Cosmic Radio Noise Intensities in the VHF Band*

H. V. COTTONY†, SENIOR MEMBER, IRE AND J. R. JOHLER†, ASSOCIATE, IRE

***Summary*—During 1948 and 1949, the National Bureau of Standards conducted continuous, broad-directivity measurements of the cosmic radio noise intensities at frequencies between 25 and 110 mc. Their purpose was to evaluate the importance of this noise from the standpoint of its interference with radio communication. The results show a regular daily variation in noise corresponding to the movement of the principal sources of cosmic radio noise across the antenna receiving pattern. This normal cosmic noise intensity pattern was found to be constant within the limits of the accuracy of the measurements. It was found convenient to present the results in terms of daily maxima and minima which bracketed the daily variations. No measurable change in these limits was observed in the course of these measurements.**

Besides the normal cosmic radio noise, periods of abnormal high noise levels, generally associated with periods of unusual solar activity, were observed and recorded.

I. INTRODUCTION

AT FREQUENCIES below approximately 30 mc, at which long-distance radio communication is normally carried on, terrestrial radio noise is likely to determine the minimum useful signal strengths. The terrestrial radio noise or "static" is generated in the tropical thunderstorm areas and propagated by ionospheric transmission. At the upper end of the hf band where dependable ionospheric propagation ceases, the terrestrial radio noise intensity rapidly decreases and seems to disappear altogether. However, radio noise emanating from extra-terrestrial sources, known as "cosmic radio noise," constitutes one of the limiting factors for radio communication in the upper portion of hf and in the vhf bands. This type of radio noise was identified by Jansky in 1931[1,2] as a characteristic hissing noise apparently originating at a fixed point in space near the center of our galaxy. Subsequently, a number of other observers, notably Reber,[3,4,5,6,7] investigated the distribution of cosmic noise with frequency and direction in space. Fig. 1 (on the following page) is a sky map showing the contours of noise intensities from the different portions of the sky as determined by Reber using directive receiving equipment at 160 mc.

In addition, Southworth[8] and Reber, independently, found that the sun itself is a radiator of noise in the radio-frequency spectrum. The intensity of this noise is considerably in excess of that to be expected on the basis of thermal radiation by a black body at the temperature of the sun's surface (6,000°K). By convention, the term "cosmic radio noise" includes both the solar radio noise originating in the sun and the galactic radio noise which arrives from interstellar space.

Since the date of Reber's early measurements, considerable work has been done on the astronomical aspects of these phenomena, both in the field of physical measurement of noise intensities and in the realm of speculation as to the nature and the character of the noise itself. The references 9 to 13, 15, 16, and 21 give a representative sample of the work accomplished to date. The importance of the cosmic noise to radio communication was discussed in some detail by Norton.[14]

In order to investigate the diurnal, seasonal, and frequency characteristics of cosmic radio noise as it would affect the operation of hf and vhf radio-communication systems, a program of measurements was initiated at the National Bureau of Standards in 1946. During 1947, some preliminary measurements were performed and reported upon by Herbstreit and Johler.[15,16] Continuous measurements were begun in March, 1948. A description of the work, including equipment and some data, was presented by Johler at URSI-IRE meetings on May 3, 1948 and November 1, 1949 in Washington, D. C.

This paper presents a more complete description of the equipment than heretofore presented, the data on cosmic noise collected to January 1, 1950, and a discussion of the results obtained from these data.

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* Decimal classification: R113.413. Original manuscript received by the Institute, May 23, 1951; revised manuscript received, April 30, 1952.

† National Bureau of Standards, Washington 25, D. C.

