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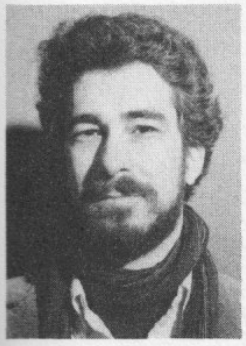
11

OVER-THE-HORIZON RADAR

Robert Horvitz



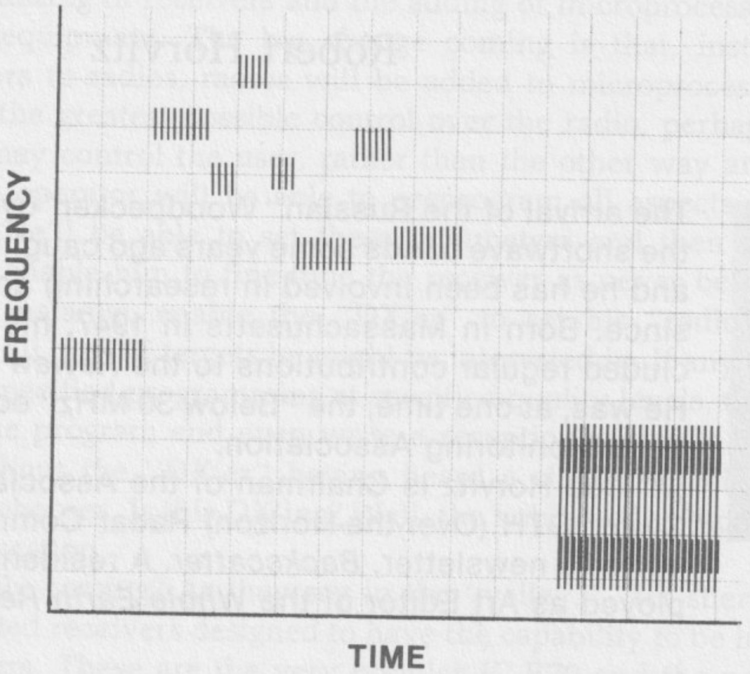
The arrival of the Russian "Woodpecker" over-the-horizon radar system on the shortwave bands some years ago caught the interest of Robert Horvitz, and he has been involved in researching and studying such systems ever since. Born in Massachusetts in 1947, his monitoring activities have included regular contributions to the *Review of International Broadcasting*. He was, at one time, the "Below 30 MHz" editor for the Radio Communications Monitoring Association.

Bob Horvitz is Chairman of the Association of North American Radio Clubs' OTH (Over-the-Horizon) Radar Committee and publishes the committee's newsletter, *Backscatter*. A resident of Washington, DC, he is employed as Art Editor of the *Whole Earth Review*.

You can't tune around the shortwave band for very long without soon encountering an annoying air-hammer-type sound. It's present 24 hours a day, but doesn't seem to be targeted against any particular station or stations, as jammers are. Nor does it avoid occupied channels, as it probably would if it were engaged in some form of communication. The sound seems totally indifferent to the havoc it wreaks as it jumps around the spectrum, causing severe interference to international broadcasters and their audiences, to amateur radio operators, and to aeronautical, maritime, and fixed stations. Because of its distinctive sound, this signal has been dubbed the ''Woodpecker.''

Fig.11-1 illustrates an impression of the Woodpecker's moment-to-moment behavior. It often seems to jump around within a band, and then disappears for a while, turning up in a nearby band, with perhaps a louder and wider signal that may be from the same site or a different site.

Fig. 11-1. An impression of the Woodpecker's moment-to-moment behavior.



The first instance of Woodpecker interference that was reported to the FCC occurred around 0300 UTC on 12 July 1976. The complainant's name has been lost to history, but he probably was a Ham operator, as the complaint concerned the band at 14,000–14,200 kHz. More complaints soon followed, concerning other bands, and the FCC began a full-scale investigation. By November 1976, they had learned enough about the signals to send a report to the National Security Agency. A summary of this report was obtained through a Freedom of Information Act request and it describes the Woodpecker in terms that are still largely true today:

> Virtually every user of the HF spectrum has been affected. The signal has a repetition rate of ten pulses per second. Its bandwidth varies greatly. At times, it may have a bandwidth of only 30 kHz. Other times, it may be as wide as 300 to 500 kHz. Its activity does not appear to have any definite pattern. It may stay on a given band for only a few seconds or it may remain on constant for several hours. At one instant,

> it may be heard on 12 kHz, then just a few seconds later may appear on 18 MHz. We have observed it throughout the HF spectrum from 6 MHz through 28 MHz. It appears to operate around the clock.... The strength of the signal, as received in this country, varies with propagation (time of day and band in use), but under optimum conditions it is extremely strong and totally disrupts other communications.[1]

A letter from the FCC to the State Department a week later gave additional details:

> After thirty-seven separate direction-finding alerts, the station's fix has averaged out to be 51° North by 31° East, the vicinity of Kiev. Information received from the British Broadcasting Corporation indicates the station is located at Gomel [between Kiev and Minsk]. Communication with Radio-Suisse Ltd. indicates the Soviet station is located in the Kiev–Gomel area. The location the Commission has been supplying to the public has simply been the general area of Minsk.[2]

When the source was determined to be in the USSR, the U.S. government sent a complaint—and another, and another, and another. Other nations complained, too—among them, Denmark, Sweden, Norway, West Germany, and Great Britain. (Although the Woodpecker is heard worldwide, even in Antarctica, its interference is most severe in northern Europe.)

The Soviet Union responded to the complaints on 3 December 1976, sending this terse note to the ITU's International Frequency Registration Board:

> In the Soviet Union tests are being carried out with radio installations operating in the HF bands. These tests may cause interference to radio installations for short periods. The necessary measures are being taken to reduce any such interference. The reports which you have sent us will be carefully studied.

But the interference did not diminish, and the number of complaints continued to grow. When no further response came from the USSR, the IFRB issued a report declaring:

> The station or stations in question should cease operation until such steps have been taken to ensure that any interference that may result from the resumption of such tests shall be below the level that would be considered as harmful interference.[3]

Unfortunately, although the IFRB coordinates international use of the radio spectrum, it has no enforcement power. It depends on the cooperativeness and good will of the ITU member nations to resolve conflicts. In this case, the Soviet Union has proven totally intransigent. They brushed off the IFRB report with a

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[1] "Summary of broadband pulse emission emanating from the USSR," (3 November 1976), FCC Woodpecker file.

[2] Letter from Robert L. Cutts, Chief, International & Operations Division, FCC, to Gordon Huffcutt, US State Department (12 November 1976), FCC Woodpecker file.

[3] "Report on Harmful Interference in the High Frequency Bands Caused by Emissions Originating in the USSR," International Frequency Registration Board (10 November 1977), includes the Soviet acknowledgment of responsibility quoted here.

note saying their monitoring showed that the measures they'd already taken to reduce interference had been effective.

Signals from a second site were detected by the FCC starting in mid-April, 1979. After 33 bearing measurements, this new source proved to be near Khabarovsk or Komsomolsk on the east coast of Siberia (average fix: 48° 33′ North by 135° 13′ East). A third transmitter site was reported by the Associated Press in an article dated 15 May 1980—though it probably had been detected somewhat earlier.[4] The location of the third site is still less certain than the first two, but if one assumes that the Woodpeckers are actually over-the-horizon radars—and this is the most reasonable explanation—then a map in the 1983 edition of the U.S. Department of Defense booklet, *Soviet Military Power*, shows the third site as just north of the Black Sea with a beam aimed toward China.

The three known Woodpecker sites, based on data from the FCC and Department of Defense are illustrated in Fig.11-2. Beam headings are as shown on a map on page 28 of *Soviet Military Power* (Government Printing Office, 1983 edition), they may be variable. Beam paths do not necessarily represent target detection zones. If one assumes they have the same range as the USAF OTH-B radars (1800 miles), their detection limits would be about as indicated by the dotted lines, even though their emissions are audible much farther away. The Pentagon claims that the Woodpeckers are designed to detect ICBMs, but there are technical reasons to suspect they are better able to detect bombers and battleships.

Shortly after the first Woodpecker started transmitting, Dafydd Williams, BBC External Broadcasting's chief engineer, estimated its power to be in the 20–40 megawatt range. That estimate seems to have stuck through time-although it isn't clear exactly what it means. Since the Woodpeckers use pulse modulation, Williams' estimate is often interpreted as peak pulse power. If the emissions were continuous, instead of being crammed into very brief (3 to 10 millisecond) bursts every tenth of a second, this would be equal to a mean continuous power between 600 and 4000 kW—this is greater than the most powerful transmitters used by international broadcasters. But complicating any estimate of power is our lack of knowledge about the antennas used. If the Woodpeckers are indeed radars, their beams must be highly directional. That is, their antennas must have very high forward gain. Not knowing the gain, we cannot accurately correlate transmitter power with effective radiated power (it's never been clear whether Williams' estimate referred to the former or the latter).

Experiments in the United States have shown that engineering a system to handle millions of watts of power is actually quite difficult. Arc-overs, burnouts, and grass fires are hard to avoid. A much better approach is to feed the signal to several transmitters operating in parallel, each driving a separate antenna. If the antennas are properly configured and phased, their emissions will combine in space to form a single powerful radiation pattern, without any element having to bear the entire load. Multiple antennas have an additional

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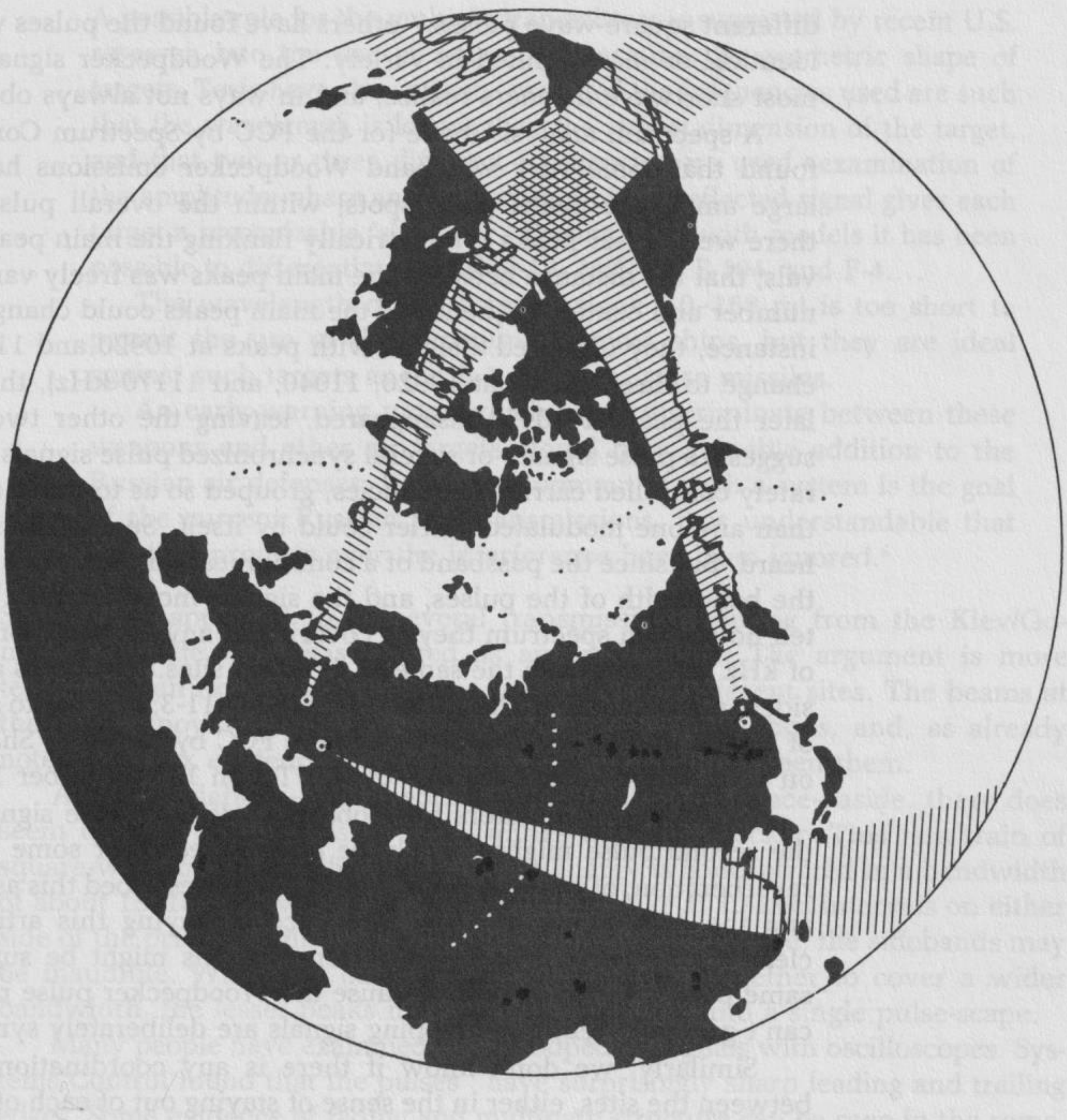
[4] Norman Black, "Russian Woodpecker," Associated Press (15 May 1980).

Fig. 11-2. Three known Woodpecker sites.



benefit for radar systems: by varying the phase of the signals fed to each antenna, it is possible to steer the composite beam in different directions to increase azimuthal coverage without physically moving the antennas. This is especially important for shortwave radars, where the antenna dimensions are huge.

There is some evidence that at least the first Woodpecker site has several antennas, transmitters, pulse- and carrier-generators that can be switched and combined in different ways. In 1977, S. A. Cook of Intruder Watch (an interference-monitoring group that watches over the ham bands) said that "the 10 p/s signal comprises a pulse train of up to 20 different square-wave pulses, some less than 2 ms in length," and he was "convinced that there are as many as four sources."[5] While the signals monitored by Cook may have contained "up to 20

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5. "Mystery Soviet Over-the-Horizon Tests," *Wireless World* (February 1977), pp. 53 & 68.

different square-wave pulses,'' others have found the pulses within a train to be identical or more limited in variety. The Woodpecker signals vary more than most shortwave listeners realize, and in ways not always obvious to the ear.

A spectrum analysis made for the FCC by Spectrum Control, Inc., in 1978 found that some very wideband Woodpecker emissions had several equally large amplitude peaks (loud spots) within the overall pulse bandwidth; that there were lesser peaks symmetrically flanking the main peaks at 10 kHz intervals; that the distance between the main peaks was freely variable; and that the number and center frequency of the main peaks could change abruptly. In one instance, they observed a signal with peaks at 10920 and 11220 kHz suddenly change to three peaks (at 10920, 11040, and 11170 kHz), then about a minute later the peak at 10920 disappeared, leaving the other two unchanged. This suggests a pulse signal—or several synchronized pulse signals—modulating separately controlled carrier frequencies, grouped so as to cover a wider bandwidth than any one modulated carrier could by itself. Such signals are still regularly heard. But since the passband of a communication receiver is narrow, relative to the bandwidth of the pulses, and the signals move around, it's always hard to tell how much spectrum they're covering at any moment, or if peaks hundreds of kHz apart are from the same or different sites. It appears as though there are sidebands something like the diagram in Fig. 11-3; it is not to scale. This diagram of a Woodpecker signal was sent to the FCC by James C. Shaw, W6JQX, based on observations made at 0636-0658 UTC on 13 November 1979.

