

II. RADIO ASTRONOMY*

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A. PULSAR SEARCH

Some long-drift scans have been carried out, using the Arecibo 1000-ft dish. The primary observing frequency was 430 MHz, with additional information taken at 195 and 611 MHz in some regions. In all cases, the final time constant used was 0.2 sec. Drifts were taken at intervals of 10 minutes of arc from declination 23° to 25° in the region of the sky $15^{\text{h}}-0^{\text{h}}-3^{\text{h}}$. The scan spacing was slightly larger than one-half beam-width at 430 MHz.

From visual inspection of the analog records, it is possible to state that no periodic pulses with peak amplitudes greater than approximately 2×10^{-26} W/m²-Hz were observed. When observing at 430 MHz a given point in the sky was in the 16 minute of arc half-power beam for approximately 1 minute. Because of the apparently random slow fading or scintillations of the pulse amplitudes occurring with periods of several minutes, pulses from some of the known pulsars are sometimes not above the level for visual detection set in these observations for approximately 10-25% of the time. It is possible, therefore, that the amplitude of an unknown pulsar could have been below the limit for detection while the source was in the 430-MHz beam. For regions where observations were simultaneously made at 195 MHz, the chance of missing a source because of fading is much lower. The source would have been in the 195-MHz half-power beam for nearly 2 1/2 minutes. It has also been noted that fading on widely separated frequencies is often uncorrelated, and thus it is unlikely that both 195- and 430-MHz signals should suffer fading over the same period of observation.

This study is continuing.

R. M. Price

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B. PULSAR FACILITY

The announcement, in February 1968, of the discovery of a new class of radio sources by Cambridge University investigators¹ has caused considerable interest among radio astronomers. These radio sources are characterized by short pulses of radiation with a highly constant repetition frequency (of the order of one part in 10^8) and are thus called "pulsars." The time of arrival of individual pulses varies with observed radio frequency. The pulses arrive later on lower frequencies than higher, because of the relative delays in propagation at different frequencies caused by electrons in the interstellar medium along the line of sight to the source. It has been postulated that the pulsars are associated with either white dwarfs or neutron stars.

In order to study these peculiar radio sources (of which 9 are now known) and to conduct a systematic search for new pulsars, we have undertaken the building of a large, low-frequency antenna. The best site readily available for the location of the antenna was an open field adjacent to the MIT-LNS LINAC project under construction in Middleton township approximately 20 miles north of the M. I. T. campus. The antenna consists of 16 50-ft spherical surface dishes in a 4×4 array with edges touching.

Each dish consists of two circles of fourteen 4×4 timber posts, at radii of 25 ft and 15 ft. The posts are approximately 8 ft and $2 \frac{1}{2}$ ft high in the outer and inner rings, respectively. One by four timber stringers are used to form a ring girder joining the outer posts. One by four radials connect the inner and outer rings of posts to provide solid attachment points for the chicken wire that forms the surface of each dish.

The feeds for each dish, which are to be crossed 3-element Yagi's, are supported on wooden tripods that are approximately 24 ft high. The f/D ratio for the dishes is approximately 0.4. The pointing of each dish in the N-S direction will be controlled by the positioning of the feed. A coverage of $\pm 20^\circ$ from the zenith in the N-S direction is planned.

The pulsars have been found to have steep spectra,² and are, therefore, best observed at lower frequencies. At too low a frequency, the galactic background brightness temperature is high, and the frequency dispersion in the time of arrival of the observed pulses also increases. This calls for the use of smaller receiver bandwidths (to obtain the desired time resolution < 10 ms) and results in a corresponding loss in sensitivity. The array will initially operate at a frequency of approximately 140 MHz.

At present, the dishes and tripods are complete, with the exception of a small amount of chicken wire surfacing to be finalized. Work is progressing on the feeds, receivers, and transmission lines.

B. F. Burke, R. M. Price

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C. 1. 75-cm APERTURE SYNTHESIS

A Ku-band interferometer is being built in order to obtain the contour maps of certain interesting discrete radio sources (Crab Nebula, Cas A, Cy A, Vir A) at this high frequency. The building blocks of this interferometer are the following.

