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A High-Resolution Rapid-Scan Antenna[1]

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An electronically scanned antenna array is described. It consists of a broadside array of seven Yagi elements spaced 1.4 wavelengths apart. Each element antenna is connected to a preamplifier-converter. Each converter is connected to a local oscillator differing by 20 c/s from that connected to the converter for the adjacent element. All oscillators are locked in phase. The converter outputs are connected to a common IF amplifier. This arrangement produces a 5.8-degree-wide beam swept over a 41.8-degree azimuth sector at a rate of 20 scans per second. The system operates at 40.92 Mc/s. The output of the system is displayed on an oscilloscope, and data on the direction of arrival and character of a distant VHF signal are presented visually.

Sample records of signal components propagated by ionospheric scatter, meteor trail reflections, and sporadic-E layer are cited.

1. Introduction

An antenna having a very narrow width of main lobe is a useful tool in the field of propagation studies. It can enable an investigator to resolve the modes of propagation arriving from different directions. Many of the important propagation phenomena are, however, subject to rapid variation with time. It is important, therefore, that, in addition to high resolving property, the antenna be capable of being scanned over the desired sector at a rate more rapid than the change of the propagation phenomena being studied. A project for the design and construction of an antenna system demonstrating this principle was authorized in July 1959. This paper describes the accomplishments on the project to date.

The application of an antenna is essential in selecting its parameters. This particular antenna had as its object the measurement of the direction of arrival of a VHF signal (40.92 Mc/s) transmitted from a point 1295 km (805 mi) away, and propagated variously by ionospheric scatter, meteor trail reflections, and sporadic E-layer reflections. It was anticipated that the direction of arrival might depart by 10 and more degrees off the great-circle route. It was not, however, anticipated to be further than about 20 deg off because the reflection points had to be visible optically from both the transmitting and receiving points. The signal scattered by the ionosphere is known to be fluctuating rapidly. The duration of the meteor trail reflection varies, but is likely to be of the order of 1 or 2 sec. For this reason the duration of the scan had to be of the order of 0.1 sec or shorter. In addition, the maximum acceptable rate of scan was, in this application, limited by considerations of pulse transmission and beamwidth.

In order to measure the path delay, it was planned to utilize pulse transmissions for some of the measurements. Earlier work by Carpenter and Ochs [1][2] showed that relative path delays greater than 0.5 msec were rare, but that reasonably numerous delays in the time of arrival up to that value could be expected. This would restrict the pulse repetition rate to 2000 pps. A pulse repetition rate of 500 pps was decided upon. The pulse repetition rate and the beamwidth of the main lobe set a limit on the maximum rate of scan. Thus, if the beamwidth were 1 deg and the pulse repetition rate —500 pps, for complete sector coverage without gaps the maximum scan speed should be limited to 500 deg/sec. For a 2-deg beamwidth it could be 1000 deg/sec. If the sector of scan were restricted to 40 deg, 20 deg to each side of the great-circle path, the maximum permissible scanning rate would, for the two cases, be 12 and 25 scans per second. This is the limit on the maximum rate of scan.

The conventional means of obtaining a radiation pattern narrow in one plane is to make an antenna wide in that plane. While there are available methods for reducing the beamwidth of an antenna of a given dimension, these methods have limitations. The array described here was designed and employed conventionally. It consists of 7 horizontally polarized 5-element Yagi antennas in a broadside array. The spacing was made as large as possible without introducing harmful directional ambiguities. The spacing settled upon was 1.4 wavelengths. This resulted in ambiguities at an angle of 20.9 degrees off the great-circle path. For any other point within the 20.9°-0°-20.9° sector, the other point of ambiguity lies outside the sector and may be presumed to be very improbable. Five-element Yagis were selected because their half-power beamwidth in the E-plane, 56 deg, permitted operation within the 40-deg sector without introducing serious inequality of

[1] Contribution from Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.
[2] Figures in brackets indicate the literature references at the end of this paper.

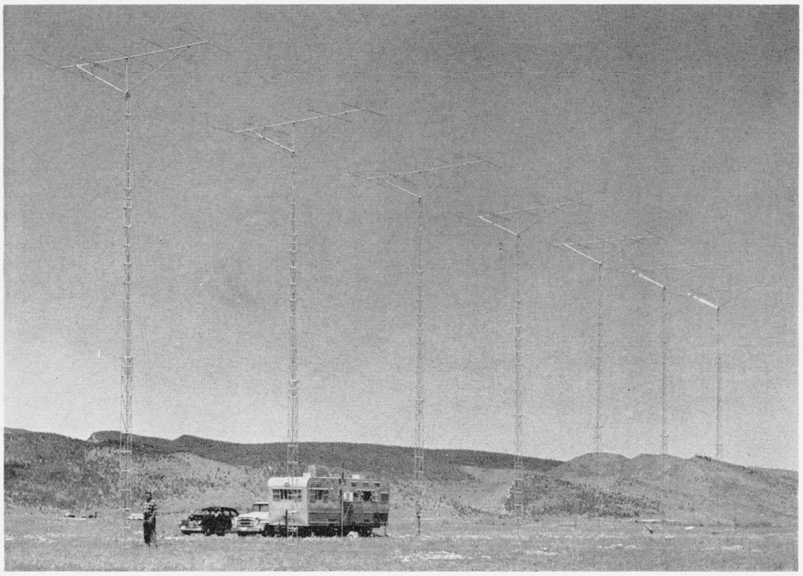

FIGURE 1. *A view of the antenna system.*

response. At the same time they were effective in discriminating against the signals outside the sector. The gain of the individual Yagi antenna was approximately 11.3 db relative to an isotropic radiator. The beamwidth of the array, when directed straight ahead, was computed to be 5.8 deg for 20-db sidelobe suppression.

Figure 1 is a view of the array. It is located on the Table Mesa near Boulder, Colo. It is directed at a bearing of 84.66° pointing along the great-circle path, towards the transmitter at Long Branch, Ill., field station 1295 km away.

2. Principle of the Electronic Scan

Because the method of electronic scan introduced with this antenna is the important contribution to the project, it is believed desirable to describe it in some detail.

Figure 2 is a diagram of a 7-element stationary array in which the directivity is obtained by proper phasing of the element currents. If the elements are equispaced with a separation d and the beam is to be directed at an angle β to the right, it is necessary to advance the phase of the current in elements 3_l, 2_l, and 1_l by phase angles 3δ, 2δ, and δ where $\delta = 2\pi(d/\lambda)\sin\beta$. The phases of the currents in the elements on the right side have to be retarded by corresponding angles. Such phasing can be accomplished either mechanically, electrically, or electronically. Many ingenious methods of doing this have been tried [2]. All of them have some drawbacks. With this antenna, a method of phasing in a mixer circuit is introduced.

It is known that when two voltages, $e_1 = A \sin 2\pi f_1$ and $e_2 = B \sin(2\pi f_2 + \delta)$, are connected to the inputs of a nonilnear network, the outputs will contain the sum and difference of frequency voltages, $e_s = C \cos[2\pi(f_1 + f_2) + \delta]$ and $e_d = C \cos[2\pi(f_1 - f_2) - \delta]$, in which the phase relationship of the original voltages is not lost. If e_2 is the local oscillator voltage, the phase of the signal contributed by an element antenna is controllable by varying the phase of the local oscillator. The practical means of doing it is by varying δ continuously in one direction so that in a time interval, t_s, it changes from 0 to 2π. Such a continuous phase change is equivalent to an incremented frequency change, $\Delta f = (1/t_s)$. To obtain proper scan of the antenna, it is necessary to connect each to its own converter with the local heterodyne voltages differing in frequency by frequency increment Δf. If the local heterodyne voltage for antenna

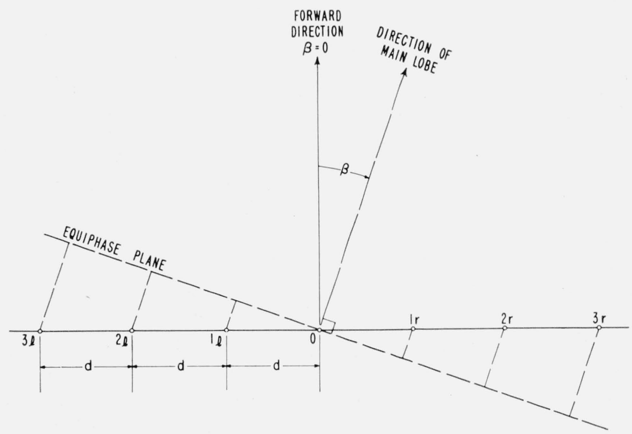

FIGURE 2. *A diagram of a seven-element broadside array illustrating the steering of the main beam by phasing.*

