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We've talked a fair amount about HF radio recently, in the context of OTH radar. Recall that an extremely useful property of HF radio here is that HF frequencies can reflect off of the upper layers of the atmosphere, causing them to rebound towards earth at a range much further than the horizon. This behavior, called ionospheric propagation or (more commonly among radio operators) skywave propagation, is the best way to achieve radio communication over ranges much longer than line of sight, without the use of satellite relays. Since satellites didn't come onto the scene as an option until the '60s, for much of the 20th century HF radio was the major method used for long-range communications when no supporting infrastructure (such as microwave relays or a subsea cable) was available along the way. This included applications like long-distance phone calls and all contact with ships and aircraft at sea.

The history of HF radio and its many interesting military and intelligence aspects could fill a book, and probably will over time on this blog. I have mentioned, for example, HAARP. That of course means that ionospheric heaters and the military-intelligence mission of HAARP are now on my list of topics to address, along with the ubiquitous HAARP conspiracy theories. First, though, I had a reader email me in response to the OTH posts. They asked about CFS Masset: a Canadian Forces Station on Graham Island, off the west coast of BC and a good ways north of Vancouver Island. I've never been to Graham Island but it's on my list, and CFS Masset is one of the reasons. The CFS consists mostly of one of few operating examples of a fascinating artifact of HF radio and military intelligence: the CDAA or Wullenweber antenna.

First, we need to back up a bit and talk a little more about theory and practice of HF radio itself.

We don't talk very much about HF radio today, and there are good reasons why. HF radio requires high power levels and more complex (and expensive) RF electronics than higher bands like UHF. After the extra effort, the low frequencies of HF offer less bandwidth for a conventional channel and so allow only limited symbol rates. HF just isn't very convenient for our modern, data-centric applications like the cellular network that operate in UHF and SHF instead. HF has one big advantage, though, that keeps it in use today: propagation. HF radio is no longer used for general long-distance telecommunications because more reliable and higher bandwidth options are available.

There remains though a large class of users who want very long distance communications with minimal infrastructure: the military. HF radio equipment is widely deployed by militaries around the world, especially at sea. A particularly vivid example of military use of HF is the "numbers station," typically HF stations that broadcast long strings of numbers or letters as a means of clandestine communication with intelligence and military assets in hostile territory. Of course one of the things that makes numbers stations such a spectacle is the mystery: it is often unknown where they originate.

This gets at a major topic in military HF radio: direction finding. When military assets such as ships at sea use HF radio, it is theoretically possible to determine their position based on direction-finding the source of the signal. This is particularly appealing since HF radio is sometimes used by assets that are otherwise very difficult to locate, like submarines. The fact that even some numbers stations (which typically operate from fixed sites on land) still haven't been located hints that this isn't exactly easy, though. Propagation is a double-edged sword: complex atmospheric propagation of HF radio allows it to span vast distances, but it also means that HF radio signals usually arrive by different paths, through different propagation modes, and with very variable strength. This all makes direction finding of HF signals very difficult.

The problem is both difficult and important enough that HF direction finding, or HFDF (sometimes pronounced huff-duff), is sort of its own field within radio communications. The earliest HFDF focused on the use of receivers on aircraft that passed very near the transmitter (in radio terms, i.e. within the radio horizon) where propagation is not a factor and there is a clearer direction of origin. Indeed, the non-directional beacon (NDB) and corresponding radio direction finder (RDF) formerly used for aircraft navigation are basically a simple case of HFDF.

Unfortunately, this technique is not that widely applicable. When the source of an HF transmission is unknown over a very large area (e.g. a submarine) or in hostile territory (e.g. enemy command and control stations), it's impractical to get a direction finding receiver close enough to provide a single, unambiguous propagation path from the transmitter. Military intelligence units spend far more of their time scratching their heads at HF signals with no known origin other than "a long ways away."

The NSA, for example, has been heavily interested in this problem for just about as long as it has existed (dating back to the SIS in WWII). Indeed, one could make an argument that the challenge of HFDF is one of the main reasons that the NSA exists in its modern form. Well before modern signals interception from a huge range of media (including cables, satellite uplinks, etc), the NSA already needed a network of multiple collection sites, coordinated centrally by cutting-edge information systems, to attempt HFDF. The NSA continues to operate a set of clandestine "research sites" with extensive HF equipment.

The larger HFDF effort, by far, was that of the US Navy. The NSA was likely limited here by their relatively small budget (at the time) and need for a high level of secrecy. The Navy, though, critically concerned with locating enemy ships at sea, openly built an enormous infrastructure of HFDF stations. The secret to long-range HFDF, it turns out, is brute force: with multiple highly sensitive direction-finding receivers at widely separated locations, it becomes easier to determine probable sources by figuring out which strong source angles at different stations can plausibly meet.

