New Life for LORAN

Part 2

by Clifford Appel

Last month, I explained how LORAN (LOng RAnge Navigation) worked as a navigational aid system and how it was originally implemented using vacuum tube transmitters. This month, we will continue with the story of the retirement of the world's most powerful vacuum tube LORAN transmitter of 1.6 megawatts at the US Coast Guard station at George, WA. The vacuum tube transmitter went on air in September of 1976 and was officially taken off air on December 8, 2003. After switching the antenna transmission line from the vacuum tube transmitter, a new solid-state transmitter was operating within about two hours. Read on to learn about the new solid-state concept and LORAN's future.

The Solid-State Transmitter

The differences between the vacuum tube transmitter(s) and the new solid-state transmitter are like night and day. This should be the case because of a 25 year period to improve transmitting efficiency and frequency/control techniques from computer technology.

The transmitter known as the Accufix 7500 is manufactured by Megapulse of North Billerica, MA. Megapulse has supplied earlier versions of the Accufix, known as the AN/FPN-64, which were of lesser output power capability for USCG LORAN stations, primarily in the inland areas of the US. Megapulse has recently finished supplying units to the nation of Japan for their LORAN chains.

The new frequency/control equipment is shown in Figure 1. At the left are two Transmitter Control Subsystems (TCS) — one active and one standby. The TCS controls precise timing of the transmitted LORAN pulses and also monitors the "quality" of those pulses.

Third from the left is the Transmit Frequency Equipment (TFE), which generates George, WA's LORAN rates of 9,940 and 5,990 as the old equipment in Figure 2 of last month's article did for the vacuum tube transmitter. To the right of the TFE is the AUX rack containing three Hewlett Packard HP-5071A Cesium Beam Frequency Standards. Each Cesium costs over $28,000.00 and they are the reason the LORAN signal is so repeatable with time to its users. In a one day period, HP rates the frequency stability as better than 3×10^{-14}. You don't get that kind of stability from a TCXO (Temperature Compensated Crystal Oscillator), which is a common option in our HF amateur radio equipment.

Two racks on the far right (only a portion of one is shown) are the RAIL (Remote Automated Integrated LORAN) equipment, similar to what was used for the vacuum tube transmitter. The RAIL — consisting of commercial grade Dell computers — provides timing corrections, system alarms, a means to input "commands" to the TFE and TCS, and also acts as a communications tool to the control monitors. For the Canadian West Coast Chain (5,990 rate) the control monitor is

Figure 1. The frequency/control equipment for the solid-state transmitter. The two left racks are the TCS, then there is the TFE, the AUX rack with three cesium beam frequency standards, and two RAIL racks on the right. Love that alphabet soup! Photo courtesy ETC K. Anderson.

located in St. Anthony, Newfoundland. For the US West Coast Chain (9,940 rate), the control monitor is located in Petaluma, CA. The control monitor insures the proper timing and synchronization of all the LORAN stations in the chain.

The TCS rack mentioned earlier controls the pulses in the new solid-state transmitter, shown in Figure 2. You will also notice there are vertical panels consisting of four sections. Each section is called an HCG (Half Cycle Generator). Two sections work in parallel to form the positive half of the LORAN pulse and the other two sections form the negative half of the pulse. The HCG consists of beefy inductors, hefty capacitors, large diodes, and large SCRs (Silicon Controlled Rectifiers), which "bang" a tuning coil to "build" the LORAN pulse. In a way, this transmitter can be thought of as a sophisticated, electronically controlled, spark-gap transmitter. This is a totally different concept than what was used in the vacuum tube transmitter that can be described as a super large class B linear amplifier.

The HCGs are fired in groups at various time intervals to resonate and amplify the 100 kHz pulse. This is no simple task because the whole output network must take into account the LORAN antenna. Once the peak of the pulse is reached, some means must be made to dampen the trailing edge of the LORAN pulse. That dampening of resonance is accomplished by a network with the distinguished title of "tailbiter." The TCS has a lot of responsibility for HCG firing, tailbiter operation, and output network tuning. The output network is constantly being massaged as the antenna sways (changing impedance) or environmental conditions change (rain, snow, icing, low humidity, dust storms).

The Accufix 7500 transmitter produces 1.3 megawatts — a bit less than the AN/FPN-45 vacuum tube transmitter's 1.6 megawatts — but the solid-state unit has some virtues that the vacuum tube rig lacks. If an HCG should fail, the Accufix will still put out a signal, albeit at a slightly reduced output power. An HCG can be swapped out while the transmitter is operational. Corrective maintenance for the Accufix is simpler, less time consuming, and a lot cheaper than what was required for the vacuum tube transmitters. There is only the one solid-state transmitter running 24/7, as opposed to the two vacuum tube rigs which were alternated every two weeks.

