal vibration from vehicles or wind gusts must have caused at least a ± 1 degree change in antenna pointing azimuth.[13] It would have been worse to have to perform corrective maintenance on the RF boxes during inclement weather; there was no rain shield provided nor spare RF boxes for such an eventuality.

The electronics on the ground were contained in four transit cases, slightly bigger than the CF carrier bays described herein, but of the very same style. The physical structure was a signature of the AT&T style of telephone central plant things. Several of the *digital* circuits (word not then in vogue for circuits operating between cut-off and saturation of tubes) used 28D7 dual pentodes.[14] It was a ***heavy***, ungainly beast of a system and suited solely for a very fixed installation. It would take a full day for a 10-man crew to install one terminal and get it going for 8 voice channel service. By contrast, a 4-man crew could install a TRC-1 or TRC-8 terminal for 4 voice channels in an hour.

As of 1952, there were a few TRC-6 links on permanent installations along the east coast of the USA and at least as many in Europe. My 1419 MOS Signal School class was divided into thirds on graduation, all assigned to those TRC-6 areas. Except my third, bound for the Far East Command at the end of 1952...where there were no TRC-6s installed. In reality, a better microwave radio relay system had already been created by the General Electric Company, another by Philco, plus some in the works at other companies re-entering the commercial market after a massive war effort. AT&T did not invent/discover/innovate everything in communications; it only seems that way because of their massive publications and public relations efforts.[15]

What AT&T developed in the TRC-6 came from a number of trials they had already done in the low microwave region, some thorough research into microwave propagation and component techniques during the 1930s and early 1940s.[16] It isn't an accident that the first transcontinental microwave radio relay system, AT&T's ***LD2***, operates in the 3.7 to 4.2 GHz band, very close to what it used in the TRC-6. On the other hand, AT&T did ***not*** use time-division multiplexing in LD2, opting to go into massive channel capacity frequency-division multiplexing advanced carrier technology. That suited the ability to handle wideband TV for which it had plans already laid out in 1947.

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[13] That doesn't sound like much. However, when trying for a half-power beamwidth of about 3 degrees, there is the beginning of some residual AM just from a 2 degree peak-to-peak beam swing.

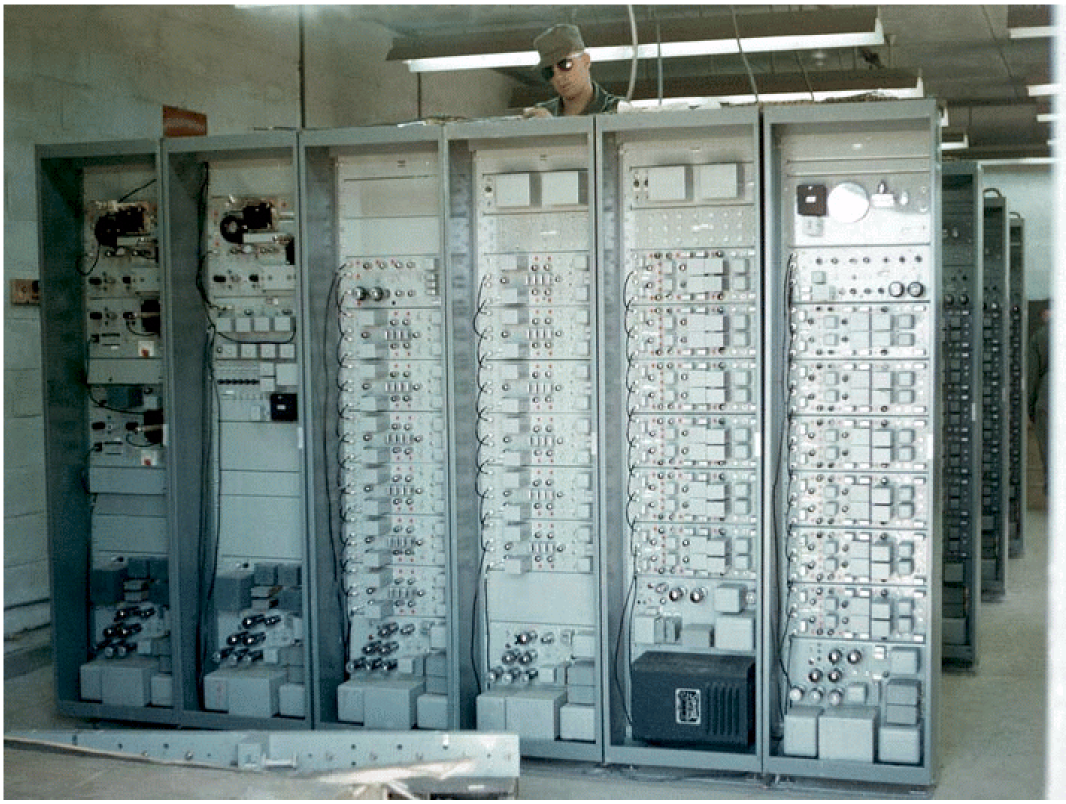
[14] Curious structure, cathodes, screen grid, suppressor grids were common between the two pentodes and allowed electrodes to be connected via only 8 pins. The filaments were common and intended for a 28 V supply. I've not encountered that particular tube type in anything seen after 1952.

