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FREQUENCY SPECTRUM OF COSMIC RADIO EMISSION IN THE FREQUENCY RANGE OF 10-207 MHz AT HIGH GALACTIC LATITUDES

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Frequency Spectrum of Cosmic Radio
Emission in the Frequency Range of
10-207 MHz at High Galactic Latitudes

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Herein are described antennas, apparatus, and techniques for measuring the frequency spectrum used by the authors in the frequency range of 40-207 MHz. In accordance with the measurements made the average spectral index of radio emission $\alpha = 0.57 \pm 0.04$ in the frequency range of 40-207 MHz. A comparison of the measurement results with the results of other authors indicate that as the frequency increases from 10 to 207 MHz the spectral index of distributed cosmic radio emission at high galactic latitudes changes relatively little.

The frequency spectrum of distributed cosmic radio emission is, as is well known, one of its basic features. A substantial amount of work has been published concerning measurements of this spectrum, but the results of the various measurements lacked good agreement up to recent times, thus hampering their application for theoretical studies. Below are listed some of the basic factors limiting the accuracy of absolute measurements of the intensity of cosmic radio emission and determining, consequently, the accuracy of measurements of the spectral index of radio emission.

1. It is difficult when using in the measurements relatively complicated antennas with a rather narrow diagram directivity to determine the losses in the antennas with the required accuracy.

2. When using antennas having a notable level of emission to the side lobes, there arises a need to consider the influence of the radio emission of the earth, which enters into the side lobes, on the measurement results.

3. As a rule, diode noise oscillators used for calibrating the receiver must, in turn, be calibrated with respect to the emission of a standard load ("black body") in harmony with the receiver. Such a direct calibration, however, is possible only in the range of relatively low noise temperatures ($T_n \lesssim 700°K$).

Measurements of the spectrum of cosmic radio emission, the results of which are listed below, were conducted in 1965-1966 at the NIRFI (Scientific Research Institute of Radiophysics, Gor'kiy State University im. N. I. Lobachevskiy). The measurement techniques were such that it was possible to reduce errors related to the factors enumerated above, which have an effect on the accuracy of the measurements, to an absolute minimum. Halfwave dipoles, elevated to a height of 0.25 λ above metallic screens, were used as receiving antennas. The side lobes were thus eliminated and the efficiency factor of the antennas was close to unity. It is felt in this case that the value of the spectral index, which was averaged for a significant part of the heavens, was determined, but, as is well known, the angular variations of the spectral index are insignificant in the region of high galactic latitudes.

The diode noise oscillators which were used for calibrating the receivers were themselves calibrated for the emission of film resistances of special construction, heated to a temperature of about 400°C. Power dividers of the measured cosmic radio emission were used during the measurements of the effective temperatures of the heavens on relatively low frequencies.

Several articles were very recently published which also deal with the measurement of the frequency spectrum of distributed cosmic radio emission [1-4].

The measurement techniques in these experiments were very similar to those used by the authors of this article. The comparison of the measurement results obtained at the NIRFI with the results of [1-4] enables us to draw rather complete conclusions concerning the spectrum of distributed cosmic radio emission in the range of 10-207 MHz at high galactic latitudes.

1. Antennas and Receiver

Simple halfwave horizontal dipole antennas, elevated to a height of about 0.25 λ above square metallic screens measuring 2 λ X 2 λ were used in the measurement of the spectrum of cosmic radio emission on frequencies of 40, 95, 151, and 207 MHz. The receiving dipoles were somewhat shorter than λ/2 and were about 0.45 λ in length, the dipoles having diameters of about 0.0037 λ. The metallic screens were made of conductors parallel to the dipoles, the distance between the dipoles equal to 0.013 λ. All receiving dipoles were oriented in the north-south direction. Since the inputs of the receivers were asymmetric, quarterwave coaxial pots were used for converting the symmetrical dipoles to an asymmetric feeder. The dipoles themselves and the quarterwave pots were silver-plated for the purpose of reducing losses.

The receiving antennas were of the relatively wide band type. The standing wave ratio of the antennas did not exceed 1.05 within the limits of the high frequency transmission bands of the receiver ($\Delta f/f$ was about 10^{-2} for all receivers). The parameters used for adjusting the antennas for the purpose of achieving the smallest possible standing wave ratios were the height of the dipoles above the screens (varying within the limits of 0.005 λ during tuning) and the length of the dipole (varying by about 0.003 λ). Modulated meters of the signals of the dense spectrum, manufactured in accordance with the block diagram illustrated in Figure 1, were used to measure the intensities of radio emission on all four fixed frequencies from 40 to 207 MHz.

