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A SURVEY OF THE RADIO BACKGROUND AT 38 MHz

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SUMMARY

The Jodrell Bank Mark I radio telescope has been used to survey the northern sky at a frequency of 38 MHz, with a beamwidth of 7·5°. The map is intended for comparisons of the spectral indices of various features of Galactic radio emission.

1. INTRODUCTION

Surveys of the long wavelength radio emission from the Galaxy have usually been made either with a very poor angular resolution, typically about 30°, with the intention of determining accurate spectral indices (e.g. Purton 1966; Bridle 1967), or with narrow pencil beams, typically about 1°, using unfilled apertures or synthesis telescopes (e.g. Williams, Kenderdine & Baldwin 1966). The surveys with high resolution are intended to delineate small features, and they are generally not reliable for large-scale structures. It is therefore difficult to use them in determining spectral indices of the Galactic plane and structures such as the Galactic spurs. The present survey used a steerable reflector telescope in which the beam was well defined and the sidelobes were small. It is therefore suitable for comparison with similar surveys at higher frequencies, and in particular in measurements of the differences of spectral index between different regions of the sky.

A previous survey at 404 MHz (Pauliny-Toth & Shakeshaft 1962) has a very similar resolution, and a comparison may therefore be made fairly directly between various features which appear in both surveys. The 404 MHz survey was, however, considerably undersampled, and reference should therefore also be made to the fully sampled map at 408 MHz of Haslam, Quigley & Salter (1970), which covers half the survey area, and which has been convolved to the same angular resolution. Further coverage of the sky with a similar resolving power is provided by the survey at 30 MHz with the 210-ft radio telescope at Parkes (Mathewson, Broten & Cole 1965), which covers declinations −90° to 0° with a beamwidth of 11°.

2. TECHNIQUES

2.1 *Antenna*

A crossed dipole feed was used at the focus of the Mark I 250-ft radio telescope. The base of the focus cabin provided a reflector plane about 4 m square for the feed: this was supplemented by the addition of four quarter-wave unipoles extending from the reflector plane, parallel to the feed dipoles. Left hand circular polarization was used, the dipoles being connected to the receiver through a hybrid network.

The beam pattern cannot be measured easily by observing celestial sources, since the main beam is comparatively wide. The whole of the beam pattern, including the distant sidelobes, was therefore measured using the Mark III radio telescope, 24 km distant, as a receiver, and Mark I as a transmitter. Large signals could then be used, and the sidelobe levels could be measured by adjustment of attenuators in the signal generator. The main beam pattern was also measured in a similar way by receiving a transmission from a dipole fed by a signal generator, situated 2 km from Mark I.

