OBSERVATIONS OF COSMIC NOISE AT 9·15 Mc/s

By C. S. Higgins* and C. A. Shain*

[*Manuscript received April 22, 1954*]

Summary

From observations made at a frequency of 9·15 Mc/s, with an aerial of beam width 29° between half-power points and directed to Dec. —32°, a curve of equivalent aerial temperature, as a function of sidereal time, is derived.

The temperatures observed were of the order of 10^6 °K. The curve is compared with curves derived for similar conditions by calculation from the results of observations at 18·3 Mc/s and at 100 Mc/s. It is found that the equivalent temperatures increase rapidly with decreasing frequency, but the ratio of maximum to minimum temperature decreases with frequency.

It is shown that " atmospheric " noise levels observed by the standard techniques sometimes contain a large contribution from cosmic noise at this frequency.

I. Introduction

The distribution over the sky of the intensity of cosmic noise has been studied at a number of widely spaced frequencies, and attempts have been made to construct theoretical models of the Galaxy based on these radio observations. It has been found that such models depend, for the quantitative evaluation of important empirical constants, on observations at comparatively low frequencies, about 10 or 20 Mc/s.

Observations in this range of frequencies are rare, the only published work at a frequency close to 10 Mc/s consisting of a few measurements at 9·5 Mc/s by Friis and Feldman (1937) which were made during tests of the original MUSA aerial. A recent paper (Shain and Higgins 1954) presented the results of a detailed survey of a restricted region of the sky at 18·3 Mc/s, but the results of some earlier work at the same frequency (Shain 1951), in which a strip of the sky was scanned by a fixed aerial directed to a constant declination, have already been used by Piddington (1951) and Brown and Hazard (1953) for comparison with their theoretically predicted intensities. Observations with such a fixed aerial are much simpler to make than a general survey and, since equipment was available which could be readily adapted for the purpose, an attempt was made to obtain similar observations at a frequency of 9·15 Mc/s. The present paper describes the results of these observations.

In the course of the present observations, interference was experienced from atmospherics and from radio stations, but, at times when ionospheric absorption was small, a background intensity, which varied with sidereal time, was observed consistently and this was undoubtedly due to cosmic noise.

* Division of Radiophysics, C.S.I.R.O., University Grounds, Sydney.

The variations in the intensity of cosmic noise at 9·15 Mc/s revealed in the present work cannot be directly compared in detail with the variations observed at other frequencies since different aerial systems have been used. Nevertheless a comparison is made between the observed variations at 9·15 Mc/s and those to be expected, by calculation from published observations, if aerials of similar directivity had been used at 18·3 Mc/s and at 100 Mc/s. The comparison shows that the trends with frequency expected from work at higher frequencies continue down to 9 Mc/s.

The intensity of cosmic noise at 9·15 Mc/s is high, equivalent temperatures being of the order of 10^6 °K. The observation of such high intensities suggests that some of the measurements of noise levels which have been assumed to be due to atmospherics might, in fact, have referred to cosmic noise, and this point will be briefly discussed.

II. Equipment

(*a*) *Aerial*

The aerial was erected at Hornsby, N.S.W. (lat. 33·7 °S., long. 151·1 °E.). It consisted of an array of 12 horizontal half-wave dipoles, 0·1 wavelength above the ground, arranged in plan as shown in Figure 1 (*a*). To reduce ground losses, wires parallel to the dipoles and extending $\frac{1}{4}$ wavelength beyond each

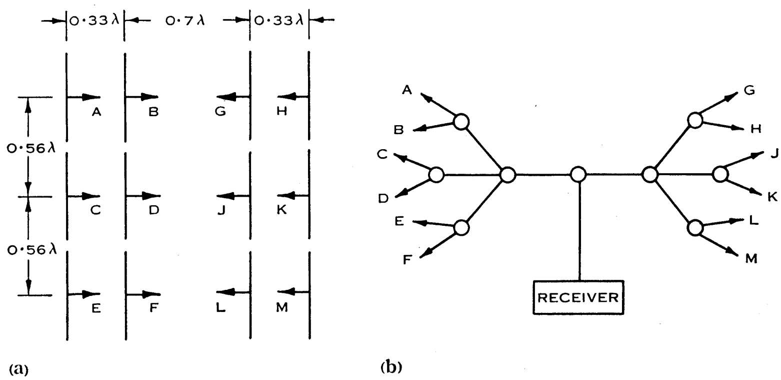

Fig. 1 (*a*).—Plan of the array.
Fig. 1 (*b*).—Connection of feeders. Each circle represents a T-type matching network. Letters indicate feeders to dipoles as shown in (*a*).

end of the array were laid 2 ft apart on the ground underneath the array. Each dipole had a balance-unbalance transformer and a separate coaxial feeder which was taken to a hut in the centre of the array. In this hut the feeders were grouped as shown in Figure 1 (*b*) with a matching network at each junction to match the impedances to the characteristic impedance of the cables used. The receiving equipment was housed in another hut outside the array.