[15] That's a small joke, folks. AT&T pioneered much in its life, gave excellent telephone service (perhaps the world leader in that). The *Bell System Technical Journal* that used to be a monthly softbound publication, plus the *Bell Laboratories Record* bi-monthly magazine are common in the larger technical libraries. Bell Laboratories came up with the transistor, was the home of Claude Shannon when he presented his 1948 mathematical theory relating data rate, bandwidth, and random noise (Shannon's *LAW* is an unbreakable one in all communications). The *touch-tone* dialing system was introduced to the public at the Seattle World's Fair of 1962-1963 and has been a success. *Picturephone* personal video-audio communications was discontinued several years ago after a very disappointing low-revenue-producing life.

[16] That had been going on over much of the world. Waveguides didn't suddenly appear at the MIT Radiation Lab during WW2, it was already in the technology. As with the first vacuum tubes, everyone in the microwave field was struggling to come up with efficient *vacuum tubes* to use at microwaves.

The *Fracs* Arrive...

At some time at the beginning of the *Cold War*, perhaps around the beginning of the Korean War which started in July, 1950, the Army began planning a series of ***Fixed*** microwave radio relays. That could have been seeded based on what General Electric, ITT, Philco, and a number of other electronic corporations were doing (in addition to AT&T) for the commercial, industrial market. General Electric Company in particular was spreading out into many areas of radio such as public safety radio (defying Motorola, an established leader then). GE aimed their new 1.70 to 1.85 MHz microwave radio relay series at the commercial market, particularly petroleum and gas pipelines and power lines (for telemetry and control) and roadways (tollway and freeway communications, signaling). Their radio relay series was flexible and adaptable, but mainly affordable.[17] In 1951 the U.S. Army contracted with GE to supply terminals for several radio relay links in Japan. The first of these was the **AN/FRC-23** and the accompanying repeater, **AN/FRC-26.**[18]



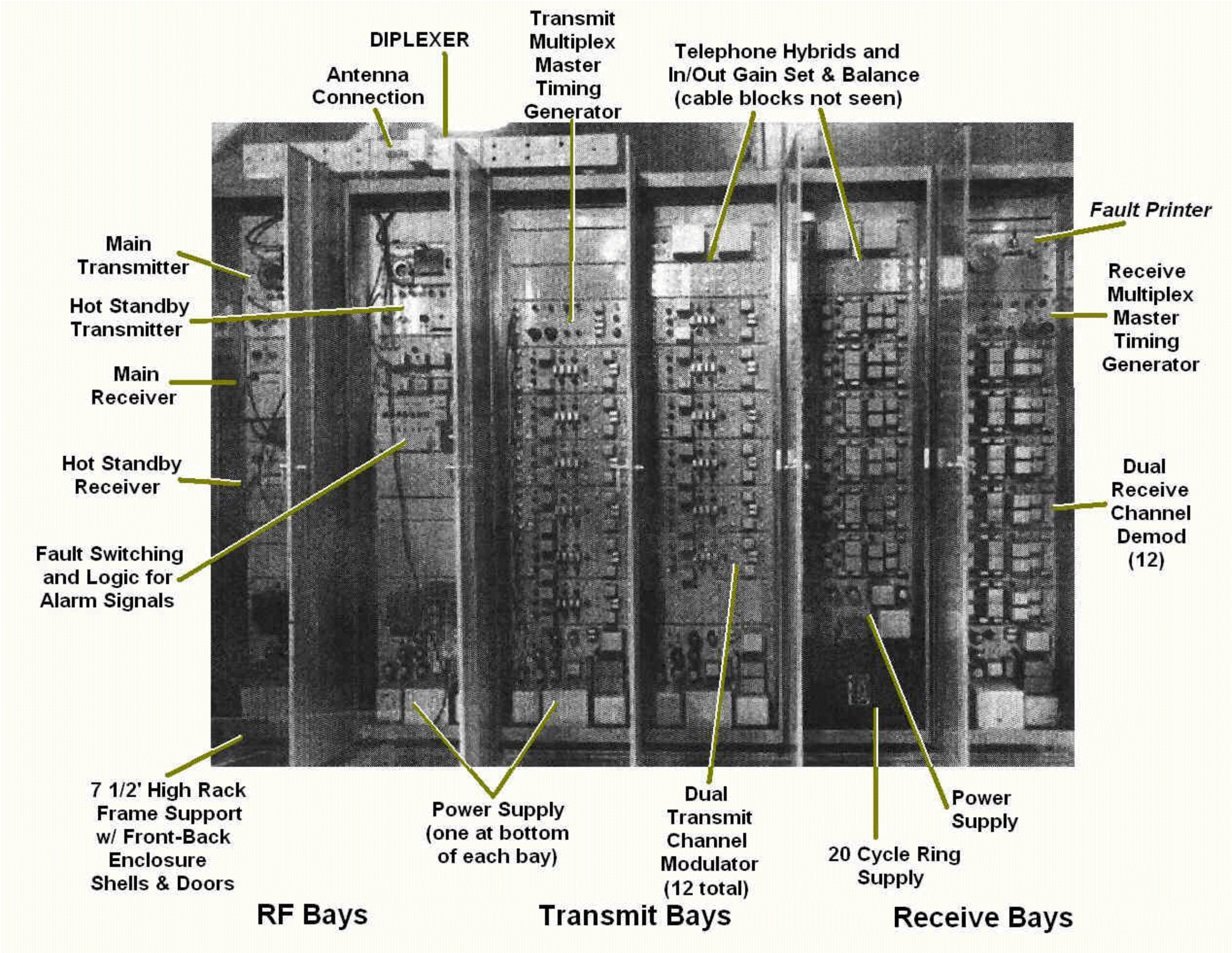
At right four terminals are being installed at station ADA transmitter site at Camp Tomlinson, Kashiwa, Japan, taken in 1954. Rigid coaxial cable has not yet been laid in. Four terminals (two main, two hot spares) will provide 46 voice-frequency (3 KHz bandwidth) channels to/from ADA Control and will the sole means of communications; it is not backing up anything but iself (the *hot* spares, meaning they are powered-up at all times). The receive-transmit ***diplexer*** is laying on the floor in front. It will be mounted on top of the three left-hand *bays.*

