New Life for LORAN

Part 1

by Clifford Appel

The US Coast Guard recently retired the most powerful vacuum tube transmitter left in its LORAN arsenal. LORAN still continues to provide navigation service using state-of-the-art technology.

It's not very often that a guy gets to witness "the changing of the guard" during his lifetime, but I've been fortunate enough to do just that. As the years have gone by, we've all seen technology change in unimaginable ways that stun us with "gee whiz" events. December 8, 2003 marked the beginning of the end in an era of vacuum tube LORAN "C" (LOng RAnge Navigation) transmitters.

The last of the US Coast Guard's highest powered vacuum tube transmitters (AN/FPN-45) — 1.6 megawatts pulsed power output — was shut down on that date. In its place, a solidstate transmitter (Accufix Model 7500) at 1.3 megawatts was placed on air to continue the LORAN legacy at LORAN C Station George, WA.

LORAN's history dates back more than six decades, with LORAN "A" sprinkled near coastlines around the world. It was the major wide area coverage navigational system before LORAN "C" was implemented, eventually replacing the "A" stations.

LORAN A operated on 1750, 1850, 1900, and 1950 kHz. Amateur radio operators using 160 meters were restricted in frequency use and DC power input — daytime and nighttime — depending upon geographic location in the US and Canada. The restrictions were imposed because of anticipated interference to LORAN A signals. Gradually, LORAN C stations took over the navigation duties and forced the LORAN A stations into history. The last series of A stations were taken off the air from July 1979 to July 1980 in the US. Amateurs no longer suffer 160 meter restrictions.

How It Works

LORAN is an electronic type of navigation for which users require a receiver. These days, most people are familiar with the ubiquitous GPS (Global Positioning System) units. The user turns on the power switch of the GPS and, in a matter of minutes, the GPS receiver automatically acquires the requisite number of satellites, makes a series of calculations, and displays geographic position in latitude and longitude. Owners of GPS units are aware that they can do a lot more than that basic function, however.

Unlike GPS — which uses a "constellation" of about 24 LEO (Low Earth Orbit) satellites — LORAN uses a "chain" of land-based transmitters. GPS uses frequencies of 1575.42 MHz and 1227.6 MHz, far removed from the 100 kHz carrier frequency of LORAN C. Modern LORAN receivers work the same way as GPS units, in that the user turns on the power switch and the receiver acquires signals, makes calculations, and

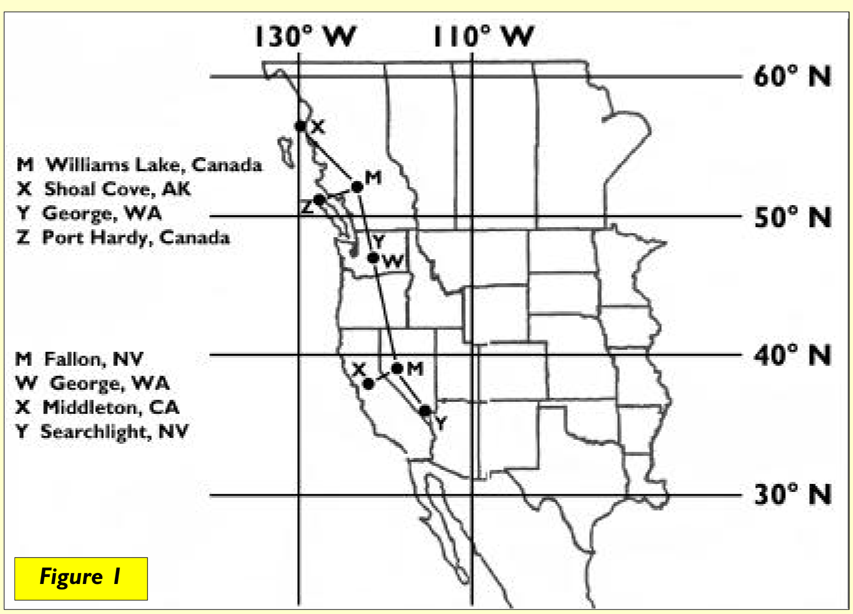


Figure 1

displays geographic positions.