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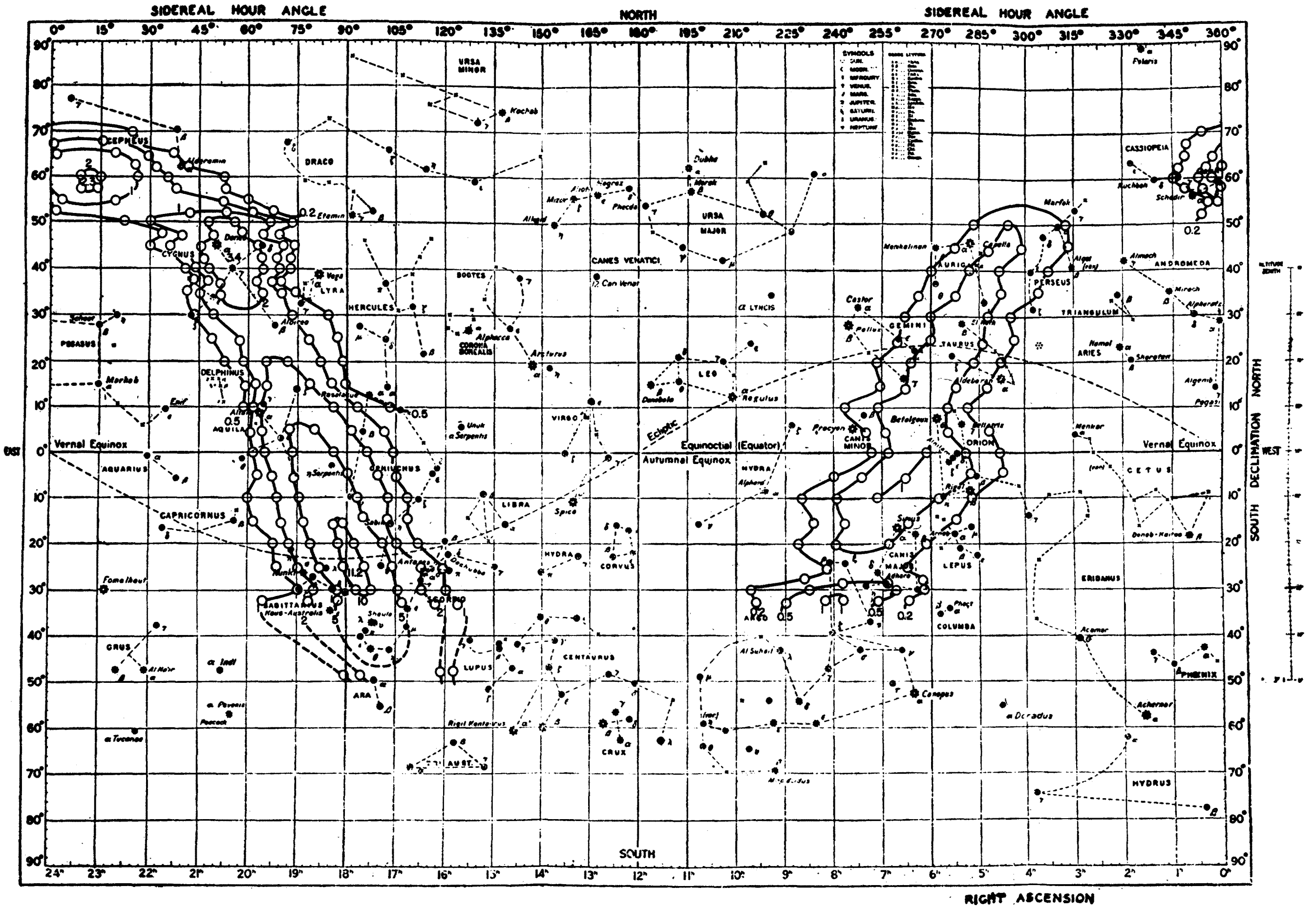

Fig. 1—Sky map showing the contours of cosmic radio noise observed by Grote Reber on 160 mc.

II. INSTRUMENTATION

The design of the receiving equipment for cosmic radio noise measurements presents special requirements: (1) high gain, (2) low internal noise, and (3) high degree of gain stability. High gain is required because the cosmic radio noise field strengths are relatively low compared with the normal atmospheric radio noise values, and also because the cosmic noise is measured at higher frequencies where the antenna delivers lower power to the receiver. Low internal noise is a consideration because the voltages to be measured are lower and, with the present knowledge of receiver design, the internal noise rapidly increases with frequency. Both of these requirements were met by the use of special two-stage preamplifiers in conjunction with modified commercial receivers. High degree of gain stability was necessary in order to obtain the desired degree of accuracy in the results, of the order of 1 db. This was met by employing well-regulated power supplies and by housing the equipment in a shelter the temperature of which was maintained constant to within $\pm\frac{1}{2}$°F.

The antennas used for measurements were half-wave, horizontal dipoles one-quarter wavelength above ground oriented in the east-west direction. In order to permit a direct comparison between the results obtained at different frequencies, all antennas were erected and oriented in an identical manner.

Fig. 2 is a block diagram which shows the interconnections between the major components of the equipment. The preamplifier-converter units include two stages of preamplification using the cascode circuit. Using this circuit, it was found possible to obtain a noise figure of 2 at 110 mc and proportionately better values at lower frequencies.

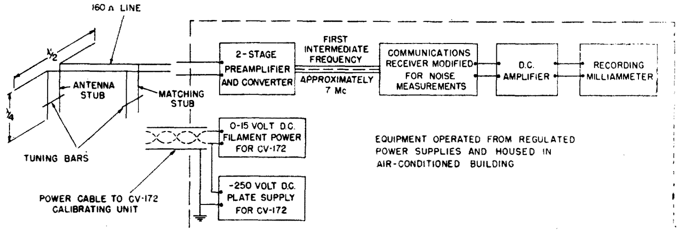

Fig. 2—Block diagram showing the major components of one receiving system and the calibrating equipment.

Fig. 3 illustrates the principle of calibration. A type CV-172 noise diode is mounted across the terminals of each dipole. The length of each dipole is adjusted for half-wave resonance. The length of the metal stub is adjusted to tune out the capacitance of the diode and the terminals. When calibrating, the dipole elements are removed and replaced by a resistor, R_a, equal in magnitude to the radiation resistance of the dipole. The space current I_s through the diode is varied by varying the filament current. The diode is then a source of shot noise current i_n which flows through the resistor R_a. The value of the shot noise current in amperes is given by the relationship

$$\overline{i_n^2} = 2eI_s\Delta f, \tag{1}$$

where e is the charge of the electron, 1.602×10^{-19} coulomb, and Δf is the bandwidth over which measurements are made in cycles per second.