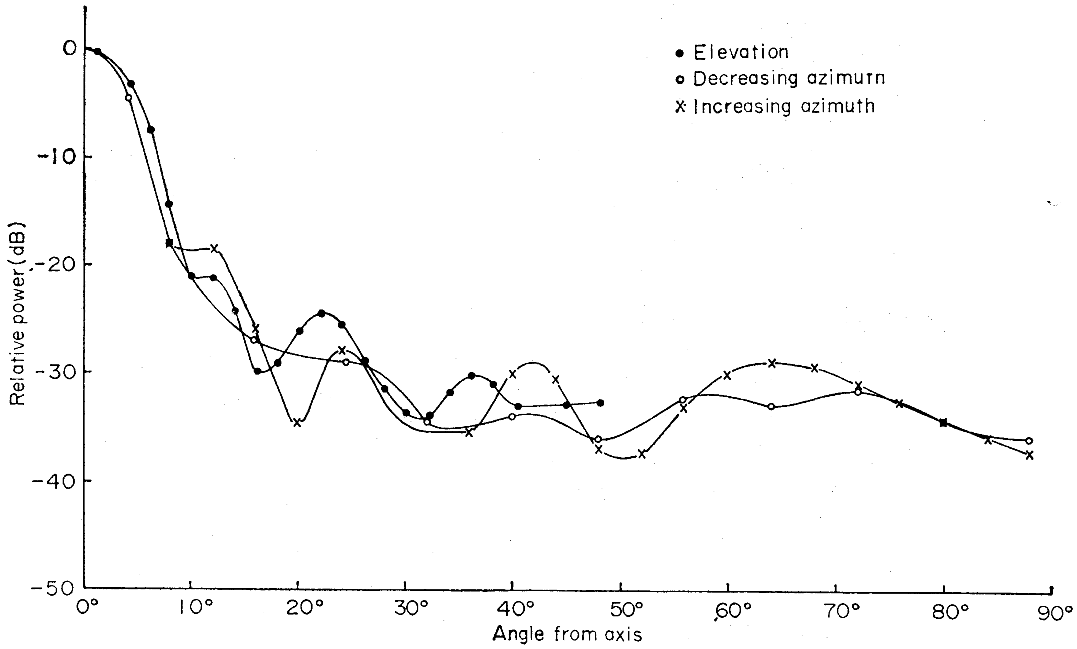


FIG. 1. *The orthogonal power polar diagrams of the Mark I radio telescope at* 38 *MHz*.

These measurements may be affected by reflections from the ground, but the following reasons lead us to believe that the effects can be neglected:

(i) For both measurements the main beam shape measured by an azimuth movement of Mark I was the same, and it was smooth and symmetrical to a level 18 dB below the beam centre.

(ii) The difference in paths between the direct ray path and a ray reflected in an ideal smooth ground is very small, and does not change as the telescope direction changes. In practice the reflected ray is probably unimportant, due to absorption in trees and other topographical features.

(iii) The main beam half-power beamwidth measured in this way was identical to that measured on Cyg A.

The sidelobes were measured carefully over two perpendicular great circles, with a partial coverage of the rest of the sky. Only one half of the polar diagram was investigated; the other half is not accessible to a ground-based transmitter.

The orthogonal beam patterns obtained using the Mark III telescope, are shown in Fig. 1. They are represented well by Gaussian curves down to about 18 dB. The half-power beamwidths are 7° in azimuth by 8° in elevation. The outer sidelobe level in the forward hemisphere does not exceed 28 dB below the maximum response, and is negligibly small over the backward hemisphere. The smoothing process which was applied in the data reduction changed the half-power beamwidth to $7\frac{1}{4}° \times 8\frac{1}{4}°$. Assuming the average power pattern to be well represented by the mean of those in the two orthogonal planes, the proportion of power received by the final main beam, out to 10°, is 83 per cent, the sidelobes in the forward hemisphere account for 16 per cent, distributed fairly uniformly, and 1 per cent is in the backward hemisphere.

2.2 *Receiving system*

The main problem in surveys at low frequencies is the recognition and rejection of spurious signals. These may range from natural meteorological phenomena, such as charged rain or distant lightning discharges, to various man-made signals, such as H.F. communication signals reflected in the ionosphere, power lines discharge or interference from industrial heating apparatus. The recording technique is therefore based on pen recordings lasting several minutes for each beam area, followed by hand analysis.

A switched receiver was used, in which the output of a noise diode was compared with the signal in the antenna. The receiver bandwidth was 1 MHz, and the gain was controlled automatically so that the mean detected power level was constant. The noise diode current was controlled by hand, so that the system was always nearly in balance. The difference was recorded, and the sensitivity of this recording was determined by measurement of the step on the recording which appeared whenever the diode current was adjusted (Fig. 2).