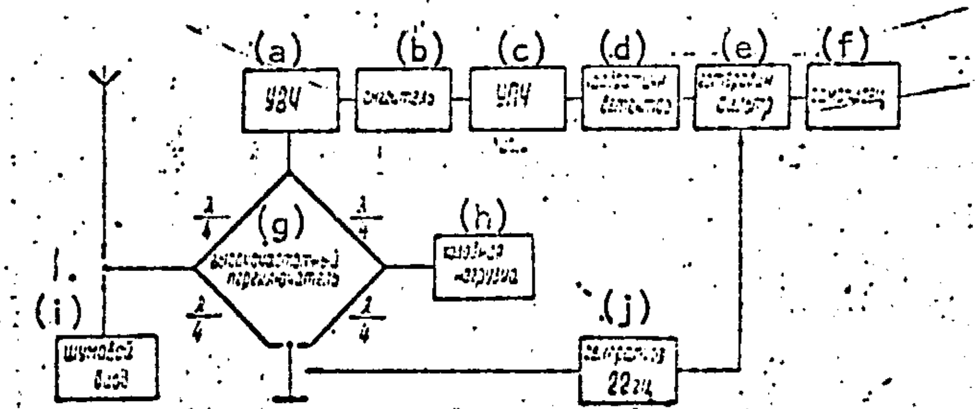

Figure 1

KEY: a, UHF; b, mixer; c, intermediate frequency amplifier; d, square-law detector; e, heterodyne filter; f, recorder; g, high-frequency switch; h, cold load; i, noise diode; j, generator, 22 Hz.

For the purposes of reducing the effect of interference instability on the measurement results the inputs of all receivers (high frequency amplifiers) were provided with a resistance of 75 ohms, which was equal to the halfwave resistance of the connecting leads and to the impedance of the antennas and noise oscillators. The noise coefficient of the receivers was thus close to 5 on all frequencies. The transmission band widths of the receivers, as noted above, were significantly less than the transmission band widths of the antenna-feeder channel, thus making it unnecessary to consider the features of the shape of the frequency characteristics of the antenna-feeder channel during the measurements.

All coaxial leads (the antenna leads and the leads to the noise oscillator and 75-ohm load) were of identical length (about 20 meters) and were subjected to identical temperature conditions. A 2D2S electron tube diode, mounted on a specially manufactured coaxial radio-frequency head, head, was used as the noise oscillator for calibrating the receivers. The diode noise oscillator was used as a secondary source of noise voltage for calibrating the apparatus during the measurements. The noise oscillator, in turn, was periodically calibrated with respect to the noises of the film 75-ohm resistance, which was applied on a glass base and installed in a special radio-frequency coaxial head and placed in a thermostat, the temperature of which could be raised to 450°C. This assembly was used, consequently, as the primary noise standard. It also incorporated every possible means for reducing heat liberation from the thermostat to an absolute minimum, thereby reducing the errors caused by uneven heating of the resistance.

The time constant of the equipment during the measurements was about three seconds. An additional averaging of the recordings, which resulted in a perceptible increase in the resultant time constant, was performed during the processing of the recordings.

2. Procedures and Measurement Errors

The measurements of the spectrum of cosmic radio emission were made in October and November of 1965. For testing purposes measurements were again conducted in October and November of 1966. The measurement procedures incorporated the continuous recording of the level of cosmic radio emission on the aforementioned fixed frequencies and periodic calibration of the receiver with respect to the signals of the diode noise oscillator.

Measurements were made each day from 5:30 a.m. to 12:30 p.m., astronomical time, on the frequencies of 207 and 151 MHz and from 8:30 a.m. to 1:30 p.m., astronomical time, on the frequencies of 95 and 40 MHz. Minimum radio emission was observed on all frequencies at about the same astronomical time, 11:30 a.m.

This astronomical time corresponds to the galactic coordinates l_{II} = 136° and b_{II} = +59°.

During the measurement of the level of radio emission the receiver was calibrated every 30 minutes with respect to the signals of the diode noise oscillator. During this time the noise oscillator was plugged into the input of the switch of the receiver in place of the antenna and a 75-ohm matching load at room temperature was placed on the other arm of the switch. On the frequencies of 40 and 95 MHz the measured effective temperatures of the sky, even in the region of minimum radio emission, were greater than the noise (room) temperature of the "cold" noise oscillator, with the result that the noise level of the oscillator could be turned all the way up to the level of cosmic radio emission during calibration.