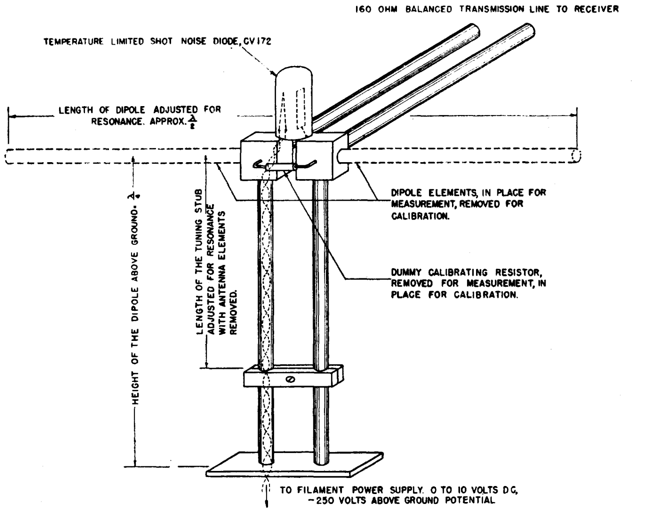

Fig. 3—A simplified view of the dipole antenna used to measure cosmic radio noise intensity, showing the method of absolute calibration employed. The diagram is not to scale. Impedance matching stub is not shown.

The open-circuit voltage developed across the terminals of the dummy antenna resistor is then equal to V given in volts by the relationship

$$\overline{V^2} = 4kTR_a\Delta f + 2eI_sR_a^2\Delta f, \tag{2}$$

where k is the Boltzmann constant, 1.37×10^{-23} joules per degree K and T is the absolute temperature of the calibrating resistor, degrees K. (For purposes of numerical computations, T is assumed to be equal to 300°K or, approximately, 80°F.)

The first term on the right side of the equation is the Nyquist's term, giving the mean-squared voltage due to the thermal agitation of the electrons within the calibrating resistor.[17,18]

It is convenient to express the intensity of the noise to be measured in terms of the fictitious temperature T' at which the resistor R_a must be to develop equal noise voltage thermally.

Then

$$4kT'R_a\Delta f = 4kTR_a\Delta f + 2eI_sR_a^2\Delta f$$

and

$$T' = T + \frac{eR_a}{2k}\cdot I_s. \tag{3}$$

Using type CV-172 diodes, which can, without burning out, carry a space current of 100 ma, it was possible to calibrate up to effective temperature T' of approximately 60,000°K. For R_a of 100 ohms and for 10-kc bandwidth, this equals approximately 1.8 μv. This was adequate for normal cosmic radio noise measurements.

III. UNITS EMPLOYED FOR PRESENTING THE RESULTS

It has been a generally accepted practice among the physicists interested in the cosmic-noise measurements to express the intensity of such noise in terms of temperature, degrees K, at which a resistor would generate thermally an equal available noise power. This, to a considerable extent, is a matter of convenience since, using temperature units, neither source impedance nor bandwidth employed need be specified. Such representation is legitimate only when the noise voltages being considered are random in character. Since this paper is intended for engineers interested in evaluating the interference value of cosmic noise, the results were also converted to terms of power intensity in watts per square meter and those of field strengths in microvolts per meter. The conversion to power intensity is accomplished by the use of the Jeans-Rayleigh black-body radiation law,

$$P = \frac{8\pi kTf^2\Delta f}{c^2}, \tag{4}$$

where P is the power radiated by a black body in the frequency interval Δf, in watts per square meter, f is the frequency at which the measurements are being made, in cycles per second, and c is the velocity of propagation in meters per second, 3×10^8.

This expression gives the power radiated by a black body in both planes of polarization. The black-body radiation is randomly polarized so that the power is equally distributed in each plane. Since the receiving dipole is sensitive to only one plane of polarization, it would receive only half the power radiated by a black body. Hence, the true power received by the dipole is half of that given by the above relationship. For a bandwidth of one cycle per second and when frequency f is in megacycles, this becomes

$$P = 1.91\times10^{-27}\times f^2\times T \tag{5}$$

The electric field strength is obtained directly from power intensity by the relationship

$$\overline{E^2} = P\times Z_0 \tag{6}$$

where E is the electric field intensity, in volts per meter, and Z_0 is the characteristic impedance of space, 376.7 ohms. If E is expressed in microvolts per meter for a bandwidth, Δf, of 1,000 cycles per second, and frequency f, is in megacycles per second, then

$$E_{\text{rms}} = 2.68\times10^{-5}\times f\times\sqrt{T}. \tag{7}$$

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[18] H. Nyquist, "Thermal agitation of electric charge in conductors," *Phys. Rev.*, 2nd ser., vol. 32, pp. 110–113; July, 1928.

IV. Results of Measurements—Normal Cosmic Radio Noise

In the course of the two years' measurements, it was found that the normal cosmic radio noise intensities have a very regular diurnal pattern. Fig. 4 presents a typical record of one week's measurements. As all measurements described here, this record was made with the dipoles oriented in the east-west direction. This orientation makes the system more sensitive to radiation from low angles in the southern and northern directions and less sensitive to low-angle radiation from east and west. The most intense source of galactic radio noise is located near the constellation of Sagittarius. At the latitude of Washington, 39°N, this source attains its highest elevation above the horizon at approximately 25° due south. Therefore, such orientation of the antenna may be expected to produce higher maximum noise intensity than the north-south orientation of the antenna. At the same time the reduced sensitivity of the antenna to low-angle radiation coming from east and west leads one to expect that when the major sources of galactic noise are east or west of the meridian the response of the east-west oriented antenna would be lower than that of an antenna oriented north and south, and it may have a lower minimum. This difference in maxima and minima was confirmed by Herbstreit[16] experimentally.