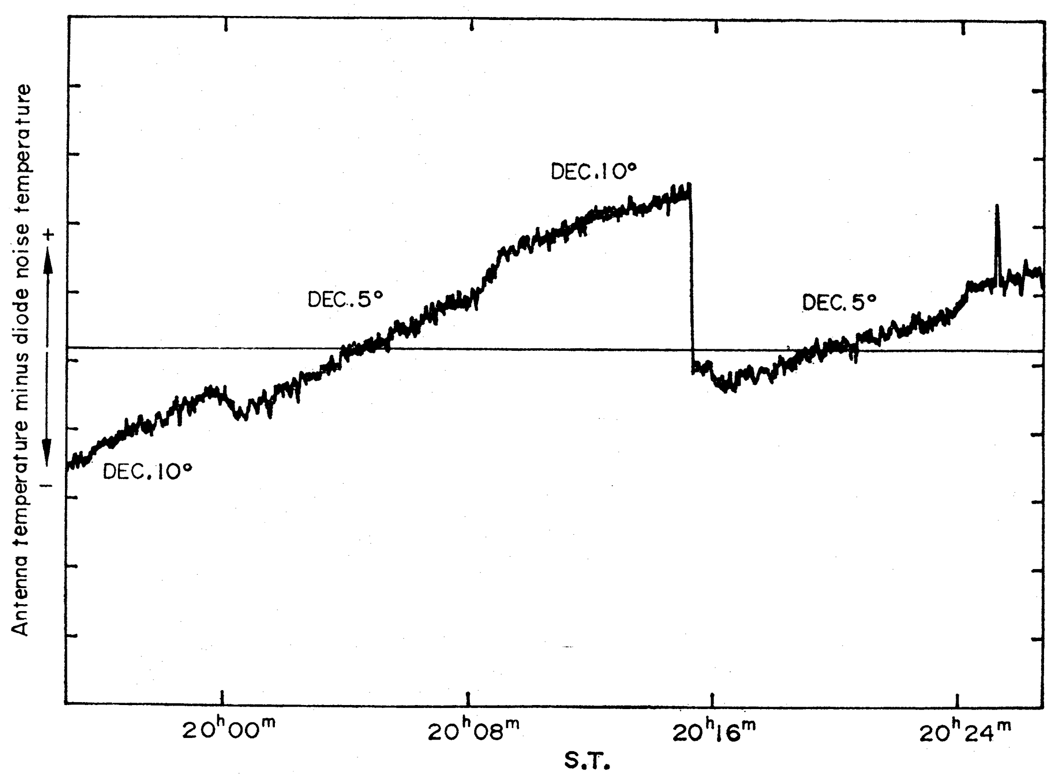


FIG. 2. *A recording of the difference in noise temperature between the antenna and the diode noise source. The central line marks zero difference. The declination was changed in* 5° *steps at intervals of* 8 *min; at* 20^h15^m *S.T. the diode current was adjusted from* 6·0 *ma to* 5·0 *ma to keep the difference in noise temperature small. The step corresponding to the change of diode current was used to calibrate the scale of differences in noise temperature.*

The receiver was calibrated by substituting a diode noise generator for the antenna connection at a point where the antenna losses were negligible, and subsequently comparing this generator with a standard coaxial diode noise source. Although no special precautions were taken, we believe our calibration of antenna temperature is correct to 5 per cent.

3. OBSERVATIONS

The survey covered the sky between declinations $-25°$ and $+70°$. The radio telescope was mainly used as a transit instrument, fixed at azimuth 180°, so that any corrections for ground reflection would be a function of declination only. Adequate sampling is obtainable from declination strips 5° apart; two strips were covered each day by stepping in declination at 8-minute intervals. This comparatively slow cycle was decided on after some experimentation in recognition and rejection of various interfering signals.

Occasionally the telescope was directed to the North Celestial Pole (NCP) as a check of the zero level of the survey. Some continuous scans through the whole range of declination were also made to check the relative sensitivity and zero levels of the normal scans.

Most observations were made during January 1967. These included most of the calibrations and the reference to the NCP. A second series of observations at night time in April and May 1967 completed the coverage of the sky. These were not calibrated accurately, and the two parts of the map were joined by finding a scale factor which provided the best fit within the common 12 hr of right ascension.

4. DATA REDUCTION

The recordings were first used to produce temperatures on a grid of points along lines of constant declination, at intervals of 4°. These points were then used in a contour plotting programme to produce maps, which were not corrected in any way for the effects of the beam sidelobes. These maps are shown in Fig. 3(a) and (b). The contour interval is 400 K away from the Galactic plane and at wider intervals at low Galactic latitudes. The contour map in Galactic coordinates is shown in Fig. 4.

5. THE ACCURACY OF THE SURVEY

5.1 *Stability of gain and zero level*

The stability of the apparatus is effectively tested by comparisons between repeated observations of the same declination strip and of the NCP. Over most of the surveyed area these comparisons showed that the standard error on an individual measurement was about 300 K or 5 per cent, whichever is the greater. For some areas, particularly in the range of R.A. 22^h to 06^h no comparisons were possible, but we have no reason to doubt the validity of the data.

There were 37 references to the NCP, distributed throughout the January observations. Apart from those which were obviously affected by interference, these measurements gave antenna temperatures distributed normally about a mean, with the value $T_a = (9{\cdot}09 \pm 0{\cdot}06) \times 10^3$ K, where the stated standard error of the mean represents only internal consistency.

With this evidence of stability, we found no necessity to apply scaling factors to our measurements.

