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Test of a Monostatic FM-CW Vertical-Incidence Sounder

by

R. B. Fenwick
J. M. Lomasney

October 1968

Technical Report No. 144

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
Advanced Research Projects Agency ARPA Order 196

RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

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Radioscience Laboratory
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Stanford University Stanford, California

ABSTRACT

The report describes a system for ionospheric vertical-incidence sounding using a low-power monostatic, FM-CW homodyne-detection technique. Advantages of such a system, as compared with the usual high-peak-power pulse-type ionosonde, are a substantial reduction in interference to other users of the HF radio spectrum, both local and distant, and a corresponding reduction of the effects of other-user interference on the sounder records.

A test was conducted on 24 August 1967, using a second-generation version of the Stanford FM-CW generator, together with a commercial digital spectrum analyzer and a facsimile recorder. Real-time ionograms were obtained over a period of 2-1/2 minutes, using a transmitted power of 1 watt. The relatively small amount of interference produced by such a sounder would allow it to be operated--if desired--in an HF radio receiving station. Further improvement in performance could be secured by increasing the isolation between the transmitting and receiving antennas.

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I. INTRODUCTION

The high-peak-power characteristic of a conventional ionosonde (ionospheric sounder) is often a liability. For example, the sounder should logically be located with other HF communication equipment. Because it incorporates a sensitive receiver, it cannot be located at a transmitting site because of the interference it would receive. Because it has a high-powered transmitter, it cannot be located at a receiving site because of the interference it would create. As a result, sounders have not been used as widely as they might, because of the cost and inconvenience of establishing a separate site especially for the sounder.

This report describes a different approach to ionospheric sounding. This new approach calls for radiating an amount of power not far different from that which is likely to leak from the high-frequency oscillator of an unshielded receiver.

The "monostatic CW ionosonde" (a monostatic, FM-CW, homodyne-detection sounder) can provide the advantages of a substantial reduction in interference caused to other users of the radio spectrum (obtained, as already noted, by the use of extremely low transmitted power) and of some reduction in complexity of sounder design (achieved by the elimination of high-voltage, high-power components and of the need for a separate superheterodyne receiver). The monostatic ionosonde is practical to the extent that spurious sidebands and hum components of the frequency-sweep waveform can be reduced to a level significantly lower than that of the energy received after reflection from the ionosphere.

An FM-CW ionosonde employing a precise, directly synthesized frequency sweep was introduced in 1964 by Fenwick and Barry [Ref. 1]. The original equipment, designated "Chirp I," was superseded by a second-generation equipment, "Chirp II," in 1966 [Ref. 2]. The principal improvements incorporated in Chirp II were provisions for easily set sweep rates and sweep limits, and an increase in the time-delay resolution capability from 10 μsec in Chirp I to better than 1 μsec in Chirp II.

At the time the Chirp II equipment was made operational, a Federal Scientific Corp. Model UA7 spectrum analyzer and an ITT facsimile recorder were obtained; these gave a capability for real-time analysis of ionospheric reflections at much lower frequency-sweep rates than could be used previously. This capability, in turn, made possible the use of very low transmitted power for vertical-incidence sounding; thus it became reasonable to attempt transmitting and receiving at a single site, using a single frequency-sweep generator both for transmitting and for received-signal demodulation. These enhanced equipment capabilities made feasible a monostatic vertical-incidence sounding test. Such a test was conducted at Stanford on 24 August 1967. The results are reported herein.

II. EXPERIMENTAL DESIGN AND EQUIPMENT

The FM-CW ionospheric sounder differs in principle from pulse sounders in that it transmits a continuous, relatively low-power signal whose frequency varies at a constant rate. For vertical-incidence sounding, the frequency of the signal received by ionospheric reflection will differ from the frequency of the signal received by the direct path between transmitting and receiving antennas because the transmitted frequency changes during the additional time required for the ionospherically reflected signal to travel to the ionosphere and back to the receiver. For a given frequency-sweep rate, the virtual height of reflection of the transmitted signal is directly proportional to the frequency difference between the direct and the reflected signal:

$$h' = \frac{c}{2\dot{f}} f_o \qquad (1)$$

where

h' = virtual height of reflection in km;

f_o = difference frequency in Hz;

$\dot{f}$ = frequency sweep rate in Hz/sec;

c = velocity of propagation in km/sec.