If you remember, earlier I mentioned that the vacuum tube transmitters could require an electrical "demand" of nearly 1,000 kilowatts and that I calculated that each transmitter required 100 kilowatts just to light the filaments. The entire building that contains the new transmitter, frequency/control equipment, heating/cooling equipment, and lighting uses about 170 kilowatts. That's a dramatic reduction of electrical energy consumption by nearly six times. Utility bills will go from about $9,000.00 per month for the vacuum tube LORAN equipment to about $2,200.00 per month for the solid-state LORAN equipment.

Figure 2. The new Accufix 7500 solid-state transmitter. The right side is a mirror image of the left side, prominent in the picture. Photo courtesy of ETC K. Anderson.

LORAN Antennas

There are three basic types of LORAN antennas used at the US Coast Guard stations (see Reference 3). Two are common monopoles (towers) — either 625 feet tall or 700 feet with top loading elements (i.e., "capacitance hats") to decrease capacitance to ground. Under each type of monopole is a counterpoise of radials buried in the earth. The monopole sits on a stout glass insulator which isolates the tower from ground. At the LORAN frequency of 100 kHz, we can calculate that one wavelength is 3,000 meters. Therefore, the 625 and 700 foot towers are about

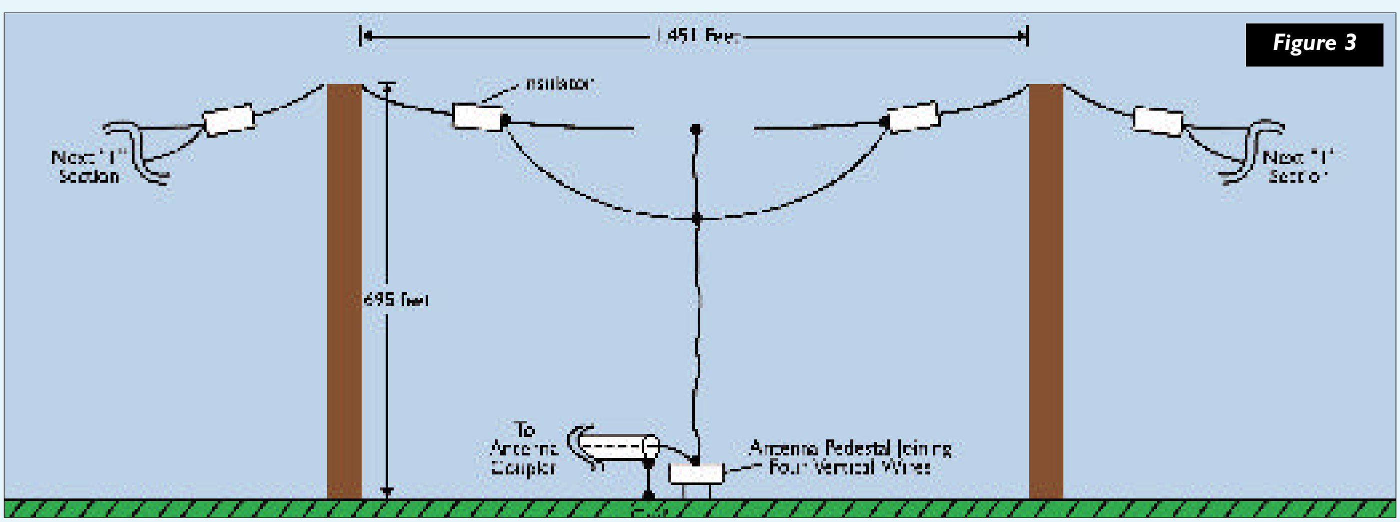

Figure 3

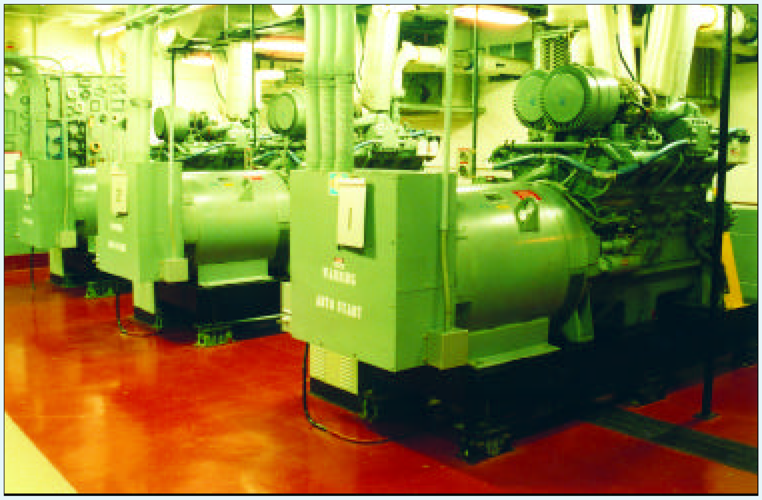

Figure 4. Backup generators for the vacuum tube transmitter. Each unit is rated at 400 kW. Photo courtesy of ET1 K. McKinley.