0 is $e_0 = A \sin 2\pi f_0$ the local heterodyne voltages for antennas 3_l, 2_l, and 1_l will be e_3, e_2, and e_1, equal respectively to $A \sin 2\pi(f_0 - 3\Delta f)$, $A \sin 2\pi(f_0 - 2\Delta f)$ and $A \sin 2\pi(f_0 - \Delta f)$. The element antennas on the right side of the array should have local heterodyne frequencies increased by the same increments. The beam of such antenna will rotate unidirectionally from left to right with a scan frequency equal to Δf. It should be noted that the range of scan is from one main lobe to another. If the element spacing, d, were equal to $\lambda/2$, for $\delta = \pm\pi$ there would be two main lobes, at $\beta = -90°$ and $+90°$, respectively. Thus, the scan would begin at $\beta = -90°$ and sweep to $+90°$. If the spacing, d, were less than $\lambda/2$, the main beam would form in the imaginery region of $\sin \beta < -1$, sweep through the real sector $-90°$ to $0°$ to $+90°$, and disappear into the imaginary region of $\sin \beta > +1$. If d were greater than $\lambda/2$, several main beams might be present at all times and the entire ensemble of main beams would rotate clockwise. For $d = 1.4\lambda$ and $\delta = \pi$, there is a main lobe in the imaginary region, $\beta = \sin^{-1} - 1.07$, two real lobes at $-20.9°$ and $+20.9°$, respectively, and another lobe in the imaginary region, $\beta = \sin^{-1} + 1.07$. In one cycle the beams sweep through one interval between lobes. In this discussion, the fact that the radiation pattern has mirror-image symmetry about the line of the array has been ignored. In physical construction, a reflecting screen or unidirectional elements would normally be employed.

The proper operation of this scanning technique is very dependent upon finding a successful solution to the problem of generating an ensemble of local heterodyne voltages. These have to differ in frequency by the increment Δf, but must be locked in phase. It is possible to accomplish this in a number of ways. The method selected here was to pulse the oscillator having a fundamental frequency f_0 at a pulse rate corresponding to Δf. If the length of the pulse is short, a spectrum of frequencies is generated with the center frequency at f_0 and other frequencies at increments of Δf up and down the frequency scale, all of these voltages will be in phase or 180 deg out of phase. If the length of the pulse is short compared to $2/(n\Delta f)$, the amplitudes of different frequency voltages will be approximately the same and the phases the same. n is the number of elements in the array. The frequencies can then be separated by crystal filters. In practice, it was found desirable to generate and separate the frequency ensemble in the 20 kc/s band, and to step up the frequencies after separation, by heterodyning against a common oscillator in two steps. The 20-c/s frequency separation produced a corresponding sweep rate. This was rapid enough to observe the propagational variations with time. It was also sufficiently slow to observe pulse transmission without gaps in the sector coverage.

3. Details of Construction

The design for the five-element Yagi antenna had been worked out in detail a number of years previously for another application. Its gain was measured to be 11.3 db relative to an isotropic radiator. The approximate half-power width of the main lobe was measured to be 50 deg. Within the sector of interest, 21°-0°-21°, the gain varied within ±1 db of the mean. The secondary lobe level was below −24 db. Each Yagi was matched to have a coaxial terminal impedance of 50.0 ohms.

The Yagi antennas were separated by 33.65 ft (1.4 wavelengths). From earlier measurements, it is known that, at this separation, the effect of one of these antennas on the radiation pattern of the adjacent one is negligible.

For communication over a 1295 km path via ionospheric scatter mode, the optimum angle of departure is computed to be approximately 6.7 deg and the height of the antenna, 2.15 wavelengths (approximately 52 ft). All of the antennas were connected to the equipment by equal lengths of RG–9B/U coaxial cable. It was contemplated that the antenna would be adjusted to have a Dolph-Chebyshev current distribution for a −20-db side-lobe level. On that basis, the beamwidth of the array was computed to be 5.84 deg.

Figure 3 presents the computed radiation pattern of the array. The curve in dashed line is the radiation pattern of the single Yagi antenna. In computing this pattern, the antennas were assumed to be in phase; this produced the main lobe in the straight-ahead position. Other main lobes are at the 45°, 135°, and 180° positions.

The frequency of 10.70 Mc/s was selected for IF amplification; therefore, for 40.92-Mc/s reception, the local oscillator frequencies had to be centered on 30.22 Mc/s. With the present state of filtering techniques, it would be difficult to separate component voltages spaced 20 c/s apart at this frequency. To avoid lengthy experimentation, the frequency of 18 kc/s was selected as being the highest at which ready separation of frequencies could be carried out.

Figure 4 presents a block diagram of the electronic circuitry involved in the production of beam scan. An 18-kc/s crystal-controlled oscillator is pulsed at a rate of $\Delta f = 20$ pps. The length of the pulse is 4 msec; a short pulse is required in order that the amplitudes of the required sidebands remain in phase and reasonably constant. The output of the pulsed oscillator contains frequencies of 18 kc/s, 18 kc/s$+\Delta f$, 18 kc/s$+2\Delta f$, . . . 18 kc/s$-\Delta f$, 18 kc/s$-2\Delta f$, . . . etc. The output is connected to seven filters in parallel, each adjusted to one of the desired frequencies. The passband of each crystal filter is essentially flat for 6 cycles, centered at the individual crystal filter design frequency. The rejection of the unwanted sidebands by each crystal filter is at least 30 db. Each selected frequency, 18 kc/s$+r\Delta f$, is stepped up by beating against a 2-Mc/s oscillator to 1.982 Mc/s$-r\Delta f$. This frequency, in turn, is filtered from 2 Mc/s and 2.018 Mc/s$+r\Delta f$ frequencies.

The 1.982 Mc/s$-r\Delta f$ frequency is again stepped up to 30.22 Mc/s$-r\Delta f$ by heterodyning with a 28.238 Mc/s oscillator, and separated from 28.238 Mc/s and

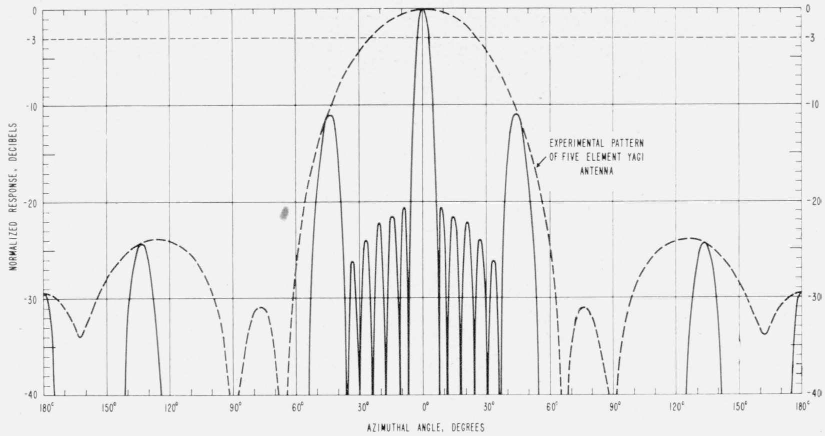

FIGURE 3. *Computed radiation pattern in E-plane of an array of 7 Yagi antennas.*

Currents adjusted to Dolph-Chebyshev distribution for -20-db side-lobe level.

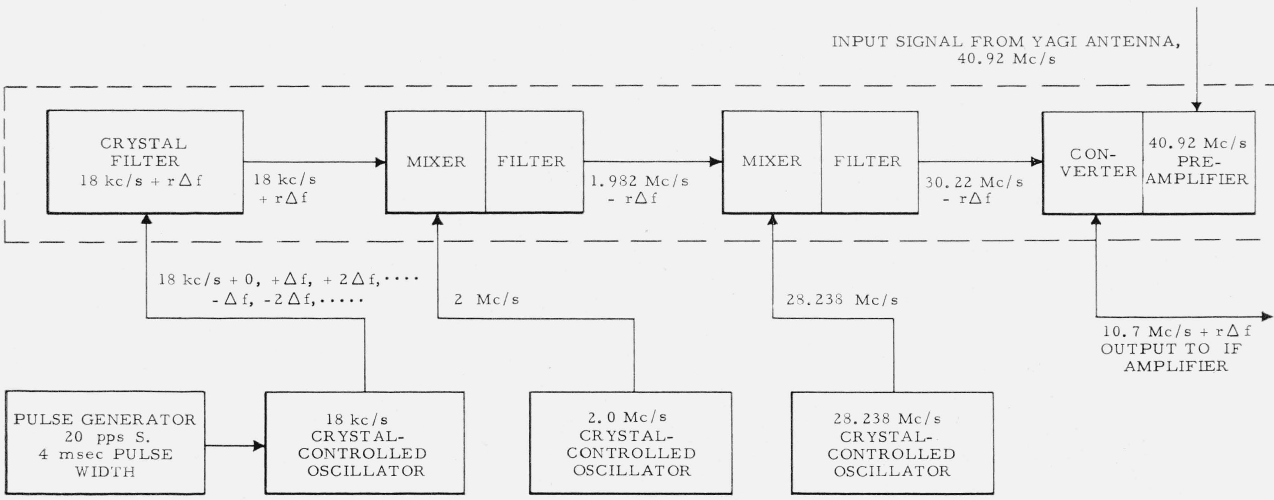

FIGURE 4. *Block diagram of one filter-mixer and preamplifier-converter channel*

26.256 Mc/s$+r\Delta f$ frequencies by filtering. From there it is connected to its appropriate, rth, converter. The seven crystal filters for the 18-kc/s frequency ensemble are the only critically adjusted items of the circuitry. Other filters and components are readily interchangeable with components of other channels because frequency separation is reasonable. In order not to introduce phase differences, care was exercised in adjusting antennas to have identical characteristics, to cut all transmission lines to be equal in length, and to construct all equipment pertaining to the seven channels to be as nearly identical electrically as possible. This avoided gross differences in phases or amplitudes. Provisions were incorporated in the frequency-generating circuits for compensating for small unavoidable discrepancies in phase. Provisions were also incorporated for adjustments in amplitude over a range of several decibels. This was to provide for tapering the current distribution of the array. Figure 5 shows a view of the equipment mounted in the rack.