Figure 1 is a block diagram of the experimental set-up. A pair of vertical delta antennas [Ref. 3; Figs. 2 and 3] situated as shown in Fig. 4 were used for transmitting and receiving. The two antennas were nearly orthogonal to each other in order to minimize coupling, and were oriented at an angle with respect to magnetic north so that both the ordinary and extraordinary transmission modes could be excited with comparable signal levels. Figure 5 shows the measured isolation between the antennas.

The swept-frequency output power of the Chirp II equipment was divided by a wideband power divider. Half the power was amplified and transmitted through coaxial cable to a second broadband amplifier located at the feed point of the transmitting antenna. The return signal picked

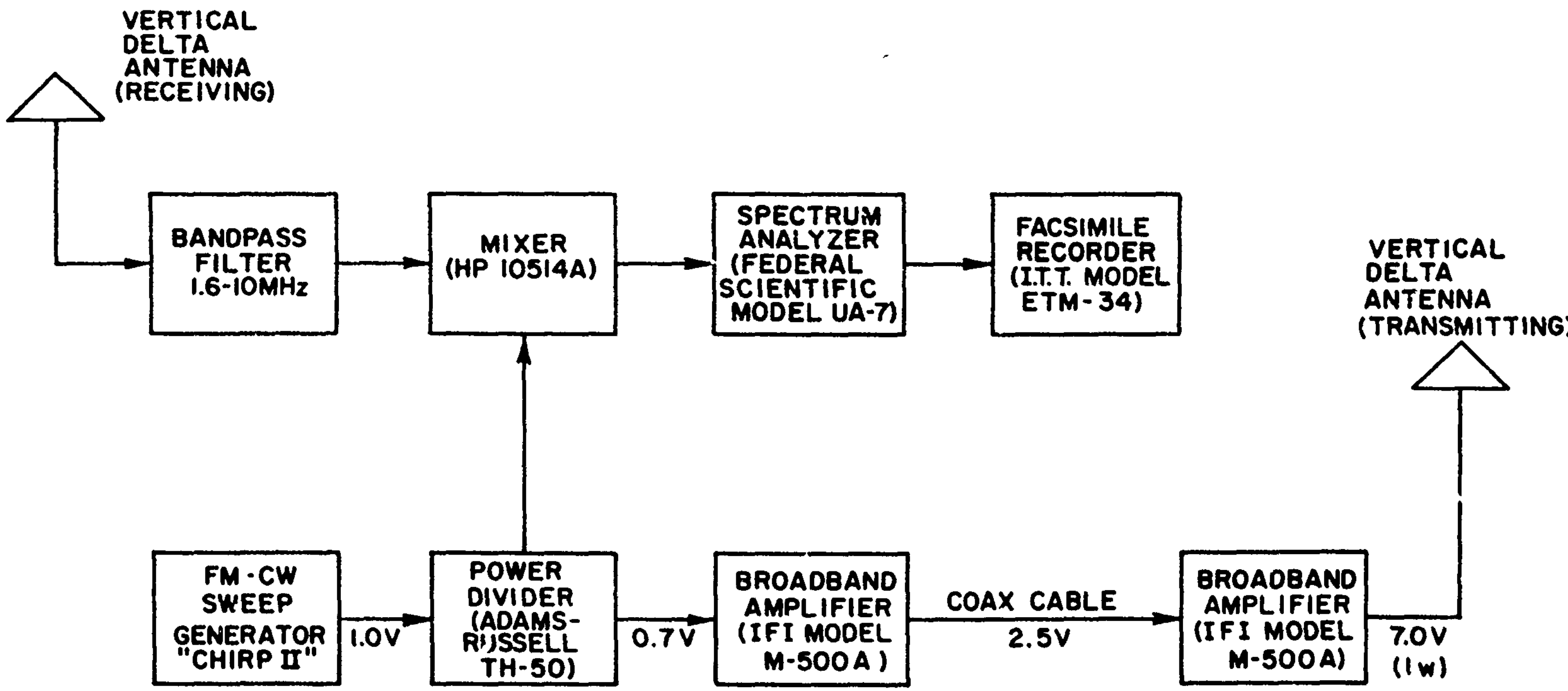

Fig. 1. BLOCK DIAGRAM OF FM-CW VERTICAL-INCIDENCE SOUNDER.