A number of monitors have observed double pulse signals. In some cases, the second pulse might actually be a strong echo, or some sort of ionospheric reverberation, of the first pulse. The FCC has described this as a ''ringing effect,'' and the oscillogram by F. C. Judd accompanying this article shows it quite clearly. In other cases, separate transmissions might be superimposed on the same part of the spectrum. Because the Woodpecker pulse rate is so stable, we can't generally tell if overlapping signals are deliberately synchronized or not.

Similarly, we don't know if there is any coordination of frequency use between the sites, either in the sense of staying out of each other's way or in the sense of joint target coverage. *Flight International* has pointed out that

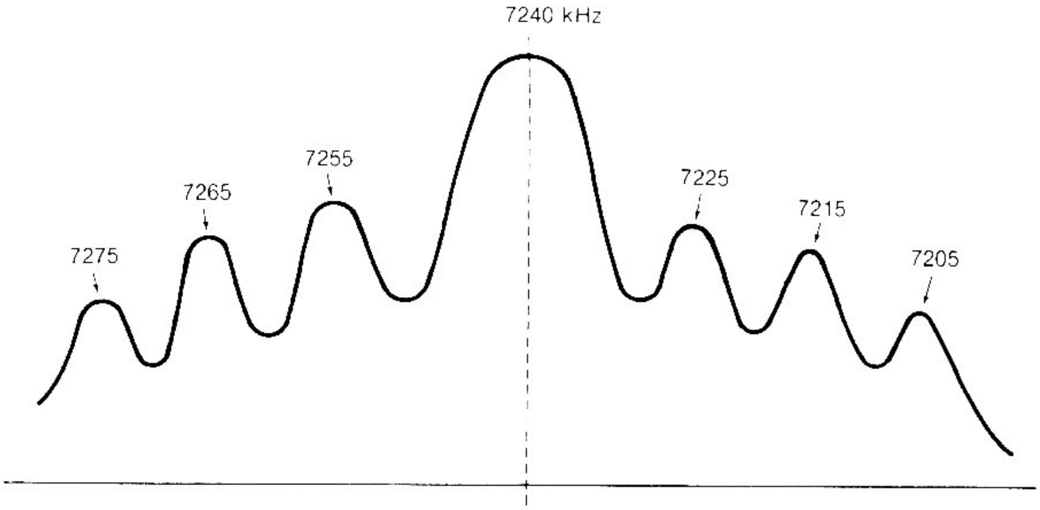

Fig. 11-3. Diagram of the Woodpecker signal sent to FCC by James C. Shaw in 1979. (From FCC Woodpecker file.)

> A possible role for the multiple transmitters is suggested by recent U.S. research into the use of radar to determine the geometric shape of targets. Tests have shown that—provided the frequencies used are such that the wavelength is longer than the largest dimension of the target, and that two or three different frequencies are used—examination of the amplitude, phase and polarization of the reflected signal gives each target a recognizable 'signature.' During trials with models it has been possible to differentiate the MiG-19, MiG-21, F-104, and F-4....
>
> The wavelength of HF transmissions (10–150 m) is too short to permit the use of this technique against ships, but they are ideal against such targets as the B-1 and the Cruise missiles.
>
> An early-warning radar which could discriminate between these weapons and other air targets would be a valuable addition to the Russian air defenses. If the development of such a system is the goal of the current Russian test transmissions, it is understandable that Western protests over the interference have been ignored.[6]

Since there appeared to be several transmissions coming from the Kiev/Gomel/Minsk site, this was offered as an explanation. The argument is more tenuous as an explanation for there being several different sites. The beams at the three known sites seem to point in different directions, and, as already noted, we lack evidence for frequency coordination between them.

All the variations—and theories about their significance—aside, there does seem to be a basic emission that typifies the Woodpecker. This is a train of square-wave pulses in which most of the energy is concentrated in a bandwidth of about 15–18 kHz, with a series of weaker peaks at 10 kHz intervals on either side of the primary emission. In periods of mild interference, the sidebands may be inaudible. When the basic modules are ganged together to cover a wider bandwidth, the lesser peaks may overlap, blending into a single pulse-scape.

Many people have examined the Woodpecker signals with oscilloscopes. Systems Control found that the pulses "have surprisingly sharp leading and trailing edges. Some evidence of fading and multipath structure can be seen in the somewhat erratic shape of the pulse at maximum signal level."[7] Others have interpreted the "erratic shape" as an intentional coding—perhaps this is to identify different pulse sources or to enhance some aspect of radar performance. These interpretations are highly speculative, of course, but not totally implausible.

J. P. Martinez has an ingenious theory based on his discovery that when the pulses are greatly dilated with a spectrum analyzer, they seem to have brief amplitude "glitches" at multiples of 100 microseconds. His plot of amplitude (log scale) versus time appeared in *Wireless World*, April 1982 (Fig. 11-4). By arbitrarily identifying the initial modulation phase as "0" and its reverse as "1," and, assuming each "glitch" represents a phase reversal, the pulse could be binary-coded. He attributes the glitches to phase reversals in the transmitted

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[6] "USSR Develops Anti-B-1 Radar?", *Flight International* (8 January 1977), p. 50.

[7] W. R. Vincent, "Spectral Characteristics of the Woodpecker Signal," Systems Control, Inc. (23 February 1978), FCC Woodpecker file.

signals. If this is the case (his equipment apparently couldn't register phase directly), and if the signal were sampled every 100 microseconds, the phase modulation could function as a binary code. He further found that the code sequence was always 31 units long (implying a pulse duration of 3.1 milliseconds), that the sequence was exactly repeated from one pulse to another, and that there were four different sequences—implying that there were four separate transmitters. Analyzing the sequences mathematically, Martinez concluded that they were each "maximum-length, pseudo-random binary sequences" of a sort that could be generated by a bit shift register:

> The interesting point about this use of p.r.b. codes arises from the shape of their autocorrelation function. If such a sequence is compared bit-for-bit, with a shifted version of itself, at all possible shifts, then, apart from the position where all 31 bits match, at all other shifts no more than 1 bit matches between the two sequences....
>
> The conclusion from all this, it seems to me, is that the woodpecker must be simply a pulse compression radar system, with a resolution of 100 μs (10 miles), but the sensitivity 31 times that of a 100 μs radar of the same power. Not only does the p.r.b. sequence cancel out shifted versions of itself in order to achieve its performance, but it has a high immunity to other codes in the same family,

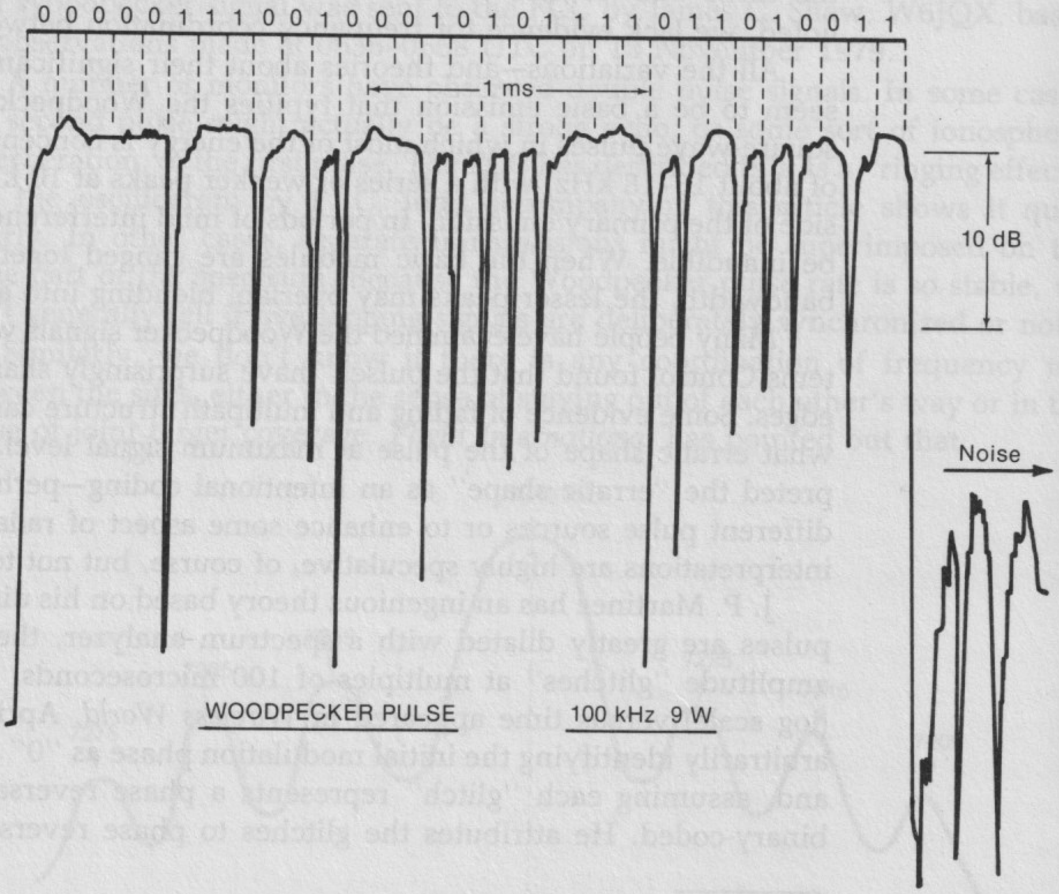

Fig. 11-4. Plot of the amplitude (log scale) versus time by J. P. Martinez. (From J.P. Martinez, *Wireless World*, April 1982.)

> thus reducing cross-interference between separately sited radars on the same frequency....[8]

It may also help cancel the effect of multipath propagation, which in the polar region can cause time spreads of 100–400 μs in the return echo and degrade range resolution.*

Martinez's elegant theory rests on two claims: first, that the glitches represent an intentional phase coding, and second, that their sequence is repeated from pulse to pulse. A more recent study by F. C. Judd seems to corroborate the second claim, although it disagrees with Martinez's duration measurements. Judd also sheds new light on how the Woodpecker signals' dwells begin:

> Prior to most transmissions of modulated pulses there are often a few seconds of unmodulated multiple pulse transmission....These may appear on any frequency and could simply be ionospheric sounding transmissions....
>
> After the initial "sounding"...the "Woodpecker" signals change to a four-pulse format, each pulse being modulated as is shown in [the illustration]. These pulses (1–4) vary in amplitude even during quite short periods...which suggests a "search mode" for best signal return from a target....The modulation on each pulse is quite different but as shown by the expanded oscillogram...it varies continuously....[9]

"These pulses last 3–4 milliseconds each," Judd says. Within each group, the interval between pulses is also 3–4 ms, with the groups coming every 100 ms. Judd adds that "when a 'target' has been located (echo received), the pulse transmission usually reverts to a single pulse of about 4 ms duration but still with the p.r. time of 100 ms."

Apparently Judd hadn't seen Martinez's letter to *Wireless World*, so it's even more fortuitous that the pulse he chose to expand to illustrate his article shows exactly the same pattern of glitches as the one Martinez presented. The glitches aren't quite as narrow, and some of the depths are different, but the sequence is definitely the same. But Judd measured its duration as 4 ms. For Martinez's theory to work, the rhythm of phase change and the sampling rate must be consistent. The discrepancy in their measurements of the pulse duration has yet to be resolved.

Judd's oscillogram of a single pulse signal (Fig. 11-5) shows a strong "pseudo-pulse" (I_s) immediately after the primary pulse (P_1). This is almost certainly what the FCC has noted as the "ringing effect." Judd attributes it to ionospheric scattering near the transmitter site. Also visible are two echoes (E_c), one strong and one weak, at different delay-times before the next pulse (P_2). Fig. 11-6 shows two more oscillograms from F. C. Judd's *Practical Wireless* article. In

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[8] J. P. Martinez (letter), *Wireless World* (April 1982), p. 59.

* Author's supposition, not Martinez's.

[9] F. C. Judd, "Over-the-Horizon Radar Systems—Beyond the Blue Horizon (Part 2)," *Practical Wireless* (September 1983), pp. 44–47.

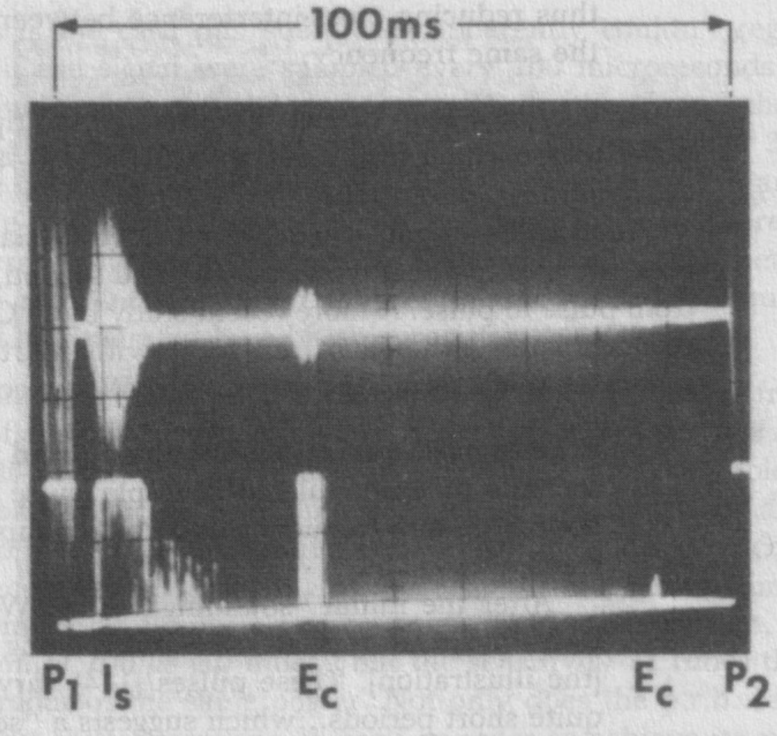

Fig. 11-5. Unrectified Woodpecker signals. (From F.C. Judd, *Practical Wireless*, September 1983.)

Fig. 11-6A an example of a four pulse modulated Woodpecker signal is given. The four pulses have different waveforms, but similar durations (3–4 ms). An expanded view of the initial pulse in Fig. 11-6B reveals it has a series of amplitude "glitches" with exactly the same time-pattern as observed by Martinez.

The discovery of what may be sounding signals adds weight to the argument that the Woodpeckers are OTH radars. Current propagation data is essential to OTH radar operation, and having a sounding signal different from the main emission implies that the purpose of the main emission isn't sounding as it might be if the Woodpeckers were for ionospheric research.