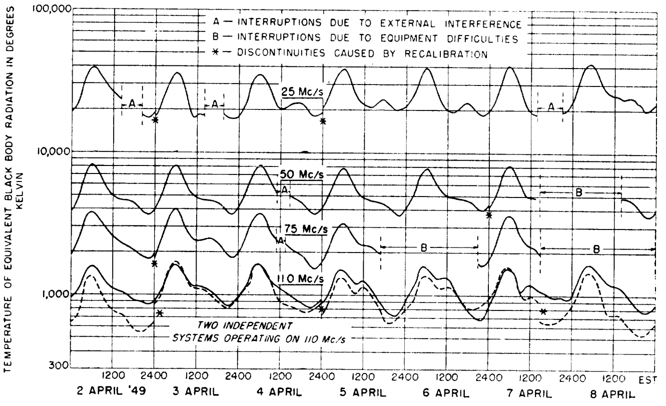

Fig. 4—A typical record of one week's measurements on four frequencies with five receiving systems plotted to a common temperature scale.

Fig. 4 shows that in early April, 1949 the maximum noise intensity was recorded on all frequencies at approximately 0600 EST, while the minimum was observed at approximately 2200 EST. These times correspond to 1900 and 1100, sidereal time, respectively. By reference to Fig. 1, it can be seen that the maximum corresponds to the time when the constellation of Sagittarius is just west of the meridian and the constellation of Cygnus is approximately the same distance east of the meridian; the antenna is thus in a position to receive the maximum of energy from the two sources. At sidereal time of the minimum, 1100, the sky is relatively free of the more intense sources of cosmic noise.

It was found convenient to present the data obtained during the twenty-two months of measurements by plotting the daily normal maxima and minima, in this way presenting the normal upper and lower limits for the noise. The yearly averages of daily maxima and minima are presented in Table I in degrees K, in micro-

TABLE I

AVERAGES OF NORMAL DAILY MAXIMA AND MINIMA FOR 1948 AND 1949

	1948 (March—December)					1949 (January—December)					(1948–1949)				
	Equiv black body temp degrees K	Field strength μv/m for 1,000 cps	Power intensity watts/sq m for 1 cps	Std deviation db	No of observ	Equiv black body temp, degrees K	Field strength μv/m for 1,000 cps	Power intensity watts/sq m for 1 cps	Std deviation db	No of observ.	Equiv black body temp degrees K	Field strength μv/m for 1,000 cps	Power intensity watts/sq m for 1 cps	Std deviation db	No of observ
			$\times 10^{-20}$					$\times 10^{-20}$					$\times 10^{-20}$		
25-mc normal daily maxima	41,800	0.137	5.00	0.7	181	34,700	0.125	4.17	0.8	304	37,300	0.130	4.48	—	485
25-mc normal daily minima	19,800	0.094	2.38	1.0	176	16,600	0.087	1.99	0.8	308	17,700	0.090	2.13	—	484
35-mc normal daily maxima	—	—	—	—	—	16,500	0.121	3.88	0.4	109	16,500	0.121	3.88	0.4	109
35-mc normal daily minima	—	—	—	—	—	8,430	0.086	1.98	0.4	112	8,430	0.086	1.98	0.4	112
50-mc normal daily maxima	7,320	0.115	3.52	0.3	231	7,550	0.117	3.63	0.3	269	7,440	0.116	3.57	—	500
50-mc normal daily minima	3,440	0.079	1.65	0.3	240	3,510	0.080	1.69	0.4	274	3,470	0.079	1.67	—	514
75-mc normal daily maxima	2,790	0.107	3.01	0.5	218	3,490	0.119	3.77	0.4	235	3,160	0.113	3.41	—	453
75-mc normal daily minima	1,230	0.071	1.33	0.6	182	1,580	0.080	1.71	0.6	222	1,430	0.076	1.55	—	404
#1 110-mc normal daily maxima	1,160	0.101	2.70	0.6	185	1,300	0.107	3.02	0.6	207	1,230	0.104	2.86	—	392
#1 110-mc normal daily minima	510	0.067	1.19	0.9	144	530	0.068	1.23	0.9	200	520	0.068	1.21	—	344
#2 110-mc normal daily maxima over ground	1,250	0.105	2.90	—	34	1,380	0.110	3.21	—	126	1,380	0.110	3.21	0.6	160
#2 110-mc normal daily minima over ground	450	0.063	1.05	—	32	600	0.072	1.39	—	113	570	0.071	1.32	1.0	145
#2 110-mc normal daily maxima over mat	—	—	—	—	—	1,310	0.107	3.04	0.6	83	1,310	0.107	3.04	0.6	83
#2 110-mc normal daily minima over mat	—	—	—	—	—	560	0.070	1.30	0.8	71	560	0.070	1.30	0.8	71

volts per meter for 1,000-cps bandwidth, and in watts per square meter per cycle per second bandwidth. Statistical analysis of the data showed that the distribution of the observations is very nearly normal. The standard deviations obtained as a result of this analysis are presented in columns 4, 9, and 14 of Table I. Examination of the tabulated values of standard deviations shows that the standard deviation for any frequency in either year never exceeds 1 db, and generally is considerably smaller.