[17] AT&T planned their microwave radio relay systems for very long-term service, which meant they could afford a high capital investment which would be amortized over a long period of service. As a result their products for the telephone system were quite robust, but also cost a small fortune in themselves. Commercial users needed lower-cost equipment for lifespans shorter than 20 years minimum planned for telephone systems.

[18] *FRC* denotes *Fixed Radio, Communications* meaning it can be bolted down in one place for years. The GE microwave terminals were **exactly the same** as the GE-number commercial units with the exception of an additional *official name plate sticker* on the front door of each of a terminal's bay enclosure. The instruction manuals were all copies of GE's for use by military as well as civilian employees of the Army. Those of us who began working with the system in 1954 referred to it as simply *GE microwave* and didn't know the *Frac* number until we got the metal stickers to affix to the units...in 1955.

General Electronic Functioning of the FRC-23

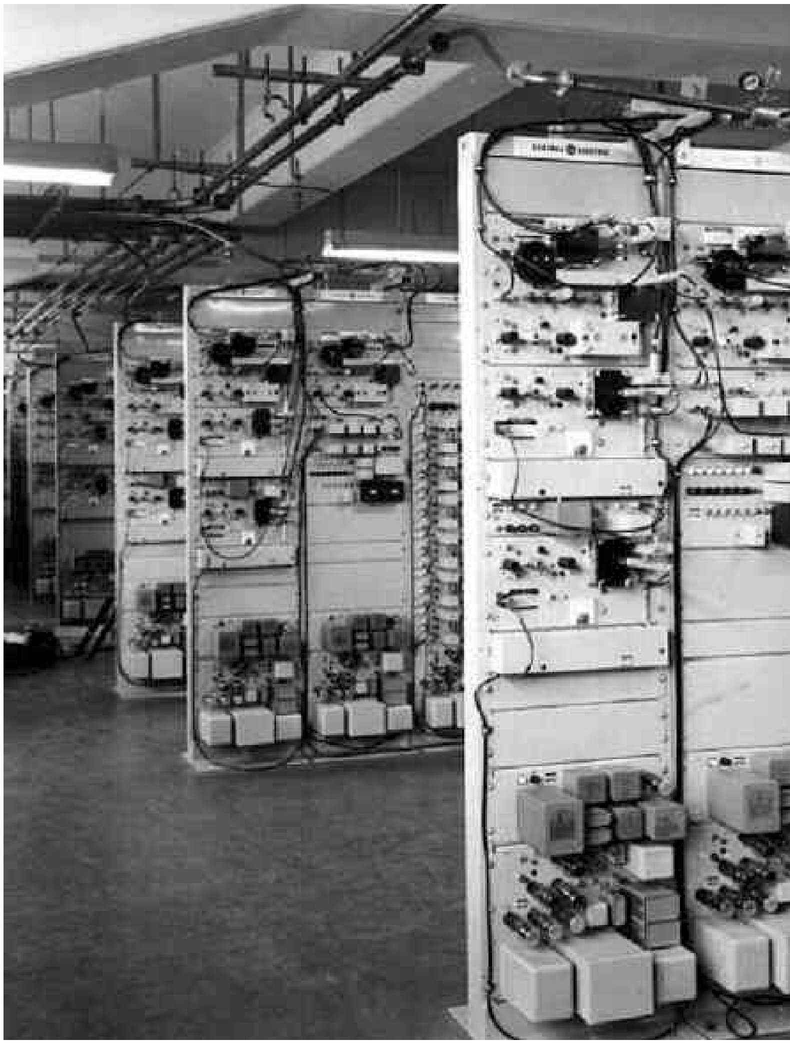
The photo with legends below explains the where of each subsection.[19]



RF Modulation was full on-off pulse of 28 half-microsecond pulses in each frame, frame length time 120 µsec (8 1/3 KHz frame repetition frequency). Duty cycle is constant at 11.7 % and peak power output about 12

[19] Signal Corps photo taken about in 1958 and used by Philippe Pagnier in a PDF presentation entitled *Les Faischeaux Hertziens* which may have been used by his employer, CSC Belgium, in 2004 to potential microwave system customers in Europe. According to the presentation, this terminal is located in Ascom City, Korea, *relocated from Camp Drake, Japan*. Ascom City is not a Korean city but rather a large camp of Army Services (the *ascom* acronym) there for the entire U.S. Army forces, Korea. In 1958 the only GE microwave terminals at Camp Drake were in the ADA Control building just outside of North Camp Drake. The doors would have the nomenclature sticker on each about 3/4 up from bottom; that is known for certain since the author is one of the label sticker-onners in 1955. On the other hand the shell enclosures on each rack were duplicated in back as well as in front and the doors might have been switched. Or the doors simply repainted; those stickers did not remove without leaving some residue or paint flaking off from the base paint. There are several factual errors of description on the CSC presentations page bearing this photo.