4. Adjustment of the Antenna

Before the antenna was placed in operation, it was expected that difficulties would be encountered with unequal phase and amplitude variations in the seven channels. It was also felt that the adjustments of the electronic equipment could not be expected to remain sufficiently stable for very long periods of time. Practical experience with the equipment, however, dispelled these apprehensions. Phase and amplitude differences were small and easily compensated for; the stability was such that adjustments remained satisfactory from one day to another, even after equipment shutdown. The process of adjust-

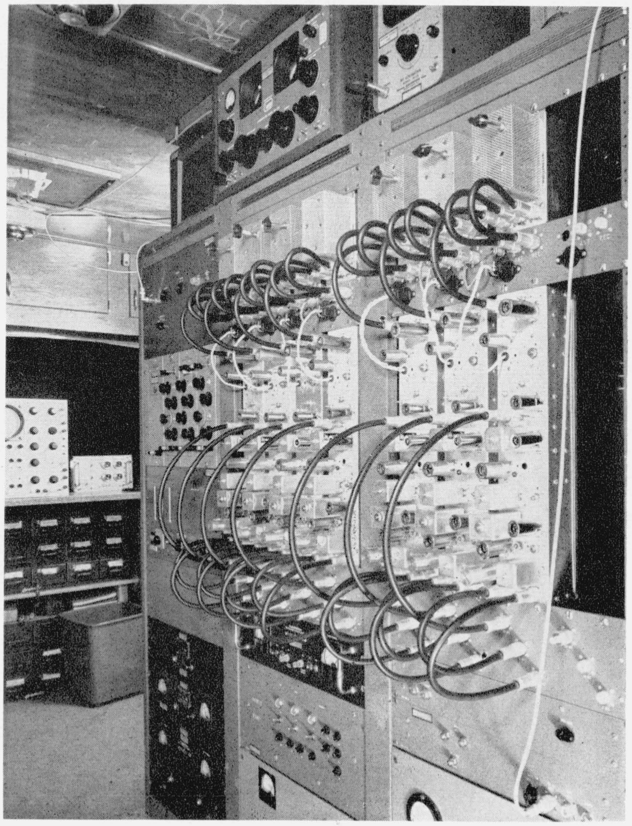

FIGURE 5. *A view of the electronic equipment for production of rapid scan.*

ment itself proved to be easier than with a non-scanning array because the effect of each adjustment was visible immediately on the oscilloscope display.

After some experimentation, a procedure for adjustment was evolved. The phases and amplitudes of each channel were adjusted, one at a time, with reference to the center element as follows: A precision coaxial attenuator with insertion loss equal to the level of the rth element for Dolph-Chebyshev distribution is inserted in the coaxial line leading to the 0th (center) element. The rth element is connected through its circuitry with an insertion of 180-deg delay (half-wavelength coaxial line). The outputs of the 0th and rth converters are then combined in the IF amplifier and displayed on the oscilloscope. The amplitude of the rth element is adjusted to obtain a null (or a series of nulls, depending on the value of r). The phase is adjusted to move the null into the center of the display. This is the complete adjustment routine for one, rth, element. After all elements are adjusted, they are connected together through their respective converters to the IF amplifier. It is desirable to check the pattern by a distant target transmitter. Minor adjustment can then be made to improve the secondary lobe level. A mobile target transmitter was also found to provide a convincing demonstration that the equipment really operated as intended.

In lieu of a distant target transmitter a signal generator can be, and has been, employed. The antennas are disconnected. Each pre-amplifier is then connected through an individual, 20-db, precision, coaxial attenuator to the signal generator. The distant target transmitter is thus simulated in the zero-degree position. If the combined input impedance of the seven circuits in parallel is matched back to the 50-ohm value, a means of quantitative calibration is provided. The equipment described is provided with solenoidally operated switches to provide means for rapid check and calibration.

5. Results

Since the output of the antenna is cyclic with a 20 c/s repetition rate, it lends itself readily to oscilloscope presentation. The horizontal sweep is triggered by the pulse, and the output of the receiver is connected to the vertical deflection plates. The display shows the signal amplitude as ordinate, with the direction of arrival as azimuth. Since a distant VHF signal arriving by ionospheric scatter mode is distributed in the direction of arrival, the display pattern is a convolution of the antenna radiation pattern and the true signal or signal pattern distribution. The phenomenon is familiar in radio astronomy and has been discussed at length by

Bracewell and Roberts [3]. When the signal arrives from a point source, as from a target transmitter, the display shows the true radiation pattern with the response maximum in the direction of the signal source. Figure 6 presents three displays recorded while a local target transmitter, mounted on a vehicle, moved in front of the antenna from left to right. It is useful for demonstrating the proper functioning of the system.

Since this system was put in operation, 2 months ago, a variety of propagational phenomena have been observed on the frequencies of 40.88 and 40.92 Mc/s. During the greater proportion of the time, the observed signal arrives by a regular ionospheric scatter mode. Occasionally, strong meteor-trail reflections have been observed and recorded. These exceed the scattered signal by several orders in magnitude, but last only a second or two at a time. Signals propagated by sporadic-*E* layer have also been observed. These are very steady, high in amplitude, and usually arrive along the great-circle path. Figures 7 through 10 illustrate the phenomena as observed using this antenna system. It should be noted that the recording camera was not synchronized with the sweep of the oscilloscope. In order to get at least one complete sweep, the shutter speed was set at 0.1 sec. Therefore, most records show two almost complete scans. These are not believed to be objectionable; in fact, they convey the transient nature of the phenomena. The interval between sweeps is 50 msec.

Figure 7 presents photographic records illustrating propagation by ionospheric scatter. While the maximum signal is generally at, or close to, the great-circle path (0-deg azimuth), it fluctuates, both in amplitude and in direction. Occasionally, it deviates by more than 10 deg. from the great-circle path. The convolution of the radiation and the signal patterns is noticeably broader than the radiation pattern by itself. This is clear evidence that the signal pattern is dispersed. A higher resolution antenna is highly desirable for more detailed examination of the fine structure of the signal.

Figure 8 is a record of several meteors. Although some are observed at zero azimuth, most are to one side or the other of the great-circle path. Because the duration of the meteor is very brief, it is not possible to adjust the sensitivity of the receivers to obtain a good full-scale deflection. Experiments are underway to adopt magnetic tape recording techniques for this application. The display pattern is very close to the radiation pattern of the antenna, indicating that the signal comes from a source which is virtually a point.

Figure 9 shows a record observed while sporadic *E*-layer propagation was taking place. The display pattern appears to be identical to the radiation pattern. This is to be expected from a specular reflection by a smooth surface. The signal is likely to remain steady for a considerable length of time and is usually along the great-circle path.