Sounding brings up the question of what determines which frequencies are used by the Woodpeckers. Although their moment-to-moment behavior is unpredictable, it is far from random. Early on, the FCC identified three modes of operation:

1. Operation which covers a 100–200 kHz band for extended periods of time.
2. An On-Off mode where transmissions are on for one minute and off for five minutes covering a given band.
3. A Sweep mode where emission may be 30 kHz wide and sweeps through a one megahertz band.[10]

The FCC gathered new data about the Woodpeckers' band use during the winter of 1982–3. A plot of 62 encounters with Woodpecker emissions during routine

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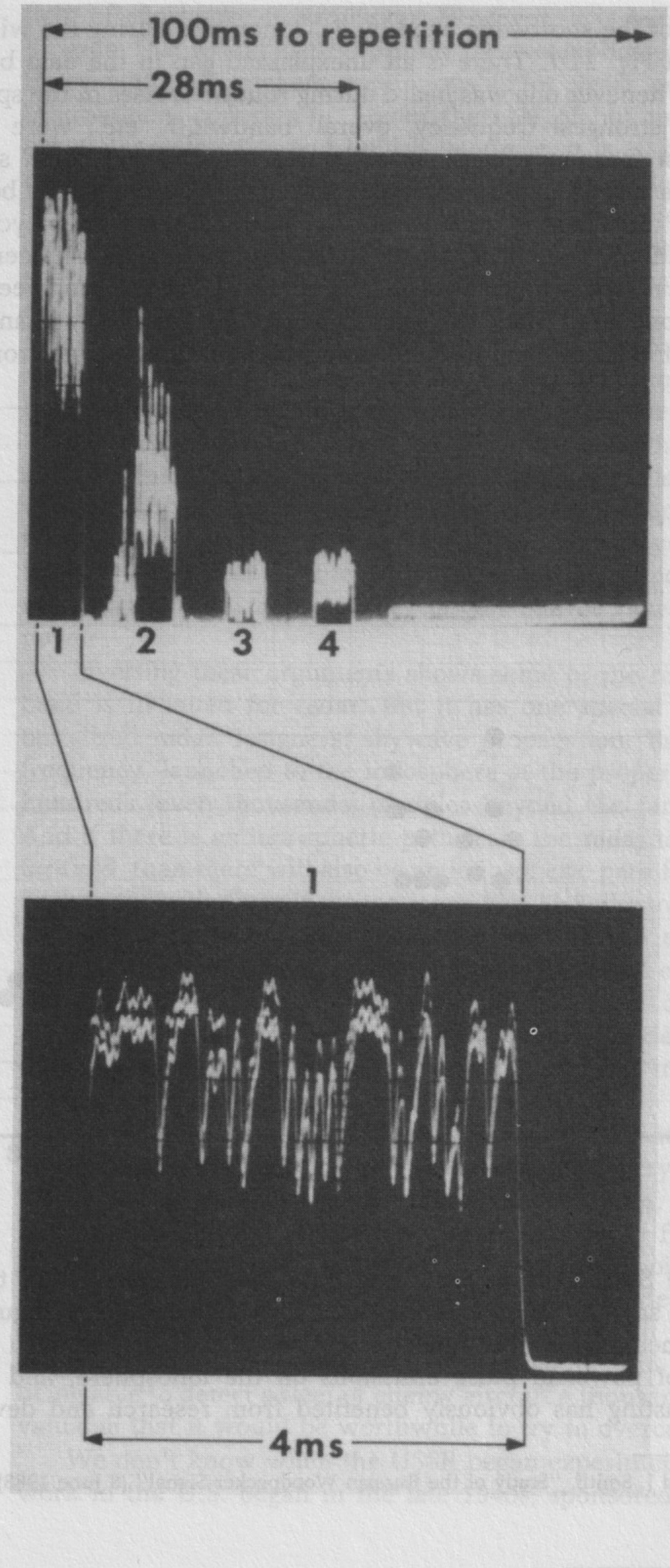
[10] Letter from Robert L. Cutts, FCC, to Gordon Huffcutt, State Department (24 February 1977), FCC Woodpecker file.

Fig. 11-6. The four-pulse modulated Woodpecker signal. (From F.C. Judd, *Practical Wireless,* September 1983.)



(A) The signal showing the four different pulse waveforms.

(B) Expanded view of the initial pulse.

cruises of the shortwave band by FCC monitors during the winter of 1982–3 is given in Fig. 11-7. There is an unexplained gap in the data between 1:30 and 4 P.M. Whenever one was heard during routine cruises of the spectrum, the time of day, strongest frequency, overall bandwidth, etc., were recorded. When strongest frequency was plotted against time of day for a sample of 62 encounters, a clear pattern emerged. Although this sample may be biased, one can see that the Woodpeckers' band use conforms to the daily cycle of ionospheric propagation. (There is an unexplained gap in the data between 1:30 and 4 P.M.; perhaps no spectrum-cruising occurred then.) The FCC engineer in charge of the study concluded that "the seemingly random frequency changes could be the result of computer control and propagation data being fed from a sounder."[11]

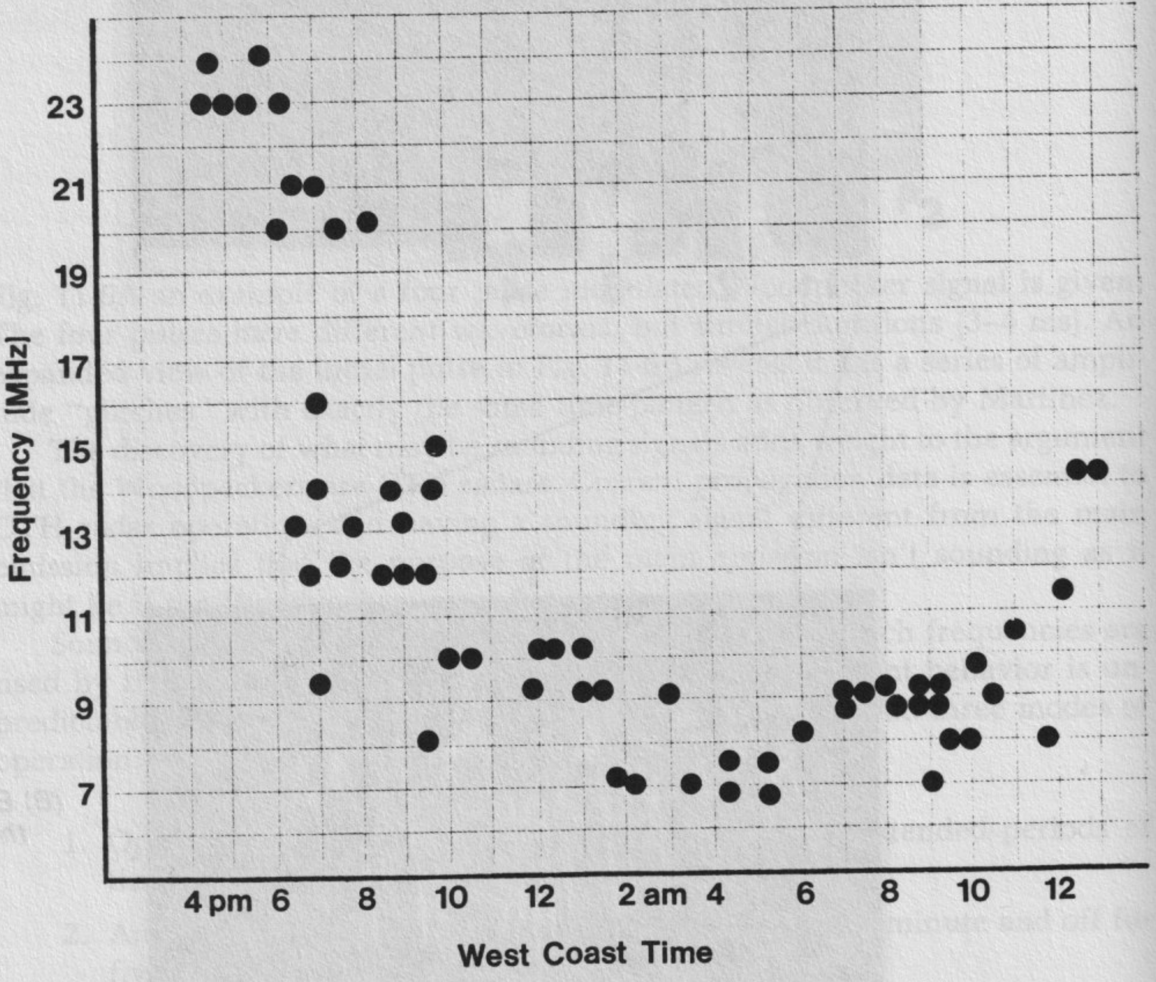


Fig. 11-7. Plot of the 62 encounters with Woodpecker emissions during routine cruises of the shortwave band by FCC monitors during the winter of 1982–83. (From FCC Woodpecker file.)

The Soviet Union has never explained the purpose of the Woodpeckers beyond saying they are for "tests." This explanation is vague to the point of being meaningless, but Soviet scientists do regularly publish papers about the effect of powerful pulse emissions on the ionosphere, and Radio Moscow's broadcasting has obviously benefited from research and development in the

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[11] David J. Smith, "Study of the Russian Woodpecker Signal" (8 June 1983), FCC Woodpecker file.

field of shortwave transmission. However, it is hard to imagine any research program that would justify running these complicated, electricity-guzzling, multimegawatt noisemakers continuously, for years on end, in defiance of the international community. Given the cost of building and running them, the signal characteristics and bullish band-use, it is all but certain that the Woodpeckers are operational OTH (over-the-horizon) radars.

The British built the world's first air defense radar system in 1938. It also operated in the shortwave band, but only because the technology for using even shorter wavelengths hadn't been developed. Nor had they figured out how to exploit ionospheric refraction for over-the-horizon surveillance. The "Chain Home" system was limited to line of sight. Even so, it proved so effective against the Luftwaffe that radar development became a top priority for many national military forces during and after World War II.

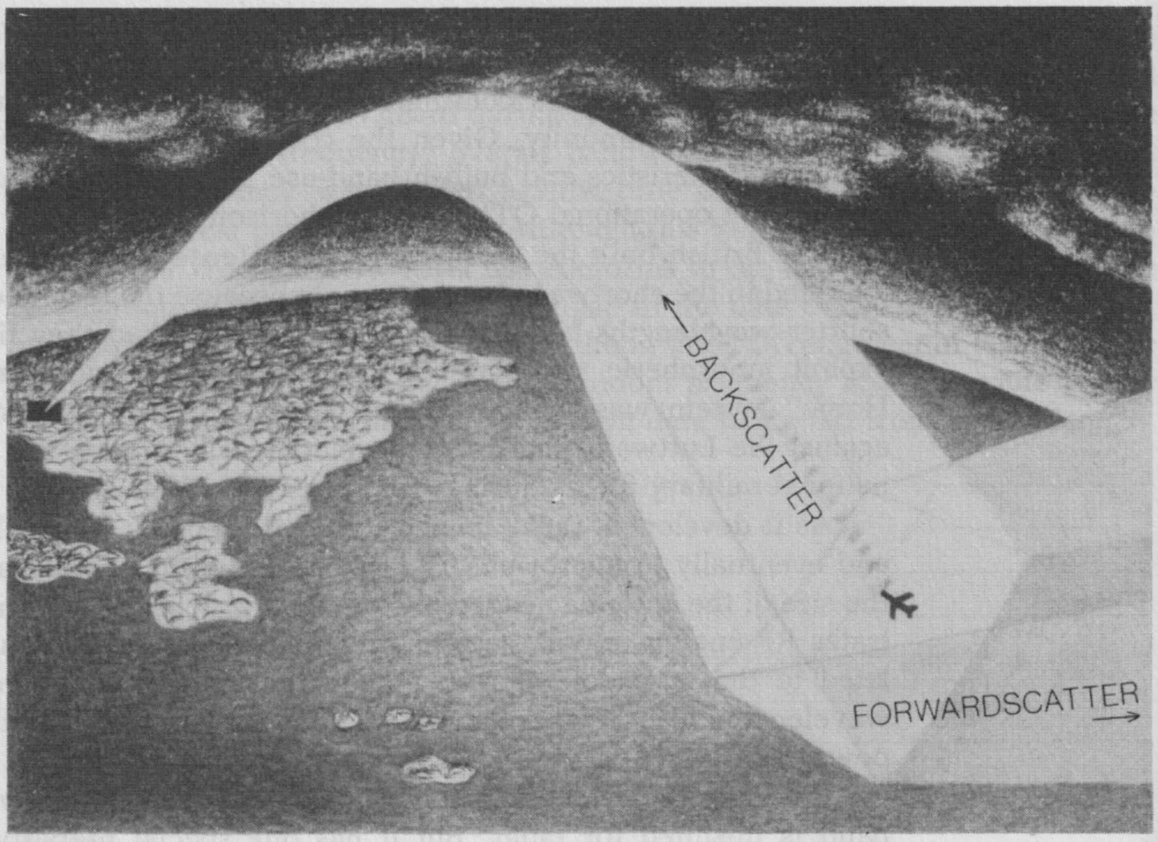
As it developed, radar tended to move up-band: from HF to VHF to UHF and eventually to microwave. Shortening the wavelength dramatically reduces the size of the antenna needed to form a narrow beam. A narrow beam concentrates RF energy into a "searchlight," thereby reducing "clutter" (echo unrelated to the target of interest) and increasing directional resolution. Shorter wavelengths also mean smaller targets can be detected with less transmitter power.

Inverting these arguments shows some of the reasons why the shortwave band is ill-suited for radar. But it has one special property that has always tantalized radar designers: skywave propagation. Radar signals of the proper frequency, launched to the ionosphere at the proper angle, will come to Earth hundreds (even thousands) of miles beyond the range of line-of-sight radars. And if there is an ionospheric path from the radar to a reflective object in the far-field, then there will also be an ionospheric path for an echo from the object back to the radar a split-second later. Fig. 11-8 illustrates the general concept of an over-the-horizon radar. A small portion of the emission is reflected back towards the transmitter, including Doppler-shifted echoes from aircraft flying through the illuminated far-field. However, most of the emission continues travelling away from the transmitter, leaving the detection zone as "forward-scatter," which can come back to Earth and cause interference far beyond the radar's surveillance range.

Very little of the radar signal will be "backscattered" toward its source. That's why extremely powerful transmitters, very sensitive receivers, and highly directional antennas are required. Even then, the echo of an airplane or battleship is minute compared with the backscatter from the land and sea—it's 40 to 80 dB weaker. Add in natural and man-made noise, multipath propagation, ionospheric storms, aurorae, everything that degrades the quality of shortwave channels, and you have some idea of how difficult it is to find the echo of a target of interest. Nevertheless, military planners in various countries felt that being able to detect a fleet of enemy aircraft a thousand miles away would be so valuable that it would be worthwhile to try to overcome the obstacles.

We don't know when the USSR began experimenting with OTH radar, but work in the U.S. began in the late 1940s, sponsored mainly by the Army Air

Fig. 11-8. General concept of an over-the-horizon radar.



Force (the Air Force had not yet become a separate service). In the 1950s, the U.S. Naval Research Laboratory established that none of the technical obstacles were insurmountable. The echo of an aircraft at shortwave frequencies, though weak, is coherent, and the Doppler shift caused by the target's motion is distinctive (not many radar-reflective objects move at 400 miles/hour). The key to successful development of OTH radar was—and still is—the processing of the backscattered echoes. Computer technology was in its infancy then, so the Navy devised "a cross-correlation signal processor that utilized a magnetic drum as the storage medium. Under Air Force and Navy sponsorship, a high-power transmitter and antenna suitable for testing aircraft detection feasibility were added, and in the fall of 1961 aircraft were detected and range tracked over the major portion of their flights across the Atlantic."[12]

Further development of OTH radar depended largely on breakthroughs in automatic data-processing and ionospheric research. The Air Force began experimenting with a somewhat simpler technique, forwardscatter OTH radar, in the mid-1960s. As the name suggests, this technique takes advantage of the fact that most OTH radar energy is not scattered back toward the transmitter; rather, it caroms forward into another ionospheric hop. The much higher power of the forwardscatter means the receiver doesn't have to be nearly as sensitive as it

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[12] James M. Headrick and Merrill I. Skolnick, "Over-the-Horizon Radar in the HF Band," *Proceedings of the IEEE*, Vol. 62, No. 6 (June 1974), pp. 664–672.

would have to be to pick up backscatter. But that second hop makes extracting Doppler information much more difficult, so the technique lends itself to a somewhat different application—instead of looking for an echo from a distant object, forwardscatter can be used to detect the appearance of a hole in the ionosphere, as might be caused by a nuclear explosion or a rocket launch.