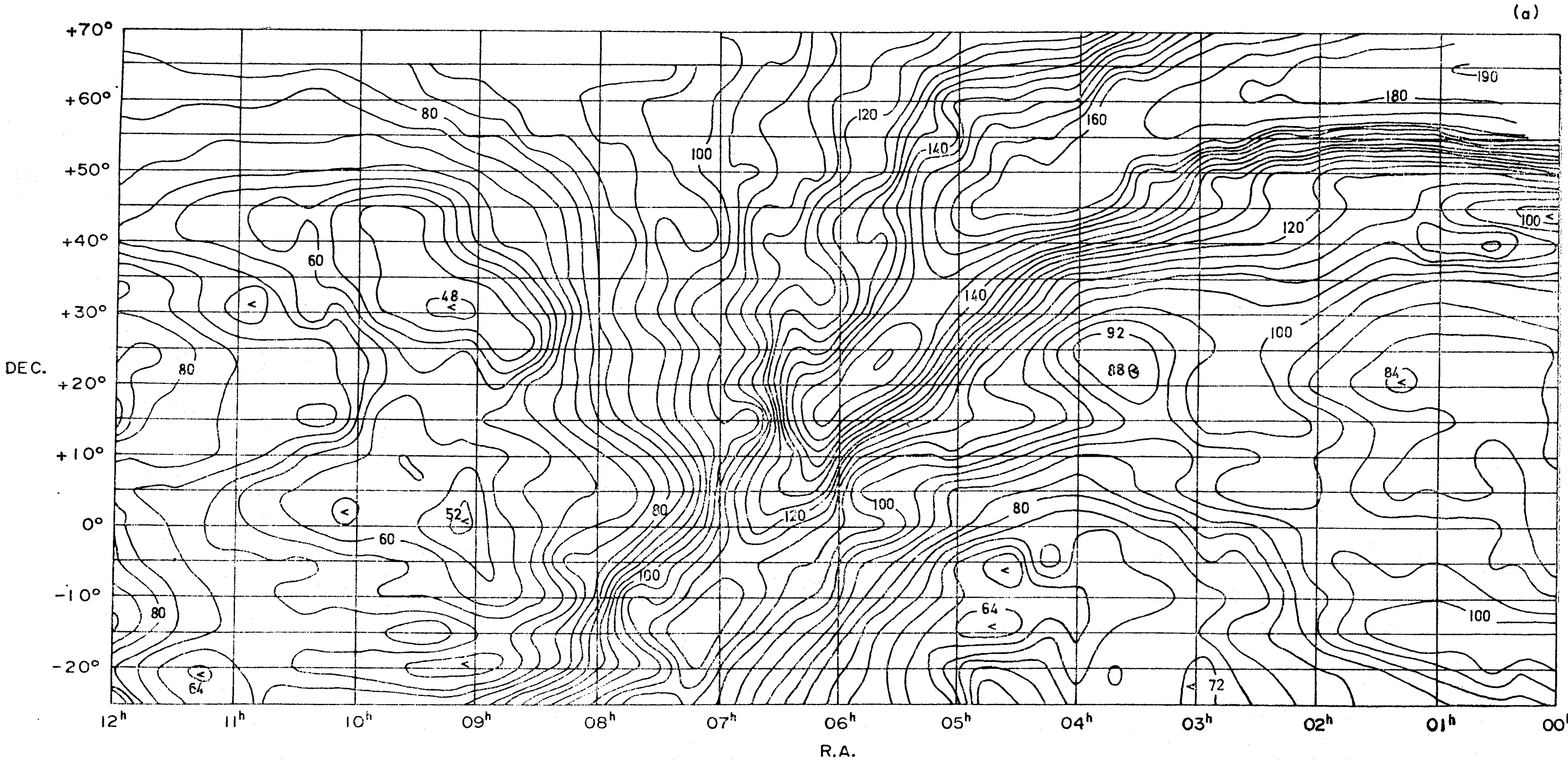