The calculated aerial diagrams for the north-south and east-west planes are shown in Figure 2; it is seen that the beam widths to half power are 31° and 26° in the north-south and east-west planes respectively. Owing to a slight slope of the ground downwards towards the north, the direction of maximum sensitivity of the aerial was not overhead; the aerial scanned a strip of the sky centred on Dec. $-32°$. This strip included the galactic centre and the south galactic pole.

Losses in the ground reflecting system were estimated from impedance measurements on individual dipoles. It was assumed that the differences between the measured dipole impedances and the input impedances of similar dipoles in free space was due to the mutual impedance of the dipole and its image. The free space impedance and the mutual impedance of a dipole and its image were taken from data given by Schelkunoff and Friis (1952). From these calculations it was estimated that ground losses, compared with a perfectly reflecting ground, amounted to 2·3 db. The losses in the feeders and matching networks were measured directly and were found to be 2·2 db. Thus the total correction due to losses in the aerial system amounted to 4·5 db, corresponding to a factor of 2·8 with an estimated probable error in this factor of ± 20 per cent.

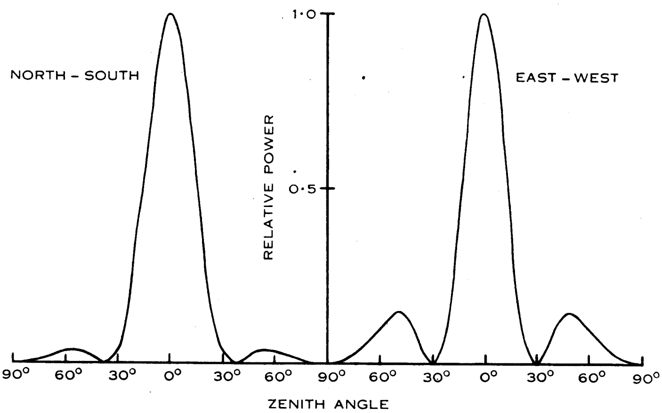

Fig. 2.—Calculated aerial sensitivity patterns.

(*b*) *Receiving and Recording Equipment*

A standard communications receiver was used, operated with a bandwidth of 400 c/s. Since the received noise powers were always high compared with the receiver noise, no attempt was made to achieve a low noise factor.

The output of the receiver was generally displayed on a recording meter. However, on some occasions, as described later, the time constant of the meter was too long and an alternative cathode-ray tube display was used with a time constant of less than 1 sec. In each case the record was calibrated using a diode noise generator the output impedance of which was made equal to the aerial impedance seen by the receiver.

III. Observations

The observations discussed in the present paper were made at intervals during the period July 1951 to September 1952. From previous experience at 18·3 Mc/s it was expected that often, and always during the day, ionospheric absorption would be high, and also that some difficulty would be experienced from atmospherics and from station interference. The objective, therefore, was to obtain as large a number of records as possible, perhaps of only an hour's duration, during which these effects were not serious. In the course of a year sufficient samples to cover a full sidereal day could be obtained.

During the morning and early afternoon on most days the record had the appearance of random noise only and there was little interference either from atmospherics or from radio stations. However, as expected, the noise powers recorded at these times were always low, due to ionospheric absorption. In the late afternoon and early evening, especially in summer, atmospherics increased in intensity. These were recognized as " crashes " when listening to the receiver output through a loudspeaker, and as " spikes " on the record. However, provided the individual spikes were not too frequent, the lower edge of the trace showed a fairly well-defined base level of apparently random noise. During the same part of the day, station interference often became serious ; as far as possible this was avoided by slight retuning of the receiver, although the frequency was always kept within 10 kc/s of 9·15 Mc/s. Atmospherics generally