Figure 1 shows two such chains on the West Coast of North America. A chain typically consists of three to five stations. One is designated as the "master" station (letter M) and the others are designated as "secondaries" (V, W, X, Y, and Z). The upper chain of stations shown in Figure 1 is known as the Canadian West Coast Chain and the lower group of stations is known as the US West Coast Chain. It is interesting to note that the station at George, WA participates in both chains (i.e., "Y" secondary in the Canadian chain and "W" secondary in the US chain). That operational mode of gymnastics is called "dual rate" and is performed by several LORAN stations throughout the US and Canada.

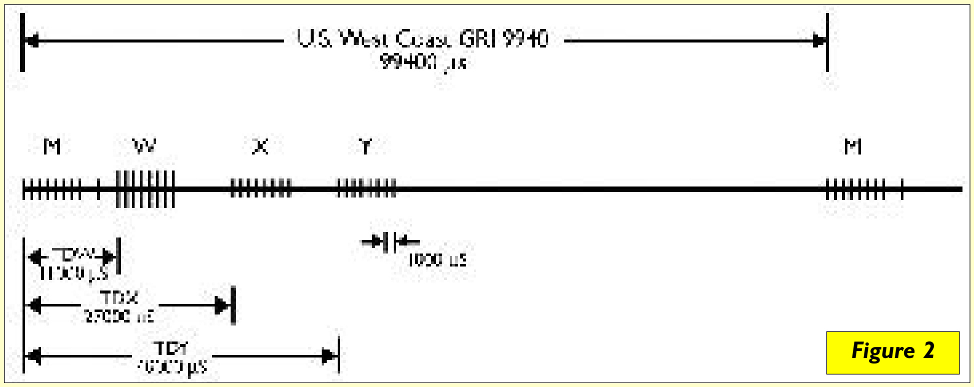


Figure 2

So, how do all these stations in a chain play together? Let's look at the US West Coast chain in Figure 1. The master station M at Fallon, NV transmits a series of pulses. The first eight are spaced one millisecond (1 ms or 1,000 microseconds) apart with a ninth pulse spaced 2 ms after the eighth (see Figure 2). A given coding "Time Delay" (TDW) — later secondary station W at George, WA — transmits a series of eight, 1 ms spaced pulses. Another coding Time Delay later (TDX) — secondary station X at Middletown, CA — transmits a series of eight, 1 ms spaced pulses. Lastly, at yet another Time Delay (TDY), secondary station Y at Searchlight, NV burps another eight pulses. The master station always transmits nine pulses for easy identification of its role as master.

The entire process repeats over again in what is called the Group Repetition Interval (GRI). To confuse novices to LORAN terminology, the GRI is given in tens of microseconds. Thus, a GRI of 99,400 microseconds is known as "LORAN rate 9,940." It is the GRI that the LORAN receiver uses to identify the chain to which it's locked on. The TDs between secondary stations vary from one chain — or GRI — to another, so that there's no confusion if the receiver picks up secondaries from another chain. Reference 1 provides information regarding all LORAN chains, station geographic coordinates, GRIs, and TDs. Do you feel like you've just been hit by a can of alphabet soup?

Figure 2 showed all those LORAN pulses as just straight lines, but what do those pulses really look like? Figure 3 shows a LORAN pulse in detail. Remember, the frequency is 100 kHz, so the time between cycles is 10 microseconds. The shape of the "envelope" of the pulse is no accident. It is built up in such a way that the peak amplitude is reached 65 microseconds after beginning the pulse.