Watts into the diplexer. 200 feet of pressurized, rigid 1 5/8 inch coaxial cable will have about 8 db loss so the RF output peak power will be 2 W at the antenna. The antenna was a commercial Andrew 10-foot diameter parabolic reflector with a sealed dipole and sub-reflector element at the focus. Antenna gain was better than 24 db from beam concentration. Transmission-reception was asynchronous with separate carrier frequencies, both transmitting and receiving frequencies directly quartz crystal controlled. The ***diplexer*** was essentially two multi-section waveguide bandpass filters common at the antenna connection. Diplexer alignment was done at the factory or at a Signal Corps depot and was said to be quite tedious given the kind of test equipment available in the 1950s. Isolation between transmitter and receiver was greater than 90 db.



At left (Signal Corps photo), the partially-installed terminals at ADA Control. Coax lines were being installed and checked in this 1954 photo. Note hangar bars for coax and the grouping of lines in parallel towards the left. This is the portal to the adjacent 200 foot tower shown below:

In the arrangement of links at Control, four dishes are pointing at the Camp Tomlinson transmitter site (two main, two hot spares). Two dishes to the left link the Camp Owada receiver site, back-ups to the 5-mile wire lines. The three in the middle are back-ups to wire circuits to Far East Command Headquarters at Pershing Heights, central Tokyo. The longest shoot is Control to transmitters, about 23 statute miles. There were no geographical obstructions in the middle of the Kanto Plain in central Honshu island so all links were quite steady in path loss.

The GE physical structure was straightforward, simple, and lowered the overall cost. It was optimum for a fixed, sheltered environment using vacuum tube circuitry. Every subassembly was built **on** a thick, drilled rack panel, all mounting to a simple, heavy-duty rack frame (visible on page 11).[20] Tubes stuck out horizontally towards the front, interwiring and small components towards the back. What appeared to be a cabinet was a four-sided sheet metal structure that bolted to the rack frame. With the doors shut a natural convection cooling plenum was created, air entering through a grille in the enclosure box and exiting through one in the top. With about 330 tubes total[21] and an average heat dissipation of 3 W per tube (perhaps conservative) and another 2 W of heat dissipated through associated passive tube components, nearly 2 KW of heat is generated from the six rack structures. The only assisted cooling in the whole terminal is done by the small squirrel-cage blowers for the transmitter final amplifier plate fins.[22]

In the then-conventional radio structure started in the 1920s, a *chassis* was a sheet-metal box with plug-in tubes mounted with long axis vertical. That was bolted to a front panel holding controls and indicators, the panel often a *rack panel* of standard 17 inch width, heights in multiples of 1 3/4 inches. That, in turn, could be mounted in a *rack cabinet* consisting of a rack frame welded to a sheet metal enclosure. While that *looked professional* to many, it was cumbersome, heavy, and expensive. It still is. Heat dissipation was largely by conduction through all the metal and tough on tubes located in the center of a chassis. Worse, a chassis with rack panel had to be unscrewed and pulled out of a rack to change most of its vacuum tubes (the most common failure item). That was clumsy and labor-intensive but some old-timers of the day were of the mindset *that's the way it IS done (and don't question it!).*

The then-new vacuum tube support structure exemplified by Howard Vollum's Tektronix oscilloscope designs of the late 1940s was picked up by a few other companies such as GE for their new TV broadcast equipment product line. Indeed, TV electronics used that so-called *dishpan* design[23] in both receivers and studio equipment while audio broadcasting kept the old chassis box format.

In the GE microwave terminal, all tubes were directly accessible by simply opening a bay door.[24] No disassembly required. Plenty of tip jack test points were provided to quickly localize faulty circuits, again all accessible from the front. If any passive component needed to be replaced, all were accessible from the back. *Down-time* (period when inoperative) maintenance is reduced to a minimum, a must in 24/7 operations.

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[20] The technique is common in the telephone infrastructure central offices but has been seldom used in commercial electronics applications such as broadcasting stations.

[21] Tube count is approximate, based on photographic evidence, done 50 years after the fact. While I was able to save a *souvenir* (sort of) copy of the GE commercial manual obtained in a quick 2-week crash course on the system in 1954 at Camp Zama, it was relegated to recycling about 30 years back.

[22] The 2C39 final amplifiers were operated under their limits but needed the extra cooling air flow over the plate fins to reduce *hot spots* in order to preserve as much operating life as possible.