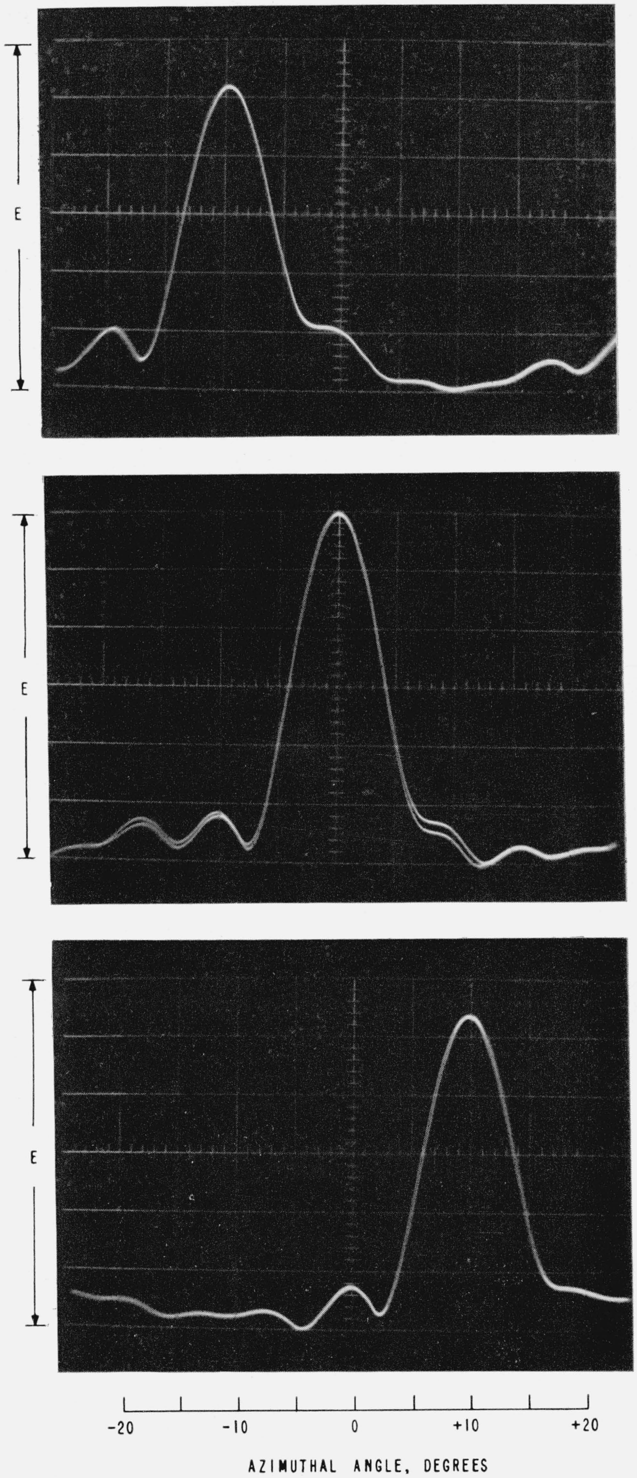

FIGURE 6. *Display of responses obtained with a target transmitter in far zone moving from left to right.*

The response to a point source of radiation is the radiation pattern of the antenna.

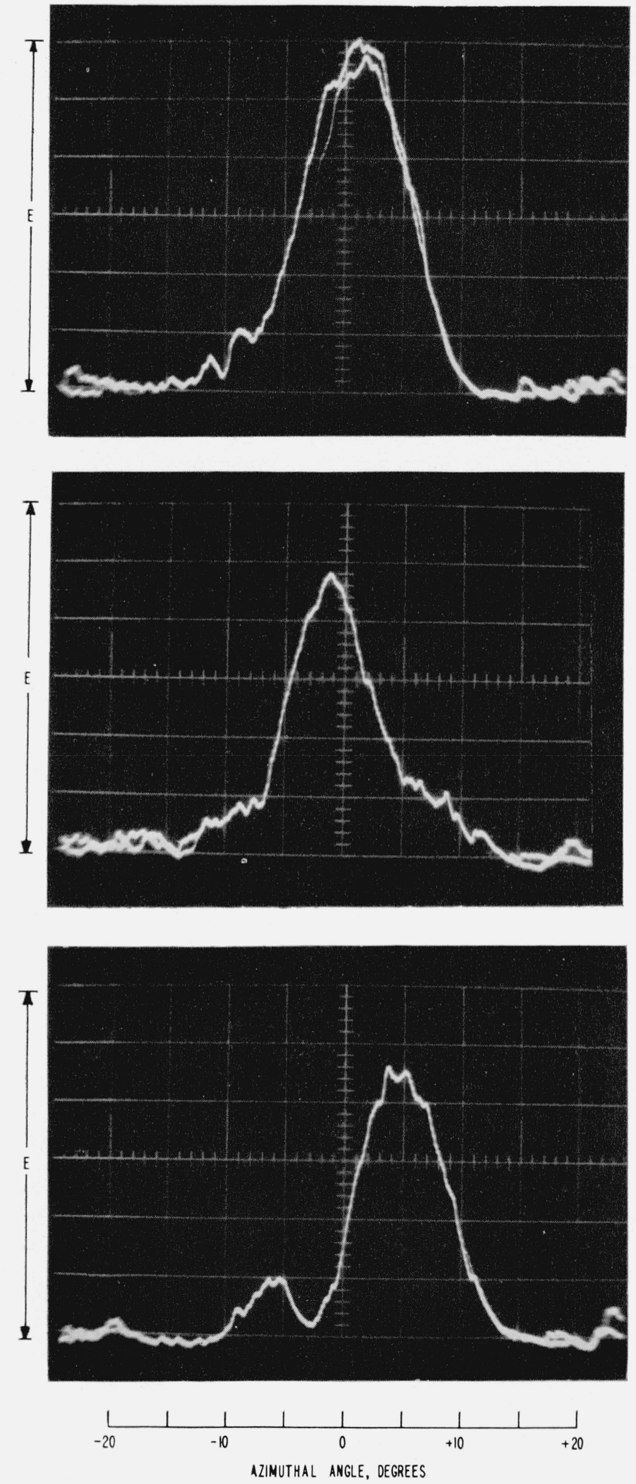

FIGURE 7. *Display of responses with signal arriving via normal ionospheric scatter mode.*

The response is a convolution of the antenna radiation pattern and the angular distribution of the signal components.

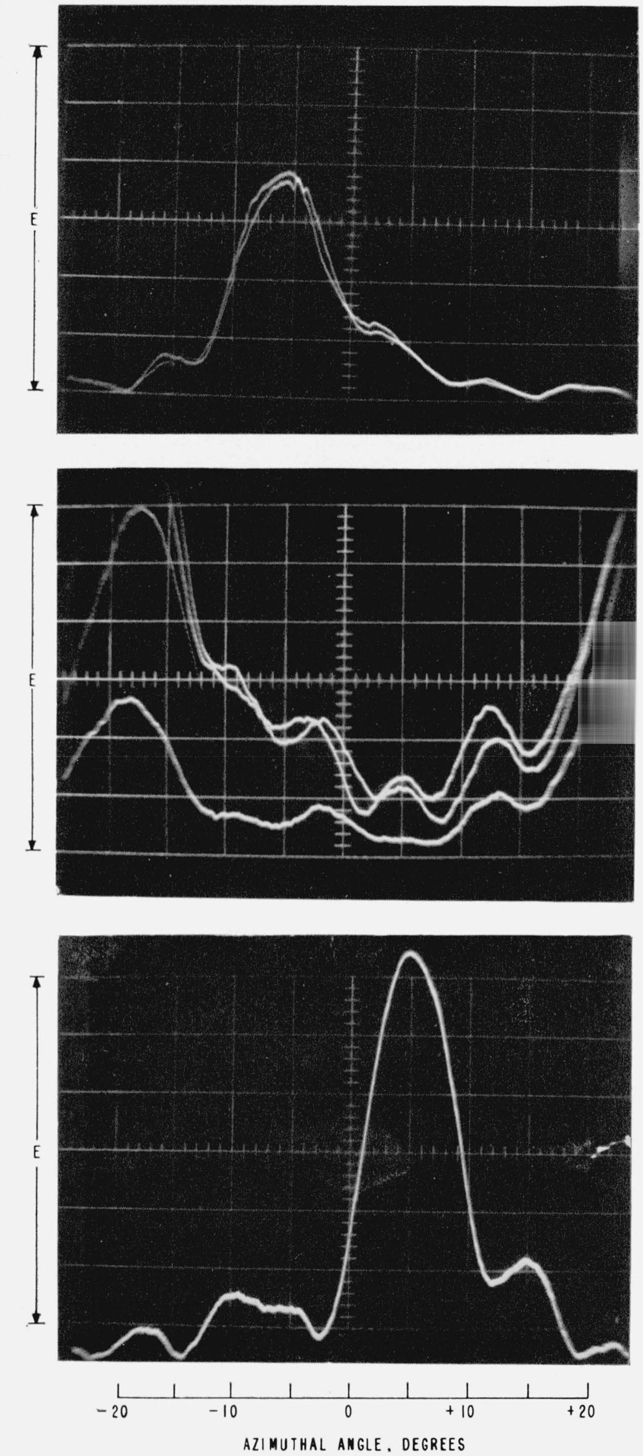

FIGURE 8. *Display of responses with signal arriving via meteor trail reflection.*

The propagation mode identifiable by enhanced signal strength, duration of the order of a second, and off-great-circle direction of arrival.
The similarity between the response pattern and the antenna radiation pattern indicates that the reflection is a point source.

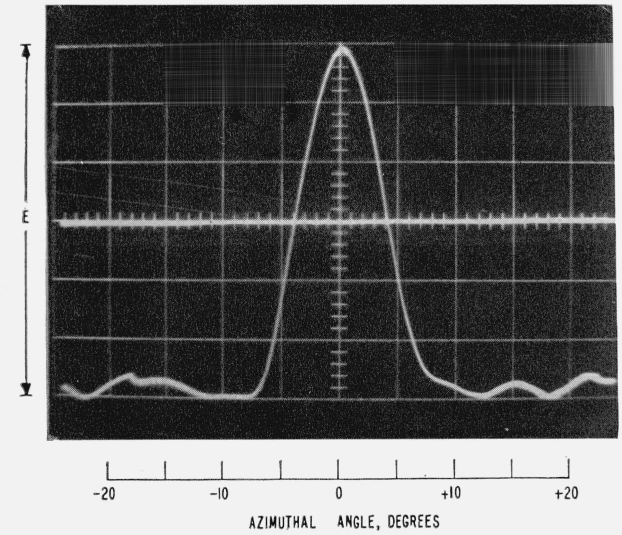

FIGURE 9. *Display of responses with signal arriving via sporadic-*E *layer reflection.*

The sensitivity of the system is greatly reduced relative to that used with scatter reception (of the order of 90 db).