The third cycle crossing "zero" on the horizontal axis (time axis) is what the LORAN receiver uses to determine Time Delays (TD) between the master and secondaries. The pulse is intentionally damped after peak so that trailing sky waves will not contaminate the beginning of the next pulse. LORAN's virtue is its ground wave, which is more predictable and repeatable than a sky wave. Because of the shape of the pulse, the bandwidth of a LORAN signal is kept to 20 kHz in the spectrum from 90 kHz to 110 kHz.

What do all these received pulses get you? They get time delays between reception of signals from stations in a LORAN chain. In the "old days," these time delays were actually displayed on a readout. The user then took those numbers and entered them into a chart with LORAN lines on it.

Do you remember plane geometry from high school? The chart contained hyperbolas, each of which was a locus of the same time delays between stations. Got that — "hyperbola" and "locus?" One time delay got you on one hyperbola on the chart. The navigator calls this a "line of position" or LOP. Another time delay got you on a second hyperbola on the chart or LOP. The intersection of the two hyperbolas, LOPs, therefore, was the receiver's (your) location and is known as a "fix" in navigational lexicon.

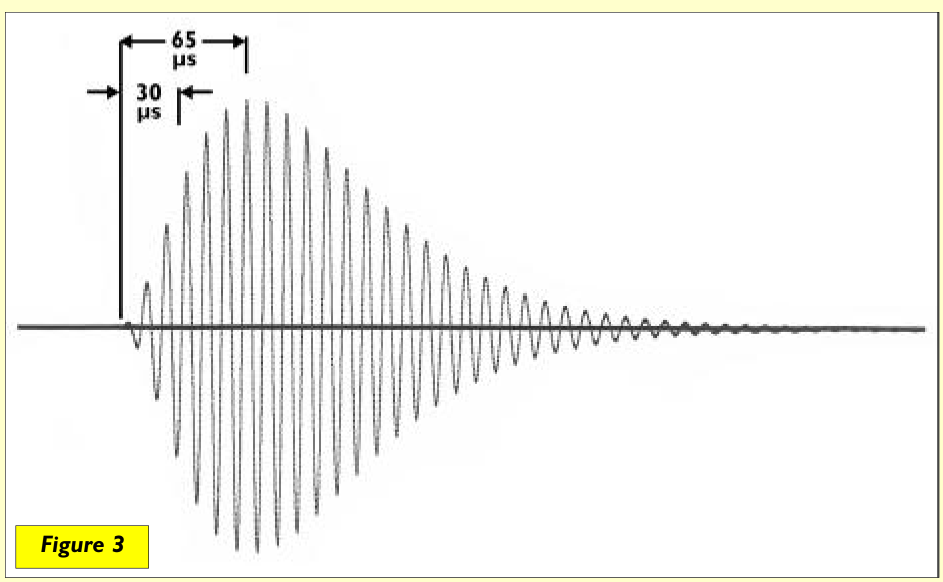


Figure 3

Figure 4. AN/FPN-54 Timing Rack where the LORAN pulses are generated for amplification in the AN/FPN-45 vacuum tube transmitter. Photo courtesy of ETC K. Anderson.

Figure 5. The first IPA, second IPA, and driver/PA tubes are shown from right to left. Note the 12" ruler. The second IPA — in the middle — weighs in at 23 pounds. The driver/PA on the left weighs 21.5 pounds.

Figure 6. One of the two AN/FPN-45 transmitters on air, cranking out 1.6 megawatts.

The receiver needs to acquire three LORAN stations in a chain to provide a fix. Modern, powerful microprocessors and algorithms perform complicated calculations that result in latitude and longitude (Lat/Lon) being displayed instead of time delays, obviating the requirement for a LORAN-specific chart. As with the GPS receiver, most LORAN receivers will do more than simply display Lat/Lon.

The above is a rough idea of the LORAN technique. In reality, it's a bit more complicated; the pulses in an eight-pulse group are phase coded, as well. The TDs are not pure integral numbers, as noted in Reference 1. Some heavy duty signal processing and intense mathematics are going on in the receiver. LORAN's useability is specified down to an SNR of 1:3. You read that correctly.