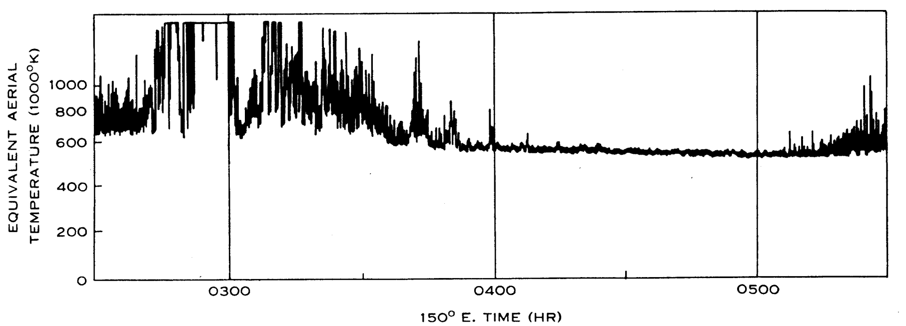

Fig. 3.—A record showing the absence of atmospherics and station interference for about an hour during the early morning of August 23, 1951. Sunrise occurred at 0627 hr (150 °E. time). Atmospherics, which appear on the record as spikes, are very frequent at about 0230 hr. Interference from a station is severe from 0240 hr but decreases in intensity, together with the atmospherics, until the record is clear of interference by 0415 hr. Atmospherics increase in intensity again soon after 0500 hr. The sidereal time at 0400 hr (150 °E. time) is 02 hr 05 min, and the gradual drop in received power is a real variation in cosmic noise intensity.

increased in intensity and frequency until about midnight, and commonly such periods of the records could not be used, although on a few occasions the record remained quite smooth throughout the night with no noticeable trace of atmospherics. Between midnight and sunrise, at times when the critical frequency of the F region was low, atmospherics and station interference decreased greatly in intensity. The majoriy of the useful observations were obtained during this period of the day. Figure 3 shows a record during which atmospherics and station interference decrease in intensity until the record is smooth from about 0415 to 0500 hr. Later, atmospherics increase again in intensity. It will be seen that even when the atmospherics spikes are moderately frequent the general variation of the cosmic noise base level can be followed. The fact that spikes due to atmospherics decreased, and on many occasions completely faded out, at the same time as interference from radio stations, suggests that even atmospherics from distant lightning flashes do not average out sufficiently to give a smooth record. If this is so, absence of spikes could be taken to indicate absence of atmospheric interference.

During summer it was difficult to find records completely free of atmospherics, even during the early morning. Although their intensity was small, the frequency of the spikes was sufficient to render uncertain the cosmic noise base level when the recording meter was used. To overcome this difficulty, the receiver output was displayed on the cathode-ray tube with a time base duration of about 30 sec, and each trace was photographed separately on 16-mm film. After several frames the noise generator was substituted for the aerial and several frames were exposed at each of several known noise levels. It was found that, on the occasions when this method of recording was used, the atmospherics could always be distinguished and a cosmic noise base level determined. When the intensity was later determined by observation of the film, it was found that, with visual integration of the base level over several minutes, the accuracy was no less than that obtainable with good meter records. However, the inconvenience of this technique accounts for the paucity of observations in the period between 05 and 09 hr, the region which passed through the aerial beam during early morning hours in summer time.

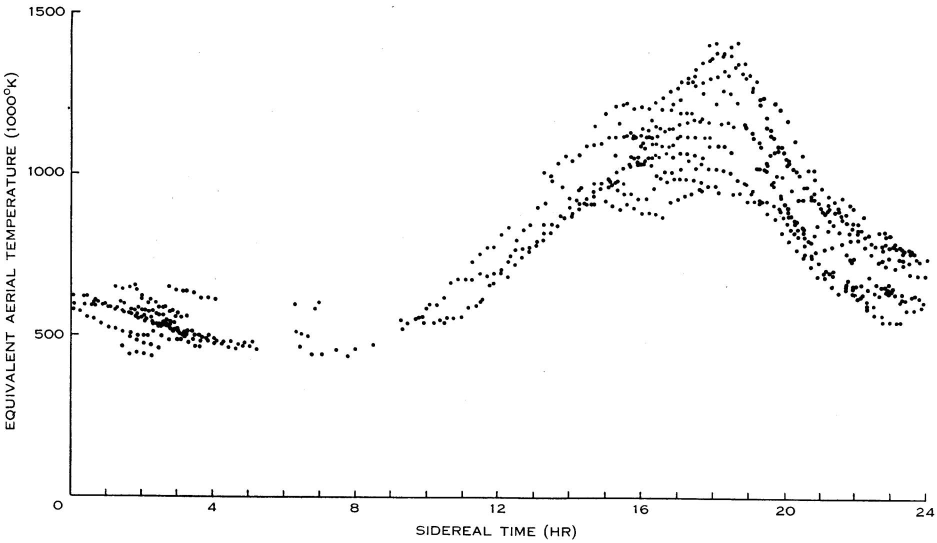

Fig. 4.—Observed equivalent aerial temperatures *v.* sidereal time (corrected for aerial losses).

