Heeschen

SEP 8 1955

Memo to Addressee

From Richard M. Emberson

Subject: Distribution of Record of Symposium on Electronic Problems in Radio Astronomy.

The attached record of the May 27, 1955, symposium was promised each participant. My thanks are due to them for their patience and cooperation and especially to Mr. Haddock and the members of his ad hoc panel, who both planned the symposium and did much of the work of preparing this record.

Record of an Informal Symposium on
Electronic Problems in Radio Astronomy

9:30 a.m., Friday, May 27, 1955

1. The symposium was arranged in connection with a general feasibility study for a National Radio Astronomy Facility; It was held jointly with a meeting of the Steering Committee for the study. Those attending and participating were:

L.V. Berkner	Associated Universities, Inc.
B.J. Bok	Harvard College Observatory
J.G. Bolton	California Institute of Technology
R.M. Brown	Naval Research Laboratory
A.J. Deutsch	Mt. Wilson and Palomar Observatories
C.F. Dunbar	Brookhaven National Laboratory
R.M. Emberson	Associated Universities, Inc.
H.I. Ewen	Harvard College Observatory
R.N. Fano	Electronics Research Laboratory, M.I.T.
W.E. Gordon	School of Elec. Eng., Cornell University
F.T. Haddock	Naval Research Laboratory
J.P. Hagen	" " "
E.F. McClain	" " "
J.P. Nash	Dept. of Physics, Univ. of Illinois
J.R. Pierce	Electronics Research, Bell Laboratories, Inc.
N. Rochester	Engineering Lab., Int'l Bus. Machines Corp.
C.W. Sherwin	Dept. of Physics, Univ. of Illinois
R.C. Spencer	Antenna Lab., Air Force Cambridge Res. Labs.
L.C. Van Atta	Microwave Lab., Hughes Res. & Devel. Labs., Hughes Aircraft Co.
J.B. Wiesner	Res. Lab. of Electronics, M.I.T.

2. After brief introductory remarks by Dr. Hagen, Chairman of the Steering Committee, the meeting was turned over to Mr. Haddock, who had served as chairman of an ad hoc Panel to arrange the program; other panel members were: R.H. Dicke, R.M. Brown, H.I. Ewen, E.F. McClain, L.C. Van Atta, and J.B. Wiesner.

3. Dr. Wiesner spoke of "seeing" limitations as they might introduce difficulties with observatories using very large apertures. He noted that the total knowledge on this subject was very meager. For this reason he suggested a cautious approach to very large apertures. In the lower atmosphere, for example, the likely gradients of water vapor across an aperture of several hundred feet could introduce relative phase shifts of several wavelengths. On the other hand, it did not appear that non-homogeneities in the ionosphere would introduce serious relative phase shifts over distances of several kilometers.

Mr. Bolton commented on his experiences, noting that at very low altutudes (0-10°) the probable positional error of a single observation was 30 minutes of arc for 100 Mc/s and 3 minutes for 400 Mc/s. At higher altitudes, the errors fell to about one-tenth these values. He suggested 20,000 feet as a possible limiting useful size.

Dr. Gordon reported that the National Bureau of Standards and the University of Texas were studying relative phase shifts as a function of frequence and antenna aperture (or separation.) For 1000 Mc/s the dimensions of non-homogeneities is between 10-100 meters. For lower frequencies, the ionospheric effects dominate. He further pointed out that for high frequencies (greater than 1000 Mc/s) the plane of polarization might be twisted only a few degrees in passing through the ionosphere whereas for low frequencies the effects were so pronounced that an initially plane polarized wave would be observed as having almost random polarization. (Further details are given in Appendix A-3). He and Mr. Berkner noted that to study atmospheric effects a sufficiently large aperture was needed to cover most of the first Fresnel zone. Dr. Wiesner agreed that a large aperture seemed fully justified by astronomical problems and should not be tied to these secondary problems. Dr. Hagen pointed out that 21 centimeter sources could be observed at the horizon without serious scintillation effects.

4. Mr. McClain next spoke on general problems of interference. Generally, it is true that man-made interference falls off rapidly with increasing frequency. A strong interference can usually be traced to its source and eliminated; or if the interference is of an intermittent nature, a pickup antenna can be pointed in the direction of the source and the signal used to blank the radio telescope receiver temporarily by using a delay line. He referred to the importance of the hydrogen frequency and its harmonics and subharmonics (1420, 2840, 710, and 355 Mc/s) and suggested that the site survey should look for average field strengths at these frequencies of no more than 10^{-2} to 10^{-4} microvolts/meter. A quiet site is much to be preferred over electronic gadgetry.

In the discussion that followed, Mr. Haddock noted that the above mentioned blanking technique had been used with some success by Mr. Covington and Mr. Broton at Ottawa. Dr. Hagen emphasized that the man-made interferences were almost absent at 10-centimeter wavelengths but had entered pre-eminently at 21 centimeters.

5. Mr. Brown summarized the state of knowledge concerning reflector designs (focal/aperture ratio); surface tolerances; horn and other types of feeds; the idealized gain of $4\pi A/\lambda^2$ as compared to the best compromise gain (about 65% of ideal) obtained with a tapered illumination (falling to 12 db down in power at the rim) to minimize side lobes. Appendix A-5 gives the charts used by Mr. Brown and also a bibliography.