In other words, if the noise is three times greater than the LORAN signal, you can still acquire a LORAN signal and use it for navigational purposes. In order to perform this magic, the LORAN receiver uses a process known as coherent detection (Reference 2).

The Vacuum Tube Transmitter

Once upon a time, the US Coast Guard had many AN/FPN-45 LORAN transmitters in operation, most of which were scattered on islands in the Pacific Ocean. Those stations were shut down a decade ago, leaving the one at George, WA as the "Lone Ranger" of the high powered vacuum tube transmitters. Presently, the USCG has 10 other vacuum tube rigs (AN/FPN-44), but they only radiate 400 kilowatts of pulsed power. All of these units will be replaced with solidstate units.

Where's the genesis of the operation? The LORAN pulse is developed in the Timing Rack — AN/FPN-54 — which is a solidstate discrete component and integrated circuit technology. Figure 4 shows the equipment. Not shown is a second set of rack panels containing three cesium beam oscillators for precise timing control. More on the cesiums will be detailed later. Also not shown is a third set of rack panels containing monitoring and alarm equipment, known as RAIL — Remote Automated Integrated LORAN. So, there's a lot of peripheral equipment involved in just getting that perfectly formed pulse of Figure 3 fed to the transmitter.

The LORAN pulse is sent to the next room to be pumped up from wimp to Schwarzenegger status in the AN/FPN-45 transmitter. Figure 7 is a block diagram of the tube complement that amplifies just the upper half of the pulse. An identical tube complement amplifies just the lower half of the pulse. I think a lot of older hams know what a 6CL6 and a 6146W look like, but take a look at Figure 5 to see the physical size of the 4PR1000A first IPA

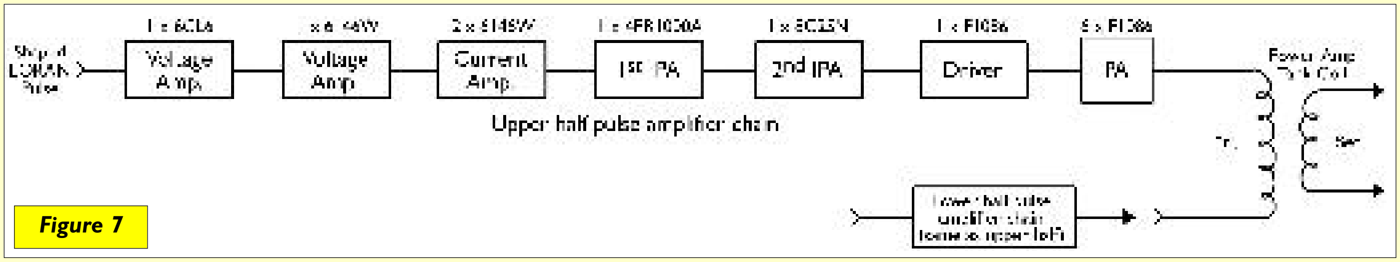


Figure 7

(Intermediate Power Amplifier), 8C25N second IPA, and the F1086 driver and power amps (PA) compared to a standard 12 inch ruler.

The first and second IPAs are air cooled, but the driver and power amplifiers are both air and water cooled. The 8C25N has radial cooling fins inside that big copper anode; the tube weighs in at a hefty 23 pounds. The F1086 has its copper anode cooled by deionized water and air; this tube is a lightweight at 21.5 pounds.

With tubes this large, you can imagine that the voltages involved are commensurate. The PA plate voltage is 21.5 kilovolts with a negative 1,100 VDC grid bias voltage. The PAs are triodes operating in push-pull, class B, with all six pairs operating in parallel. Both IPAs and the driver use a plate voltage of 10,750 volts. Even the bias on the driver tube is wicked at a negative 1,800 volts.