- a. The RF front end.
- b. The phase-lock system which will keep the frequency of the 2 klystrons stable within 1 part in 10^7 .
- c. The multiplier which will give the averaged product of the signals coming from the two dishes. This multiplier has a dynamic range of 40-50 dB and is flat over the IF bandwidth which is 50-70 MHz.
- d. The concurrent calibration and the synchronous detector: A small amount of phase-switched noise is injected in the signal path and is later on detected by means of the synchronous detector. Thus we have a continuous indication of the gain stability of the system.
- e. The antenna control units which enable us to control the dishes either manually or by means of the computer.
- f. The computer program and interface for the PDP-8 which will perform the following functions:
 - (i) Point the dishes to the source and track it for a programmed amount of time after which they automatically switch to a calibration source which they track for a short time. Upon the completion of the tracking of the calibration source the dishes switch, again automatically, to the original source. This procedure continues for approximately 12 hours, the time allowed by the hour angle span of the dishes.
 - (ii) Sample the outputs of the multiplier and the synchronous detector. These samples are then converted into a 10-bit binary word which is fed into the computer. The output of the multiplier is sampled every 0.2 sec. To these samples a least-squares fit is applied in real time.
 - (iii) Compensate for the RF signal path difference by digitally inserting and extracting fixed amounts of delay placed in the IF strip. In this manner we are continuously looking at the white fringes.

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All of these units have been built and 80 per cent of them have been tested. Observations and system-checking will begin as soon as the cabling between the antennas and the control house is completed.

G. D. Papadopoulos, D. C. Papa, B. F. Burke

D. GALACTIC STRUCTURE STUDIES

Further studies of galactic structure have been carried out using the 1000-ft dish of the Arecibo Ionospheric Observatory (operated by Cornell University for AFOSR). These current observations at 195, 430, and 611 MHz supplement earlier observations at 450 MHz made at the Algonquin Radio Observatory (ARO) of the Canadian National Research Council.

The ARO observations were made with a beamwidth of slightly more than 1° , whereas the Arecibo beamwidth at approximately the same frequency is 0.25° .

The combination of the results of the two surveys will give information about the size distribution of nearby continuum emission regions in the Galaxy. The reduction and interpretation of the Arecibo measurements is in progress.

R. M. Price

E. VERY LONG BASELINE INTERFEROMETRY

The very long baseline interferometry technique is being extended to allow measurements of source positions, baseline vectors, and relative time to accuracies consistent with the extremely high spatial resolutions that have been achieved. An interferometer operating at X-band, from 7.3 to 8.2 GHz, between the Haystack 120-ft and the NRAO 140-ft antennas is under construction. It uses phase coherent frequency switching of local oscillators to obtain an effectively large fractional bandwidth over which phase can be extrapolated without ambiguity. It will first be used early in October 1968 to observe the gravitational "bending" of electromagnetic waves, which should produce an apparent shift in the position of the quasar 3C279 as the Sun passes within approximately 1° of it. The theoretical absolute mensuration capabilities of the instrument will be put to their first empirical test.

Extensive use is being made of the Haystack facility of the Lincoln Laboratory, M.I.T.

H. F. Hinteregger, B. F. Burke, I. I. Shapiro

F. ESTIMATION OF ATMOSPHERIC ELECTRICAL PATH LENGTH FROM SIMULATED MICROWAVE RADIOMETRIC DATA

The statistical data inversion technique described in a previous report¹ has been applied to the problem of estimating the electrical path length of the terrestrial atmosphere. Knowledge of the atmospheric path length is of value in any experiment

requiring phase stability between two separated receiving stations, such as the recent long baseline interferometer experiments.

The increase in the electrical path length caused by the earth's atmosphere is

$$L = \int_L (n-1) dl, \quad (1)$$

where n is the index of refraction, and L is the path of the electrical signal. The index of refraction can be related to meteorological quantities. For frequencies below approximately 30 GHz, the relation is²

$$(n-1) = \frac{7.76 \times 10^{-5}}{T} \left(P + 4.81 \times 10^3 \frac{e}{T} \right), \quad (2)$$

where T = temperature (degrees Kelvin)