Readings were taken from all suitable records for periods between half an hour after sunset and half an hour before sunrise. When a record showed no interference for some time, readings were taken every 12 min. The results of all these observations, in the form of equivalent aerial temperatures corrected for losses in the aerial system, are plotted against the sidereal time of observation in Figure 4. Although a contribution from atmospherics to the received noise powers plotted in Figure 4 cannot be completely ruled out, it is considered that any such contribution must be very small. This is confirmed by the fact that there is a marked sidereal diurnal variation of intensity in Figure 4, while intensities measured at roughly the same sidereal time at intervals of up to 4 months showed no systematic variation with season.

IV. Analysis

(a) *Corrections for Ionospheric Absorption*

Since the observations were limited to the night hours, and mainly to the period between midnight and half an hour before sunrise, absorption in the D region could be neglected. However, Mitra and Shain (1953) have shown that appreciable absorption of cosmic noise takes place in the F region when the critical frequency of this region, f_0F_2, is greater than about one-third of the operating frequency. There were insufficient observations to obtain a curve of absorption of 9·15 Mc/s cosmic noise against f_0F_2 and it was decided to use the results of the 18·3 Mc/s absorption measurements, assuming that F-region absorption depended only on the ratio of the operating frequency to f_0F_2. For example, Mitra and Shain found that absorption at 18·3 Mc/s, measured at Hornsby, was 0·4 db when f_0F_2 at Canberra was 8 Mc/s ; it was assumed that at 9·15 Mc/s the absorption would be 0·4 db when f_0F_2 was 4 Mc/s.

Values of f_0F_2 were taken from data issued by the Ionospheric Prediction Service of the Commonwealth Observatory in "Ionospheric Predictions—Series D". Where possible, the data for Canberra (lat. 35·3 °S., long. 149·0 °E.—about 250 km south-west of Hornsby) were used. Unfortunately, for observations during several months no Canberra data were available. At such times f_0F_2 at Canberra was estimated using the values observed at Brisbane (lat. 27·5 °S., long. 153·0 °E.—about 600 km north of Hornsby), and the trend of f_0F_2 with latitude indicated in "Ionospheric Predictions—Series W", also issued by the Ionospheric Prediction Service. Although this procedure introduces some uncertainty in the application of the corrections for ionospheric attenuation, it is not serious since in any case the corrections were all small, generally less than 10 per cent. Also attenuations calculated according to the above procedure using Brisbane data agreed well with values calculated directly from Canberra data when the latter were available.

The values of equivalent temperature shown in Figure 4, corrected where necessary for ionospheric attenuation, are replotted in Figure 5. The main part of the scatter of the points is due to the uncertainty of reading from the records. A smooth curve is drawn through the averages of all points within hourly intervals. The accuracy of the curve in Figure 5 is estimated to be better than 10 per cent. for relative values, except for the dashed section where it is somewhat less, and 20 per cent. for the absolute scale.

(b) *Comparison with Observations at Other Frequencies*

The curve in Figure 5 has features similar to those of corresponding curves for other frequencies. There is a pronounced maximum (near 18 hr) as the galactic centre passes through the aerial beam, and the minimum near 05 hr agrees with the positions found at 18·3 Mc/s and at 100 Mc/s. The values of equivalent aerial temperature are, however, considerably higher. Direct comparison with observations at other frequencies is not possible since the temperatures observed, especially near the maximum, would depend fairly critically on the aerial directivity. In a previous paper (Shain 1954) it was pointed out that the aerials used in surveys by Shain and Higgins (1954) at 18·3 Mc/s and by Bolton and Westfold (1950) at 100 Mc/s had main lobes of nearly the same shape, although the side lobe pattern was different in each case. In addition, Shain corrected the results of these surveys for the effects of side lobes. This gave contours of equivalent aerial temperature which would have been obtained if, at each frequency, an idealized aerial which had a single lobe, the shape of the main lobe in the two surveys, had been used.