It is a generally accepted assumption that the intensity of the galactic radio noise, at least when averaged out over the visible area of the sky, is constant. If this were so, the variations in the measured values of cosmic noise intensity must be attributable to errors in measurements, or are due to absorption by the ionosphere. To verify this, an effort was made to evaluate the accuracy of the measurements by estimating or computing the errors from the various sources. The analysis itself is too lengthy to be presented here in full; however, a summary of the results is presented in Table II. The table shows that the root-sum-square error from all the sources considered is of the same order of magnitude as the standard deviation of the measured values. This confirms the assumption that the variations in the measured values of cosmic radio noise are not the result of variations in the phenomenon being measured, but are introduced by the instruments and methods used in measurement.

Examination of the cosmic radio-noise data, averaged month by month, revealed no sign of absorption by the ionosphere at frequencies of 50 mc and higher. The 35-mc equipment was operated for too short a period of time for any conclusion to be made for this frequency. However, 25-mc equipment showed definite signs of variations attributable to the ionospheric absorption. Because of the earth's movement around the sun, the times of daily occurrence of the maximum and minimum cosmic radio-noise intensity change, being approximately four minutes earlier each succeeding day. Thus, the time of the maximum coincides with noon at approximately December 31, while the time of the minimum coincides with noon at approximately September 1. The 25-mc records reveal that around November and December in either year, when the maximum is measured at the time of maximum ionospheric absorption, the daily maximum values of cosmic-noise intensity are lower than at other times of the year. The daily minimum values of cosmic radio noise have a corresponding trough around September and October when the daily minimum is observed in the late morning hours. By using the departures of monthly mean values of daily maxima and minima from the annual mean values, root-mean-square errors were computed for variations due to ionospheric absorption. These errors appear in line 9 of Table II.

In Fig. 5 the cosmic noise intensities in microvolts per meter for 1,000-cps bandwidth are presented together with the atmospheric radio-noise data. The latter were derived from the National Bureau of Standards circular No. 462, "Ionospheric Radio Propagation," June 25, 1948. It should be noted that the early tentative values of cosmic radio noise intensities presented in that circular were in error, being 9 db too low. The cosmic noise values in this figure are normal daily maxima and minima averaged over the 22 months of measurements. Included are also some observations, curve *E* made in the Arctic in 1947, of atmospheric radio noise,

TABLE II

ESTIMATES OF THE MAGNITUDES OF ERRORS, IN DECIBELS, IN THE MEASURED VALUES OF COSMIC RADIO NOISE

Sources of Errors	25 mc		35 Mc		50 mc		75 mc		110 mc	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1. Inaccuracies in reading recorder chart	0.05	0.08	0.06	0.08	0.05	0.07	0.08	0.17	0.08	0.17
2. Changes in sensitivity of equipment	0.30	0.28	0.24	0.26	0.25	0.25	0.28	0.39	0.43	0.70
3. Inaccuracies in reading calibrating diode current	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02
4. Errors in the measured values of radiation resistance*	(0.21)	(0.21)	(0.21)	(0.20)	(0.20)	(0.19)	(0.19)	(0.17)	(0.16)	(0.09)
5. Variations in radiation resistance with weather	0.21	0.21	0.21	0.20	0.20	0.19	0.19	0.17	0.16	0.09
6. Variations in absorption by the ground	0.20	0.20	0.20	0.20	0.20	0.19	0.18	0.16	0.15	0.08
7. Variations in temperature of calibrating resistor**	±0.00 ∓0.05	±0.00 ∓0.05	±0.00 ∓0.05	±0.01 ∓0.05	±0.01 ∓0.05	±0.02 ∓0.05	±0.02 ∓0.05	±0.04 ∓0.04	±0.04 ∓0.04	±0.10 ∓0.02
8. Interference	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
9. Absorption by ionosphere	0.62	0.74	nil	nil	nil	nil	nil	nil	nil	nil
10. Natural fluctuation in galatic noise	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
Root-sum-square error due to all random effects	0.75	0.85	0.39	0.39	0.34	0.38	0.39	0.49	0.49	0.74
Mean standard deviations (From Table I)	0.75	0.90	0.40	0.40	0.30	0.35	0.45	0.60	0.60	0.90

* Errors in measured values of radiation resistance are systematic and are not included in the summation.

** The two errors due to this cause are in opposite direction and their difference is used in the root-sum-square summation.

in vlf and lf bands. In addition to the cosmic and atmospheric noise there is plotted the noise field intensities produced by black-body radiation at the temperature of the earth's surface (taken to equal 300°K or, approximately, 80°F). However, this noise does not necessarily exist at that level of intensity since most of the surroundings, notably the ground itself, depart considerably from being perfect black bodies. Also, the surrounding objects including the ground occupy only half of the sphere. Fig. 5 also shows, for comparison purposes, the noise field strengths, curve *B*, corresponding to the internal noise of well-designed receivers. This latter curve was obtained from the empirical relationship presenting best available noise figures for a range of frequency which appeared in a paper by Norton and Omberg.[19] Fig 5 displays the fact that for a well-designed, high-gain, low-noise receiver, cosmic radio noise may well present the limit to communications up to approximately 200 mc. For receiving systems using directive antennas the interference value of cosmic noise may be important at a considerably higher frequency for such times as the direction of the maximum sensitivity of the antenna coincides with the direction of the more intense sources of cosmic radio noise.