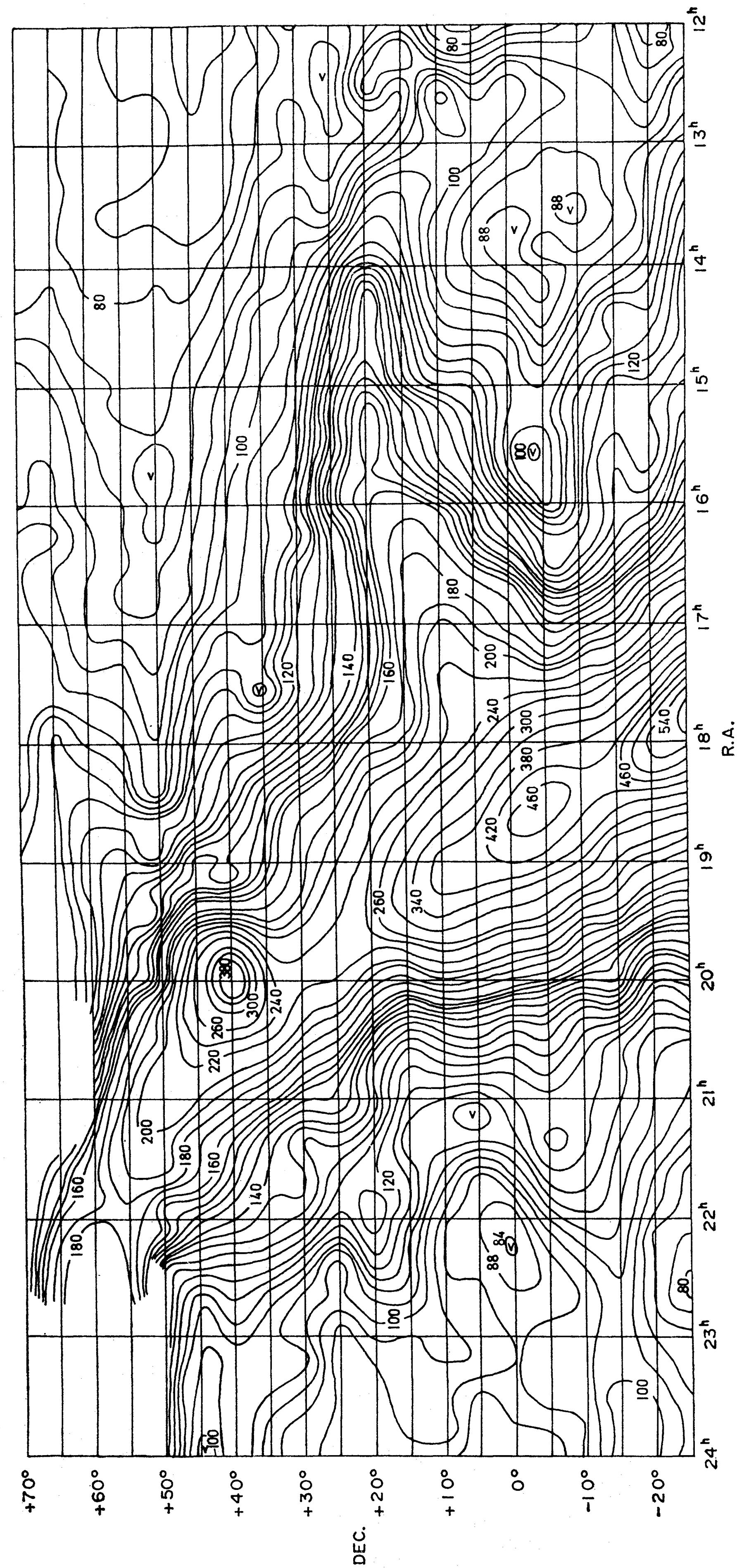