The Naval Research Laboratories' MADRE OTH-B radar, located at Chesapeake Bay, Maryland, is pictured in Fig. 11-9. The large array measures about 140 feet tall by about 320 feet wide and consists of 20 corner reflector elements arranged in two rows of ten. The beam can be steered ±30° with "mechanically actuated line stretchers." Above and behind the large array is a rotatable corner reflector antenna for experiments in directions not within the main antenna's coverage. Built in 1961, MADRE's present status is unknown.

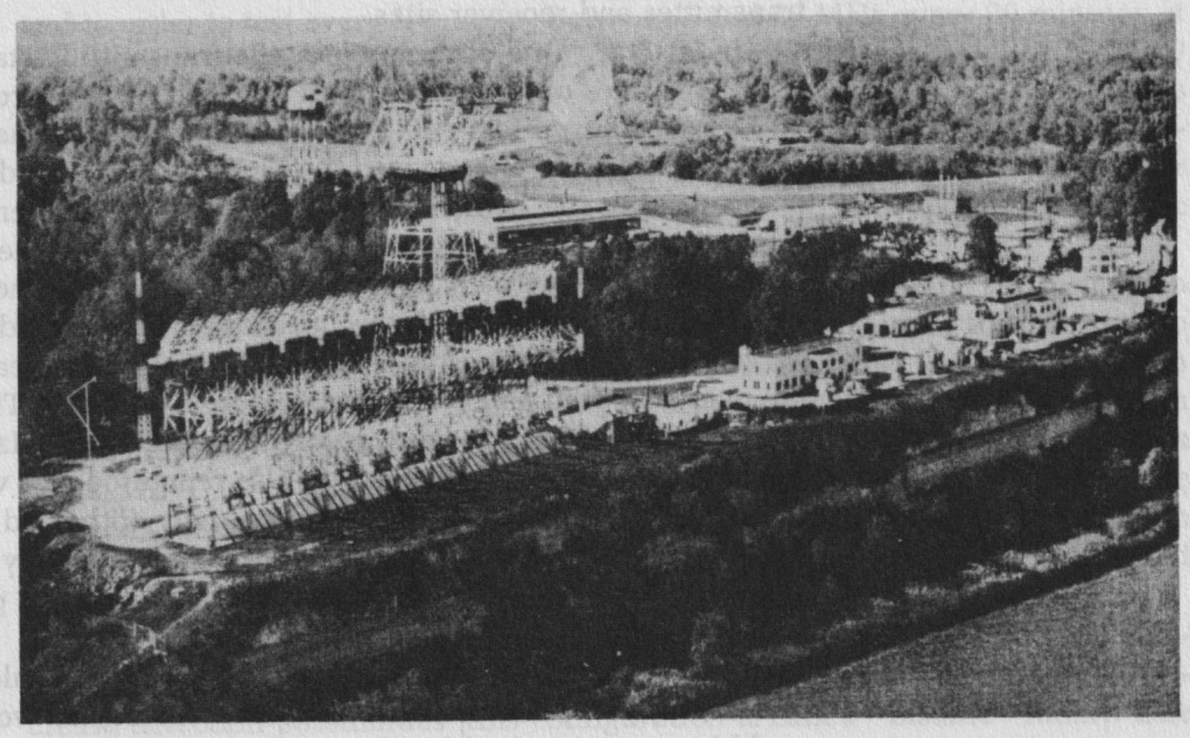

Fig. 11-9. The Naval Research Laboratories MADRE OTH-B radar in Chesapeake Bay, Maryland. (From *Aviation Week & Space Technology*, 6 December 1971.)

With four transmitter sites in the Far East and five receiver sites and a correlation center in Western Europe from 1968 to 1975, the Air Force used Project 440-L, a forwardscatter OTH system, for this very purpose. In other words, the continuous-wave emissions skipped across the Soviet Union.

Thus, the USSR was exposed to American OTH signals for years before the appearance of the Woodpecker. In 1971, the USAF's Director of Command, Control, and Communications was asked if the Russians knew about this system. "Yes sir, I'm sure they do," he replied.[13]

The Air Force's OTH station in Japan was subsequently dismantled and shipped to Australia, where it became the core of Project Jindalee, the most

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[13] Philip J. Klass, "HF Radar Detects Soviet ICBMs," *Aviation Week & Space Technology* (6 December 1971), pp. 38–40.

ambitious OTH backscatter radar project to date, outside of the U.S. and USSR. Desmond Ball described it in 1978:

> The transmitter site, consisting of a phased array antenna 185 meters long, several other masts to support communication and radar calibration antennas, power house, etc., is located in the Hart's Range about 160 km northeast of Alice Springs. The main receiving site, in the Mt. Everard area about 15 km north of Alice Springs, features a 600 m long receiving array, calibration and communication aerials, and large earth mats providing stable ground planes; some 300 km of wire was used to make these mats. About six or seven technicians from WRE [the Weapons Research Establishment] reside in Alice Springs, and these provide a 24 hour a day manning of both the transmitter and receiver sites.
>
> Under Stage One of the project, the transmitting station at Hart's Range operates on a power output of some 50 kW, provided by five 10 kW subtransmitters—40 kW is utilized in the actual radar transmission, and 10 kW feeds into the "ionospheric sounder" dedicated to monitoring the behavior of the ionosphere. Sixteen further subtransmitters are being installed under Stage Two....The Hart's Range station should eventually operate on at least 1 MW. The basic operating frequency spectrum of the installation is expected to be 5–29.5 MHz....It could at times go up to 60 MHz. On overseas experience, the operating frequency will centre around 14 MHz. The bandwidth will be quite wide, probably varying from about 30 kHz to more than 300 kHz at some times. The basic pulse repetition rate will depend to some extent on how the system is eventually optimized for the detection and tracking of high-Mach aircraft and relatively slow-moving ships. It should be somewhere from about 3 pulses per second to about 10/sec.
>
> For early warning, an actual operating system would require two or three such "Jindalee" installations....An actual working system could be operational within five years from today....[14]

One ham radio operator who wishes to remain anonymous said, "the Australian OTHR has a quieter attack and usually stays on a channel longer than any of the other Woodpeckers." This remark was made early in 1983, but we don't know anything more about signal characteristics or the system's present status. Signals like the woodpeckers, but with different pulse rates and bandwidths, are heard from time to time. Their source remains a mystery, but some may be from Australia.

According to Dr. Ball, Jindalee, like the Woodpeckers, was designed to transmit variable but potentially very wide bandwidths throughout most of the shortwave band. This suggests that spectrum-hogging isn't just due to a bad attitude toward other users of the band on the part of the Soviet Union but is in

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[14] Desmond J. Ball, *Electronics Today International* (February 1978), pp. 35–40.

the nature of OTH radar technology. Many different combinations of wavelength and beam elevation angle are needed to illuminate different air spaces—the best combination depends on ionospheric conditions at a given moment—and wide bandwidths are necessary for range resolution. Propagation data is obtained with sounders that sweep through all the frequencies available to the radar. A sounder receiver at the radar receiver site, with a passband that sweeps in tandem with the sounder transmitter, picks up the echoes so radar operators can check the time-delay (ionospheric height and distance to reflection point), path loss, distortion, etc., of each frequency. Shortwave listeners are thus more likely to encounter signals from a sounder operating in support of an OTH radar than from the radar itself. Fortunately, sounders don't have to be very powerful, and in order to test every frequency between 5 and 28 MHz every 20 minutes, it must sweep at least 19 kHz per second. That means its signal will cross a 10 kHz-wide channel in about half a second. Many of the brief zips one hears crossing a shortwave channel are ionospheric sounders—they are not necessarily connected with OTH radars, however. The data they yield is valuable for any radio service that relies on skywave propagation, as well as for scientific research. Their use is rapidly spreading.

One system definitely not active today is Polar Cap III. The Canadian Defense Research Board and the U.S. Air Force collaborated on this project "to determine the cost and effectiveness of OTH radar to detect airborne targets in the polar region."[15] From a military perspective, a long frozen border between Canada and the USSR is where OTH capability would be most valuable—as a super DEW Line able to "look" right into Soviet air space. The DEW Line stations, based on 1950s technology, are limited in coverage and expensive to maintain. The idea of replacing them all with one or two OTH radars had obvious appeal.

The Polar Cap III transmitter was located at Hall Beach on Melville Peninsula in Canada's Northwest Territories. There were two receiver sites, to increase detection possibilities (this configuration is called "bistatic" radar). One was near the transmitter, and the other was at Cambridge Bay on Victoria Island, 550 miles to the west. Equipment and supplies were air-lifted in during the summer of 1972. Although very large, the antennas went up quickly and tests began in October. The results proved disappointing. When presenting its Continental Air Defense Plan to the House Armed Services Committee in 1981, the Air Force explained, "We have found that when OTH is looking north, the auroral interference degrades its performance so the OTH may not give us the quality warning we need."[16]

This must raise questions about the Woodpeckers' effectiveness as radars, since some of their beams skirt the polar region. However, ionospheric turbulence is believed to have a worse impact on Doppler-based systems like the Air Force's than on time delay systems like the Woodpeckers. That may be why the Soviets use the latter.

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[15] Scotty Yool, "Polar Cap III," *Sentinel* (January 1973), pp. 24–25.

[16] Lt. Gen. James V. Hartinger, *Full Committee Hearing on Continental Air Defense*, Committee on Armed Services, US House of Representatives (22 July 1981), p. 31.

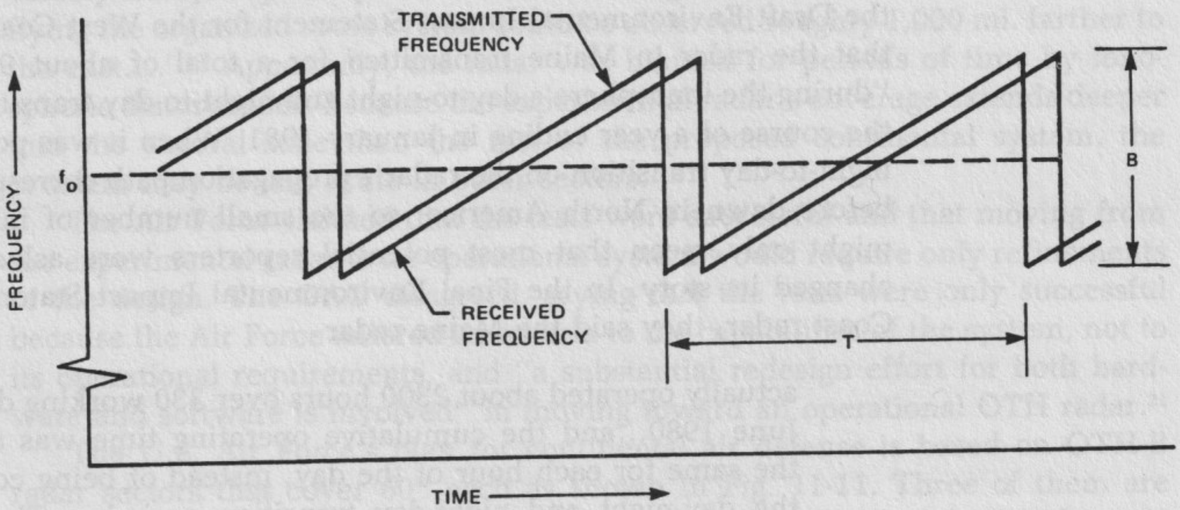
Given our unhappy familiarity with the Woodpeckers, it's not surprising that a shock wave swept through the shortwave community in 1980 when the Air Force announced it was starting to test a powerful OTH backscatter radar in Maine, and if the tests were successful, more and bigger radars would be built near the Atlantic, Pacific, and Gulf coasts. According to O. G. Villard:

> The U.S. counterpart of the woodpecker is still experimental.…The mission…is to give early warning of bomber attack via the northeast oceanic approaches to the U.S. and Canada.…Since all aircraft flying over the water must routinely file flight plans in advance, those seen by the radar…are then compared with their reported plan; if a target or targets cannot be associated with such a plan, appropriate action is taken.…
>
> Although the Soviet radar transmits on-off pulses (a conventional approach that permits the transmitting and receiving functions to share one antenna), the U.S. radar employs separate transmitting and receiving sites so that the transmitter can radiate a continuous signal which is FM-modulated or 'chirped' for range resolution.
>
> …the broadside receiving array…located at Columbia Falls, Maine, is about 4000 feet in length. Since mechanical rotation would hardly be practical, scanning is accomplished by digital beamforming and slewing. The beam is made unidirectional by means of a reflecting screen located about a quarter-wave behind the radiating elements.
>
> Essentially the same design is used at the transmitting location, except that the transmitting beam is made wider so as to floodlight the area within which multiple receiving beams conduct a fine-scale search. The average transmitter power is roughly 1 megawatt.…
>
> Economic considerations have dictated the present operating frequency range—6.7 to 22 MHz. It would be nice to be able to go both lower and higher, and perhaps this will be possible in the future.…
>
> The radar is, of course, computer-controlled and extraordinarily flexible. It is provided with a low-power auxiliary sounder which repeatedly checks all the available frequencies to determine what propagation paths are present.…A separate facility automatically checks all the available channels for interference, measuring not only the level at any given instant, but also the time history of that channel's usage.
>
> All these input pieces of information plus many, many more (such as worldwide geophysical data) are taken into account by the radar's main computer.…
>
> So long as it is performing its mission satisfactorily, the radar's operating guideline is to cause as little interference as possible. Thus, when propagation is good, it can reduce power.…
>
> There is little problem in recognizing the Soviet OTHR signals, so long as they continue the present format.…The American radar signals, by way of contrast, will sound on an AM receiver more like power-line hum, but at any one of several modulation frequencies

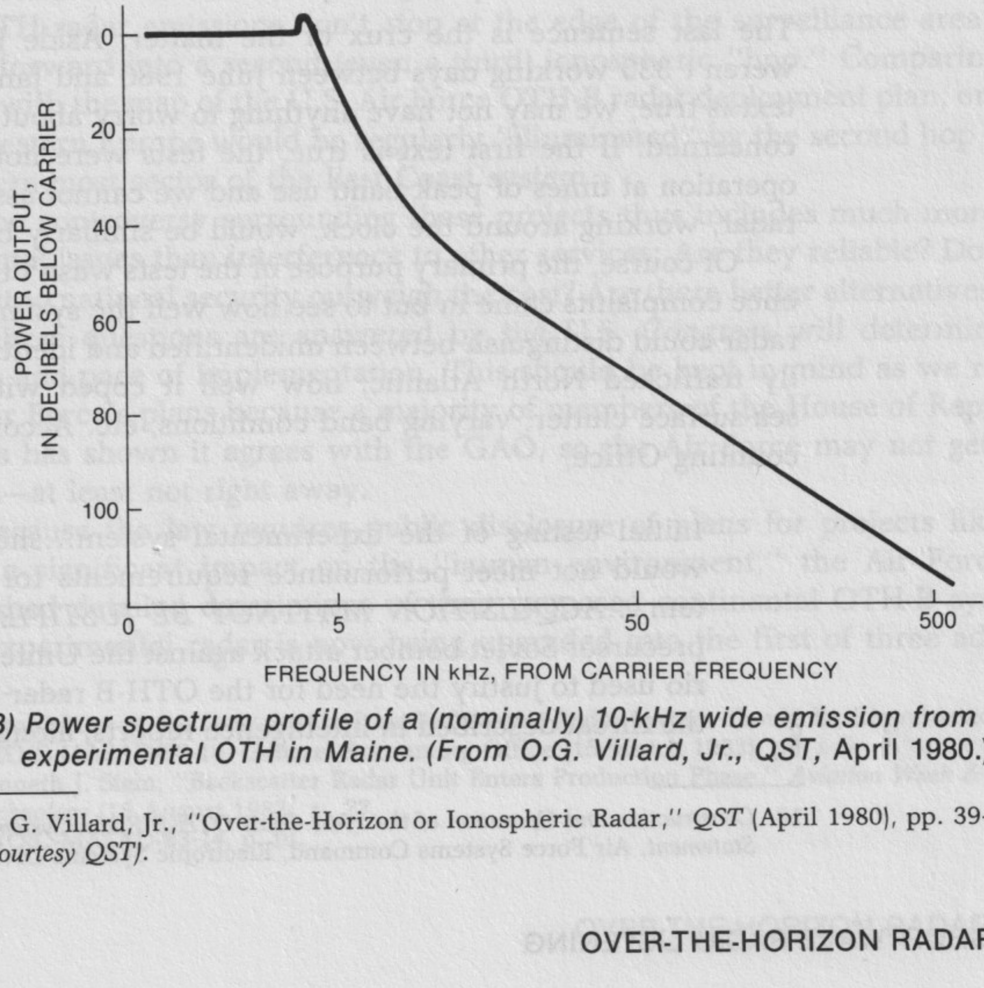
> from 20 Hz to 60 Hz. They should be much less irritating than on-off pulsing. Because they will be coming from a source physically closer to some U.S. amateurs [and shortwave listeners], however, they may be troublesome when propagation is exceptionally good....[17]

A typical USAF OTH modulation waveform is given in Fig. 11-10A and the power spectrum profile is given in Fig. 11-10B.