Besides high intensity, this mode is characterized by great-circle path direction of arrival and stability over a period of an hour or greater.

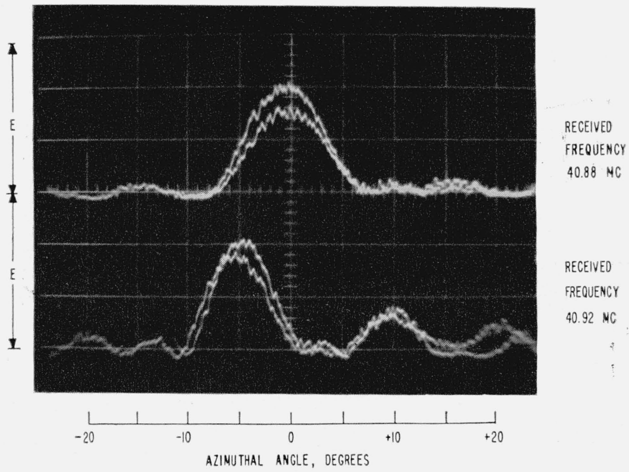

FIGURE 10. *Display of simultaneous responses to signal at 40.88 and 40.92 Mc/s.*

In addition to frequency difference, the 40.88-Mc/s transmission was characterized by narrow (5-deg) beamwidth. 40.92-Mc/s transmission used 50-deg-wide antenna beam; 10-db difference in transmitted power maintained intensity of illumination at approximately equal level.

Simultaneously with the 20-kw signal at 40.92 Mc/s, used for the above experiments, there was a 2-kw transmission at 40.88 Mc/s. Both originated at Long Branch, Ill. The 40.92 Mc/s signal was radiated by a corner-reflector antenna with a half-power beamwidth of approximately 50 deg. The 40.88 Mc/s signal was radiated by a rhombic antenna with a beamwidth of about 5 deg. Because the area of the ionosphere illuminated by one was so much greater than that illuminated by the other, it was considered desirable to compare signals received simultaneously on two frequencies. Two IF receivers tuned to10.70 and 10.66 Mc/s were connected to the output of the antenna system at the same time. The outputs of the two receivers were connected to sections A and B of a dual-trace oscilloscope. Figure 10 illustrates the comparison between the two signals. While the study of propagational phenomena is beyond the scope of this paper, the application illustrates the versatility of the scanning principle. The principal limit on bandwidth of operation was, in this case, presented by the Yagi antennas comprising the antenna system.

In the earlier discussion of the principles of the scan, it was mentioned that measurements using pulse transmissions were contemplated. In 1958 and 1959, Carpenter and Ochs [1], using pulsed 40.92 Mc/s transmissions, with 3-μsec pulse, at 250 pps and 700 kw peak power, measured relative delay time for meteor reflections. Delays of over 1 msec relative to the normal scatter signal were observed. By recording the distribution, they were able to deduce the direction of arrival of reflected signals. The equipment employed by Carpenter and Ochs has been, to a large extent, incorporated in this project. It is planned to modify the display so as to present the direction of arrival as azimuth (as it is now) but to show the relative delay in microseconds as ordinate and with intensity modulation amplitude. The display is similar to that familiar in television. Figure 11 shows the raster

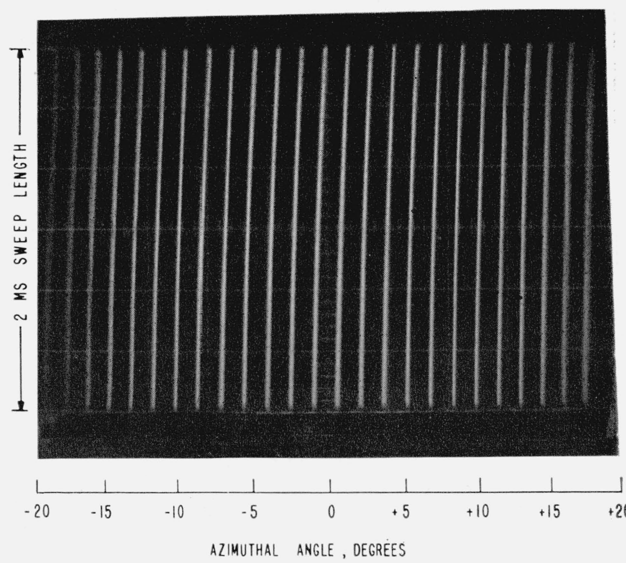

FIGURE 11. *Scan "Raster" for reception of pulses.*

Two-millisecond scan corresponds to pulsing period (500 pps).

form of the display. It should be noted that the line separation is 2 deg; this illustrates the discussion of the interrelations of minimum beamwidth and the maximum scanning rate earlier in this paper. Figure 12 presents a record of a signal arriving by a

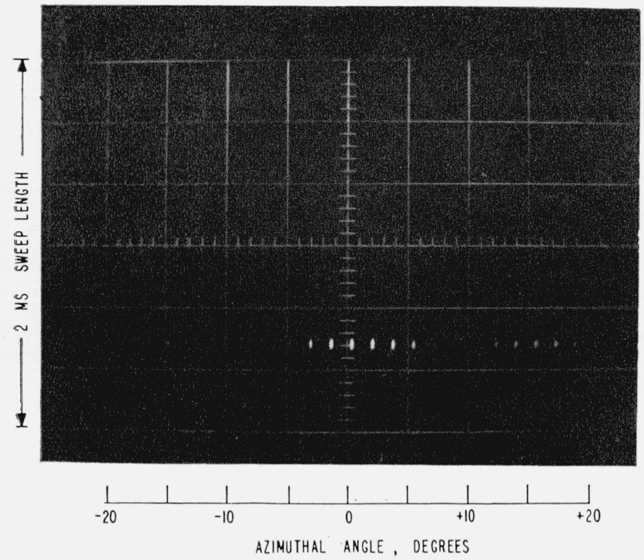

FIGURE 12. *Display of response to pulse transmission using intensity modulation of oscilloscope and vertical sweep sychronized with pulsing rate.*

sporadic-E mode. Because of lack of power in the pulse transmitter, reception of regular ionospheric scatter has been unsatisfactory.

Work is under way to overhaul the transmitter for high-power pulse transmission. Work is also under way to increase the size of the array to 25 elements. This would permit a beamwidth of 1.5 deg with the present 20-db side-lobe level. A more detailed study of propagation phenomena can then be possible.

6. Applications

The significant characteristic of this antenna is the ease of obtaining very rapid rates of scan. The 20 c/s rate was the slowest which was deemed readily realizable, without experimentation. As the scan rate is increased, the problem of separating the spectral frequencies of the pulse becomes easier. Scanning rates in the order of kilocycles, and even megacycles, appear realizable.

The availability of very rapid scanning rates opens up an opportunity for use of sampling technique for both measurement and communication. If the period of scan is shorter than the Nyquist interval for the message received, the information is fully preserved, even though the antenna is directed at the source only a fraction of the time. By proper gating, the information arriving from different sources can be directed into appropriate channels. The technique is analagous to that familiar in other applications.

The antenna described in this paper scans in a single dimension. With a minor modification, the principle is equally applicable to a two-dimensional scan. Figure 13 illustrates this application. A

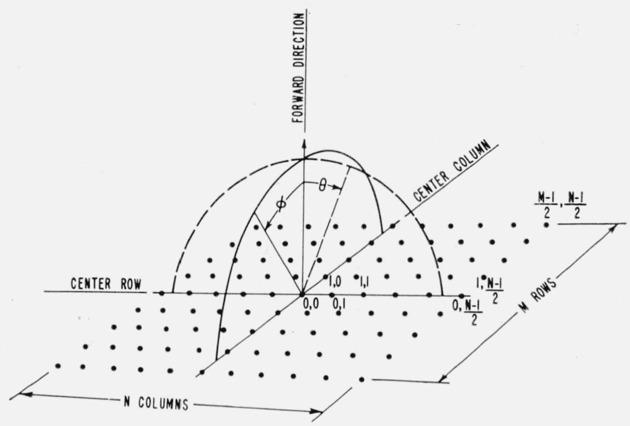

FIGURE 13. *Application of electronic sweep to scanning in two dimensions.*

rectangular array of $m \times n$ elements is shown. These are arranged in m rows and n columns, $n[(m-1)/2]$ elements to each side of the center row, and $m[(n-1)/2]$ elements to each side of the center column. The elements may be identified by their position in the array, by row and column.