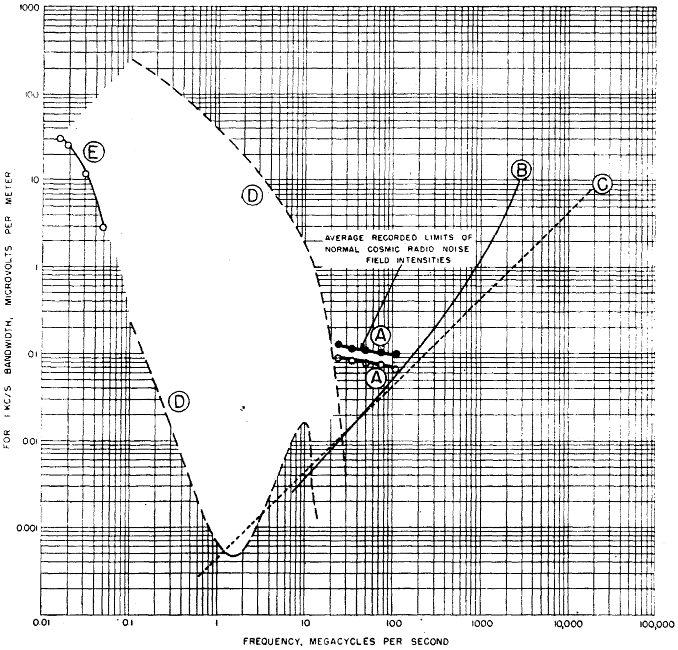

Fig. 5. Comparative intensities of radio noise of natural origin in the spectrum of radio frequencies.
A—Average daily upper and lower limits of the normal cosmic radio noise field intensities.
B—Noise field intensities corresponding to internal noise of well-designed receiver (derived from Norton and Omberg[19]).
C—Noise field intensities (in one plane of polarization) produced by "black-body" radiation at 300°K (80°F).
D—Upper and lower limits of atmosphere radio noise intensities. Derived from the National Bureau of Standards Circular No. 462. Also radio propagation unit report RPU-5.
E—Atmospheric radio-noise intensities measured in Arctic (Cottony[20]).

Herbstreit,[16] in reporting the early phases of this work, attedpted to correct for the absorption by the ground. He found it necessary to add approximately 1 db to the measured results at 25 mc and 1.7 at 110 mc to obtain the incident noise intensities. During this program of measurements, an attempt was made to verify these deductions by operating two 110-mc receiving systems, one over the ground, the other over a metallic screen. No significant difference was observed in the results. A review of Herbstreit's computations and a measurement of the ground constants showed that the relative dielectric constant of the ground at Sterling, Virginia was 23 rather than the assumed 4, and that the actual distribution of noise sources resulted in reflection at more nearly a grazing angle than with a uniform distribution of noise sources assumed by Herbstreit. Both of these factors contributed to a significantly lower recomputed value of absorption by the ground. It is now estimated that at 110 mc the absorption by the ground should lower the observed noise intensity by approximately 0.65 db. At lower frequencies the correction is still smaller. Because the corrections are only estimates, and since the possible error is of the same order of magnitude, these corrections were not applied to the results in this paper.

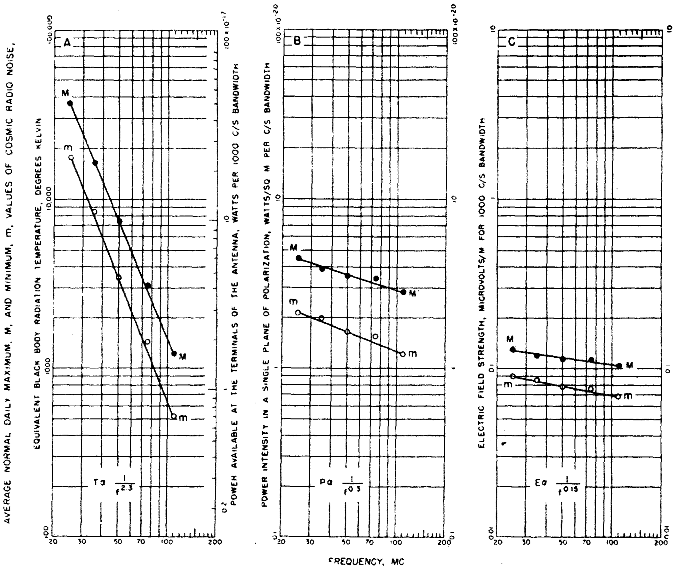

Fig. 6—Variation of cosmic radio noise intensity with frequency.

One of the aims of this investigation has been to determine, with some accuracy, the frequency law of cosmic noise intensity. Fig. 6 presents the comparison of noise intensities with frequency graphically in the three sets of units. The graphs are plotted to a logarithmic scale in each case. The intensities are averages for the duration of the measurements.

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[19] K. A. Norton and A. C. Omberg, "The maximum range of a radar set," PROC. I.R.E., vol. 35, pp. 4–24; January, 1947.