The Navy's HFDF program, build during the 1960s, was directly based on research done in WWII Germany. Indeed, the ability of both the Soviet Union and the Allies to inspect Germany's highly advanced HFDF sites after WWII means that nearly the entire global military HFDF effort was directly based on the German work. This history is mostly to explain how the German code-name for HFDF research, Wullenweber, came to be a common name for the type of antenna the Germans developed. More generally, it is known as a Circularly Disposed Antenna Array or CDAA.

A typical Wullenweber or CDAA is an array of dipole antennas pointed in different directions. Practically speaking the easiest way to build a CDAA is by arranging the antenna elements in a circle, usually as a couple of rings of towers or frames supporting the dipole elements with a circular groundplane underneath. Many CDAAs have additional inner circles of reflector elements that improve directionality of the dipole antennas (rear and side lobe rejection). Because of the long wavelengths of HF (and the general principle that, to be efficient, an antenna's length must be a small integer division of the wavelength such as 1/4 or 1/2), the individual dipole antennas must be quite large. A fairly typical CDAA occupies a circle of about 1,000' across, with elements on towers as much as 150' tall. The large size and dense arrays of elements made "elephant cage" a common nickname for CDAAs.

The Navy's CDAA design is the AN/FRD-10. The FRD-10 was designed by the Naval Research Laboratory with the University of Illinois, and full-scale construction was contracted to ITT Federal. ITT is more widely remembered today in the form of for-profit university ITT Tech, but this form of ITT is almost completely unrelated to the original ITT: International Telephone and Telegraph. ITT started out as a telephone company serving Puerto Rico and through a series of acquisitions became a major conglomerate with extensive government contracts. ITT, in its heyday, was the kind of company that managed to be peripherally involved in multiple international scandals and coups. Since then ITT has sort of fallen into pieces, but some of those pieces remain major players in the defense industry, like the Harris part of L3Harris (not directly descended from ITT but made up in large part by several acquired ITT business units).

From 1959 to 1972 ITT built 16 FRD-10 sites for the Navy at a cost of around 20 million bucks a piece in 1970 dollars. A full FRD-10 with ground plane was right about 1000' across and 90' tall. It actually consisted of two separate CDAAs, tuned for higher bands and lower bands, colocated on the same center point. The inner low band ring contained 40 unit antennas aimed at 9 degree increments, and the outer high band ring (where more precise direction finding is theoretically possible due to the shorter wavelength) contained 120 elements at 3 degree spacing.

While physically impressive, the actual FRD-10 antenna was in some ways the more minor component of the site. Far more complex and expensive were the supporting electronics, including receivers and a computerized control and recording system. Because of the large number of unit antennas, it was not practical to install a receiver for each antenna. Instead, complex beam-forming networks were used to couple receivers to small subsets of antennas with phase-matching delays to achieve a very directional receive pattern. At the same time, the collective array of antennas was combined by another phase-matching network to produce an omnidirectional output used for receive strength comparisons.

FRD-10 sites were fitted with a complex switching network that allowed multiple independent operator positions to use the array simultaneously. These operators sat at "goniometers," a general term for angle-measuring devices, where they could turn a wheel to change the receive azimuth of their station and observe changes in reception. Operation was not all that manual, though: for clearer signals direction-finding was automatic. Several operators at each FRD-10 site were freed from turning wheels on manual goniometers and instead participated in a semi-automated system that was impressive for the era.

A "signal screener" monitored the omnidirectional output of the antenna for any signals of interest, and upon finding something good pressed a button that caused the computer control system to automatically inform other FRD-10 sites via an HF, SSB teletypewriter network. At the same time an automated direction finder determines the source of the signal and reports it to the network as well. As multiple stations located the signal, a computer system at the network control point compared the bearings from each site and reported a likely source location and confidence interval. An operator at this computer system manually reviewed each reported fix, and had the option of rejecting a fix, at which time the computer would wait to obtain more direction reports and improve confidence.

And now for CFS Masset: of the 18 AN/FRD-10 sites, most were located in the United States where they were initially designated as Naval Security Group Activities (NSGAs). For example, NSGA Homestead in Florida and NSGA Adak in Alaska (very near the never-constructed Alaskan OTH-B). For better precision, it is useful to have sites further apart. For this reason some AN/FRD-10s were installed in allied countries, like NSGA Hanza in Japan and NSGA Edzell in Scotland. Due to the unusually close relationship of the US and Canadian militaries, though, the two sites built in Canada are not US Navy sites like those other countries, but were fully operated by the Canadian Forces. These were CFS Masset on the west coast and CFB Gander in Newfoundland on the east coast (most notable for Gander, the historic dog, and certainly not for any peripheral events of 9/11 later rendered as insufferable musicals).

By the '90s, the relevance of the Navy's HFDF network was declining. The system was expensive to operate, the Cold War had spun down, and our major adversaries were making increasing use of satellite communications and avoiding HF transmissions. In the meantime, HFDF technology had improved and smaller, cheaper systems were starting to perform nearly as well as the FRD-10 (later Navy Security Group sites, for example, used the smaller AN/FRD-13 antenna which was lightly modified from a design by Plessey in the UK). The Navy began to decommission the AN/FRD-10 sites, and by 1999 only two remained in operation, the last two built (in 1972): CFS Masset and CFB Gander.