Fig. 3(*a*) *and* 3(*b*). *Contour map of antenna noise temperature, in units of* 100 K. *The contours are plotted every* 400 K *starting from the lowest temperature up to* 16 000 K, *every* 1000 K *between* 16 000 K *and* 20 000 K, *every* 2000 K *between* 20 000 K *and* 26 000 K *and every* 4000 K *above* 26 000 K. *The contour interval is chosen to represent generally the reliability of the map, except in the areas* 3^h < *R.A.* < 5^h, *Dec.* < 0°; 0^h < *R.A.* < 1^h, *Dec.* ≈ 40°; 16^h < *R.A.* < 18^h, *Dec.* > 50°; *and* 12^h < *R.A.* < 13^h, *Dec.* ≈ 15°, *where the observations were less accurate.*

(b)


R.A.
DEC.
12h
13h
14h
15h
16h
17h
18h
19h
20h
21h
22h
23h
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+70°
+60°
+50°
+40°
+30°
+20°
+10°
0°
-10°
-20°

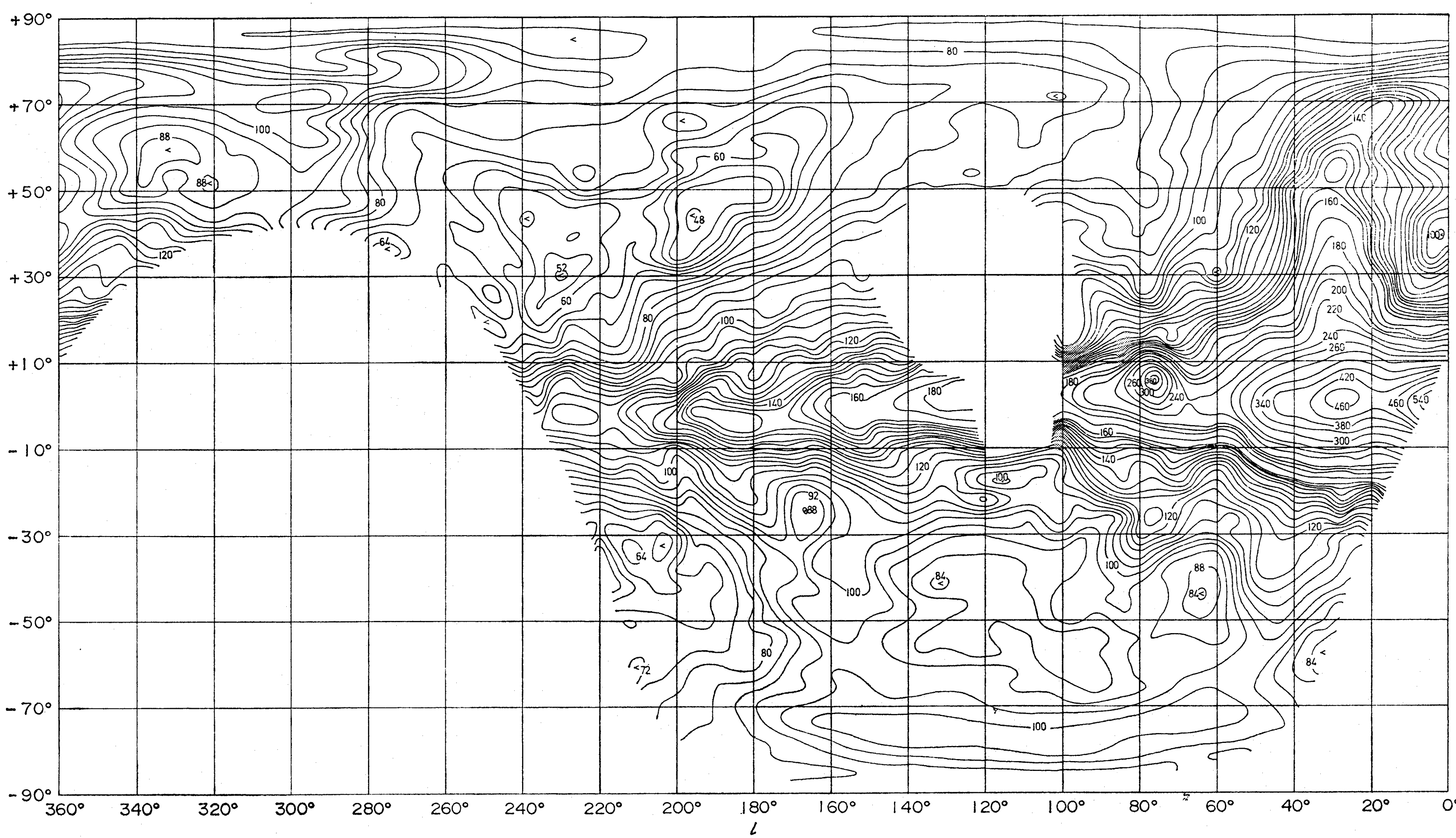

FIG. 4. *Contour map of antenna noise temperature in Galactic coordinates, in units of 100 K.*

5.2 *The effects of sidelobes*

The smoothing effect of the main beam is best taken account of in spectral work by convolving all surveys to the beamwidth of the survey with poorest resolution. The sidelobes are more difficult to correct for, and some examples of their effects may be helpful.

Discrete sources cannot give rise to noticeable spurious features on the map except within a distance of about 15° from the source. Sidelobe responses to the strongest source, Cas A, reach an antenna temperature of less than 100 K beyond 15° distance.

Examples of the differences between antenna temperatures and main beam temperatures due to the sidelobe contribution of a beam closely similar to that of the present survey are seen from the work of Pauliny-Toth & Shakeshaft (1962). These differences are largest within about 20° of the Galactic plane. An extreme example of sidelobe response in the 38 MHz survey is given by the point $l = 40°$, $b = 0°$, where the measured antenna temperature is 40 400 K. The main beam temperature at this point corrected for sidelobes is 44 750 K.