The center element (0,0) is connected to a converter with a heterodyne frequency f_0. The array can then be scanned in the θ-plane at a scanning rate Δf if each converter receives its proper heterodyne voltage frequencies. For element (r,q), it should be $f_{rq}=f_0 \pm q\Delta f$. To obtain scan in the ϕ-plane, at a scanning rate δf, the heterodyne voltage frequency for the same element should be $f_{rq}=f_0 \pm r\delta f$. To scan in both planes simultaneously, $f_{rq}=f_0 \pm r\delta f \pm q\Delta f$. The scanning operation itself would be analogous to the scan in the television picture. The ratio $\Delta f/\delta f$ would determine the number of "lines" in the scan. It should be equal to, or greater than, the ratio of $\Phi/W\phi$ where Φ is the width of the sector scanned in the ϕ-plane and W_ϕ is the half-power beamwidth in that plane. Since W_ϕ varies roughly inversely as the aperture, $(m-1)d$, the ratio $\Delta f/\delta f$ should equal approximately the number of rows, m.

A special case of interest above is a possible application of Mills' cross array. In this application, the rectangular array reduces to the central row and the central column with a common center element (0,0). The multiplicative process essential to the operation of Mills' cross can be added in addition to the scanning. A complete picture of a phenomenon varying with time over an area can then be obtained instantaneously. This might be of interest, for example, in radio astronomy in the study of solar eruptions.

All of the above applications are from the standpoint of receiving antennas. The principle is applicable to transmission, but the techniques have to be modified considerably.

7. Conclusions

The 2 months of operation of this antenna system provide adequate evidence of the practical value of the scanning principle described here. In the particular application detailed here, it provided a visual view of rapid variations in amplitude and direction of arrival with time. The information value of such a display is considerably greater than that of single-dimensional variation of amplitude with time.

The stability of the system with time, temperature changes, etc., appears to be satisfactory. It should be noted that, in many respects, the equipment as it is at present may be termed "breadboard." With some refinements, a very high order of dependability should be realizable. The adjustment of the array is actually much easier than that of a conventional array without scan. Since the pattern can be displayed on an oscilloscope, the effect of changing individual adjustment controls is instantly visible. The process of adjustment, therefore, becomes greatly expedited.

The 5.8 deg beamwidth of the seven-element, 8.4 wavelength-wide array is barely adequate to demonstrate the possibilities of the system. Reduction in beamwidth is, however, a matter of adding to the array. Work is under way to increase the number of elements to 25, and the overall array width to 33.6 wavelengths. The beamwidth of the main lobe can then be reduced to 1.5 deg with 20-db side-lobe level.

The generation of a phase-locked ensemble of frequencies for heterodyne use may be accomplished in a number of ways other than that described here. Phase-lock oscillators can be employed. A single oscillator at a frequency Δf may be used to generate harmonics which can be amplified and stepped up in frequency by beating against a common oscillator.

Application to two-dimensional scan appears to be straightforward but, of course, remains to be tried.

8. References

[1] Carpenter, R. J. and Ochs, G. R., High resolution pulse measurements of oblique radio reflections from meteor trails at 41 Mc/s. (A paper delivered at URSI-IRE meeting Oct. 20, 1959, San Diego, Calif.)

[2] Electronic Scanning Symposium, Apr. 29–May 1, 1958. USAF Cambridge Research Center, Bedford, Mass. AFCRL-TR-58-145 (I), ASTIA Document No. AD 152409.

[3] Bracewell, R. N. and Roberts, J. A., Aerial smoothing in radio stronomy. Australian J. Phys. **7**, No. 4, 615 (Dec. 1954).

(Paper 65D1–108)

Publications of the National Bureau of Standards*

Selected Abstracts

Amplitude and phase of the low- and very-low-radiofrequency ground wave, J. R. Johler, L. C. Walters, and C. M. Lilley, *NBS Tech. Note 60 (PB161561) (1960) $0.75.*

Graphs and tables of the low- and very-low-radiofrequency ground wave are presented as a function of frequency, 100 c/s to 1000 kc.

On the excitation of electromagnetic surface waves on a curved surface, J. R. Wait, *IRE Trans. Ant. Prop.* **AP–8,** *446 (1960).*

The excitation and propagation of surface waves on a spherical inductive boundary is considered. The source is taken to be a vertical electric dipole. The circumferential attenuation rate of the various modes are discussed where it is indicated that the dominant mode is very similar to the trapped surface wave for a plane inductive boundary. The results appear to conflict with those of Barlow, but are in sympathy with some numerical data of Elliott for the circumferential attenuation rate of the dominant mode.

Carrier-frequency dependence of the basic transmission loss in tropospheric forward scatter propagation, K. A. Norton, *J. Geophys. Research* **65,** *2029 (1960).*

A further interpretation is given of certain Lincoln Laboratory data obtained in an experiment using scaled antennas as published by Bolgiano [1959]. This paper has three objectives: (1) to consider the significance of these data as regards the theory of radio propagation through a turbulent atmosphere; (2) to describe a suitable method for the measurement of the meteorological parameters entering the theory; (3) to apply a further statistical analysis to these data. On the basis of this analysis of the Lincoln Laboratory data, it is concluded (1) that the

$$\{2/\Gamma(\mu)\}(\rho/2)^{\mu}K_{\mu}(\rho)$$

correlation model provides a description of tropospheric turbulence adequate for the description of these data with μ assigned the fixed value 1, and (2) that the variation of the carrier-frequency dependence of the basic transmission loss from hour to hour arises simply from a lack of correlation in the hourly median losses on widely separated carrier frequencies rather than from changes of μ in this correlation model.

The use of geostationary satellites for the study of ionospheric electron content and ionospheric radio-wave propagation, O. K. Garriott and C. G. Little, *J. Geophys. Research* **65,** *2025 (1960).*

This paper describes a proposed radio propagation experiment utilizing a geostationary satellite. The experimental methods for determining the total electron content of the ionosphere are discussed, and the advantages and capabilities of the methods are summarized. Other possible studies utilizing the satellite transmissions are also outlined.

Photochemical rates in the equatorial F_2 region from the 1958 eclipse, T. E. Van Zandt, R. B. Norton, and G. H. Stonehocker, *J. Geophys. Research* **65,** *2003 (1960).*

The F_2-region electron-density data from the eclipse on October 12, 1958, at Danger Islands has been analyzed with a new method. It is shown that (1) temperature changes and transport of electrons were probably negligible during the eclipse, and (2) the rate of photoionization $q(h)$ and the linear recombination coefficient ('attachment coefficient') $\beta(h)$ can be approximated between 290 km and 400 km by

$$q(h)=880 \exp[-(h-300)/186] \text{ electrons cm}^{-3}\text{sec}^{-1}$$

$$\beta(h)=6.8\times 10^{-4} \exp[-(h-300)/103] \text{ sec}^{-1}$$

where the height h is measured in kilometers. The rate of formation of ion pairs between 290 and 400 km is $(.76)10^{10}$ ion pairs/cm^2 sec, or about (0.25) ergs/cm^2 sec. This implies a total rate of energy absorption in the F region of at least 2 ergs/cm^2 sec.

On the theory of the slow-tail portion of atmospheric waveforms, J. R. Wait, *J. Geophys. Research* **65,** *1939 (1960).*

The propagation of the slow-tail portion of atmospherics is considered from the waveguide-mode viewpoint. The source, which is a lightning discharge, is represented by a vertical dipole. The transient response of the distant electric field is then computed for various forms of the source current waveform. The results are then employed to reinterpret the experimental data of Hepburn. As suggested by the present theory it is found that the observed separation t_s between the oscillatory head of the atmospheric and the maximum of the slow-tail amplitude varies with distance ρ to the source according to a law of the form

$$(t_s)^{1/2}=A+B\rho.$$

The constant A is related to the pulse width of the source, and the constant B depends on ionospheric parameters. Values of effective ionospheric conductivities deduced from the theory are consistent with earlier results for the VLF band. The influence of nonvertical currents in the discharge channel is also briefly discussed.

VLF attenuation for east-west and west-east daytime propagation using atmospherics, W. L. Taylor, *J. Geophys. Research* **65,** *1933 (1960).*

Daytime attenuation characteristics have been computed by comparing the amplitude spectra of atmospheric waveforms recorded at four widely separated stations. The results of these attenuation measurements are presented for the band of frequencies from 3 to 30 kc/s and involving distances of 1000 to 10,000 km. Nonreciprocity is evident from this study. Attenuation rates over sea water for east-to-west propagation were about 3 db/1000 km greater for frequencies below 8 kc/s, and about 1 db/1000 km greater for frequencies above 10 kc/s, than for west-to-east propagation. East-to-west attenuation rates over land were about 1 db/1000 greater than for over sea water.