The measured effective temperatures were always less than room temperature on the frequency of 207 MHz and in the region of least radio emission on the frequency of 151 MHz. Consequently, during the determination of the level of measured radio emission using the noise oscillator, the phase of the difference signal of the oscillator and the phase of the "cold" 75-ohm load plugged into the radio-frequency switch differed by 180° from the phase of the difference signal of the 75-ohm load and of the measured radio emission. In this situation we had to be certain that the switch and the heterodyne filter of the apparatus were completely symmetric with respect to the phase of the low frequency modulation of the measured difference signals. The necessary symmetrization was checked and adjusted frequently during the measurements.

As was noted in the preceding section, the diode noise oscillator was periodically calibrated with respect to the noises of the primary noise standard, the design of which was described above. In this case the standard resistance was heated to 300°C and its noises were compared with the readings of the diode noise oscillator. A comparison was made on all frequencies on which measurements were made. It was established during calibration that the noise signal of the diode oscillator was always greater than the theoretical value and the separation between the noises of the oscillator and the standard resistance is determined by the following coefficients: 40 MHz, 1.00; 95 MHz, 1.01; 151 MHz, 1.03; 207 MHz, 1.07.

It was naturally necessary during the absolute measurements, made in accordance with the procedures described above, to devote a great deal of attention to bringing about the equality of the impedances of the antenna, of the noise oscillator and of the equivalent load plugged into the input of the meter. In preparing for the experiment all of the elements listed above were carefully checked by measuring the standing wave ratio in the systems loaded by these elements (the standing wave ratios did not exceed 1.05 for all of the elements enumerated above). Moreover, a direct experimental check was made prior to the measurements for the absence of the various parasitic effects which could be attributed to the inequality of the impedances of the loads, oscillators, and antennas.

Much attention was devoted during the measurements to the measurement of the temperatures of the equivalent load and of the load of the diode noise oscillator. Furthermore, the equivalent load and the load of the oscillator were located in the very same holder so that their temperatures would always be about the same during the measurements. Turning our attention now to the evaluations of the measurement accuracy of the spectral index, let us examine first of all the systematic measurement errors.

1) Corrections for the amplitude and frequency characteristics of the diode noise oscillator were made with an error of $\Delta T/T$ not exceeding ±2% with respect to the noises of the heat standard and for the use of the power divider of the received signal on the frequency of 40 MHz. This error also includes those errors related to the recording inaccuracy of the signal levels from the readings of the output instruments (recorders) of the receiver systems, attributable, in particular, to the asymmetry of the switch and balance mixer, and also the systematic reading error of the anode current of the diode noise oscillator.

2) In determining the values of the effective temperatures of the heavens on the various fixed frequencies, we made corrections related to the absorption of the measured cosmic radio emission in the dipole antenna and to the balancing quarterwave pot (~ 1%) [5], as well as to the "percolation" of radio emission through the wire antenna reflector (~ 0.3%). It was assumed here that the finiteness of the dimensions of the screen did not involve appreciable errors, which is in conformity with the conclusions of [2, 3][1]. In spite of the fact that the systematic errors in the determination of the level of radio emission which are related to the consideration of absorption of radio emission in the antenna and in the reflector are, generally speaking, small, as we will see, it is, nevertheless, extremely difficult to make exact allowances for them. These errors can actually be considered to an inaccuracy of the order of magnitude of the error itself. We may thus consider that in the determination of $\Delta T/T$, the resultant inaccuracy related to the nonidealness of the antenna being used, and

[1] In carrying out the experiments described herein, a direct test was made when the dimensions of the screen were quite great. The dimensions of the screen have almost no effect on the level of recorded radio emission or on the value of the input resistance of the vibrator (standing wave ratio at the input of the vibrator depended greatly on the height of the vibrator above the screen).

for which allowances have not been made, is about ±1%.

3) Consideration of the absorption of cosmic radio emission in the ionosphere may have, according to evaluations already performed, an appreciable effect only on the frequency of 40 MHz, since the measurements made on this frequency in 1965 and 1966 were obtained during the night and morning hours, when ionospheric absorption is minimal. The greatest absorption during these hours should not exceed 2% on the frequency of 40 MHz for the dipole antenna being used in the measurements, having a wide diagram directivity, and on an average it should be about 1.5-2% less [6]. Consequently, the measured levels of cosmic radio emission were increased by 1%, while the inaccuracy not taken into account in the determination of $\Delta T/T$ on the frequency of 40 MHz barely exceeded 0.5%.