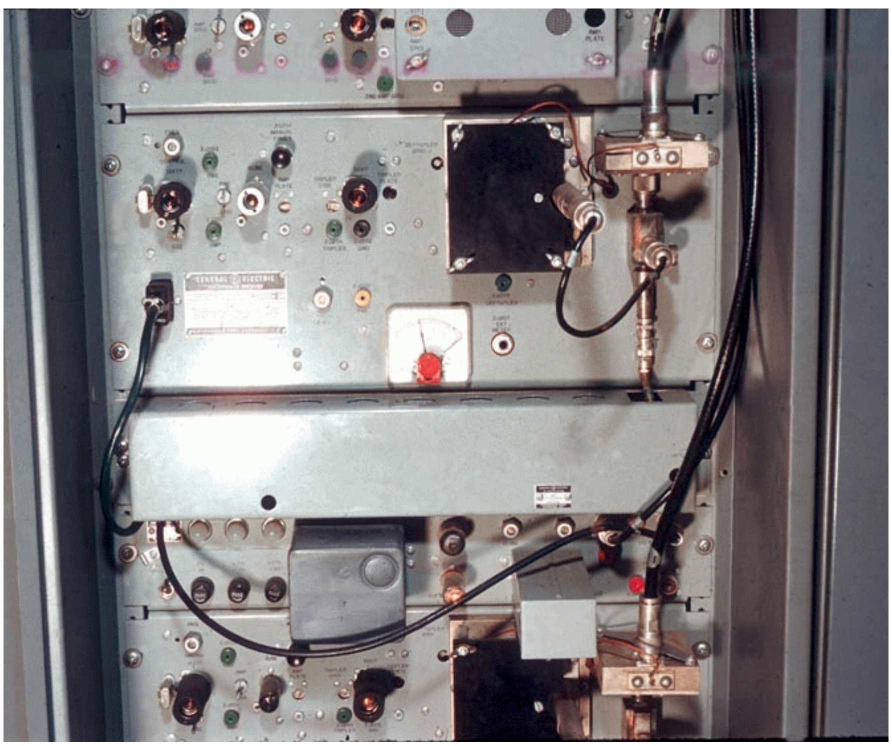
[23] Memory serves that Emerson's TV receivers of about 1955 first used and applied the term *dishpan* to their main TV chassis wiring (all but the channel tuning front end structure). It was economical to produce.

[24] The term *bay* is from telephone central office parlance. The general electronics industry would use the term *rack*, the original telephone word. All racks remain physically standardized in sizes to the original telephone working standard even though the telephone infrastructure electronics changed the dimensions beginning about a decade after the end of WW2. *Bay* must have some egalitarian emotional loading while *rack* is coarse, plebian.

The GE system design allowed for flexibility in the audio interface. One could connect up the internal hybrid transformers and ringer supply for a standard full-duplex telephone circuit...or use separate audio transmit and receive connections for telemetry and control, as done in pipeline and powerline radio relay circuits. Each audio channel was made individually flexible by appropriate jumper wires.

Series-regulated high-voltage plate and screen supplies were used throughout for excellent voltage regulation. There is one regulated supply assembly at the bottom of each rack/bay. While this may seem overkill, the system was designed for flexibility and common use among several different system versions. A repeater terminal (FRC-26) would have the same RF bay grouping but the audio multiplex would be reduced to a *Drop-and-Insert-Unit* assembly for the channel 1 order-wire used for radio relay link maintenance. *B+* requirements for that rack were slightly different.[25] Excellent voltage regulation meant stable pulse and digital circuit operation regardless of local power variations. This was carried to a fine art by Tektronix in their 530 and 540 series oscilloscopes introduced in the 1960s.

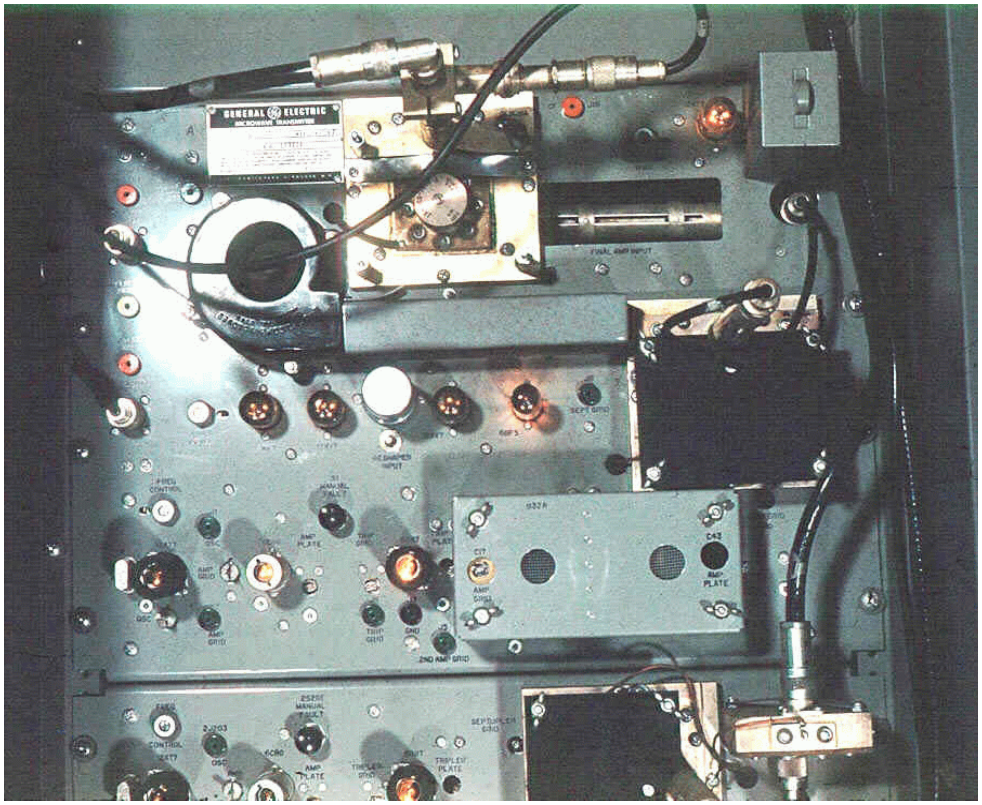
Since the RF section was considered the most likely area for operating failure, two *identical* transmitter and receiver assemblies were designed in, one as the main, the other as a *hot-spare* (always on). Automatic switch-over to the spare was provided by sensing the detected RF out of the transmitter (detector probe), receiver mixer current (as a result of local oscillator injection to a single point-contact radar-style diode). The latter used a microammeter having an adjustable extra contact for the meter needle (so-called *meter relay*).