[20] H. V. Cottony, "Observations of Atmospheric Radio Noise in Arctic Regions," Memorandum Report; January 15, 1948. (Not published, not available for distribution.)

It can be seen that when the intensities are expressed in terms of temperatures of equivalent black-body radiation, they vary inversely as the 2.3 power of the frequency, when in terms of electric field strength, inversely as the 0.15 power and, when in terms of power intensity, inversely as the 0.3 power. Moxon,[21] who investigated the variations of cosmic radio noise intensity with frequency in the range of 40 to 200 mc, found the intensity (expressed as temperature of equivalent black-body radiation) to vary inversely as the 2.7 and as 2.1 power of the frequency in the plane of galaxy and away from the plane of the galaxy, respectively. Comparison of daily maxima and minima obtained in this investigation does not disclose any indication of difference in the frequency law of radiation.

V. RESULTS OF MEASUREMENTS—ABNORMAL PHENOMENA

In addition to the normal cosmic radio noise intensities characterized by their regularity, there have been observed from time to time abnormal phenomena which in all observed instances appear to be associated with solar disturbances. Two such observations are described here as illustrative of such phenomena.

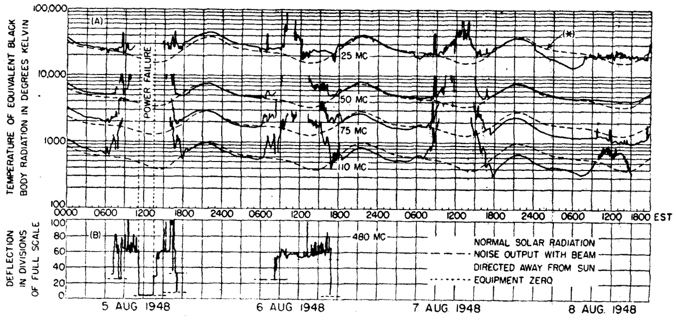

Fig. 7—Transcribed records of abnormal cosmic radio noise obtained during a period of high solar activity. (A) Broad directivity measurements of cosmic radio noise on 25, 50, 75, and 110 mc. (B) Directional measurement of solar radio noise on 480 mc. (*) Normal level of cosmic radio noise.

Fig. 7 presents the cosmic noise measurements made on August 4–8, 1948. On those dates a large group of sunspots travelled across the face of the sun passing close to the center of the solar disc. This phenomenon was accompanied by an enhanced level of cosmic noise. The figure shows two sets of observations. The upper portion of the figure presents the transcribed record made by the equipment described in this paper on the frequencies of 25, 50, 75, and 110 mc. The lower portions of the figure present the transcribed record made by a radiometer located near the site of the cosmic-noise equipment and operated by Reber in connection with solar-noise studies. This radiometer consisted of a 480-mc receiver with a directive antenna consisting of a dipole located in the focus of a 25-foot parabolic reflector. It is automatically directed at the sun in the daytime. The radiometer measures the relative level of solar activity as evidenced by the intensity of radio-frequency radiation from the sun.

The two sets of records show that, while the broad directivity measurements show considerable increase in the noise in the middle of the day, amounting to several times the normal noise power level, the radiometer shows only a moderate increase in the noise level intensity accompanied by relatively short-duration, high-intensity bursts. An examination of the detail of the noise records shows that there is a close qualitative correspondence between the bursts of noise as recorded by the radiometer on 480 mc and those recorded by the broad-directivity equipment. This indicates that in each case the noise is apparently of solar origin. However, the general increase in noise is greater in the case of broad-directivity measurements. Since the broad-directivity receiving systems receive the radiation from a relatively great area in the sky, they are relatively insensitive to radiation from a small area unless the intensity of radiation from that area is very high. Thus a quiet sun, assuming equivalent black-body radiation temperature of 1,000,000°K at radio frequencies, would produce a maximum increase in the measured noise intensity equivalent to approximately 10 to 15°K, which is below the resolving power of the equipment. The fact that the broad-directivity equipment at 25–110 mc is affected to a greater degree by the solar radiation than the relatively directive equipment pointed at the sun at 480 mc may be explained by the fact that the radiation from a disturbed sun is far more intense at the lower frequencies or that, possibly, the radio noise is generated in the vicinity of the earth although induced by solar emission.[22] In either case the phenomenon invites further investigation.

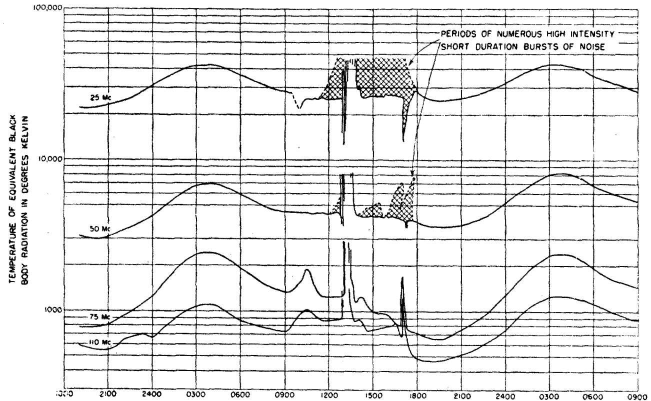

Fig. 8. Transcribed record of sudden ionospheric disturbance of May 7, 1948, with the accompanying solar bursts plotted to a common temperature scale.