4) The analysis of the systematic inaccuracies, conducted by the authors and attributable to other factors (variation in the feeders leading to the antenna and to the noise oscillator, the presence of a reactive component in the input resistance of the antenna on the fringes of the transmission band of the receivers, etc.) indicates that they are negligible and may be disregarded when evaluating the accuracy of the determination of the spectral index.

Random measurement errors were caused by reading errors of the anode-current of the diode noise oscillator, by inaccurate consideration of the temperature differences of the "cold" load of the diode oscillator and of the 75-ohm equivalent load, by reading errors of the signal level on the recorder scale, by the effect of weather conditions on the measurement results, which were particularly notable on the highest frequency of 207 MHz, and so on. An accurate theoretical determination of all of these random errors involves a great deal of difficulty, and for this reason it is hardly necessary under the conditions of repeated measurements.

The construction of the histograms of the reproduction frequency of the various spectral indexes found by averaging the measured values of the radio emission intensities on two neighboring frequencies showed that they are described by a smooth bell-shaped curve approximating the normal distribution law of random values. The standard deviation from the mean (most probable) value of α according to measurements on, for example, the frequencies of 151 and 95 MHz was 0.015. The very same value was also obtained for the standard during the measurements on the frequencies of 40-95 MHz. A somewhat higher value, 0.04, was obtained for the standard by the determination of α according to measurement data on the frequencies of 151 and 207 MHz. Since α was measured repeatedly on the various frequencies and the standard random deviation from its mean value was rather insignificant, it may be considered when finding α according to the measurements on the frequencies of 151-95 and 95-40 MHz that the random errors may, for all practical purposes, be disregarded when finding the mean value of α. For instance, when α was determined for the frequencies of 151-207 MHz the mean value of α due to random errors was determined to an error of ± 0.005.

In summarizing the above statements relative to the measurement accuracy of the effective temperatures of the heavens during the specified measurements, it should be considered that the overall systematic error in the determination of the effective temperatures should be about 3 to 3.5%. As regards random measurement errors of the effective temperatures, they, as we have just shown, do not, because of averaging, involve notable error because of the large number of measurements, and they may therefore be disregarded.

3. Measurement Results

The mean values of minimal effective temperatures of the heavens on the appropriate frequencies, corresponding to astronomical time $11^h 30^m$ and to the galactic coordinates $l_{II} = 136°$ and $b_{II} = +59°$ are listed in the table below.

Table 1

Frequency (MH_z)	40	95	151	207
Effective Temperature (°K)	8480 ± 300	942 ± 30	284 ± 9	125 ± 4

The measurements on the frequencies of 151 and 207 MHz, as mentioned earlier, were made daily for a period of seven hours, whereupon the effective temperature varied by about 20% during the time of observation due to the rotation of the heavens. The most graphic representation of the variations in the effective temperature during the period of observations is illustrated by the graph shown in Figure 2, where the values of the effective temperature on the frequency of 207 MHz are arranged along the abscissa and the values of the temperatures corresponding to the same period of time on a frequency of 151 MHz are arranged along the ordinate. The experimental function, as shown by the graph, is rather well approximated by a straight line, which is evidence of the lack of significant angular variations of the spectral index when using a receiver of diagram directivity with respect to the heavens during the time of observation. Analogous functions can be constructed for any other pair of frequencies on which measurements were made. These functions are entirely analogous to the graph illustrated in Figure 2. The range of variations in effective temperatures represented by the graph in Figure 2 is, unfortunately, too narrow to enable them to be used for the separation of galactic and metagalactic radio emission components in accordance with the method outlined in [7]. We will notice furthermore that if we continue the straight line in Figure 2 in the direction of low effective temperatures, it will pass approximately through the origin of the coordinates. Thus the function represented in Figure 2 is indisputable evidence of the lack of a significantly large isotropic component of radio emission.

Figure 3 illustrates the frequency spectrum of cosmic radio emission in logarithmic scale as constructed according to data of effective temperatures listed in the table and converted to the values of the intensity of distributed cosmic radio emission. The limits characterizing the accuracy of the measurements are represented in the figure by the vertical marks.