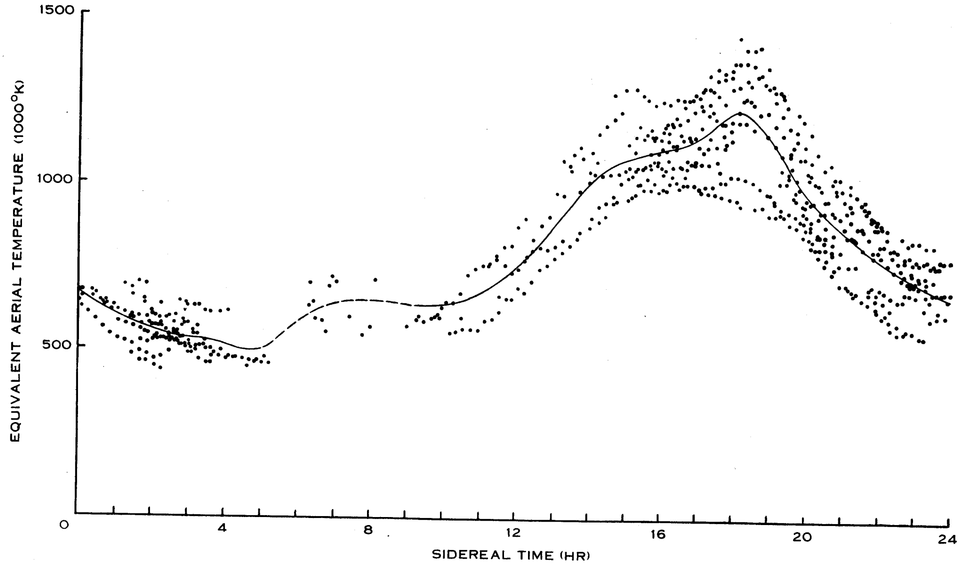

Fig. 5.—The observed equivalent aerial temperatures of Figure 4, corrected for the effects of ionospheric absorption. The curve is drawn through hourly averages, except for the dashed section between 4 and 9 hr.

The equivalent aerial temperature is the average, weighted according to the aerial sensitivity in different directions, of the brightness temperatures over the visible sky. If observed equivalent aerial temperatures are available for a single lobe aerial, aerial A, say, having a comparatively small beam width, it is possible to determine the equivalent temperature that would be observed by a broader-beamed aerial by taking suitably weighted averages of the equivalent temperatures seen by aerial A when pointed in appropriate directions. This procedure was adopted to obtain the equivalent aerial temperatures that would have been observed at 18·3 Mc/s and at 100 Mc/s with an aerial having the same directivity (including side lobes) and pointed in the same direction as that used for the 9·15 Mc/s observations.

Curves of the calculated equivalent temperature as a function of sidereal time for such hypothetical observations at 18·3 Mc/s and at 100 Mc/s are shown in Figure 6, together with the curve for observed 9·15 Mc/s equivalent temperatures taken from Figure 5. The scales of the curves have been adjusted so that the curves coincide near their minima.

Several points of interest in Figure 6 may be noted. The general shapes of the curves at the three frequencies are very similar, and the differences in shape show a progressive trend with frequency. The ratio of maximum to minimum temperatures decreases with frequency although the actual values of the equivalent temperatures increase rapidly as the frequency is lowered.