Indeed, the Canadian Forces continue to operate both AN/FRD-10s to this day. CFS Masset is now properly the Masset detachment of CFS Leitrim, a major Canadian Forces signals intelligence facility located across the country in Ottawa. The antenna at Masset is operated by remote control. While CFB Gander remains an active base, the FRD-10 itself there has similarly been made a detachment of CFS Leitrim.

The Navy was not the only user of the AN/FRD-10. The NSA itself built two, installed nearby each other at Naval Radio Station Sugar Grove (the location on a Navy installation was effectively a cover, the Naval Security Group that operated the rest of the Navy HFDF network had no involvement in these two antennas). Sugar Grove was closed entirely in the 2010s and has since been sold into private ownership.

Several similar systems were built by other organizations. The slightly earlier AN/FRD-9 CDAA antenna was used by the Army and Air Force. Because its mission was more focused on battle in theater than coastal defense, the AN/FLR-9s were mostly located in more exotic locations closer to the conflicts of the time: the Philippines, Thailand, and Turkey. Compared to the AN/FRD-10 the AN/FLR-9 covered a larger frequency range but was somewhat less precise. It met a similar fate, with all sites now inactive. Interestingly, the AN/FLS-9 was converted into an outdoor amphitheater (using the screening frames as part of the structure) for the Philippine Centennial International Exposition in 1998.

The AN/FLS-9 sites tended to be located in more remote areas and so more survive today. The AN/FRD-10, on the other hand, has suffered greatly from both urban expansion and weather. Most AN/FRD-10 sites were either demolished or collapsed in hurricanes, which the design turned out to not stand up to well. Today the Canadian sites are the only remaining examples of the AN/FRD-10 in North America and two of only three total, the third being in Panama. Still, a construction the size of a Cold War CDAA does not fade away easily. Nearly all of the AN/FRD-10s are still quite apparent in satellite images by the ground and vegetation disturbance. One example of a former AN/FRD-10 site is located in the San Pablo Bay National Wildlife Refuge, northeast of the San Francisco Bay area, part of which was formerly NSGA Skaggs Island.

Like OTH radar, HFDF is not dead but no longer requires the enormous facilities it once did. The Department of Defense continues to operate a mostly automated network of distributed HFDF stations, but it is now based primarily on compact portable equipment. Pretty much every large military deployed some type of HFDF, mostly using CDAAs, during the Cold War. In fact, the United States was if anything a latecomer. Besides the CDAA design having originated in Germany, the Soviet Union and United Kingdom built similar CDAA stations as much as a decade before the US. Most of these systems have disappeared like the AN/FRD-10.

True to their early involvement in the technology, Germany remains a relatively large user of the CDAA design. At least two CDAAs in Germany appear to be operational, one under control of the military and one under control of the intelligence agency BND. China, relatively new to the status of world power, is quickly catching up. The PLA constructed at least one CDAA just in the last few years.

One might wonder why there is still any interest in ground-based CDAAs, given the widespread use of signals intelligence satellites. I can speculate on at least two lines: first, with increasing military reliance on satellites comes the specter of ASAT or anti-satellite warfare. The resistance of satellites to attack is very poor and it is reasonable to believe that an adversary like China has the ability to eliminate a large portion of intelligence satellites relatively quickly, and this makes it appealing to have ground-based alternatives (a major reason I am a proponent of eLORAN, which I will write an article about one day). Second, efficient reception of HF requires large antennas. Satellites can rely on line-of-sight which mitigates the issue, and satellite builders have plenty of tricks for fitting large antennas into small launch envelopes, but still, space and weight on satellites is very costly. A ground-based capability can be faster and cheaper than a space-based one, which would be very appealing to for example China which does not have as much benefit of legacy capability and instead needs to field an all-new system quickly.

And there is some longstanding cultural and political impact of the era of HFDF. As I said, one could argue, or at least I would, that HFDF and HF propagation is key to the history of the NSA. Without the unusual demands of HF monitoring, the NSA would have had less motivation to deploy large signals intelligence stations in the United States during the Cold War. These NSA HF stations are the same stations that were later repurposed to satellite monitoring and programs like ECHELON. While I'm very much frustrated that the capabilities of programs like ECHELON and PRISM are often hysterically overstated by the media, they are nonetheless pillars of the modern surveillance state. Sure, they probably would have happened either way, but there would have been more friction without the history of HF interception.

HF radio has always gone hand-in-hand with signals intelligence. Indeeed, it's the reason that signals intelligence came into existence. Later, we'll dig into that a bit more: what if intelligence agencies could modify the ionosphere for their own purposes? Here in the US, the intelligence community built a tool to find out: HAARP.