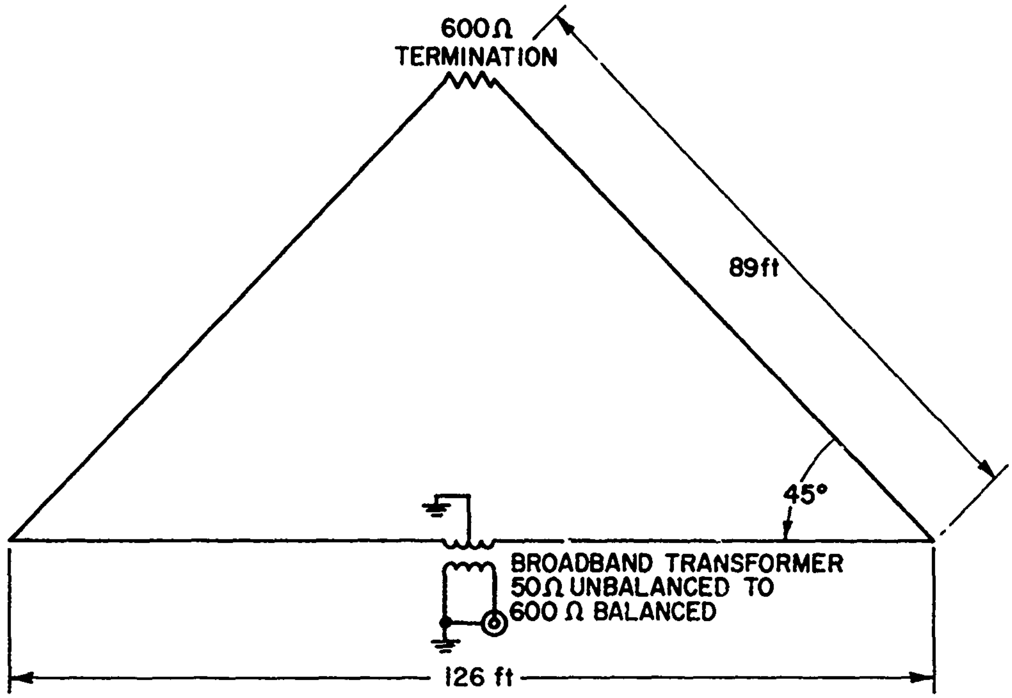

Fig. 2. VERTICAL DELTA ANTENNA USED FOR VERTICAL-INCIDENCE SOUNDING TEST.

up by the receiving antenna was band-pass filtered in order to reduce interference, and was mixed (in a balanced mixer) with the other half of the original signal from the power divider. The difference-frequency output of the mixer was analyzed by the spectrum analyzer and recorded on the facsimile recorder. On the resulting records, the horizontal (time) axis can be calibrated in transmitted frequency, while the vertical (difference-frequency) axis can be calibrated in virtual height to the reflection point, in accordance with Eq. (1).

Fig. 3. VERTICAL DELTA ANTENNA.