Influence of earth curvature and the terrestrial magnetic field on VLF propagation, J. R. Wait and K. Spies, *J. Geophys. Research* **65,** *2325 (1960).*

An account is given of some recent work on the mode theory of VLF ionospheric propagation. Attention is confined to the behavior of the attenuation coefficient of the dominant mode. The ionosphere is assumed to be a sharply bounded and homogeneous ionized medium. It is indicated that earth curvature increases the attenuation rate by as much as a factor of 2 as compared with the corresponding attenuation for a flat earth. The influence of the earth's magnetic field is also shown to be important. In fact, east-to-west propagation paths suffer much greater attenuation than west-to-east paths. The theoretical results in the present paper appear to agree well with the experimental data of W. L. Taylor.

Rapid frequency analysis of fading radio signals, J. M. Watts and K. Davies, *J. Geophys. Research* **65,** *2295 (1960).*

Examples of frequency analysis of fading radio signals for long periods of time are demonstrated, and the method of obtaining them is explained. They include both regular HF propagation and VHF ionospheric forward-scatter samples. The procedure is also useful for the analysis of other natural phenomena having long time scales and slow variations.

A study of 2-Mc/s ionospheric absorption measurements at high latitudes, K. Davies, *J. Geophys. Research* **65,** *2285 (1960).*

Ionospheric absorption (L) at high latitudes is studied using the published data on 2.0 Mc/s at five Canadian stations during 1957 and 1958. The seasonal and diurnal variations are considered, and it is found that a pronounced winter anomaly in noon absorption occurs at Churchill but not at Resolute Bay. The diurnal variations indicate that the dependence of absorption on solar zenith angle decreases with increase of latitude. The distribution of midnight absorption with latitude shows that, although the maximum occurs in the auroral zone, high absorption is also encountered over the polar cap. A study of the duration of long-lasting blackouts shows that in summer the duration is longer as the latitude increases.

On the excitation of electromagnetic surface waves on a curved surface, J. R. Wait, *IRE Trans. Ant. Prop.* **AP-8,** *445 (1960).*

The excitation and propagation of surface waves on a spherical inductive boundary are considered. The source is taken to be a vertical electric dipole. The circumferential attenuation rates of the various modes are discussed where it is indicated that the dominant mode is very similar to the trapped surface wave for a plane inductive boundary. The results appear to conflict with those of Barlow, but are in sympathy with some numerical data of Elliott for the circumferential attenuation rate of the dominant mode.

Diffractive corrections to the geometrical optics of low frequency propagation, J. R. Wait, *Electromagnetic Wave Propagation (International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition), edited by M. Desirant and J. L. Michiels, p. 87–101 (Academic Press, New York, N.Y., 1960).*

The radiation fields are computed for an axial slot on a cylinder whose surface is regularly corrugated. The mathematical idealization is a magnetic line source on a cylindrical surface whose boundary impedance is specified. Special attention is given to surfaces whose radii of curvature are large compared to the wave-length.

Radiation from a slot on a large corrugated cylinder, J. R. Wait and A. M. Conda, *Electromagnetic Wave Propagation (International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition), edited by M. Desirant and J. L. Michiels, p. 103–109 (Academic Press, New York, N.Y., 1960).*

The radiation fields are computed for an axial slot on a cylinder whose surface is regularly corrugated. The mathematical idealization is a magnetic line source on a cylindrical surface whose boundary impedance is specified. Special attention is given to surfaces whose radii of curvature are large compared to the wave-length.

Atmospheric bending of radio waves, B. R. Bean, *Electromagnetic Wave Propagation (International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition), edited by M. Desirant and J. L. Michiels, p. 163–181 (Academic Press, New York, N.Y., 1960).*

Meteorological data from many diverse climates and seasons indicate that the refractive index gradient over the first kilometer above the earth's surface is highly correlated with the surface value of the refractive index. Further, 60% of the bending of radio rays passing completely through the earth's atmosphere is accomplished in the first kilometer above the earth's surface. These observations have led to the development of several models of the height distribution of the refractive index that yield more realistic values of radio ray bending than the effective earth's radius approach and have the further advantage of being adjustable for any season or location for which standard surface weather observations are available.

Low and medium frequency radio propagation, K. A. Norton, *Electromagnetic Wave Propagation (International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition), edited by M. Desirant and J. L. Michiels, p. 375–444 (Academic Press, New York, N.Y., 1960).*

During recent years, extensive progress has been made in understanding the nature of ionospheric propagation in the frequency range from 30 to 1000 kc. In particular, Wait and Conda have developed suitable methods for determining the effect of the curvature of the earth on the illumination of the ionosphere by antennas radiating at angles near and below grazing incidence, Belrose has developed empirical formulas for ionospheric absorption in the range 70 to 250 kc, Watt has analyzed data which makes possible the extension of these formulas to still lower frequencies, and Bean has developed a radio standard tropospheric atmosphere which makes possible good estimates of the bending of the radio waves in propagation to and from the ionosphere. Making use of these results, together with earlier studies made by the author of the absorption of radio waves in the band 540 to 1600 kc and some new results on focusing by the curved surface of a rough ionosphere, predictions are made of the propagation loss expected in ionospheric propagation between short vertical electric dipoles for waves propagated by m reflections at the ionosphere. The predictions appear to be in general agreement with the available experimental data, although the paper clearly points up the desirability of more definitive studies of the influence of absorption and polarization, particularly as regards the larger distances which involve propagation by more than one ionospheric reflection. The methods in this paper indicate that the propagation loss increases only very slowly as the angle of departure approaches and goes well below grazing incidence with the earth; this provides an explanation for recent experimental data obtained with a pulse system as reported by Doherty which indicates very large intensities for one-hop sky waves on 100 kc both day and night at ranges up to 1800 miles.

On the computation of diffraction fields for grazing angles, J. R. Wait and A. M. Conda, *Electromagnetic Wave Propagation (International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition), edited by M. Desirant and J. L. Michiels, p. 661–670 (Academic Press, New York, N.Y., 1960).*

The diffraction of electromagnetic waves by a convex cylindrical surface is considered. Attention is confined primarily to the region near the light-shadow boundary. The complex-integral representation for the field is utilized to obtain a correction to the Kirchoff theory. Numerical results are presented which illustrate the influence of surface curvature and polarization on the diffraction pattern. Good agreement with the experimental results of Bachynski and Neugebauer is obtained.

The resonance excitation of a corrugated-cylinder antenna, J. R. Wait and A. M. Conda. *Inst. Elec. Engrs. Mono. 386E (June 1960).*

Radiation from an axial magnetic line or slot source on the surface of a corrugated cylinder is considered. It is indicated that the power radiated in a given mode for the structure depends critically on the surface reactance and the circumference of the cylinder. In fact, for certain values of these parameters, particular modes are strongly excited and contain most of the radiated power. Numerical results are presented for several interesting cases.
The analysis is extended to an elliptic cylinder whose surface also possesses an inductive reactance. In order to facilitate the solution it is necessary to assume a special azimuthal variation of the surface reactance. For the model as chosen, strong resonance characteristics are again obtained. This model may be adapted to study the problem of a corrugated panel on a flat metallic ground plane which is excited by a parallel slot source.

Other NBS Publications

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Heat of formation of decaborane. W. H. Johnson, M. V. Kilday, and E. J. Prosen.
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Spestrophotometric determination of the ionization constant of 2,4,6-trinitro-*m*-cresol in water at 25° C. M. M. Davis and M. Paabo.
Method for the separation of titanium, zirconium, iron, and aluminum from one another and for their subsequent determination. T. J. Murphy, W. S. Clabaugh, and R. Gilchrist.

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Characteristics of fifteen coating-grade asphalts. S. H. Greenfeld.