GE main receiver assembly in center with IF strip in long horizontal box structure below the mixer current meter (tubes for IF strip enclosed also). Crystal oscillator at upper left, 5th overtone type, followed by buffer amplifer, multiplier, and septupler multiplier (2C39) under the black plastic plate. Large flexible coax comes from the top into a square pancake-style preselector cavity, then down to a diode mixer assembly (LO injection connected via small flexible coax from septupler's output matching unit. IF signal flow is right to left. Panel just below IF strip is part of the receiver fault sensing and switch-over control that can select an identical hot-spare receiver shown partly at photo bottom.

The bottom of the main transmitter panel is at photo top. This is the left-most rack/bay in the FRC-23.

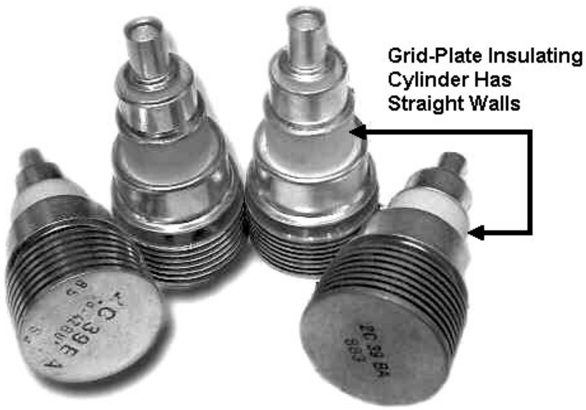
[25] *B+* is an old, old term for a plate supply for tubes, originating when radios were solely battery powered from A batteries (filament supply), B batteries (plate supply), and C batteries (bias voltage). For some reason, *B+* always means *plate supply* to old-timers who began learning about radio in the 1940s and 1950s.



Main transmitter panel with 5^{th} overtone crystal oscillator at lower left, buffer amplifier, multiplier (miniature glass tubes), 832 buffer amplifier at UHF inside the gray square box at lower right, that feeding a 2C39 septupler under the black plastic cover plate (same as the receiver), to the final amplifier 2C39 at top middle (cover plate removed for photo). A small squirrel-cage blower supplied forced air to both septupler and final through the rectangular air guide in middle of assembly. A sliding-stub coax tuner is seen through the panel cutout towards top right, placed between septupler output and final amplifier input. Final amplifier output cavity exit is towards the camera at the top middle, large flexible coax to the RF relay below the diplexer (out of photo), small flexible coax for RF output detector probe assembly video output connects back to the panel at upper left for fault detection circuitry. Note the use of type N connectors for microwave RF and type BNC connectors for video and low-power RF, new to the RF world of 1950.

At right the partly installed terminals at ADA Control. The top panel assembly of the right-most rack in a terminal was the *fault printer*, a kluge-like thing that consisted of a solenoid-driven ***pencil*** that made marks on a paper tape. The solenoid was activated by alarm signals sent from repeater terminals and had a pulse code (very slow speed data) corresponding to one of several different detected faults or operating conditions along with a repeater terminal identifier. That design appeared to be an afterthought without a lot of effort into it. It was never used at ADA, principally because no repeaters were used in the ADA links during 1954-1956. The big black box at photo lower left is the 20 cycle ringer supply (commercial unit made by another company) for telephone circuit ring purposes. The rack frame bottom flanges were attached to the floor via *RamSet* fired bolts, new to fastening in the mid 1950s.