Fig. 11-10. The USAF OTH-B radar signal.



(A) Typical modulation waveform. B = nominal bandwidth, f_o= carrier frequency, and 1/T = waveform repetition rate. (From Draft, Environmental Impact Statement, West Coast, pg. A-6.)



(B) Power spectrum profile of a (nominally) 10-kHz wide emission from the experimental OTH in Maine. (From O.G. Villard, Jr., QST, April 1980.)

[17] O. G. Villard, Jr., "Over-the-Horizon or Ionospheric Radar," *QST* (April 1980), pp. 39–43 *(Courtesy QST).*

The initial furor caused by this article faded as the radar tests, much to everyone's surprise, ran more or less unnoticed. The Air Force says it got over a dozen interference complaints, but only one was verified: a Military Affiliate Radio System station in Florida, using 20937.5 kHz on 30 January 1981. All the other complaints were for bands or times where the radar wasn't operating.

The significance of this excellent noninterference record is hard to gauge because the Air Force has released contradictory information about the tests. In the Draft Environmental Impact Statement for the West Coast radar, they said that the radar in Maine transmitted for a total of about 900 hours, usually "during the ionosphere's day-to-night and night-to-day transition periods," over the course of a year ending in January 1981. When it was pointed out that the night-to-day transition on the radar's propagation path corresponds to the hours before dawn in North America, so the small number of interference reports might only mean that most potential reporters were asleep, the Air Force changed its story. In the Final Environmental Impact Statement for the West Coast radar, they said the Maine radar

> actually operated about 2300 hours over 330 working days beginning June 1980...and the cumulative operating time was approximately the same for each hour of the day, instead of being concentrated in the day-night and night-day transition periods....Thus, there was much more opportunity than previously stated for ham radio operators, shortwave listeners, and Fixed Service providers to notice interference.[18]

The last sentence is the crux of the matter. Aside from the fact that there weren't 330 working days between June 1980 and January 1981, if the second text is true, we may not have anything to worry about, so far as interference is concerned. If the first text is true, the tests were not representative of radar operation at times of peak band use and we cannot assume that an operational radar, working around the clock, would be similarly benign.

Of course, the primary purpose of the tests wasn't to see how many interference complaints came in but to see how well the system worked—how well the radar could distinguish between unidentified and identified aircraft in the heavily trafficked North Atlantic, how well it coped with auroral disturbances, sea-surface clutter, varying band conditions, etc. According to the General Accounting Office,

> Initial testing of the experimental system...showed that the radar would not meet performance requirements for an operational system....*ACQUISITION MAY NOT BE JUSTIFIED*...The threat of a precursor Soviet bomber attack against the United States is the scenario used to justify the need for the OTH-B radar system. Considering the threat described in intelligence reports, along with alternatives to

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[18] *Construction and Operation of the West Coast OTH-B Radar System—Final Environmental Impact Statement*, Air Force Systems Command, Electronic Systems Division (February 1984), p. 330.

> OTH-B, GAO questions the need to acquire the OTH-B radar system as now planned....[19]

Since the bulk of the GAO report was classified, we don't know what shortcomings were revealed by the tests, but *Aviation Week & Space Technology* said that when the radar was demonstrated for them, "severe ionospheric disturbances crossing Newfoundland and extending about 200 mi. south of Greenland adversely affected system performance. Not long after, however, tracks of aircraft flying the organized route system could be observed roughly 1,000 mi. farther to the east...."[20] Apparently, the radar was blinded for periods of time by ionospheric disturbances. Because the experimental radar's coverage extends deeper into the auroral zone than the rest of the proposed continental system, the problem may be less acute in other sectors.

The Air Force claimed that the tests were successful and that moving from the experimental radar to an operational system would require only refinements of the design. The GAO disagreed, saying that the tests were only successful because the Air Force tailored its criteria to the capabilities of the system, not to its operational requirements, and "a substantial redesign effort for both hardware and software is involved" in moving toward an operational OTH radar.[21]

The U.S. Air Force's plan for continental air defense is based on OTH-B radar sectors that cover 60° each as shown in Fig. 11-11. Three of them are based in Maine, three in the Pacific northwest, two are slated for Alaska, and four for the northern midwest. Each sector is subdivided into eight subsectors (each 7½° wide). The radars will step from one subsector to another about every ten seconds. A different frequency may be used in each step.

OTH radar emissions don't stop at the edge of the surveillance area, they carry forward into a second (even a third) ionospheric "hop." Comparing Fig. 11-12 with the map of the U.S. Air Force OTH-B radar deployment plan, one can see Western Europe would be regularly "illuminated" by the second hop of the northern-most sector of the East Coast system.

The controversy surrounding these projects thus includes much more fundamental issues than interference to other services: Are they reliable? Does the benefit to national security outweigh the cost? Are there better alternatives? The way these questions are answered by the U.S. Congress will determine the extent and pace of implementation. This should be kept in mind as we review the Air Force's plans because a majority of members of the House of Representatives has shown it agrees with the GAO, so the Air Force may not get all it wants—at least not right away.

Because the law requires public disclosure of plans for projects likely to have a significant impact on the "human environment," the Air Force has published detailed descriptions of their proposed continental OTH-B systems. The experimental radar is now being upgraded into the first of three adjacent

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[19] "Acquisition of the Over-the-Horizon Backscatter Radar System Should Be Reevaluated," GAO/C-MASAD-83-14, General Accounting Office (15 March 1983), pp. i–ii.

[20] Kenneth J. Stein, "Backscatter Radar Unit Enters Production Phase," *Aviation Week & Space Technology* (16 August 1982), p. 77.

[21] GAO/C-MASAD-83-14, p. iii.

Fig. 11-11. The USAF OTH-B radar deployment plan.

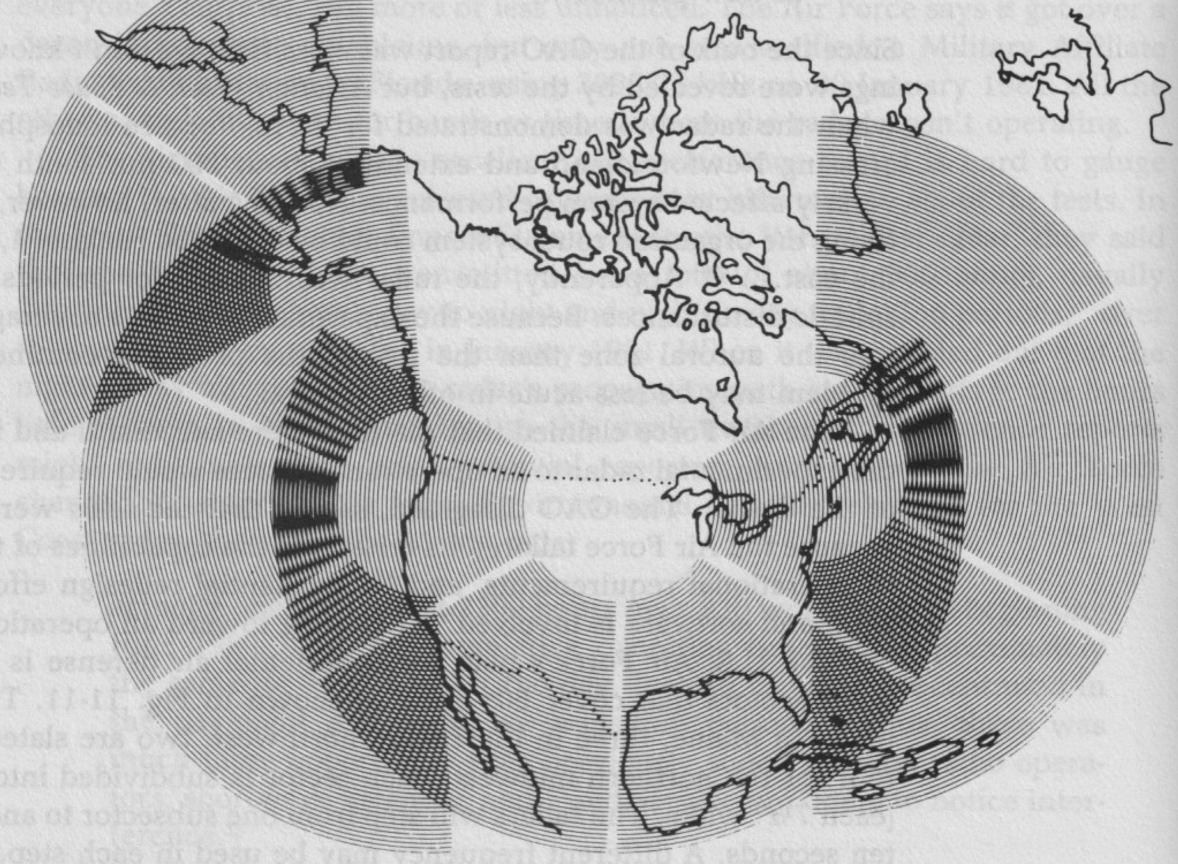
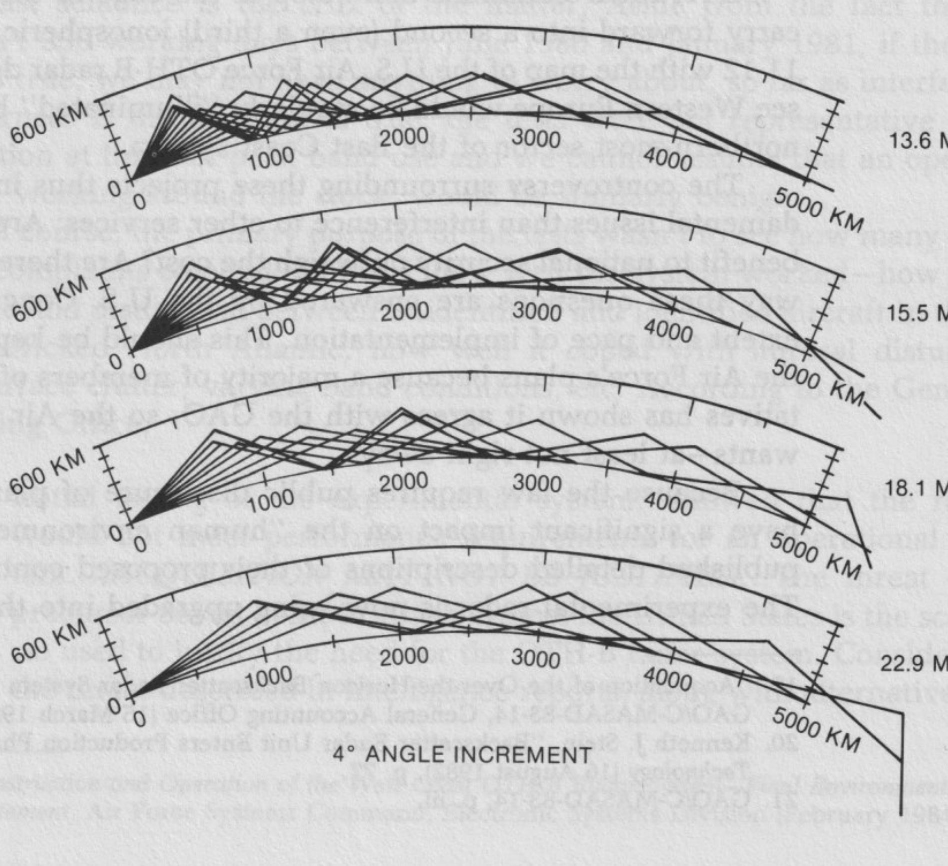


Fig. 11-12. Chart of the OTH radar emissions. (Courtesy *Proceedings of IEEE*, 62 (1964), pg. 668.)



identical sectors to be based in Maine, each covering 60° of azimuth out to a distance of 1800 miles. (There is an inner limit to the detection range of 500 miles, due to the length of the ionospheric "skip" zone.) Each sector will have twelve 100 kW transmitters for a maximum power output of 1.2 megawatts; six separate phased-array antennas, only one of which would be driven at a time; a 10 kW sounder; and a receiving station with a mile-long linear array of active antennas. The transmitters will be located at 45° 10′ 38″ North by 69° 52′ 23″ West, in Somerset County—oddly enough, near a small town named Moscow—and the receivers will be about 100 miles east, in Washington County, near the Maine coast. An operations center at Bangor International Airport will house the data processing and control the transmitters and receivers of all three sectors.

Essentially the same design has been proposed for the West Coast. The plan for the transmitting arrays of the three sectors in the West Coast OTH system is given in Fig. 11-13. The receiving arrays would be similarly arranged. The three sectors of the East Coast system are more dispersed, presumably to fit the landscape better. (Diagram from the Draft EIS, West Coast, p. A-8) There the operations center would be at Mountain Home Air Force Base in Idaho; the transmitters at Buffalo Flat, Oregon (43° 16′ North by 120° 30′ West) and the receivers at Rimrock Lake, Oregon as shown in Fig. 11-14.

Unlike the East Coast system, which is aimed out over the ocean, the West Coast system's surveillance coverage includes huge tracts of U.S. territory—the southern half of California and virtually the entire state of Alaska. These areas could be "illuminated" by the radar beams about every 80 seconds. Shortwave listeners in Alaska and southern California thus would be more likely to hear the radars—and hear them louder—than listeners elsewhere.

The Air Force has also expressed the desire to build a 120° south-facing OTH system somewhere in northern Texas or Oklahoma by the late 1980s. If built, the two sectors of this system would illuminate much of Central America.