Stabilization of free radicals at low temperatures, edited by A. M. Bass and H. P. Broida. NBS Mono. 12 (1960) $1.50.
New description of thorium spectra, R. Zalubas. NBS Mono. 17 (1960) 65 cents.
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Protection against radiations from sealed gamma sources. NBS Handb. 73 (1960) (Supersedes H54) 30 cents.
Standardization activities in the United States. A descriptive directory, S. F. Booth. NBS Misc. Publ. 230 (1960) (Supersedes M169) $1.75.
Hydraulic Research in the United States, 1960, H. K. Middleton. NBS Misc. Publ. 231 (1960) $1.00.
Alphabetical index to tables of chemical kinetics. Homogeneous reactions. Supplement 2 to NBS Circ. 510 (1960) 35 cents.
A survey and bibliography of recent research in the propagation of VLF radio waves, J. R. Wait. NBS Tech. Note 58 (PB161559) (1960) 75 cents.
Measurements and standards in plasma-physics and astrophysics at the National Bureau of Standards. NBS Tech. Note 59 (PB161560) (1960) $1.00.
Proceedings of the 1960 conference on the propagation of E.L.F. radio waves. NBS Tech. Note 61 (PB161562) (1960).
Single scattered neutrons from an isotropic point sourse, E. R. Mosburg, Jr., and W. M. Murphey. NBS Tech. Note 63 (PB161564) (1960) 50 cents.
An analysis of an absolute torsional pendulum viscometer, E. A. Kearsley, Trans. Soc. Rheology III, 69 (1959).
The black void reactor concept, C. O. Muehlhause, Nuclear Sci. and Engr. **7,** No. 6, 505 (1960).
Dewar system for low temperature experiments, C. T. Zahn, Rev. Sci. Instr. **31,** No. 3, 328 (1960).
Radio echoes from field-aligned ionization above the magnetic equator and their resemblance to auroral echoes, K. L. Bowles, R. Cohen, G. R. Ochs, and B. B. Balsley, Letter J. Geophys. Research **65,** 1853 (1960).
Measurement on the smoothness of paper, T. W. Lashof and M. Mandel, Tappi **43,** No. 5, 385 (1960).
Geomagnetic and solar data, J. V. Lincoln, J. Geophys. Research 65, 1639 (1960); J. Geophys. Research **65,** 1821 (1960).
The spark of originality, A. T. McPherson, The Chemist **37,** No. 7, 275 (1960).
Infrared emission spectra of gaseous B_2O_3 and B_2O_2, D. White, D. E. Mann, P. N. Walsh, and A. Sommer, J. Chem. Phys. **32,** No. 2, 481 (1960).
A demonstration of color perception with abridged color-projection systems, C. S. McCamy, Photographic Sci. and Engr. **4,** No. 3, 155 (1960).
Heat of formation of nitrogen trifluoride and the N–F bond energy, G. T. Armstrong, S. Marantz, and C. F. Coyle, Commun. to Editor, J. Am. Chem. Soc. **81,** 3798 (1959).
Elastic constants of synthetic single crystal corundum at room temperature, J. B. Wachtman, W. E. Tefft, D. G. Lam, R. P. Stinchfield, J. Am. Ceram. Soc. **43,** No. 6, 334 (1960).
A simple centering jig and goniometer for punching or drilling spheres for structural models, D. K. Smith, Am. Mineralogist **45,** No. 5–6, 273 (1960).
Propagation of electromagnetic pulses in a homogeneous conducting earth, J. R. Wait, Appl. Sci. Research **B8,** 213 (1960).
Shielded coaxial leads for low temperature electrical measurements, N. L. Brown and R. N. Barfield, Rev. Sci. Instr. **31,** No. 5, 517 (1960).
Rapid impact loading of textile yarns, J. C. Smith, Book "High Speed Testing", Vol. 1, p. 67 (Interscience Publ. Inc., New York, N.Y. 1960).
The absolute zenith intensity of [OI] 5577 at College, Alaska, F. E. Roach and M. H. Rees, J. Geophys. Research **65,** 1489 (1960).
Studies on sudden commencements of geomagnetic storms using IGY data from United States stations, S. Matsushita, J. Geophys. Research **65,** No. 5, 1423 (1960).
Photometric observations of the twilight glow [OI] 5577 and [OI] 6300, L. R. Megill, J. Atmospheric and Terrest. Phys. **17,** 276 (1960).
Microwave spectrum and internal rotation of ethyl cyanide, V. W. Laurie, J. Chem. Phys. **31,** No. 6, 1500 (1959).
A study of local geomagnetic influence on the [OI] 5577 nightglow emission at Fritz Peak, J. W. McCaully, F. E. Roach, and S. Matsushita, J. Geophys. Research **65,** No. 5, 1499 (1960).
Local standards laboratories, A. T. McPherson, Handbook of Electrical Measurements, 1960 Ed., p. 72 (1960).

Infrared emission spectrum of gaseous HBO_2, D. White, D. E. Mann, P. N. Walsh, and A. Sommer, J. Chem. Phys. **32,** No. 2, 488 (1960).

The Stokes flow problem for a class of axially symmetric bodies, L. E. Payne and W. H. Pell, J. Fluid Mech. **7,** Pt. 4, 529 (1960).

A further note on "sweepers," J. M. Watts, J. Atmospheric and Terrest. Phys. **18,** 81 (1960).

The incidence equation $AA^t = aA$, K. Goldberg, Am. Math. Mo. **67,** 367 (1960).

Analysis of two-factor classifications with respect to life tests, M. Zelen, Book "Contributions to Probability and Statistics," Paper 42, p. 508 (Stanford Univ. Press, Stanford, Calif., 1960).

Compressive properties of hard tooth tissues and some restorative materials, J. W. Stanford, K. V. Weigel, G. C. Paffenbarger, and W. T. Sweeney, J. Am. Dental Assoc. **60,** No. 6, 746 (1960).

OH emission in the earth's atmosphere, D. M. Gates and E. Jones, Proc. 2d Natl, Infrared Information Symp. **4,** 145 (1959).

Microwave spectrum of trans-crotononitrile, V. W. Laurie, J. Chem. Phys. **32,** No. 5, 1588 (1960).

Tropospheric fields and their long-term variability as reported by TASO, P. L. Rice, Proc. IRE **48,** 1021 (1960).

On the power of some rank-order two-sample tests, J. R. Rosenblatt. Book "Contributions to Probability and Statistics," Paper 32, p. 358 (Stanford Univ. Press, Stanford, Calif., 1960).

Disc distribution of flares associated with certain radio bursts, C. Warwick, Proc. Symp. Physical Processes in the Sun-Earth Environment, July 20–21, 1959 (Ottawa, Defence Research Telecommunications Establishment) DRTE Publ. No. 1025, 249 (1960).

Effect of tensile properties of reinforcement on the flexural characteristics of beams, R. G. Mathey and D. Watstein, J. Am. Concrete Inst. **31,** No. 12, 1253 (1960).

The ionization potential of fluorine, J. T. Herron and V. H. Dibeler, Jr., Chem. Phys. **32,** No. 6, 1885 (1960).

The intensity of [OI] 5577 in the subauroral region as a function of magnetic activity, F. E. Roach, J. Geophys. Research **65,** No. 5, 1495 (1960).

Valences of the elements in analytical procedures, J. I. Hoffman, Chem. Anal. **49,** No. 1, 30 (1960).

A comparative study of absolute zenith intensities of [OI] 5577, F. E. Roach, J. W. McCaulley, E. Marovich, and C. M. Purdy, J. Geophys. Research **65,** No. 5, 1503 (1960).

Clay mineral content of two domestic kaoline, W. C. Ormsby and J. M. Shartsis, J. Am. Ceram. Soc. **43,** No. 6, 335 (June 1960).

Some canons of sound experimentation, C. Eisenhart, Bull. Inst. Intern. Stat. **XXXVII,** No. 3, 339–350 (1960).

Thermodynamic properties of helium at low temperatures and high pressures, D. B. Mann and R. B. Stewart, Trans. Am. Soc. Mech. Engrs. J. Heat Transfer **81,** No. 4, 324–326 (November 1959).

Interpolation of platinum resistance thermometers, 20° to 273.15° K, R. J. Corruccini, Rev. Sci. Instr. **31,** No. 6, 637–640 (June 1960).

Low-temperature transport properties of commercial metals and alloys. IV. Reactor grade Be, Mo, and W, R. L. Powell, J. L. Harding, and E. F. Gibson, J. Appl. Phys. **31,** No. 7, 1221–1224 (July 1960).

A rating scale method for evaluating research positions, H. A. McKean, J. Mandel, and M. N. Steel, Personnel Admin. **23,** No. 4, 29–36 (July-Aug. 1960).

Post office mechanization, B. M. Levin, M. C. Stark, and P. C. Tosini, Proc. Information Processing and Retrieval, Am. Inst. Elec. Engrs. General Meeting, June 19–24, 1960, Atlantic City, New Jersey, Am. Inst. Elec. Engrs. Paper CP60–937 (1960).

Sensitive thermal conductivity gas analyzer, J. R. Purcell and R. N. Keeler, Rev. Sci. Instr. **31,** No. 3, 304–306 (March 1960).

A study of two water resistance testers for shoe upper leather, R. L. Hebert, J. Am. Leather Chemists Assoc. **LV,** No. 7, 388–405 (July 1960).

Transfer of liquid hydrogen through uninsulated lines, R. J. Richards, W. G. Steward, and R. B. Jacobs, Proc. 1959 Cryogenic Engr. Conf., Vol. 5, Advances in Cryogenic Engineering, p. 103 (Plenum Press, New York, N.Y., 1960).

Bounds on the dissipation of energy in steady flow of a viscous incompressible fluid around a body rotating within a finite region, E. A. Kearsley, Arch. Rational Mech. and Analysis **5,** No. 4, 347–354 (1960).

Cavity resonator dielectric measurements of rod samples, H. E. Bussey, Conf. Electrical Insulation (Annual Report of 1959), Natl. Acad. Sci., Natl. Research Council Publ. **756,** 15–20 (1960).

Analysis of fractionally replicated 2^m3^n designs, R. C. Bose and W. S. Connor, Bull. Inst. Intern. Stat. **XXXVII,** No. 3, 141–160 (1960).

Influence of source distance on the impedance characteristic of ELF radio waves, J. R. Wait, Proc. IRE Letter to Editor **48,** 1338 (1960).

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