Radiation from the sky entering the sidelobes after reflection from the ground will constitute a small fraction of the measured antenna temperature. Computations show that there are no serious effects from ground reflection for elevations above 15°. The contribution of reflected radiation is estimated not to exceed 2 per cent at any point.

5.3 *Ionospheric absorption*

Although the effects of ionospheric absorption were unimportant in most of our observations, some correction is necessary for those parts of the sky which were observed in the daytime. Schwentek & Gruschwitz (1970) have made direct 'riometer' measurements of ionospheric absorption at 27·6 MHz. They attribute most of the absorption to the D and E regions of the ionosphere, and almost none to the F region, so that night-time observations are practically free from absorption. We have used their measurements directly, since they were made at Lindau, at the same latitude as Jodrell Bank and only 12°.4 further east. They used a fixed corner reflector antenna, with a half-power beamwidth of 58°, directed towards the North Celestial Pole.

Their measurements for January 1967 have been used to compute the absorption at 38 MHz, on the assumption that the absorption varies as the secant of the zenith angle, with no difference between northern and southern latitudes. The difference in observing frequencies was compensated for by reducing the absorption by the factor $(27 \cdot 6/38)^2$.

The results of this computation are presented as contours of equal absorption overlaid on the map of antenna temperature (Fig. 5). The map itself has not been corrected for absorption.

Over much of the map, and particularly at high declinations, the computed absorption is less than 1 per cent and is thus completely negligible. It reaches 5 per cent over a considerable area of the map, and in a small region at the lowest declination it exceeds 20 per cent. We suggest that these corrections should be made before studying spectra of this part of the sky; but we point out that their validity depends on the assumption that the mean absorption for the month at Lindau can properly be used in the way we have described. Any differences between the