Another type of disturbance recorded by the equipment is illustrated by Fig. 8. This presents cosmic noise measurements of May 7, 1948. These show a series

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[21] L. A. Moxon, "Variation of cosmic radiation with frequency," *Nature*, vol. 158, no. 4021, pp. 758–759; November 23, 1946.

[22] H. V. Cottony, "Radio noise of ionospheric origin," *Science*, vol. 111, no. 2872, p. 41; January 1950.

of sudden bursts of noise beginning about 1300 EST and lasting for approximately one hour. These bursts of noise are also accompanied by a sharp drop in noise at 25 mc and, to a lesser extent, at 50 mc. It is believed that this drop in cosmic noise intensity at lower frequencies is caused by increased absorption in the ionosphere. The period of increased absorption is, in this case, of a few minutes in duration. On the same day, a few hours later at approximately 1700 EST, there is a record of a lesser noise burst on 75 and 110 mc with a simultaneous sudden decrease in cosmic noise intensity on 25 and 50 mc. In this case there are no noticeable bursts of noise at the lower frequencies. However, it may be a phenomenon similar to the first, the lack of the noise bursts being possibly explainable by the more oblique path of radiation from the sun which lengthened its path through the absorbing medium. This type of phenomenon is invariably associated with sudden ionospheric disturbances, a phenomenon which was first reported in 1935 by Dellinger.[23,24] The sudden ionospheric disturbances (SID) consist of failures in radio communication due to disappearance or fading-out of all signals presumably due to high absorption in the ionosphere. Their connection with eruptions on the sun and the normal presence of bursts of nonatmospheric radio noise were likewise noted by Dellinger. On May 7, 1948, three SID were observed at Washington, D. C. at 1000 to 1025, 1248 to 1440, and 1704 to 1755 EST. These coincide with the periods during which intense bursts of noise on 75 and 110 mc and drop in noise on 25 mc were noted on cosmic radio noise recorders. The phenomenon illustrated by the observations of May 7, 1948 appears to be distinct in character from that observed in August 5–8, 1948; but both are apparently closely connected with solar disturbances.

VI. CONCLUSIONS

On the basis of the two years' radio noise measurements in the vhf band the following conclusions are reached:

1. The normal cosmic radio noise in the vhf band, although relatively low in intensity, may, under conditions of good receiver design and proper antenna match, be the limiting factor to communications.
2. With the present knowledge of receiver design and for broad-directivity antenna systems, the cosmic radio noise may be the limiting factor to communication in the vhf band up to approximately 200 mc.
3. For receiving systems employing directive antennas the range of diurnal variation in cosmic radio-noise intensity may be expected to be much greater than that measured with the broadly directive antenna systems described here. Under these circumstances, if the direction of the signal to be received coincides with the direction to the more intense sources of the galactic radio noise, the frequencies at which the cosmic radio noise can be the limiting factor may be considerably higher than 200 mc.
4. Under the condition of abnormal solar activity, which is not an infrequent phenomenon, the level of the radio noise is greatly enhanced, and may, on occasion, be expected to present serious interference to radio communication in the vhf range.

[23] J. H. Dellinger, "A new cosmic phenomenon," *Science*, vol. 82, no. 3028, p. 351; October 11, 1935.

[24] J. H. Dellinger, "Sudden disturbances of the ionosphere." PROC. I.R.E., vol. 25, pp. 1253–1290; October, 1937.

The Effective Bandwidth of Video Amplifiers[*]

F. J. TISCHER[†]

IN DEALING WITH problems concerning video amplifiers with very wide bandwidth, the bandwidth as defined in the usual way does not seem to be useful for characterizing the utility of the amplifier for pulses and video reproduction. The attempt is made to derive an "effective" bandwidth which takes into account the phase characteristic but is, within certain limits, independent of the direct shape of the amplitude characteristic.

This "effective" bandwith, which is determined directly from the complex transfer function on the steady-state basis, is defined as the bandwidth of an "ideal" amplifier, giving the same steady final state and the same rise time of the transient response if excited by an unit step signal. The effective bandwidth as a new figure of merit can replace the double indication of bandwidth and rise time, as usually applied heretofore.

As most amplifier coupling networks are "minimum phase-shift" networks, the phase characteristic is at the same time defined by the amplitude characteristic, and it is therefore sufficient to know this characteristic in order to determine the effective bandwidth. This is very important in the case of amplifiers with very wide bandwidth, because the amplitude of amplification is the only value that can be measured in a comparatively simple way at all frequencies. The values of the effective bandwidth for some theoretical standard transfer functions give a good idea of the values that can be expected in practice for amplifiers with normal transfer functions and influence of phase distortions.

The improvement of the effective bandwidth by compensation of the phase error and the possible reduction of the number of stages of an amplifier in cascade coupling, constant gain being assumed, and the limits of this improvement are also investigated.

[*] Decimal classification: R363.4. Original manuscript received by the Institute, February 28, 1951; revised manuscript received April 7, 1952. In print for publication in the *Transactions of the Royal Institute of Technology*, Stockholm, Sweden.

[†] Runebergsgatan 6, Stockholm, Sweden.