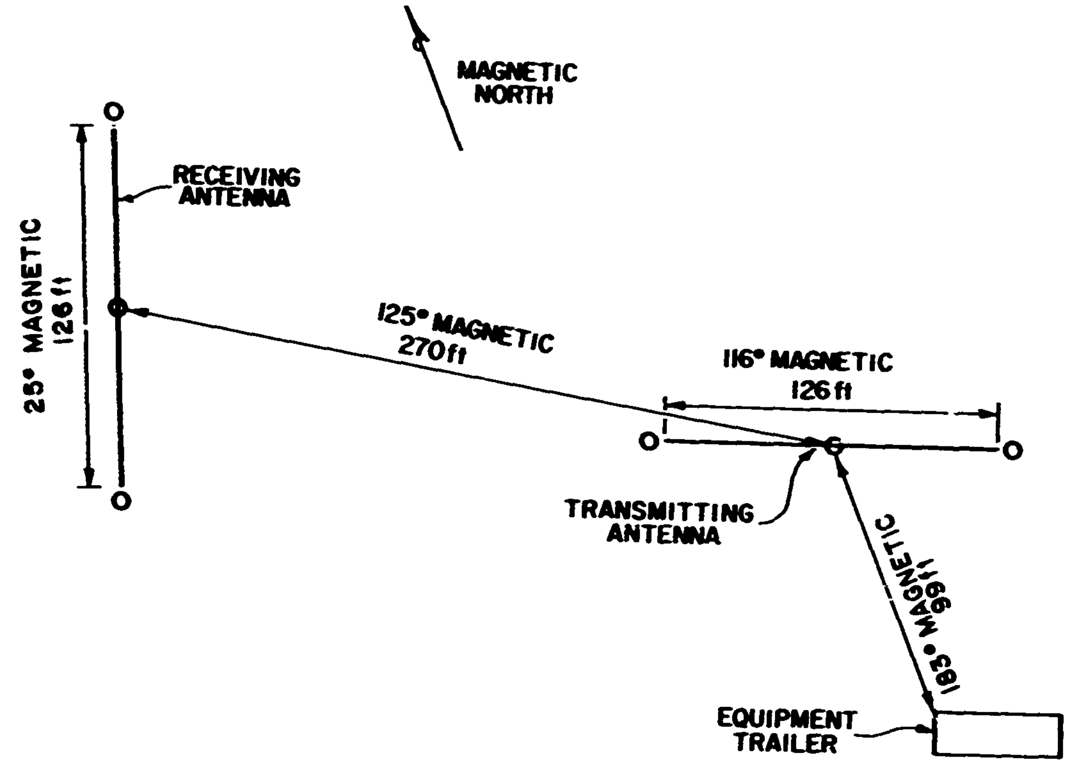

Fig. 4. PLAN VIEW: POSITIONS OF DELTA ANTENNAS FOR VERTICAL-INCIDENCE SOUNDING.

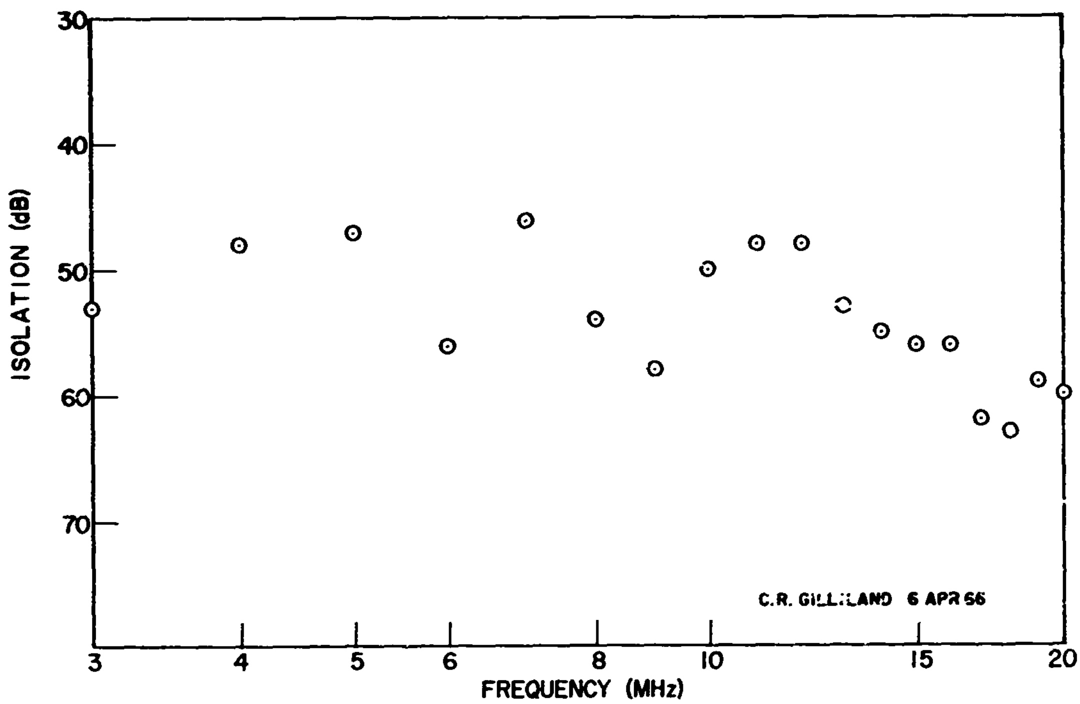

Fig. 5. ISOLATION BETWEEN DELTA ANTENNAS OF FIG. 4.

III. EXPERIMENTAL RESULTS

The equipment was operated for several hours on 24 August 1967. With the arrangement shown in Fig. 1, the nominal power output was 1 watt. Figure 6 is an example of the vertical ionograms obtained. F-region X- and O-modes are clearly shown above 5 MHz; the O-mode is still visible at the 3-MHz lower limit of the ionogram. Note the interesting traveling-disturbance effect at 4.5 MHz. The 60-Hz, 120-Hz, and 180-Hz hum lines are quite apparent on the record of Fig. 6.

Some records were made with higher power, i.e., in the 50-to 60-watt range. The records thus obtained appeared identical with those obtained at lower power (since the noise level on the record is primarily sounder self-noise and not atmospheric noise or interference).