Each radar sector would be on the air continuously and simultaneously. The detection beams would not sweep across their sectors but rather would step in 7.5° increments from azimuth to azimuth, "sometimes in a seemingly random manner."[22] A total of eight steps are required to cover each 60° sector. The frequency and elevation angle used at each step are chosen independently so that up to 24 frequencies could be used during each 180° work-cycle, three at once. If the East, West, and Gulf Coast systems are all built, up to 64 frequencies could be involved in the total work-cycle, eight of them on the air at once.

"Frequency" here means frequency *band*, of course, as the emissions are variable in bandwidth from a minimum of 5 kHz to a maximum of 40 kHz, with some weak overspill into adjacent bands. The typical waveform would be a continuous-repeat frequency-modulated (FM) sawtooth. When the bandwidth is 5 or 10 kHz, the waveform repetition rate could vary from 10–20 per second in 2.5 Hz increments; when the bandwidth is 20 or 40 kHz, the rate could vary from 20–60 per second in 5 Hz increments. On an audio receiver, these would all sound like low frequency buzzes, the pitch set by the repetition rate.

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[22] *Construction and Operation of the West Coast OTH-B Radar System—Draft Environmental Impact Statement*, Air Force Systems Command, Electronic Systems Division (March 1983), p. C-1.

Fig. 11-13. Plan for the transmitting arrays of the three sectors in the West Coast OTH system. (From Draft, Environmental Impact Statement, West Coast, pg. A-8.)

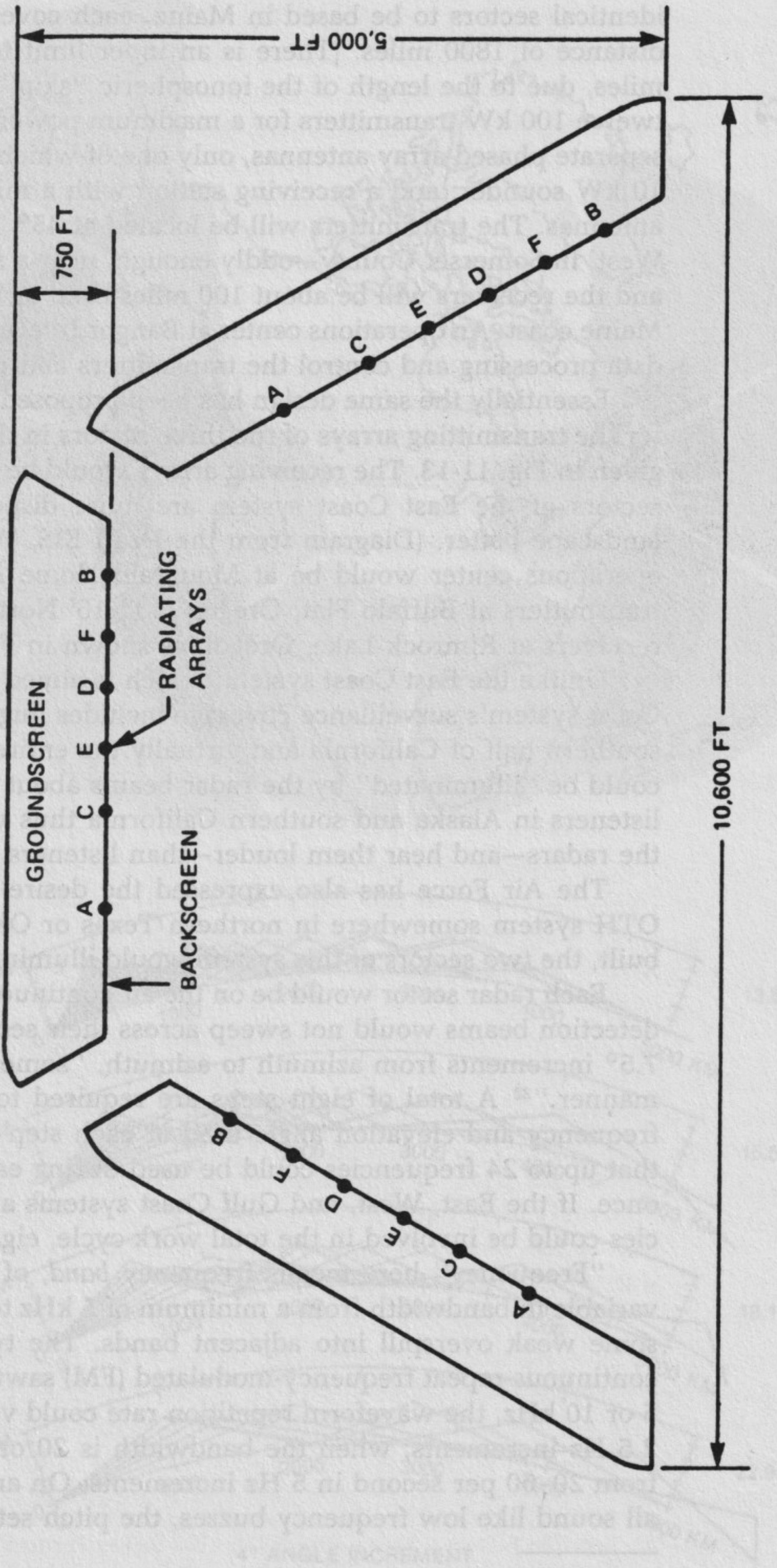


Fig. 11-14. Transmitter and receiver sites for the Air Force's proposed West Coast OTH-B radar system. (From Draft, Environmental Impact Statement, West Coast, pg. 2–8.)

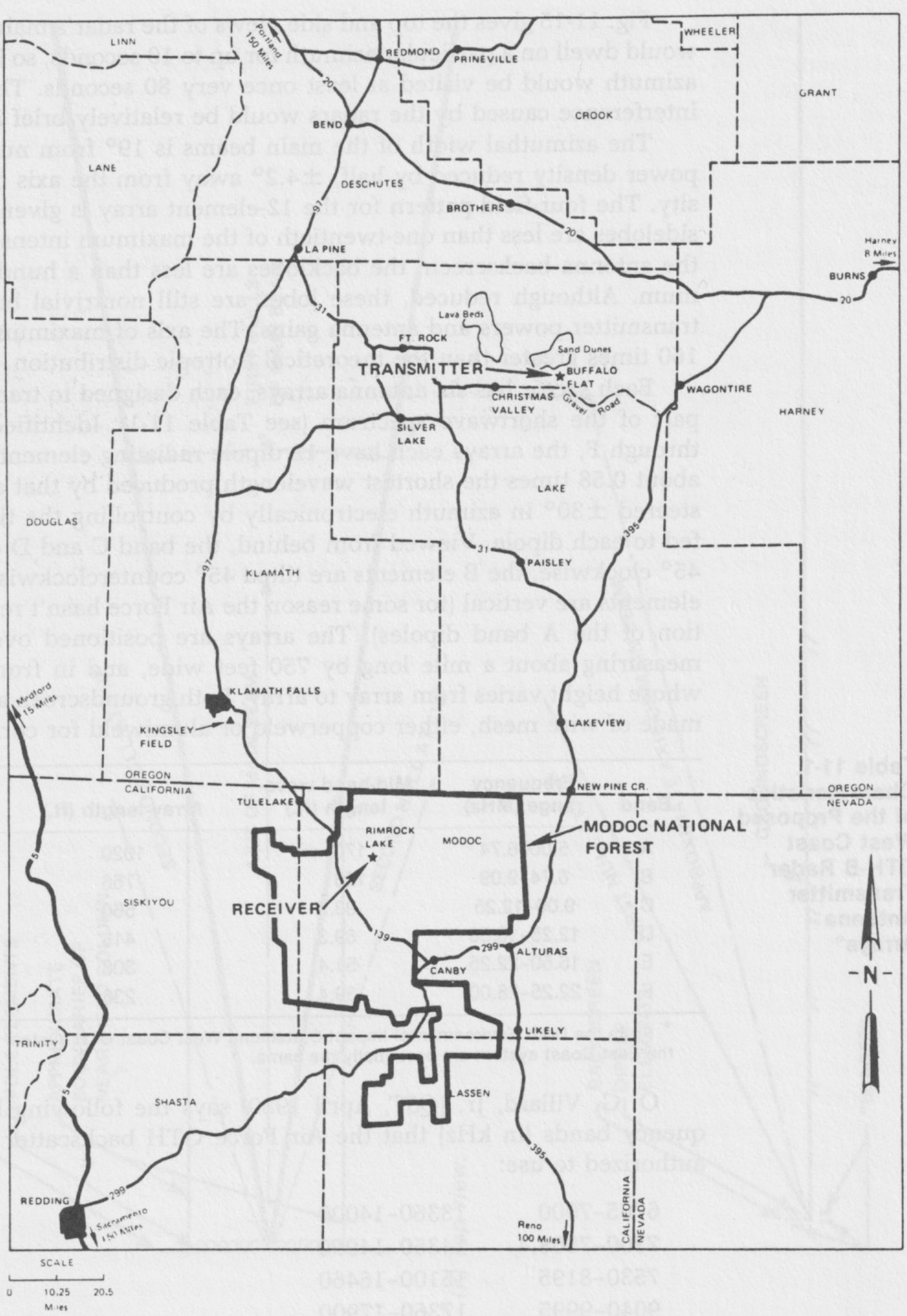


Fig. 11-15 gives the top and side views of the radar's main beam. The beams would dwell on a particular azimuth for up to 10 seconds, so in each sector, each azimuth would be visited at least once very 80 seconds. That means that any interference caused by the radars would be relatively brief and episodic.

The azimuthal width of the main beams is 19° from null to null, with the power density reduced by half, ±4.2° away from the axis of maximum intensity. The four-field pattern for the 12-element array is given in Fig. 11-16. The sidelobes are less than one-twentieth of the maximum intensity, and because of the antenna backscreen, the backlobes are less than a hundredth of the maximum. Although reduced, these lobes are still nontrivial because of the high transmitter powers and antenna gains. The axis of maximum intensity is some 160 times greater than the theoretical isotropic distribution.

Each sector has six antenna arrays, each designed to transmit in a different part of the shortwave spectrum (see Table 11-1). Identified by the letters A through F, the arrays each have 12 dipole radiating elements spaced evenly at about 0.58 times the shortest wavelength produced by that array. The beam is steered ±30° in azimuth electronically by controlling the timing of the signal fed to each dipole. Viewed from behind, the band C and D elements are tilted 45° clockwise, the B elements are tilted 45° counterclockwise, and the E and F elements are vertical (for some reason the Air Force hasn't revealed the orientation of the A band dipoles). The arrays are positioned over a groundscreen measuring about a mile long by 750 feet wide, and in front of a backscreen whose height varies from array to array. Both groundscreen and backscreen are made of wire mesh, either copperweld or alumiweld for corrosion resistance.

Table 11-1. Characteristics of the Proposed West Coast OTH-B Radar Transmitter Antenna Arrays*

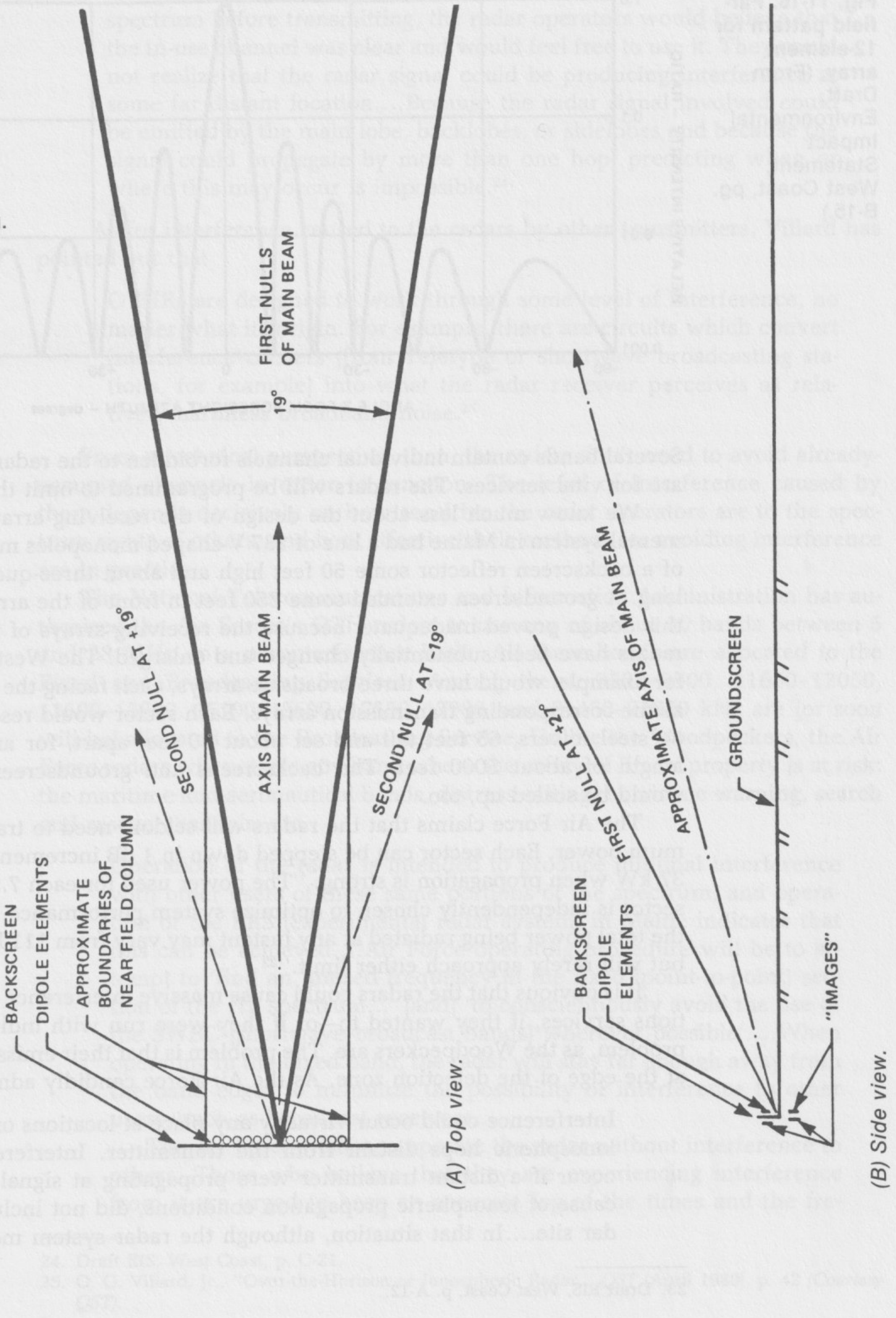
Band	Frequency range (MHz)	Mid-band wave-length (ft.)	Array length (ft.)	Backscreen height (ft.)
A	5.00–6.74	170	1020	135
B	6.74–9.09	126	756	100
C	9.09–12.25	93.3	560	75
D	12.25–16.50	69.3	416	55
E	16.50–22.25	51.4	308	45
F	22.25–28.00	39.4	236	35

* From the Draft Environmental Impact Statement, West Coast OTH system (p. B-4). Figures for the East Coast system are essentially the same.

O. G. Villard, Jr. (*QST*, April 1980) says the following bands are the frequency bands (in kHz) that the Air Force OTH backscatter radars have been authorized to use:

6765–7000
7300–7508.4
7530–8195
9040–9995
10100–11175
11400–11975
12000–12330
13360–14000
14350–14990
15100–16460
17360–17900
18030–19990
20010–21000
21450–21850

Fig. 11-15. Top and side views of the US OTH-B radar main beam. (From Draft, Environmental Impact Statement, West Coast, pg. A-11.)