If the plate voltages seem awesome, let me throw some numbers at you regarding the filaments. The 8C25N second IPA uses a filament voltage of 7.1 VAC at 110 amps per tube. The F1086 driver and PA filaments use 12.6 VAC at between 270 to 290 amps per tube. I made some cursory measurements during testing when the vacuum tube transmitter was removed from on-air service and discovered that just lighting the filaments for each transmitter gobbled up about 100 kilowatts.

Taking a look at Figure 6 gives you an idea of the size of the transmitter; there's one on each side of the passageway. One is on-air while the other is in standby to act as a "ready backup." Every two weeks, the transmitters are switched to keep the operating hours about the same on each unit. Every day, there is a requirement to run up the standby transmitter into a dummy load to insure it will function properly in the event the on-air unit fails. At that time, the power demand from the local utility for total LORAN station operation is nearly 1,000 kilowatts. Remember that number when we get to the new solidstate transmitter.

Figure 8 shows the two first IPAs and the two second IPAs in their cabinet. Note the warm glow of the filaments. You can be sure the plate and grid voltages were not on. Figure 9 shows two of the PA tubes (with filaments lighted) and the associated "plumbing" between the two. These tubes are air and water cooled. Thus, you can see the copper pipes and red hoses carrying deionized water to and from them.

Figure 10 shows the inside of a transmitter. The gray unit at the bottom left is the transformer providing the 21.5 kV plate voltage. The red hoses on the bottom right are carrying the deionized water to the driver and PA tubes. The big circular object in the middle is the power amplifier tank coil. It is three feet in diameter and four feet long. The wire forming the coil uses insulation the same as the spark plug wires on your automobile.

I mentioned that the transmitter is air cooled. We don't just open doors and let the wind whistle through. At the end of the transmitter is another room called a "plenum." It's a space about 40 feet wide, 28 feet deep, and 11 feet

Figure 8. The two tubes in the middle are the first IPA (push-pull, class B) amplifying the upper and lower halves of the LORAN pulse. The two outboard tubes with the black anodes are the second IPA, also operating class B. Gotta love those filaments! Photo courtesy of ET1 K. McKinley.

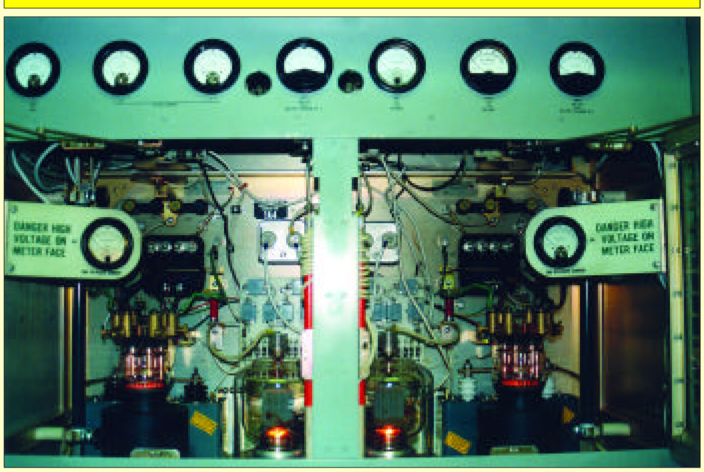
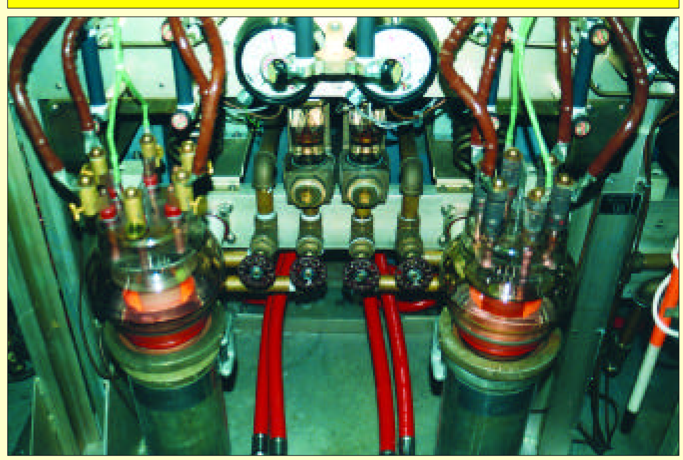