7% of a wavelength. As a result, the impedances of the 625 and 700 foot tall antennas are 2.5-j25 Ω and 4.0-j23 Ω, respectively. Not much there, huh? You can bet that great effort is made to produce a good counterpoise to reduce ground loss as much as possible.

The third type of LORAN antenna — the one used at George — is the SLT. I've seen "SLT" defined several ways, but the drawings at LORAN Station George call it a "Sectionalized LORAN Transmitting" antenna. There are four other LORAN stations using an SLT, so it's not unique to George. The SLT is a wire antenna consisting of four "T" sections slung between four towers. Each tower is 695 feet tall and arranged in a perfect square — 1,451 feet on a side. One "T" section held up by two towers is shown in Figure 3. The horizontal sections are suspended and insulated from the towers; the towers do not radiate electromagnetic waves. None of the "T" sections are connected to another. The bottom of the vertical wire is connected to the bottom of the other three vertical wires from their respective "T." If you use your imagination, you can think of the SLT as a conical monopole with the upper half sliced off or you can think of it as a "fat" monopole.

I will relate to you this "sea story" regarding the SLT, although I have yet to find the source of the story. More than 30 years ago, when the Coast Guard was modeling SLT antennas, the computer predicted an impedance of "about" 5.5 "real" Ω. Compared to a 700 foot monopole resistance of 4.0 Ω, that's a big increase and, hence, more power radiated (in theory, assuming loss resistance is a fixed value). However, when the SLT was erected and impedances were measured on the actual antenna, it was found to be 3.3-j15 Ω, a true disappointment. My guess is, though, that the bandwidth of the SLT is much broader than that of a monopole. If nothing more, the sight of flashing aircraft warning lights makes an impressive display from 25 miles away, as seen while driving on Interstate 90 at night!

Backup Power

I mentioned earlier that the vacuum tube station could use as much as 1,000 kilowatts at one time and that the new solid-state station uses about 170 kilowatts. What happens when the lights go out? The Coast Guard doesn't want that LORAN signal off air for very long. Despite the very good service and reliability of the local utility (Grant County Public Utility District), power interruptions do occur.

References

1 — **www.navcen.uscg.gov/loran** — then 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.

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

3 — **www.navcen.uscg.gov/pubs/rnavbull/rnbull38.pdf** — then go to page 13 for details.

4 — **www.loran.org/Newsletters/NewsletterIndex.htm** — then click on September 2003. **www.loran.org** is the homepage of the ILA (International LORAN Association) previously known as the Wild Goose Association.

5 — **www.loran.org/Newsletters/April,2003.pdf** — page 3, "US Coast Guard reports interference to GPS from TV antennas;" an incident involving certain powered (active) UHF/VHF marine television antennas creating interference to GPS receiver operation.

6 — **http://webhome.idirect.com/~jproc/hyperbolic/loran_c_future.html** — "Excellent though GPS may be, its problem is that it is so low powered that the signal can easily be blanked out or disrupted — as demonstrated at a 1997 Moscow air show, where a jammer destroyed the signal over a radius of 200 km." The website — maintained by Jerry Proc — is loaded with all sorts of information regarding LORAN and its history, as well as information regarding other forms of radio navigation.

7 — A nautical mile is approximately 6,076 feet or about 1.151 statute mile. It is defined as one minute of longitude at the Equator — 1,852 meters.

8 — **www.megapulse.com/how%20used.html** — A concise article with diagrams explaining the extension of LORAN use.

The vacuum tube station has three 400 KW diesel generators, which will immediately start up, parallel themselves, and operate an automatic transfer switch (ATS) to provide station power when utility power is lost. Despite the fact that under emergency operation some of the station's load is shed ("non-essential" circuits), it still takes at least two of those generators in parallel to put George back on air. A view of the three generators is shown in Figure 4. The generators can be up to speed and supplying three phase 460 V AC in less than 30 seconds. The transmitter can then put itself back on air about 30 seconds after that, so the total lost signal time lost is about one minute.

Figure 5. The crew at LORSTA George who helped put the new equipment on air and shut down the legacy vacuum tube transmitters. Standing left to right: ET1 Ken McKinley, ETC Kevin Anderson, ET3 Ross McDermott, MK1 Richard Boxleitner, SK1 Sterling Van Horn. Kneeling: FN Ryan McDermott (no relation). Photo courtesy of ETC K. Anderson.