(A) Top view.

(B) Side view.

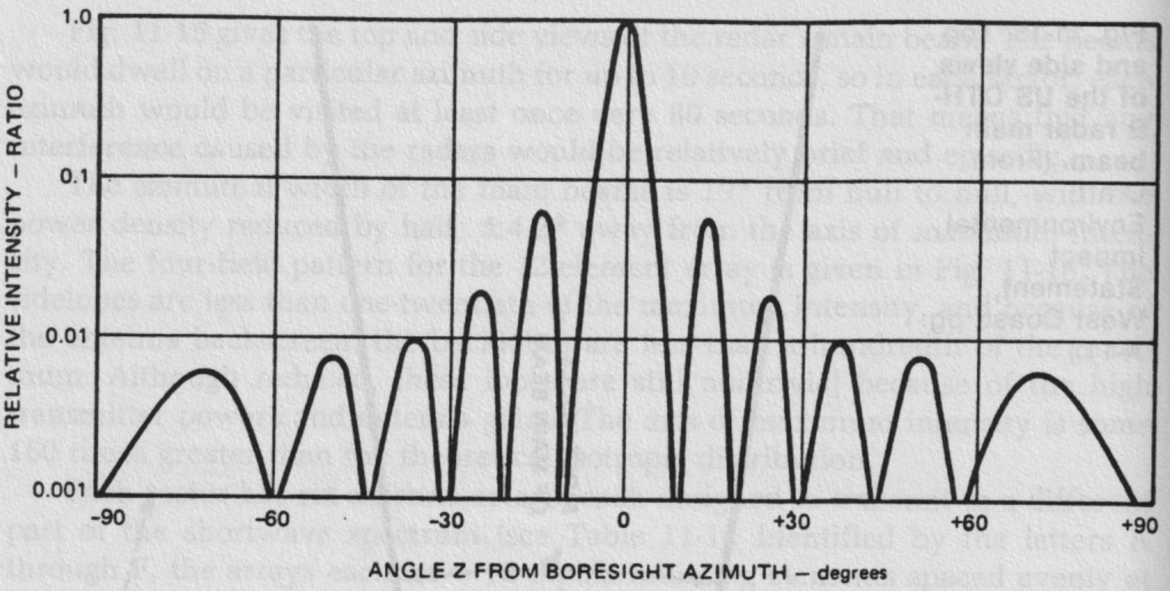


Fig. 11-16. Far-field pattern for 12-element array. (From Draft, Environmental Impact Statement, West Coast, pg. B-15.)

Several bands contain individual channels forbidden to the radars because they are for vital services. The radars will be programmed to omit them.

We know much less about the design of the receiving arrays. The experimental system in Maine had a line of 137 V-shaped monopoles mounted in front of a backscreen reflector some 50 feet high and about three-quarters of a mile long. A groundscreen extended some 250 feet in front of the array. Apparently this design proved inadequate, because the receiving arrays of the operational radars have been substantially changed and enlarged. The West Coast system, for example, would have three broadside arrays, each facing the same direction as the corresponding transmission arrays. Each sector would resemble a row of 84 steel towers, 65 feet tall and set about 60 feet apart, for an overall array length of about 5000 feet. The backscreens and groundscreens presumably would be scaled up, too.

The Air Force claims that the radars will seldom need to transmit at maximum power. Each sector can be stepped down in 1 dB increments to as little as 37 kW when propagation is strong. "The power used for each 7.5° surveillance sector is independently chosen to optimize system performance. Consequently, the total power being radiated at any instant may vary from 111 kW to 3.6 MW, but will rarely approach either limit."[23]

It is obvious that the radars could cause massive interference to communications services, if they wanted to—or if they were run with indifference to the problem, as the Woodpeckers are. The problem is that their emissions don't stop at the edge of the detection zone. As the Air Force candidly admits:

> Interference could occur virtually any place at locations one or more ionospheric hops distant from the transmitter. Interference could occur if a distant transmitter were propagating at signal...that, because of ionospheric propagation conditions, did not include the radar site....In that situation, although the radar system monitors the

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[23] Draft EIS, West Coast, p. A-12.

> spectrum before transmitting, the radar operators would believe that the in-use channel was clear and would feel free to use it. They could not realize that the radar signal could be producing interference at some far distant location....Because the radar signal involved could be emitted by the main lobe, backlobes, or sidelobes and because the signal could propagate by more than one hop, predicting when or where this may occur is impossible.[24]

As for interference caused to the radars by other transmitters, Villard has pointed out that

> OTHRs are designed to work through some level of interference, no matter what its origin. For example, there are circuits which convert interference carriers (from Teletype or shortwave broadcasting stations, for example) into what the radar receiver perceives as relatively harmless broadband noise.[25]

From a technical perspective, then, the radars don't need to avoid already-occupied channels in order to function. The level of interference caused by them depends decisively on how sensitive the radar operators are to the spectrum rights of others, and how effective their methods for avoiding interference are in practice.

The National Telecommunications and Information Administration has authorized the Air Forces's OTH radars to use any of about 30 bands between 5 and 28 MHz on a noninterference basis. All these bands are allocated to the Fixed and Broadcasting Services. Among them, 9500–9900, 11650–12050, 13600–13800, 15100–15600, 17550–17900, and 21450–21850 kHz are (or soon will be) allocated to the Broadcasting Service. Unlike the Woodpeckers, the Air Force radars will not use any band where the safety of life or property is at risk: the maritime and aeronautical bands, distress calling, hurricane warning, search and rescue channels, etc.

> Operation of the radar is intended to produce minimal interference with other users of these same portions of the spectrum, and operation of the ERS [experimental radar system] in Maine indicates that this can be achieved....Air Force operating procedure will be to attempt to 'find an unused frequency in the fixed (point-to-point) section of the HF spectrum...' [and] 'to conscientiously avoid the use of the SWBC [shortwave broadcast bands] wherever possible'....When operating in the Fixed band, the radar will stay far enough away from the band edges to minimize the possibility of interference to other users, such as broadcast receivers....
>
> The Air Force wishes to operate the radar without interference to others. Those who believe that they are experiencing interference from it are urged to keep an accurate log of the times and the fre-

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24. Draft EIS, West Coast, p. C-21.
25. O. G. Villard, Jr., "Over-the-Horizon or Ionospheric Radar," *QST* (April 1980), p. 42 *(Courtesy QST)*.

> quencies and to provide that information to the Air Force. The address is: HQ ESD/SCU-4, Hanscomb Air Force Base, MA 01731.[26]

These are certainly commendable statements, so far as shortwave listeners are concerned. Unfortunately, other more recent statements are less reassuring. When they were asked for clarification of the phrase "wherever possible" in the above quote—which implies that under certain conditions the radars could transmit in the broadcasting bands—the Air Force replied:

> Whenever possible, the radar would operate in the Fixed part of the spectrum. However, if at some time the Air Force considers it to be in the national interest to use a frequency in the International Broadcast band, this would be done—without prior notification and probably without producing interference. Military systems of all nations have that right; U.S. systems do not abuse it.[27]

In support of their claim that all military forces "have that right," they cited Article 38 of the International Telecommunications Convention, which says that nations signing the Convention "retain their entire freedom with regard to military radio installations of their Army, Naval, and Air Forces." According to the Air Force, "This means that a nation's military forces are not bound by the 'no harmful interference' rule in any case where it is determined, unilaterally by the military, that a given transmission is important to the nation's defense."[28]

It is discouraging that they base such a bold interpretation on just one phrase from Article 38—especially since the very next phrase reads, "Nevertheless, these installations must, so far as possible, observe statutory provisions relative to...the measures to be taken to prevent harmful interference...."[29]

The Air Force's claim that they can unilaterally ignore NTIA's noninterference stipulation "in any case ... important to the nation's defense," gives them a loophole large enough to negate the stipulation entirely. It's the kind of statement one might expect from the Russians—if they were willing to admit that the Woodpeckers are military systems (they've never done that). We can only hope that the Air Force will rarely invoke it.

The risk of interference obviously depends on how the radars' operating frequencies are chosen. Villard described the process this way:

> First, the useful band of frequencies is determined from soundings and other data. Then the open [i.e., not already occupied] allocated channels within that band are identified and ranked in order of desirability. Low path loss, low multipath and low noise are the chief criteria. The radar then comes up on the most desirable frequency and continues there until conditions change or interference develops, at which point [it] instantaneously changes to the frequency which at

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[26] Draft Environmental Impact Statement (EIS), West Coast, pp. C-19 through C-22.
[27] Final EIS, West Coast, p. 332.
[28] Final EIS, West Coast, p. 328.
[29] International Telecommunication Convention, *US Treaties and Other International Agreements*, 1976–77, Vol. 28 Part 3, p. 2531.

> that moment is at the top of the continuously updated 'most desirable allowable frequency' list.
>
> Often the radar will shift from an otherwise excellent frequency in order to resolve range or Doppler (velocity) ambiguities.[30]

The radar may also alternate quickly between two or three frequencies as it switches between search mode and tracking mode (this might occur if a suspicious target has been spotted).

The process described by Villard occurs separately for each azimuth, so when the radars change azimuth—every ten seconds or so—they'll probably change frequencies, too. The Air Force adds that the radars will generally operate near the highest frequency that will propagate to the desired range at a given time.

The keys to avoiding interference are not using frequencies already being used by others—this requires effective monitoring of the spectrum prior to radar transmission—and responding quickly to valid complaints of interference. The Association of North American Radio Clubs' OTH Radar Committee sent several suggestions along these lines to the Air Force during the environmental impact assessment process. The first suggestion was to eliminate the problem of radar operators not being able to detect distant stations using a channel because their signals didn't propagate to the radar sites: give the operators real-time access to monitoring assets located elsewhere in the world—particularly in areas that would be regularly reached by the radar beams in one hop (southern California and Alaska) or two hops (western Europe and Japan). The Air Force rejected this, saying, in essence, that the radar receiver is so much more sensitive than a remote monitoring station that the latter is unnecessary. Aside from the fact that this contradicts the Air Force's own description of how they could fail to identify a channel as occupied, and ignore the splotchiness of propagation, it hints at a capability discussed openly during the 1970s but rarely since. As Desmond Ball put it:

> Because of the great sensitivity, wide bandwidths and ability to cover such bandwidths over a wide frequency range, OTH-B receivers are admirably suited for gathering electronic intelligence.... This is especially significant because of the amount of military signals and communications which are transmitted on the HF band.... It may even be possible to modulate the frequencies so that the radar detection and the elint intercept capabilities can be operated simultaneously....[31]

The Air Force has never mentioned the gathering of electronic intelligence as part of the mission of their OTH radars, and considering some of the comments made by critics of the program in Congress and the GAO, the classified statements of mission may not contain it either. But it's plausible.

Our second suggestion had to do with the prompt processing of complaints. We suggested that there be an "800" telephone number and/or a Telex address

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[30] O. G. Villard, Jr., "Over-the-Horizon or Ionospheric Radar," *QST* (April 1980), p. 42 *(Courtesy QST)*.

[31] Desmond J. Ball, *Electronics Today International* (February 1978), p. 40.

so that reports of interference could reach the radar operators with the least possible delay. They replied:

> The Air Force is currently developing procedures by which authorized users of the HF bands who believe that the radar is creating interference would have the opportunity to report their complaint in real time. Their complaint would be received and evaluated by a person who would have the responsibility and authority to immediately eliminate interference caused by the radar....
>
> At this time, neither the communication link from the complainant to the interference-mitigating authority nor the operational procedures for establishing the validity of a complaint have been determined because testing and operation of the radar would not begin until 1985–1986. However, toll-free (i.e., 800-area code) phone numbers are under consideration for the communication links. When the procedures have been developed for receiving and evaluating reports of interference to authorized users, and for acting on complaints that are valid, the Air Force will make existence of these procedures widely known. ANARC will be able to help in this notification process.[32]

However, they rejected our suggestion that something like an "800" number be provided for potential complainants in northern and western Europe and Japan—areas likely to be affected by the second-hop signals.

Our final suggestion was that the Air Force express its commitment to this policy in the Final Environmental Impact Statement for the West Coast system:

> If a complaint of interference is received, it will be evaluated promptly. If found to be valid, and if the interference condition still exists at the time of validation, the radar will be taken off the offending frequency immediately.

In the Final EIS they wrote: "The paragraph suggested by ANARC...describes precisely the Air Force's philosophy and obligations in the matter."[33]

So far, then, the Air Force's attitude toward the concerns of shortwave listeners has been quite accommodating—though they pointedly assert the right to suspend their commitment to noninterference whenever they think "a given transmission is important to the nation's defense," and they haven't actually developed procedures for responding to complaints in real-time, though they've promised to do so by the time the first radar sector goes on the air in 1985–6. We won't know how well their good attitude will translate into behavior for a while yet.

The first sector is the experimental radar, upgraded. Work on the second 60° sector in Maine began in 1984 and will continue to 1987–8. In granting funds for the second sector, Congress made clear that "The purpose of this

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[32] Final EIS, West Coast, p. 333.
[33] Final EIS, West Coast, p. 333.

action is to expand the test database available to ensure that subsequent procurement decisions can be made on the basis of the most complete information possible.''[34] In other words, they want to see how well the first two sectors perform before they authorize money to start additional ones. This is only prudent, as the results of the experimental radar's tests appear to have been mixed, and the cost of building both the East and West Coast systems is expected to total over a billion dollars.

As this book goes to press, the Air Force announced it was dropping its request for authorization to begin building the West Coast system. The question now facing the Congress is whether to appropriate money to start the third sector of the East Coast system before the first two have been tested. Their decision will have been made by the time you read this.

Meanwhile, the U.S. Navy, which played a pivotal role in the development of OTH backscatter technology, isn't sitting by idly. They're developing transportable OTH systems ''to cover several critical ocean gaps and choke points around the world.''[35] Gerald Green explains that the

> primary mission would be in support of maritime air defense of the Navy's carrier battle groups and selected sea lanes. The [relocatable radars] also could be assigned to support Rapid Deployment Force (now US Central Command) operations in remote areas of the world. ROTHRs are expected to be the primary wide-area search systems for regional air defense operations in critical ocean areas not covered by existing or planned surveillance systems. The initial ROTHRs are scheduled to become operational in the mid- to late 1980s.[36]

We don't know anything about the design or emission characteristics of the Navy systems yet, but since they say they're building upon the WARF and Air Force experience, one can assume that they will probably use continuous-wave FM modulation and some sort of frequency-hopping. Because transportability imposes limits on antenna size, we suppose these radars will mainly operate in the upper two-thirds of the shortwave band. *Aviation Week & Space Technology* has said that the first area covered by a Navy ROTHR will probably be the sea between Iceland and Norway, with construction of an automated command center to begin in Iceland in Fiscal 1985.[37]

Several OTH-type systems have been around for years. The WARF (Wide Aperture Research Facility) has been operated by SRI International since the 1970s. With transmitters and log periodic antenna arrays near Lost Hills, in south-central California, the repeater/transponders at several sites in the western part of North America, WARF was the test-bed for many of the OTH concepts now being applied by its sponsor, the U.S. military. Because of the

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[34] *Conference Report, Fiscal 1984 Authorization, Department of Defense* (1 August 1983), Senate Report 98-213, p. 170.

[35] Melvin R. Paisley, *Appropriations Hearings*, Armed Services Committee, US House of Representatives (15 March 1983), p. 497.

[36] Gerald Green, ''C^3I: The Invisible Hardware,'' *Seapower* (April 1983), pp. 121-2.