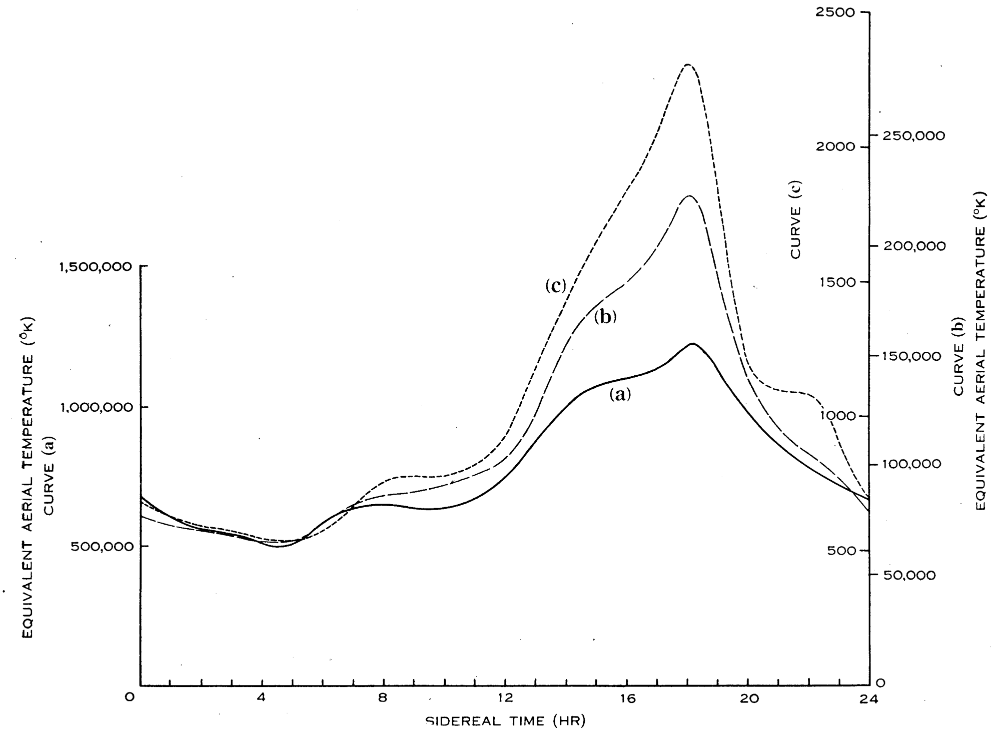

Fig. 6.—Comparison of equivalent temperatures at three frequencies. (*a*) Equivalent aerial temperature *v*. sidereal time as observed at 9·15 Mc/s (from Fig. 5). (*b*) Equivalent aerial temperature *v*. sidereal time to be expected at 18·3 Mc/s with an aerial similar to that used at 9·15 Mc/s; calculated from 18·3 Mc/s observations as explained in the text. (*c*) A similar curve to (*b*) but for 100 Mc/s.

Figure 7 shows the maximum and minimum equivalent temperatures and their ratio plotted against frequency using logarithmic scales. The points in Figure 7 (*a*) corresponding to the minimum temperatures are fitted closely by the relation.

$$T \propto f^{-2.8}$$

where T °K is the minimum equivalent temperature observed at a frequency f Mc/s.

The bump in each curve in Figure 6 centred on about 15 hr sidereal time is largely an instrumental effect, due to the side lobes of the aerial in the east-west plane, but it was found that, even after side lobe effects had been removed, small bumps were still evident on the curves for 18·3 and 9·15 Mc/s. Calculations showed that passage of the aerial beam over discrete sources previously observed at 18·3 Mc/s could account for these bumps at 18·3 Mc/s, and the presence of similar bumps at 9·15 Mc/s suggests that discrete sources are contributing appreciably to the radiation at 9·15 Mc/s. No accurate evaluation of source intensities can be made, but it appears that at 9·15 Mc/s they stand out against the background at least as clearly as at 18·3 Mc/s, possibly more so.

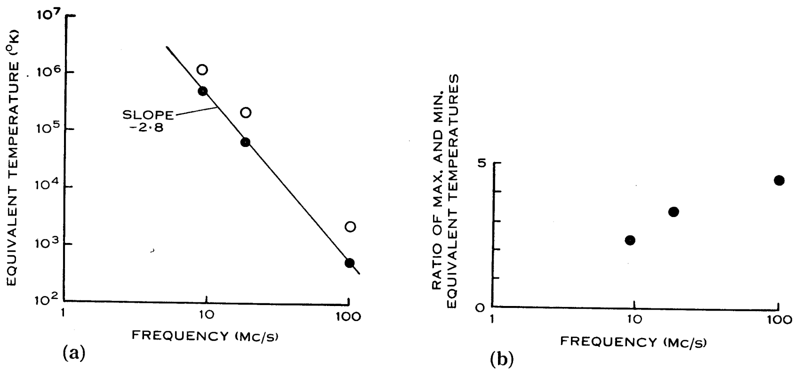

Fig. 7 (*a*).—Maximum (open circles) and minimum (full circles) equivalent temperatures (from Fig. 6) as a function of frequency.

Fig. 7 (*b*).—Ratio of maximum and minimum equivalent temperatures as a function of frequency.