Thus a nominal power of 1 watt appears ample for the purpose of vertical-sounding. In fact, results from oblique sounding experiments (unpublished) suggest that usable records ought to be obtainable with only a few milliwatts of transmitted power. Levels of 100 milliwatts to 1 watt are probably optimum; increasing power much beyond this level will only increase interference caused by the sounder to other equipment. The use of antennas separated by a greater distance than was the case in this experiment (270 feet) is desirable to reduce "self interference" by noise sidebands on the frequency sweep because of mutual coupling between the antennas. Careful attention to feeder balance and antenna orthogonality would also reduce mutual coupling.

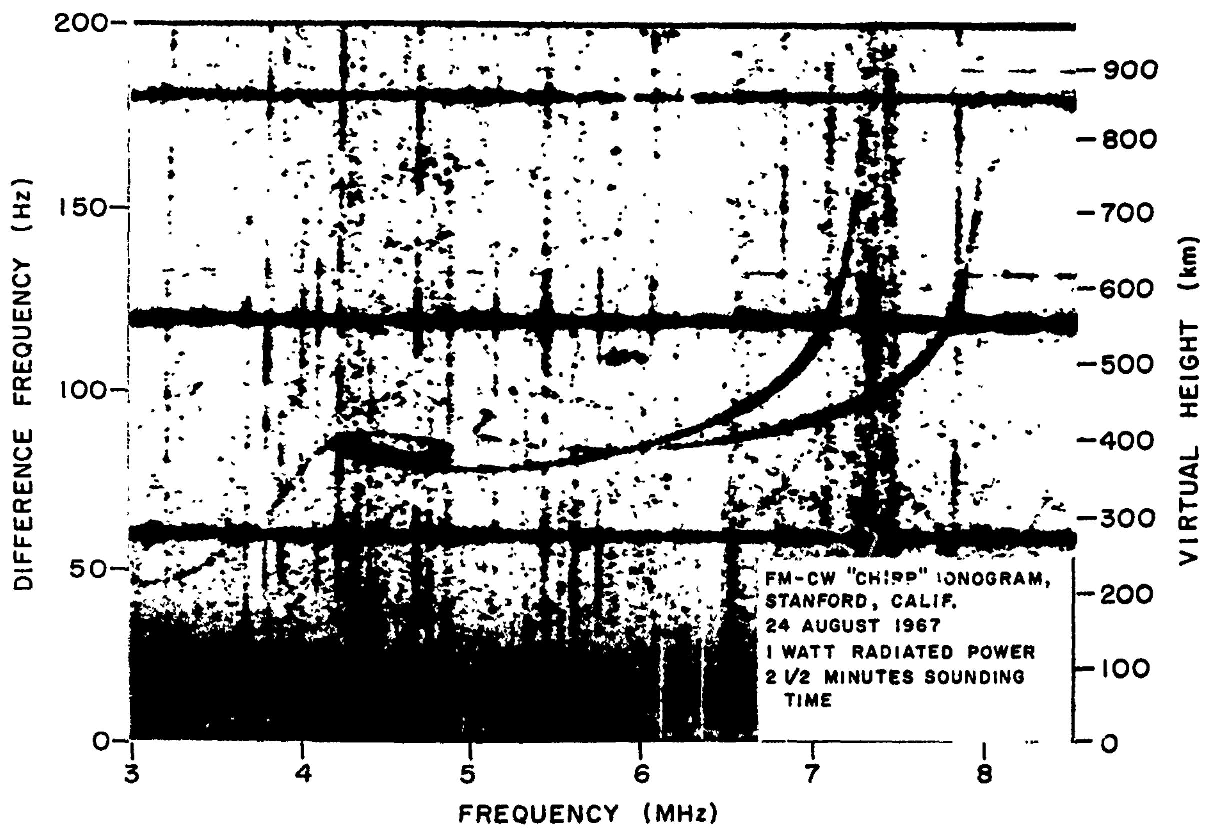

Fig. 6. EXAMPLE OF IONOGRAM OBTAINED BY FM-CW SOUNDING METHOD.

IV. CONCLUSION

This experiment showed that usable high-resolution vertical-incidence ionograms can be obtained with a monostatic FM-CW sounder transmitting a power of the order of 1 watt. Using so low a power level, transmitting and receiving functions can be performed conveniently at a single site and with a single frequency-sweep generator. No separate receiver (in the usual sense) is required. Also, interference caused by the sounder to other spectrum users is minimized.

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