[37] Clarence A. Robinson, Jr., ''Defense Decision Hikes Strategic Funds,'' *Aviation Week & Space Technology* (23 August 1982), pp. 17-19.

type of research done there, WARF's band use, emission characteristics, and schedule all vary, but at times it probably sounds something like the Air Force radars.

The Rome Air Development Center at Ada, New York has a number of transmitters and antennas for radar experiments and ionospheric research. They have been known to transmit in a series of 200 kHz bands at approximately 2 MHz intervals between 6.5 and 30 MHz, at powers up to 100 kW. Though RADC has been used to track aircraft approaching Canada's east coast, it is more often used to generate backscatter from the ocean surface and aurorae.

OTH radars designed for aircraft detection treat environmental backscatter as clutter, to be suppressed and removed by filters, but in fact, the clutter contains information useful for other purposes. Ocean waves happen to reflect the frequencies used by OTH radars quite well. By charting their echoes, it is possible to deduce the surface wind pattern over hundreds of square miles of ocean. Scientists have long known that the interacton between the atmosphere and the oceans is the pump that churns the weather, but they couldn't monitor this interaction synoptically and in real time until techniques like OTH radar evolved. As the air/ocean relationship becomes better understood, and radar signal-processing techniques improve, the meteorological use of OTH radar is likely to increase. Right now there are perhaps a dozen experimental sea-state monitoring programs, dispersed worldwide.

The use of shortwave radar for ionospheric research is also growing. OTH radar relies on the ionosphere simply to carry signals to and from a distant air space. But if the beam is aimed higher, or straight up, scatter from the ionosphere itself can be processed to map its structure in various ways—to reveal the interaction between the solar wind and the Earth's magnetic field, to help us understand how spacecraft in low orbit become electrically charged, etc. One of the largest ionospheric research programs now underway is sponsored by the Defense Nuclear Agency, which wants to know how nuclear war would affect ionospheric support of long-distance radio communications. Several relocatable ionosonde transmitters, operated by SRI International, are involved.[38]

Since 1970, scientists have been using high-powered shortwave transmitters to heat up parts of the ionosphere. This might seem to be a long way from OTH radar, but listeners could easily mistake an RF heating signal for a radar signal. Tests have shown that a few hundred kilowatts fed into simple dipoles tuned to 0.5 to 1.0 times the ionosphere's critical frequency (the highest frequency that will be reflected when the incident beam is vertical) can raise the electron temperature in the overhead region enough to refract obliquely aimed signals over the horizon, all the way up to the UHF band. "Voice, teletype, and facsimile transmissions have been sent, by means of the scattering region above the modifier, between ground terminals separated by several thousands of km and using frequencies which would not otherwise have been useful for those

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[38] C. L. Rino, J. F. Vickrey, R. C. Livingston and R. T. Tsunoda, "High-Latitude and Equatorial Research Support for Predicting High-Altitude Nuclear Effects," Report DNA-TR-81-176, Defense Nuclear Agency (1982).

paths."[39] NTIA has a 2 megawatt facility at Platteville, Colorado (40° 10′ 48″ North by 104°43′ 48″ West) for ionospheric modification experiments, with two ring-array antennas that cover 4.5–10 MHz and 2.7–3.5 MHz, respectively. Since the ionosphere's local critical frequency varies, the modifier's emitted frequency must vary, too. The process is regulated by monitoring backscatter from the modified region, and Platteville's frequency coverage is broad enough to permit 24-hour-a-day operation. Pulse, continuous-wave, and chirp modulation have all been used, so the facility doesn't have a readily identifiable "sound," but in general it must choose lower frequencies than an OTH radar would.

As you can see, noncommunication uses of the shortwave band are increasing and are likely to increase substantially in coming years. A striking aspect of this trend is that it is occurring without there being any allocation for radar or radio determination anywhere in the shortwave band. Shortwave radars and radar-related systems use channels assigned to communications services. And they use many of them, consuming far more spectrum than the stations to which they are assigned. The Air Force has laid claim to some 30 bands between 5 and 28 MHz because their OTH-B radars need different frequencies at different times to cover different ranges. Of course, the same could be said for international broadcasters wishing to beam programs to audiences in different parts of the world. Need alone doesn't establish a spectrum right. Radars using other parts of the spectrum do so in bands specifically authorized by the International Table of Frequency Allocations—but not OTH radars. And regarding this particular band, Article 9 of the ITU Radio Regulations says:

> Members recognize that among frequencies which have long-distance propagation characteristics, those in the bands between 5 MHz and 30 MHz are particularly useful for long-distance communications; they agree to make every possible effort to reserve these bands for such communications.[40]

What right, you may ask, does any nation have to operate OTH radars in channels reserved for long-distance communication?

When the Soviet Ministry of Posts and Telecommunications told the IFRB that the Woodpeckers were for tests, the IFRB replied that this doesn't entitle them to disrupt authorized services. Article 19 of the Regulations says, "Any harmful interference resulting from tests and experiments shall be eliminated with the least possible delay."

The U.S. Air Force cited the International Telecommunication Convention about nations' retaining their "entire freedom with regard to military radio installations." This would certainly allow a government to authorize its military to use any part of the spectrum. But contrary to the Air Force's assertion that

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[39] W. F. Utlaut, forward to "Special Issue: Ionospheric Modification by High Power Transmitters," *Radio Science*, Vol. 9, No. 11 (1974), p. 881.

[40] *Final Acts of the World Administrative Radio Conference, Geneva (1979)*, International Telecommunication Union (1980), p. 156.

''entire freedom'' includes the right to cause interference, the Convention specifically denies this.

It would seem, then, that OTH radars are only allowed to use the shortwave band on a noninterference basis, whether they are for tests, experiments, or national defense. Unfortunately, for some reason, ''not allowed'' means very little in the shortwave band.

We aren't sure how much interference will be caused by the American systems, but the Woodpeckers have been doing it on an unprecedented scale for nearly a decade. The Russians have set a horrendous example, and their refusal even to admit there is a problem is infuriating. None of the planned or existing OTH systems that we know about are likely to cause anywhere near as much harmful interference as the Woodpeckers. Which is good news, in that we've probably already seen the worst of the problem. But can't something be done about those wretched pulsers?

There have in fact been several types of protest. In 1977-78, communications workers in ten European countries organized a boycott of Soviet shipping. ''After that threat of boycott the transmissions were reduced for a prolonged period,'' says the *Oslo Aftenposten*[41], which recalled the event in connection with renewed threats of a boycott by labor unions in northern Europe, as a result of what they perceive as an increase in Woodpecker interference in 1983. The Norwegian Federation of Trade Unions and the Norwegian government have been leading voices in protesting the Woodpeckers—no doubt because Norway is subjected to the worst interference.

Norway, Sweden, Denmark, Switzerland, and West Germany were among the nations endorsing a statement in the Final Protocol of the 1978 World Administrative Radio Conference for Aeronautical Mobile Services that condemned the Woodpeckers' blocking of enroute civil aviation channels—a particularly dangerous practice. Once again, the USSR brushed this aside with the claim that the measures they'd already taken had been effective.

The ANARC OTH Radar Committee submitted a proposal to the State Department's Office of International Communications Policy arguing that the U.S. Delegation to the 1984 WARC for HF Broadcasting should offer the Conference this resolution:

> High-powered pulse transmissions within the HF Broadcasting Service bands are incompatible with the rational utilization of those bands by stations in the Broadcasting Service. Elimination of these emissions is essential to the development of effective plans for the future use of the HF broadcasting bands.[42]

We pointed out that since the U.S. Air Force radars won't use pulse modulation, they would not be encumbered by this resolution in any way. Although inter-

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[41] Rolf L. Larsen, ''Protest Action Against Kiev Transmitter Considered—Boycott of Soviet Ships?,'' *Oslo Aftenposten* (6 July 1983), p. 40; translation in *Worldwide Report: Telecommunications Policy, Research and Development* #283.

[42] Memorandum to Earl S. Barbely, Office of International Communications Policy, US State Department, from Robert Horvitz, ANARC OTH Radar Committee (July, 1983), p. 4.

ested in the idea, one State Department official responded that such a resolution would probably get more support if it were to be introduced by a delegation other than the one from the U.S. Too little time was left to find another sponsor after this polite rejection, but we have a second chance with the follow-up WARC in 1986.

One tactic that has proved to be a waste of effort—although it's probably the most common response among U.S. citizens—is writing to the FCC. They didn't issue the Woodpecker's license. Government-to-government complaints are handled primarily by the State Department, so if you want to write someone in the U.S. Government, try:

Office of the Coordinator
International Communication and Information Policy
U.S. Department of State
Washington, DC 20520

Better yet, send your comments to Radio Moscow, or to:

Embassy of the Soviet Union
1825 Phelps Place NW
Washington, DC 20008

There has been speculation in the amateur radio community for many years about the possibility of forcing the Woodpecker to change frequency by sending counter-transmissions to confuse or spook the operators. Most often the idea has been to send Morse Code dots at 10 per second on a frequency where a Woodpecker is audible. Some have even claimed success with this method. The published literature on OTH radar, however, suggests that these systems have little trouble rejecting any waveform that isn't part of their own backscatter. Martinez's analysis suggests how fine their discrimination could be—so it is especially significant that he thinks that it would be possible to devise a counter-transmission capable of "jamming these signals, or at least puzzling the distant radar operator."[43] This is a strategy that certainly deserves more study. Its main drawback is that the counter-transmissions themselves would cause some interference.

At the moment, there's no evidence that any form of protest short of an international shipping boycott is likely to subdue the Woodpeckers. On the other hand, not protesting guarantees that the situation won't improve.

Over the longer term, all systems eventually wear out, and with the rapid development of electrotechnology, systems are often superceded before they fail. If we knew more about Soviet progress in radar, what the true purpose of the Woodpeckers is and how well they perform, we might be able to foresee when they'll be taken off the air. The limitations of the USAF OTH-B radars—and incidents like the Korean airliner tragedy in 1983—suggest that their performance is less than spectacular. If this is the case, the Russians could be working on improvements and alternatives right now.

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[43] J. P. Martinez (letter), *Wireless World* (April 1982), p. 59.

The U.S. Air Force is. Even as it asks for a billion-plus dollars for the bicoastal system, it is pushing development of microwave radar satellites for tactical surveillance. Satellites could provide early warning capability comparable to the OTH-B systems but on a global scale.[44] The alternative that the General Accounting Office seems to favor is "using existing airborne warning assets"—that is, AWACS planes patrolling the approaches to U.S. territory—"until a more endurable system than OTH-B can be deployed." GAO doesn't say what "more durable" system it has in mind, but it points out that "Both the Air Force and Navy plan to develop tactical warning systems for use during the 1990s that will withstand a greater threat environment than the OTH-B."[45]

OTH-B radars for early warning air defense thus are likely to be superceded in the next decade, and even if development of follow-on systems runs into trouble, they may well be rendered useless by progress in "stealth" techniques, which can reduce the radar cross-section of a bomber or Cruise missile a thousandfold. According to the *Wall Street Journal*, "The Air Force admits it can't even be positive that the new over-the-horizon radar it is building on America's coasts will be powerful enough to pick up small Cruise missiles now being developed...."[46] It is ironic—though hardly unusual—that the same arms race that stimulated the development of OTH radars may soon make their air defense application obsolete.

There is something truly marvelous about being able to "see" a thousand miles over the curve of the Earth. Shortwave listeners, who hear over the same distances, are uniquely able to appreciate the difficulties that have been overcome, the sophisticated frequency-selection process required for continuous operation, and the incredible sensitivity of the receivers. And international broadcasting could benefit from the adoption of sounding and backscatter-monitoring techniques derived from radar experience. Stanley Leinwoll has suggested that Radio Moscow monitors its tune-up signals' backscatter to determine the best beam elevation angle to reach its target area.[47] If this is true, they probably learned how to do it from their Woodpeckers.

The problem, of course, is interference. There would seem to be enough "holes" in the Fixed Service bands to handle all the OTH radars likely to be built in the 1980s, but doing so without interference would require more international cooperation and skillful spectrum management than we've seen so far. The proliferation of shortwave radars and radar-like systems is going to continue, no doubt about that. It is possible to operate them in ways that minimize interference, though not all radar operators wish to do so. We must not lose sight of the fact that they have no right to cause harmful interference to other authorized users of the band. Since the ITU has no enforcement power, some responsibility for enforcement devolves to individual nations and spectrum

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[44] James A. Calder, "Space-Based Radar Comes Over the Horizon," *Aerospace America* (January 1984), pp. 112–114.

[45] GAO/C-MASAD-83-14, p. ii.

[46] Gerald F. Seib, "Unfriendly Skies—Worried by Russians, US Plans to Sharpen Its Weak Air Defenses," *Wall Street Journal* (28 March 1984), pp. 1 & 29.

[47] Stanley Leinwoll, "Why Radio Moscow is Winning the dB War," *Radio-Electronics* (December 1981), pp. 55–57.

users. Shortwave listeners should learn to identify the various man-made noises that litter the spectrum. Remember: a complaint to an interference source takes no more time to write than a reception report to a station offering QSLs.

There have been some important developments since this chapter was written. The U.S. Air Force has expanded its plans for deployment of OTH B radars. Two 60° sectors would be built near the coast in Alaska, with surveillance coverage extending into eastern Siberia, and four sectors would be put in the northern midwest. The midwestern sectors are intended to cover the southern approaches to U.S. territory and fill in the "skip-zones" of the east and west coast OTH installations. However, they would also cover about 80% of the continental U.S. with millions of watts of shortwave power, 24 hours a day. The midwestern sectors have the greatest potential for causing harmful interference to shortwave listeners living in North America.

Testing of the east coast OTH radar in Maine began late in 1985, without causing any complaints of interference in the first few months.

In February, 1984, the Australian government awarded study contracts for the conversion of their Jindalee system from an experimental to an operational configuration. Contrary to Dr. Desmond Ball's article describing the system in the late 1970s (quoted previously), more recent articles say that Jindalee uses continuous-wave FM modulation similar to the US OTH-B radars. We don't yet know when it will go into regular operation.

Japan has decided to deploy OTH radars on its territory, in cooperation with the US Navy, and has committed about $173 million for this purpose. The islands around Okinawa were mentioned as a likely site. The *Nichibai Times* reported that the U.S. Navy also plans to install moveable OTH radars on Amchitka Island in the Aleutian archipelago, and on Guam.

A cooperative research program involving the U.S. and England may result in OTH radar being deployed in the United Kingdom. Several possible sites have been mentioned: Orford Ness (for coverage of the Norwegian and Arctic Seas), Cricklade (for coverage of the North Atlantic), and northern Scotland. British scientists are also working on development of a *ground-wave* OTH radar, which would take advantage of radio waves adhering to the sea's surface and traveling along the curve of the Earth. A test system with a detection range of about 200 km has been built at Angle in Wales.

A worldwide, coordinated effort by shortwave listeners to assess the extent of the interference caused by the Soviet OTH radars took place in October, 1985. One hundred and eleven volunteers from 20 countries took part in the "Woodpecker Project," organized by ANARC. In addition to over 2500 specific observations of the Woodpeckers' band-use, we got 115 reports of harmful interference caused to 39 shortwave broadcasting stations. The evidence suggests that the original Woodpecker site, between Minsk and Kiev, was not transmitting during the monitored periods, but the other two sites were. Since these two sites are not well-heard in Europe and the eastern part of the U.S., the overall level of interference seemed less than in earlier years.