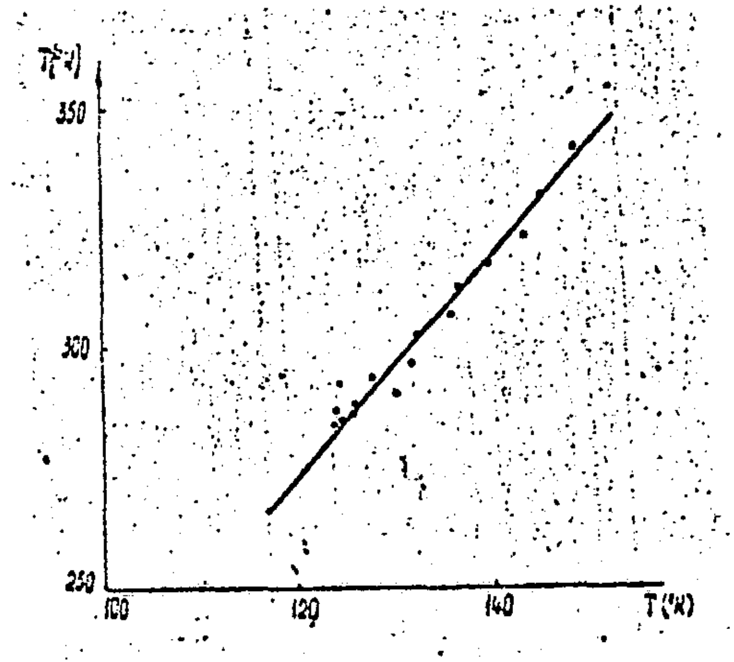

Figure 2

The slope of the frequency spectrum, as shown by Figure 3, and consequently, the spectral index characterizing this slope are almost identical through the entire range of frequencies from 40 to 207 MHz. By generally disregarding the variation of α in this frequency range, it is not difficult to determine from the graph or table that $\alpha = 0.57$ and that the error of this value $\delta\alpha = \pm 0.04$. Furthermore, there is probably some tendency of the spectral index to increase in passing from the low frequencies to the high frequencies. Thus, for example, if the value of the spectral index on frequencies in the area of 40 MHz is found using the graph in Figure 3, it is found to be equal to 0.54, while on the frequencies near 200 MHz the spectral index is 0.62. Such variations in the spectral index are always within the limits of the measurement error, but they reflect, in all probability, the natural tendency of the spectral index to decrease in passing from the relatively high frequencies of the UHF frequency range to the relatively low frequencies.

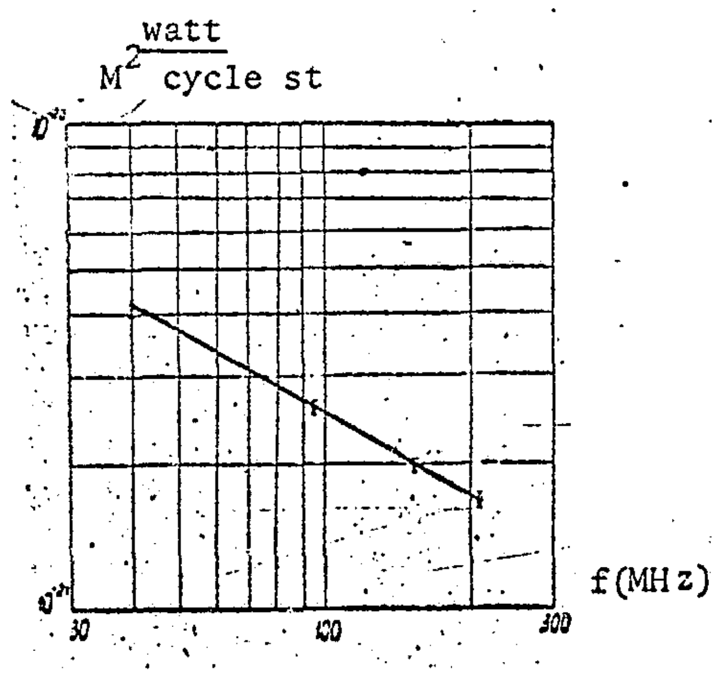

Figure 3

4. Comparison with Results of Other Authors. Conclusions

The comparison of the results obtained in this work with the results recently obtained by other authors is of notable interest. In 1964 Yu. S. Korobkov of

NIRFI measured the frequency spectrum of cosmic radio emission in the frequency range of 40-6.3 MHz in the region of the Milky Way, with central coordinates of $l_{II} = 98.5°$, $b_{II} = -5.3°$ [1]. A direct accurate comparison of the effective temperatures found in [1] with those obtained in this work is not possible, since the measurements were made with antennas of differing design and are related to different sectors of the heavens. As regards the spectral indexes of radio emission intensity, however, according to Yu.S. Korobkov, $\alpha = 0.5 \pm 0.2$ on the frequency of 40 MHz, which conforms with the results of this article. As the frequency is reduced, according to [1], the spectral index drops smoothly to $\alpha = 0.4$ on $f = 18$ MHz and $\alpha = 0.2$ on $f = 13$ MHz[1].