A Problem



The 2C39 tuned cavities had a flat pancake-style which required straight grid-plate insulating cylinders shown at left from a modern photo.[26] GE's tube division made them that way but the industry standard allowed a slight bulge in the grid-plate insulator. Matchlett, a known good supplier of higher-frequency tubes, made an industry and military approved 2C39 which had the bulge. Those tubes would not fit the GE cavities. Murphy's Laws took hold and the spares supplied to the Far East Command were mostly made by Matchlett. Station ADA had 18 terminals in the late summer of 1955. Those used a total of 108 2C39s and some of the originals had started to degrade after a year of operation. A small fuss in higher command circles started but we were eventually supplied with straight-insulating-cylinder tubes to keep running 24/7. All the other vacuum tubes were standards, no specials even though many were new types in 1950. So-called *miniature* 7-pin and 9-pin all-glass-envelope tubes were standard in most of the panel assemblies (except the power supplies).[27]

At right, 9 terminals in operation, prettied-up with full enclosures at ADA Control at Chuo Kogyo just outside of North Camp Drake, Japan. The only task was to finish sticking on the door labels making them an *official* FRC-23. The *scope cart* was brand new and holding the Tektronix 511AD scope so necessary for the proper video measurements and observation needed.

[26] There are at least a dozen different ways to make a tuned cavity for the same frequency. Actual choice is dictated by size and weight constraints but often by the confidence of the designer familiar with certain types. GE designers naturally used tube specifications from the GE vacuum tube division...all one company.

[27] *Miniature* in the 1950s referred to being smaller than the old standard 8-pin octal tubes. The solid-state era had not yet taken hold in electronics and truly miniature devices such as the integrated circuit had yet to appear in new designs then.

Some Miscellany and References

A number of electronic historians refer to Pulse Position Modulation as *PCM* (Pulse Code Modulation) as if there were analogue-to-digital converters used. Those weren't practical in the 1950s, took way too much circuitry with tubes. Pulse Position Modulation has a constant duty cycle, important for the on-off keyed microwave transmitters. Sample-and-hold circuits could be done in the fifties and this was the basic sampler of the input. The short time-constant of the hold circuit was good enough to vary the bias on a one-shot triggered from the master transmit timing. That bias controlled the width of the one-shot. The trailing edge of the one-shot triggered a fixed pulse width blocking oscillator. That output was combined with all the other channel pulses for the transmitter, plus the four-pulse frame timing pulse burst. For receiving a channel, the process was done in reverse. A video sync stripper got the master timing generator synchronized with the framing pulse burst. Master timing also enabled a demodulator to trigger a one-shot at the channel time slot start. The gated video then allowed the proper channel pulse (varying in time position) to force the one-shot off. The one-shot output resembled a Pulse Width Modulated signal. That was sent into a lowpass audio filter which averaged the width modulation into the original audio signal (efficiency is terrible that way but it is very simple and the input amplitude available was quite high so losses didn't much matter). To send a ring signal for a telephone circuit, the transmit pulse position was moved to its maximum time for the duration of the ring. Not a problem since no one was talking during a ring. The receiver demod final one-shot was made parallel to an R-C integrator with diode clipper; a maximum channel time position would result in a DC output of the diode which drove a relay to put the ring generator 20 cycles on the telephone line.

The FRC-35 was another version of the GE 24-channel radio relay terminal, same modulation format, same RF range. The FRC-34 was the repeater version of the -35. According to a brochure produced by my battalion in 1962, some of the ADA radio relay terminals had been changed to the -35s but some of the -23s remained judging from a single photograph in that brochure.[28] I don't know the differences between the GE units; those could be discerned by sending for copies of old military equipment (at least $30 minimum cost) but that isn't worth it personally. I spent a year and a half of my military service on the -23 as an operations and maintenance supervisor and most of the details in here are from a good memory and lots of personal photos. Details and minutiae of technology of a half century ago remain just more minutiae of the past in a radio world that long since entered the semiconductor era.

According to many publications of AT&T, they did everything in radio relay. They did much but just not everything. David Massey's excellent website on AT&T, especially the *Long-Lines* (long distance service between local exchanges) is a good reference for historical information on telephone radio relay and some of the higher-level military communications systems during the Cold War. One reproduction from the *Bell Laboratories Record*, August 1967, *The LD2 Story - From Research to the Field*, pp 284-285, claims the TRC-6 was "*the first microwave radio relay to see combat*" during the crossing of the Rhine River in 1945 (-6 operates in the same portion of C Band as the LD2 would after WW2). I might question that but have had an extraordinarily difficult time getting detailed equipment history from Army historical sources via the Internet; it is hard enough for a civilian to access the Army Center for Military History or the Signal Center Museum at Fort Gordon, GA even if one were there in person. Published historical accounts from both sources indicate the TRC-1s and the CF carrier equipment were operating in the field in Italy in 1943 and in France-Belgium-Germany during 1944-1945. The *Army Communicator*, a bimonthly news magazine for Signal Corps

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[28] Brochure copy courtesy of Mr. James Brendage, retired civilian engineer who worked for the U.S. Army, then the Air Force at the same transmitter sites I worked at.

professionals and contractors, has many stories about military radio and its uses archived on-line since the sixties (they are still catching up on archiving everything). Those archives indicate the SCR-293 and SCR-294 mobile FM low-VHF *tank* radios were proven in actual armor combat in the North African campaign of 1942-1943. *In combat* isn't quite the same as *in the field* where most radio relay systems dwelt.