Figure 9. A view of two of the 12 PA tubes with filaments lighted. The red hoses carry deionized water around the tube for cooling. Additionally, all the tubes inside the transmitter are cooled by circulating air at 55° F. Photo courtesy of ET1 K. McKinley.



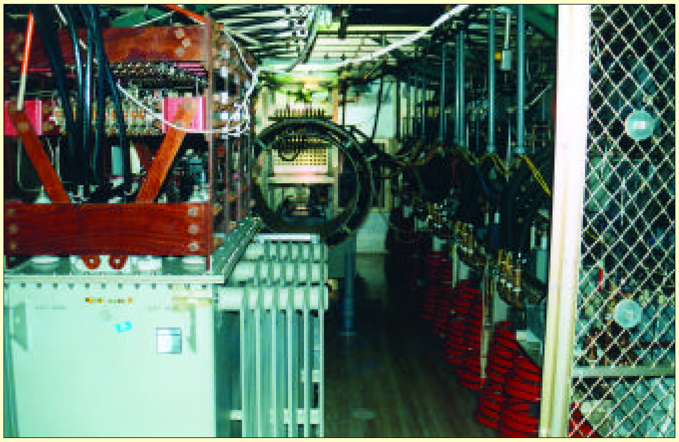


Figure 10. A view inside the transmitter with plate and bias voltages off, of course. Photo courtesy of ET1 K. McKinley.

Figure 11. This is what it takes to remove the heat from the transmitters. The A/C units are rated at 30 tons each. There are four heat exchangers (HEX) to cool the deionized water used for the driver/PA tubes. Photo courtesy of ET1 K. McKinley.

high with three "air handlers" — or blowers — that circulate refrigerated air around the plenum. That cold air (kept at 55° F) is sucked into the transmitter cabinet for cooling those big tubes.

The cooled air for the plenum is provided by three, 30 ton air conditioning units, which are shown in Figure 11. The devices with the white pipes on them are the heat exchangers (same concept as an automobile radiator) that cool the deionized water used for cooling the PA tubes. You have to get rid of the heat from that big transmitter somehow and you can see what a major effort it is by noting the physical size of the equipment.

Everything about this transmitter is big: the power consumption, the vacuum tube sizes, the heat generated, the lethal voltages used, the cost of parts, and maintenance time and costs. The monthly electric utility bills were running over $9,000.00 per month. All first IPAs are swapped out every three months. Every six months, the second IPAs are swapped out if they even show a hint that they are deteriorating. Those big drivers and PAs are "nominally" changed out at two-year intervals, depending upon each tube's condition.

The 4PR1000A first IPA costs about $1,300.00 new. The 8C25N second IPA is no longer made, so they are rebuilt to the tune of about $1,600.00 each. The F1086 drivers and PAs are no longer made, either, and it costs about $2,300.00 to rebuild one. Remember, there are 12 PAs and two drivers per transmitter. Okay, you "bean counters," break out your calculators.

Now you know why the US Coast Guard is investing in a new transmitter to replace the aging vacuum tube gear. Next month, I'll introduce you to the details of the solid state transmitter. **NV**

References

Reference 1 — **www.navcen.uscg.gov/loran**
Click on "LORAN-C User Handbook." Although this publication contains information regarding LORAN stations long since shut down, it is a good tutorial for providing insight as to how LORAN works.

Reference 2 — Private correspondence March 5, 2004 with Bill Roland, a retired engineer from Megapulse, Inc.

About the Author

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