V. Discussion

It is not proposed to compare in detail the observational results with the predictions of published theories of the origin of the cosmic noise. Qualitatively, at least, the 9·15 Mc/s results fit the assumptions of an origin in discrete sources together with an absorbing (at 9·15 Mc/s) disk of interstellar gas. Shain (1954) showed that certain differences in the brightness distributions at 18·3 Mc/s and at 100 Mc/s could be accounted for if absorption in interstellar gas occurred at 18·3 Mc/s towards the galactic centre. From Shain's results, it would be expected that near the galactic centre the optical depth for 9·15 Mc/s radiation would be greater than unity for latitudes within 10° of the galactic equator. This could then account for the comparatively low value of the maximum temperature at 9·15 Mc/s and for the different variation with frequency of the maximum and minimum observed temperatures. It may be noted from Figure 7 that at 9·15 Mc/s the observed temperatures are still increasing rapidly with decreasing frequency. The rate of change of the minimum temperatures with frequency is greater (numerically) than that of the maximum temperatures. Observations at low frequencies may even show that minimum equivalent temperatures occur towards the galactic centre rather than near the pole.

The absolute values of the equivalent temperatures are considerably higher than values deduced from the observations of Friis and Feldman (1937). Townes (1947) has shown that the maximum noise intensity observed by Friis and Feldman at 9·5 Mc/s corresponded to an equivalent temperature of only 120,000 °K. Although their aerial was not directed near the galactic centre, their maximum value is considerably less than the minimum value obtained in the present investigation. Their aerial had its maximum sensitivity at low angles and consideration of the ionospheric conditions at the time of their observations (Gilliland *et al.* 1937) indicates that the low values recorded by Friis and Feldman were due to ionospheric attenuation.

Since Friis and Feldman could measure cosmic noise with a communications-type aerial, it is of interest to compare received cosmic noise powers with the noise field strengths measured during the world-wide survey described by Horner (1953). These noise levels were attributed to atmospherics. After considering the effect of receiver noise on the measurements, especially during daylight when measured noise levels are low, due to absorption, Horner also briefly considered cosmic noise. He concluded that under the normal conditions of measurement its intensity was too low to be significant by comparison with receiver noise.

Using a relation derived by Pawsey, McCready, and Gardner (1951), we find that the typical value of equivalent aerial temperature due to cosmic noise of 10^6 °K corresponds to a noise field strength of 4 db below 1 μV/m for 10 kc/s bandwidth at 9·15 Mc/s. As an example of the noise levels measured in Horner's survey, the median noise levels at midnight throughout the year at Tatsfield, England, at 10 Mc/s, were within a few decibels of 10 db below 1 μV/m for 10 kc/s bandwidth (i.e. some 6 db below the typical cosmic noise level). From September to February the medians were even lower than 10 db below 1 μV/m. But these figures cannot be compared directly with the observed cosmic noise field strengths, since in Horner's survey vertical aerials, having maximum sensitivity at low angles, were used. Cosmic noise arriving at low angles will normally suffer considerable attenuation, and for large angles of incidence on the ionosphere it may be cut off completely. Under these conditions the cosmic noise levels measured with the vertical aerials would be much lower than the value given above. However, during the winter months at Slough, the mean midnight values of f_0F_2 were less than 3 Mc/s (Department of Scientific and Industrial Research 1953) so that at these times cosmic noise should not have been attenuated greatly, while the reception of atmospherics at 10 Mc/s would be poor. It therefore appears that, at least near midnight during winter, the measured noise level of 10 db below 1 μV/m was largely due to cosmic noise. In summer, of course, f_0F_2 was higher and atmospherics probably predominated.

This investigation will not be pursued in this paper, but it is apparent that for frequencies of about 10 Mc/s cosmic noise, at least at some times, makes a major contribution to the noise levels observed during the " atmospheric noise level " programme.

VI. Conclusions

Results have been presented of observations of cosmic noise at 9·15 Mc/s made with a fixed aerial which scanned a strip of the sky centred on Dec. $-32°$. Although, if possible, a detailed survey with a sharper aerial beam should be undertaken, the observations described in this paper should prove useful in checking theoretical models of the radio Galaxy. With the smaller ratio of maximum to minimum temperatures and the large magnitude of the equivalent aerial temperatures, they continue trends established from observations at higher frequencies and, at least qualitatively, they are in accordance with what would be expected on current theoretical ideas.

The high intensity of cosmic noise suggests that it will be necessary, at some times, to allow for a considerable cosmic noise contribution in measurements of atmospheric noise levels.

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