By contrast, the solid-state station has two physically smaller diesel generators, rated at 400 kW each. When loss of utility is sensed, they both start up, but only one picks up the load. They do not parallel. After five minutes, the "loafing" generator shuts itself down. All load is carried; there are no non-essential circuits, but the major difference is that the LORAN signal does not go off air at any point because there is a 240 KW UPS (Uninterruptible Power Supply) that continues electrical power to the solid-state transmitter. There's also an 8 KW UPS that supplies power to the timing and frequency control equipment shown in Figure 3 of last month's article. The UPS equipment really doesn't power the station for long because the generator can pick up the load in about 10 seconds. Wow!

The combinations of reliable, solid-state transmitting equipment, computerized control equipment, and the UPS equipment will result in LORAN signal continuity of from 99.85% to a target of 99.99% (see Reference 4). The vacuum tube equipment was achieving signal continuity of 99.70%, on average. The Coast Guard prides itself on keeping that signal on air and in tolerance for its users as much as possible.

The Future of LORAN

Where do we go from here? After spending approximately $100 million — so far — upgrading the vacuum tube stations to solid-state transmitters, will anyone use the signal? Yes, but probably not in the way LORAN was originally intended to be used.

Without question, the dominant form of electronic navigation around the world is GPS. The units are so small, inexpensive, and packed with features that a lot of amateurs have them married to a TNC (Terminal Node Controller) and two meter FM rig for APRS (Automatic Position Reporting System).

GPS is not infallible, though. Since the system was built for military purposes, the owner can move satellites around in orbit to meet whatever need there might be. This would leave other areas on the globe with "holes" of coverage. The GPS signal operates at L band and, therefore, doesn't penetrate buildings or heavy foliage very well. Its signal is so weak that it can be jammed (unintentionally) by something as simple as a poorly maintained active marine TV antenna (see Reference 5). It can also be jammed (intentionally) by a simple, low wattage, portable transmitter in the hands of the wrong people (see Reference 6).

The LORAN signal can be used as a backup to GPS because of its robust signal-to-noise capability and its low frequency of operation. It does not, however, have the pinpoint accuracy of GPS — which can be as good as 10 meters and as poor as 100 meters. The US Coast Guard lists LORAN's accuracy as 0.25 nautical mile (NM) nominally with 0.1 NM at the best of times (see Reference 7). The signal's coverage can be from 600 NM to 1,000 NM, depending upon the time of day and path.

LORAN's strong suit is that the position displayed is repeatable every time the user returns to that same position. In other words, even though the Lat/Lon displayed on the receiver readout may not be precise, a user can return to that exact geographical position each time that those Lat/Lon numbers are duplicated.

The Coast Guard is attempting to create an extremely accurate clock among LORAN stations known as Time of Emission (TOE) control; the Coast Guard prefers its own jargon, using Time of Transmission (TOT) process. A simple explanation of how it works is given in Reference 8. This will enable a position fix using only two stations, stations in multiple chains, or even two GPS satellites and one LORAN station.

The LORAN signal can be used for more than navigation. Because of the stable cesium beam oscillators used at every LORAN station, the LORAN signal can provide precise timing for commercial users. Wireless telephone services, the radio and television industry, satellite communications companies, and the banking industry can use LORAN to keep TDM (Time Domain Multiplex) format signals synchronized. The electric utilities can use LORAN as a clock to "time tag" all their events and circuit breaker operations. A precise coordinated time tag will assist in determining the order of occurrence of happenings, such as the northeast US blackout in August of 2003.

LORAN C Station George went on air September 29, 1976. The original station complement was 10 people. With computer technology beefed up in the late '80s, the crew was reduced to seven. The new, solid-state transmitter will require a crew of only four. The savings in people costs, maintenance costs, and electricity costs will eventually pay for the up-front expenditure. The George crew that helped make it all happen is in Figure 5. As a Coast Guard Reservist, I'm honored to have worked with these professionals at this premier LORAN station. **NV**

About the Author

Clifford J. Appel, K7SPS, wrote this article for three reasons: First, he wanted to inform people that there is more to navigation than just GPS. Second, it is his salute to the Coasties, past and present, assigned to LORSTA George who've kept the equipment in top operational form since 1976. Third, he wrote it as a tribute to a deceased friend; Stan Pickarski was his working mate when he was stationed at the Coast Guard District 14 office in Honolulu, HI, from 1974 to 1976. Stan helped erect the LORAN A and C stations in the Pacific region and helped shut down the A stations decades later. He died in February, 1999, at age 78. He is missed for his friendship and his wonderful sea stories. You can contact Cliff at P.O. Box 241, Electric City, WA 99123, or by Email at cjappel@juno.com