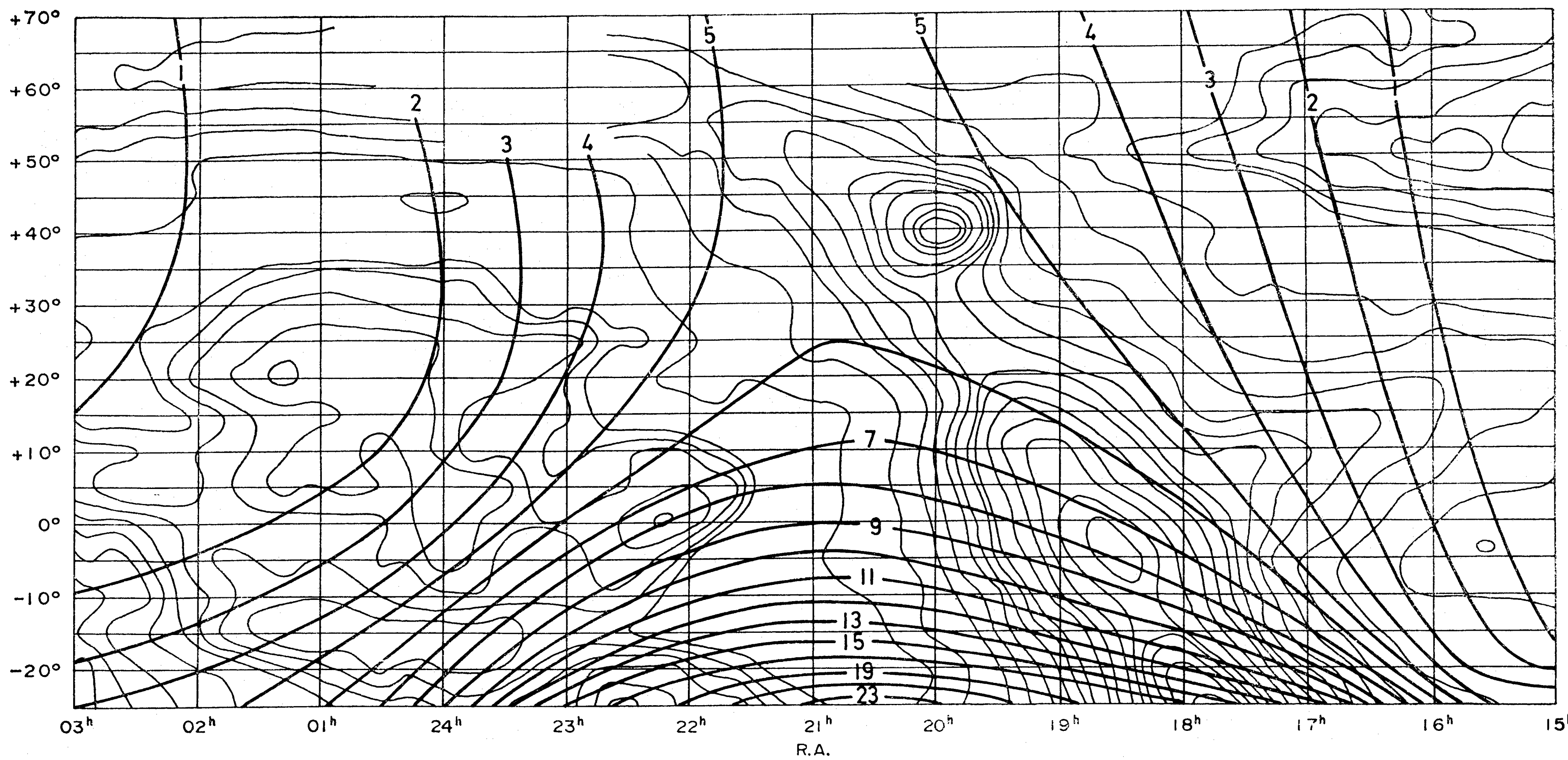

Fig. 5. *Contours of equal percentage absorption overlaid on the map of antenna temperature.*

predicted and true absorption are expected to be greatest at the lowest declinations.

Some support for our computation of the magnitude of ionospheric absorption was obtained by following two areas of sky, at R.A. 22^h and 10^h, both at Dec. = 0°, through a range of elevations. The first area was observed in the day-time, and the second at night. No change in antenna temperature was observed at night time in interference free intervals over a period of 10 hr, during which the elevation changed from 37° to 15°. Below elevation 15° both recordings were strongly affected by interfering signals. Above this elevation the effect of daytime absorption was seen as the first area moved from elevation 33° to elevation 15°; during this observation the antenna temperature fell by 4·5 per cent, as compared to a computed absorption of 4·8 per cent. Comparison of April data with January data demonstrates the presence of absorption following the contours of Fig. 5. Thus we are able to conclude that the computations of absorption are reasonably correct and also that there are no serious contributions from ground reflections for elevations above 15°.

6. DISCUSSION

Attention is directed to the main features of Galactic radio emission which appear on the maps or can be derived from them.

(i) The emission from the plane. Although this has a very similar width and position to the plane on the maps at 404 MHz, a detailed comparison shows that considerable absorption by ionised hydrogen occurs at 38 MHz on the Galactic plane. This is especially so for $l < 20°$ and for the Cygnus X region.

(ii) The spurs and arcs of emission already delineated by Large, Quigley & Haslam (1962), Quigley & Haslam (1965), Berkhuijsen, Haslam & Salter (1971) and Berkhuijsen (1971) are very distinct on the 38 MHz maps. These features are:

R.A. = $2^h.5$, Dec. = 30° to R.A. = 21^h, Dec. = −5° (Cetus Arc)
R.A. = 3^h, Dec. = 45° (possible continuation of Loop III)
R.A. = 5^h, Dec. = 15° (negative latitude spur at l = 185°)
R.A. = 5^h, Dec. = 60° (Loop III)
R.A. = 8^h, Dec. = 15°
R.A. = 17^h, Dec. = 10° (North Polar Spur)
R.A. = 19^h, Dec. = 55° (Loop III)
R.A. = 22^h, Dec. = 20°

A spur at R.A. = $22^h.5$, Dec. = 40° was pointed out by Milogradov-Turin (1972) to be a possible continuation of Loop III. A further discussion of the geometry of these spurs is given by Milogradov-Turin (1970). These features have differential spectra between 38 MHz and 404 MHz which are steeper than that of the underlying background radiation.

(iii) Away from the Galactic plane the temperature spectral index, β, of the total background radiation between 38 MHz and 404 MHz varies very little, lying generally between 2·48 and 2·58. For example, the value of β obtained for the North Galactic Pole is $2{\cdot}56 \pm 0{\cdot}05$. The spectrum of the total radiation at this point was found by Bridle (1967) to follow a power law of index $2{\cdot}55 \pm 0{\cdot}04$ between 13·15 MHz and 404 MHz.

The results of detailed analyses of spectral index will be published separately.

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