While the commercial designers-producers of radio relay equipment did quite some pioneering in that and other civilian communications systems, both in circuit and physical structure techniques, information on half-century old products is negligible on the Internet. What remains is primarily personal-narrative sort (such as the IEEE *Oral Histories* collection of notable persons), associations or of private individuals (such as myself). Some early Motorola WW2 history information is available and Corning Frequency Control has a few historical documents concerning quartz crystal units of earlier days. The Army Training and Doctrine Command Digital Library has a number of public-release Field Manuals (FMs) such as FM 24-24, a catalog of all Signal Equipment. However, FM 24-24 is nearly 20 years old and the website is getting hard to access by ordinary citizens. A few private collectors of TMs (Technical Manuals) such as BAMA (Boat Anchor Manual Archive) have some interesting tidbits of information: The TM for the AN/PRC-6, the VHF FM *handie-talkie* successor shows how two PRC-6s can be connected back-to-back to serve as a temporary radio relay link in hilly areas such as that of Korea during the Korean War. An adapter cable was operational issue for just that purpose. Similarly, two AN/PRC-8, -9, -10 *VHF FM walkie-talkies* (backpack portables) could be connected as a temporary radio relay repeater. This predated the amateur radio VHF repeaters that would begin arriving over a decade later in the United States.[29]

Many military and civilian radio relay systems are yet to be described/discussed by their attendants. For example, the AN/TRC-24, a versatile 40 to 400 MHz radio relay with self-contained carrier frequency multiplexer and *spiral-four* cable repeater-amplifiers (powered from terminals through the cable), saw much service in Southeast Asia conflicts in the 1960s. It was new in 1955 but hasn't appeared in literature or on the 'web except as brief mentions or photographs of its square planar broadband antennas. It has become obsolete as yet another vacuum tube *boat anchor*.

The modern U.S. military uses mature digital radio relays of higher capacity, lighter weight, some capable of linking via military communications satellites. Land forces have the analog/digital *SINCGARS* family that can be ***netted*** over small geographic areas.[30]

A composite form of radio relay exists today in the Community Access Television or CATV, serving the majority of TV viewers all required to pay a subscription fee for access. CATV operators are required to carry local TV broadcasts on their (mostly) wired systems, sometimes translating their carrier frequencies to provide

[29] That requires some careful choice of frequencies due to chance of overload of one receiver by the other units' transmitter since neither have sufficient bandpass filtering in themselves. Amateur radio repeaters usually add on a diplexer or other high-attenuation bandpass or notch filter to avoid that, as do quite a few civilian repeater stations whose technology information is not easy to obtain.

[30] The SINgle Channel Ground Air Radio System (SINCGARS) family is probably the most-produced small radio transceiver in military history. To date, over 250 thousand sets have been produced, most by ITT Aerospace-Ground Communications division in Fort Wayne, IN. It operates 30 to 88 MHz, with or without frequency hopping, in-clear or encrypted, voice or data. COMSEC (COMmunications SECurity) is built-in. Its internal time reference can be updated by connecting to an AN/PSN-11 GPS receiver (called *Plugger* although most soldiers have a cruder familiar name for it). The UK and some NATO nations have adopted the same system for their military land forces.

a more compact channel occupancy. Some, as with the author's service, convert the analog TV signals to a digital form so that an enormous number of TV channels may be carried on a wideband wired network. Most of the non-broadcast channels are obtained from satellite radio downlinks. Those can also supply FM broadcast and audio-only channels for non-viewing pleasure. Communications satellites are radio relays and were first described by science-fiction-author-notable-to-be Arthur C. Clarke in an issue of *Wireless World* in 1946.[31]

Wireless LANs are a commercial form of radio relay used over relatively short distances on long-wavelength microwaves (1, 2.4, 5.6 GHz *ISM* bands, license-free). In one way, the ubiquitous cellular telephone cell site is a form of radio relay on the 1 GHz band; many cell sites are coupled to central offices via dedicated microwave radio links.

A half century ago none of those modern services existed. Radio and electronics was still in the vacuum-state era, doing well and advancing, but doomed to become obsolete as vacuum-state within a few decades. For one young artist-illustrator the exposure to *big time* radio was the final key in unlocking a whole new career once my military service obligation was completed. I don't regret that exposure or change in careers. It has been rewarding personally and financially. It is a bit of pleasant nostalgia to wander back to a definite turning point in the technological field of radio as it was in the fifties. It was a fascinating transition time.

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PS: Lest anyone accuse me of cribbing photos or information, all the color photos are from my camera; except for the one photo of 2C39 tubes, all the black and white photos are mine or obtained from U.S. government sources. Textual information is either from memory or from the various sources mentioned plus a few more; no specific scholarly reference notes are done as I am not trying for an advanced degree in anything

31 In early 1975 my employer was RCA Corporation and had just expanded its technical library at the old EASD in Van Nuys, CA. Among the items was a number of Wireless World issues of the past. It was a thrill to see the article so often mentioned in literature as the spark or seed of the now-large satellite communications industry. Clarke was a *boffin* or civilian engineer with the RAF during WW2 and worked on the first GCA (Ground Controlled Approach) landing systems. He is living in semi-retirement in Sri Lanka, still writing about alternate futures involving science.