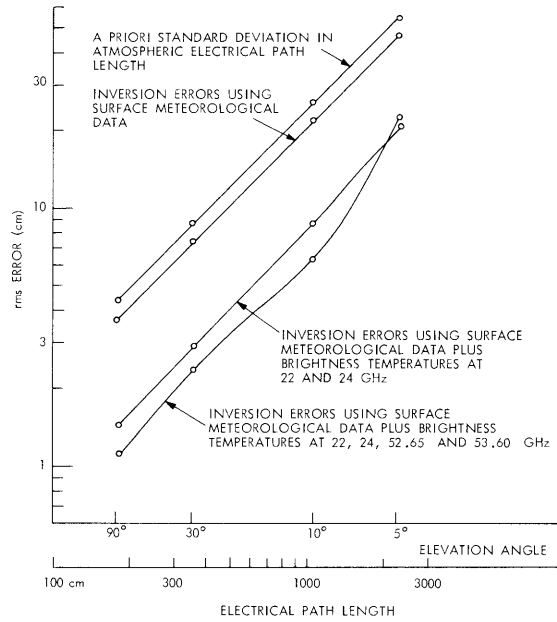
P = total pressure (millibars)

e = partial pressure of water vapor (millibars).

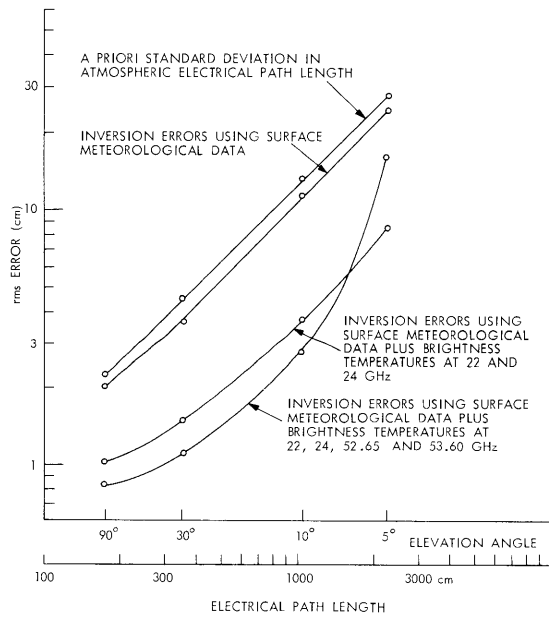
The index of refraction has separate contributions from dry air and from water vapor. Although most of the atmospheric electrical path length is due to dry air, the variability in the path length is dominated by water-vapor variability.

Using Eqs. 1 and 2, we calculated the atmospheric electrical path length at various elevation angles from an ensemble of U.S. Weather Bureau radiosonde records. Fifty summer and fifty winter records from Huntington, West Virginia, were used. The refractive bending attributable to the atmosphere was included in the calculations, but the effects of clouds were not. Brightness temperatures at selected frequencies, as would be observed by microwave radiometers looking at the respective elevation angles, were also calculated from this ensemble of records. Inversions were then performed on this computed data to infer atmospheric electrical path lengths. Surface values of temperature, pressure, and relative humidity were also included in the data. The same ensemble of records was used for performing the inversions as for computing statistical correlations required by the inversion algorithm. The inferred path length was compared with the path length calculated directly from the radiosonde data to determine errors in the inferred value.

Figure II-1 gives inversion error statistics for the summer and winter ensemble of records. The rms error in the inversion results is plotted as a function of elevation angle, or equivalently, the total electrical path length increase of the atmosphere. Also shown is the a priori standard deviation in the path length. Inversion results are shown, with the use of surface meteorological data alone and surface meteorological data plus brightness temperatures at frequencies near the 22.235 GHz water-vapor and 60-GHz oxygen resonances as indicated in the figure. Calculations were performed with data containing simulated noise.



(a)



(b)

Fig. II-1. Results of estimating atmospheric electrical path length increase. (a) Summer. (b) Winter.

Gaussian noise of following rms value added to data before performing inversions:

- i. 2% for surface relative humidity
- ii. 0.1°K for surface temperature
- iii. 1 mb. for surface pressure
- iv. 0.2°K for brightness temperatures.

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The results of these calculations indicate that, neglecting clouds, atmospheric zenith electrical path length increase can be inferred with an accuracy of 1 or 2 cm from measurements of a two-channel microwave radiometer operating near the 22.235 GHz water-vapor resonance and surface measurements of meteorological quantities. For summer, this is approximately a factor of three better than could be done from a priori statistical information alone, and a factor of two better than could be obtained by only measuring surface meteorological quantities. Preliminary calculations indicate that a typical cloud will add approximately 0.5 cm to the expected rms error in inferring zenith electrical path length from the radiometric data.

L. W. Schaper, Jr., D. H. Staelin, J. W. Waters

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