In the recently published work of Andrew [3], the spectrum was measured in the frequency range of 10-38 MHz. These measurements relate to the region of high galactic latitudes of the northern galactic hemisphere and were made with simple dipole antennas similar in design to the antennas used in this work. Andrew, on the basis of his measurements, gives the spectral index $\alpha = 0.43 \pm 0.03$ for the 38-10 MHz range. By combining data on radio emission intensities which

[1] The authors of this work undertook, in 1966, preliminary measurements of the intensities of cosmic radio emission on 18 and 25 MHz on a horizontal dipole antenna in the region of high galactic latitudes and obtained a spectral index $\alpha = 0.6 \pm 0.2$. We should stress once again that these measurements were of a preliminary nature and their accuracy is rather low.

Ye. A. Genediktov had the generosity to furnish the authors with unpublished experimental curves for the relative value of the level of distributed cosmic radio emission on various fixed frequencies of the decameter band, attributed to the motion of the heavens relative to the vertical directivity diagram of the receiver antennas used by Yu. S. Korobkov for measuring the spectrum. Using these curves the authors transformed the measurement results of Yu. S. Korobkov in the region of high galactic latitudes $\alpha = +59$ and found the spectral index $\alpha = 0.6 \pm 0.2$ for the 9-40 MHz frequency band. In every case, in spite of the relatively low accuracy of the measurements of α in the decameter band, these measurements show that $\alpha \gtrsim 0.4$ for decameter waves.

he obtained for the frequencies of 38-10 MHz with Purton's data [4], Andrew affirms that $\alpha = 0.43 \pm 0.03$ in the broad frequency range of 10-178 MHz in the region of high galactic latitudes of the northern galactic hemisphere, where α increases slightly with increasing frequency and is reduced somewhat on the relatively low frequencies.

According to the data in [2] the spectral index of radio emission intensity on the high galactic latitudes in the southern hemisphere in the frequency range of 14.1 to 85 MHz varies from 0.51 (+0.15 - 0.05) on the high frequencies to 0.3 ± 0.2 on the low frequencies. The measurements in [2] were made with simple dipole antennas similar to those used in our work.

In [4] Purton revises the measurement results of Turtle and his coauthors, according to whom the spectral index in the northern galactic hemisphere changes sharply in the frequency range of 40 to 178 MHz, increasing with frequency from 0 to 0.9. By making the corrections for the frequency characteristic of the diode noise oscillator used in [7] for calibrating the apparatus, Purton concludes that the spectral index is more or less constant in the frequency range of 13-100 MHz and is equal to 0.38 ± 0.05, increasing to $\alpha \approx 0.9$ on a frequency of about 400 MHz. The data of [8], according to whom $\alpha \approx (0\text{-}0.28)$ in the 10-30 MHz range, while in the 30-50 MHz range $\alpha \approx (0.6\text{-}0.77)$, are in sharp disagreement with Purton's results and with the results of our work.

On the basis of published data and data obtained in our work, it is possible, as we see it, in spite of the significant diversity of the values for the spectral indexes as measured by the various authors, to draw a rather concrete conclusion concerning the nature of the frequency spectrum of distributed cosmic radio emission in the region of relatively high galactic latitudes.

In the wide frequency range of approximately 10-207 MHz, the spectral index α changes little, and $\alpha \approx 0.57 \pm 0.04$ in the 40-207 MHz range. On the lower frequencies ($f \approx 10$ MHz) α is probably somewhat less, but is known to be $\alpha \gtrsim 0.4$[1]. This general conclusion is in particularly good agreement with results of earlier spectral measurements of cosmic radio emission completed by Adgie and Smith [9], and also by Baldwin [10].

From the standpoint of future measurements of the frequency spectrum of distributed cosmic radio emission on relatively high galactic latitudes, the authors feel that the measurements of relatively small angular variations of the spectral index and measurements of the spectral index in the decameter wave band will be very important.

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[1] It should be noted, however, that [2-4] discuss α for galactic radio emission. But in this work the spectral index was measured for the complete radio emission.

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