Dr. Spencer commented that the best results seemed to come with a small amount of uniform illlumination across the aperture (a pedestal) to which is added illumination that is strongest at the center and tapes to zero at the rim. He referred to a recent article in the Bell Technical Journal that showed that relative changes in gain were proportional to the average phase error across the aperture.

6. Dr. Van Atta continued this discussion, noting that relative phase shifts introduced by atmospheric irregularities were equivalent to phase shifts introduced by the deviation of the reflector surface from a true paraboloid. He then commented on seeing limitations as a factor in determining useful sky coverage; cross-polarization problems; the use of four element feeds; the distribution of radio sources and their strengths at various frequencies as a parameter in the requirements for radio telescopes; the use of arrays for longer wavelengths ; and radome problems. His remarks are given in more detail in Appendix A-6, attached hereto.

7. Dr. Wiesner next spoke on correlation and phase-comparison systems, comparing the various methods of interferometry. He pointed out, among other things, that in the post-detection comparison system as used by Hamburg Brown, the angular accuracy is proportional to the signal-to-noise ratio raised to the 4th. power whereas in the comparison system it is raised to the 2-nd.power.

Mr. Bolton reopened a suggestion by Prof. Dicke that the Mills Cross signals be squared. Dr. Wiesner commented that this would not appear to give an improved signal/noise ratio or more information.

Luncheon Break

8. Dr. Spencer next spoke. As the symposium was runnning behind schedule, he made only brief comments on two papers: "Paraboloids for Radio Telescopes" by Carlyle J. Sletten, and "Multiple Feed High-Gain Antennas for Radio Astronomy" by Roy C. Spencer. Copies of these papers are attached hereto as Appendices A-8-1 and A-8-2. The material in these papers is covered more extensively in a paper, "Antennas for Radio Astronomy", presented by title at the symposium on astronomical optics, April 18-23, 1955 at the University of Manchester, England. Dr. Spencer discussed general concepts of antenna gain, beam width, phase errors; off-axis properties of paraboloids; and the limitations of spherical surfaces. It will be noted that Appendices A-8-1 and A-8-2 are companion papers and the latter, by Dr. Spencer, carries an extensive bibliography.

9. Mr. Haddock spoke briefly on the problems of testing the surface of very large reflectors and of locating the center of the antenna beam. He noted that the Coast and Geodetic Survey utilized standard techniques in surveying the 50-foot reflector at NRL. This procedure is too time consuming for routine checks, particularly for much larger sizes. Optical range finders might be modified for use and could possibly provide a distance measuring accuracy of 0.04% for a 600-foot reflector. (For a 300-foot focal length, this corresponds to about 2 inches.) The limitation in the range of variation of parallactic angle and range of focus are the biggest weaknesses of using an optical range finder. Various high frequency radio schemes have been proposed using height-finder Pulse or phasing techniques, but none has been tried in this application to date.

   Dr. Bok reported on a development by Dr. McLeod, of the Eastman Kodak Co. Conical optical elements, called axicons may be used for defining lines or planes with great precision and the application of these devices might offer a partial solution to the problem of a quick test of a very large parabolic surface.

10. Dr. Ewen discussed receivers, with particular reference to the stability problems in 21 centimeter work. The instability of the overall gain results from two sources: (a) the statistical variation of the receiver noise; to combat this, the bandwidth must be made narrow, which requires longer integration times; and (b) actual fluctuations in the gain, which can be held down by numerous ingeneous devices that require further study and development. Appendix A-10 gives a preliminary description of the 21-cm. receiver that is being built for the new 60-foot radio telecope being erected at the Agassiz Station of the Harvard College Observatory.

11. Mr. McClain followed with brief description of a chopped d.c. receiver, using a lossy wheel. This receiver permits equally stable simultaneous observation of both hydrogen line radiation and adjacent continuum radiation. This feature is essential for absorption studies. (Block diagram is attached as Appendix A-11).

12. Dr. Pierce pointed to the advantages of RF amplifiers if they could be built with noise figures comparable to those for I.F. amplifiers. For one thing they would make the rejection of the unwanted image signal much easier. He gave the following noise figures for travelling-wave tubes operating at the specified frequencies:

Frequency (Mc/sec)	Noise Figure (db)
3,000	5-6
6,000	8
10,000	12

It was his opinion that the increase of noise figure with frequency was due, in part, to the manufacturing tolerance necessary with the very small components of the high-frequency tubes. Some noise results from inhomogeneities of the electron beam, which is reduced somewhat if an attempt is not made to capture all electrons emitted by the cathode. Also collimation of the beam will tend to smooth out noise irregularities.

With extreme care, a travelling-wave tube might be built for 21-cm. work with a 3-4 db noise figure. Finally, he noted that the noise figures given above are for 100 Mc bandwidths; it might be possible to design tubes with 1,000 mc bandwidths. For further information on these topics, Dr. Pierce referred to a recent paper he had published in the December, 1954, Proceedings of the IRE: "Some Recent Advances in Microwave Tubes".

13. Mr. Haddock discussed briefly the receiver calibration problem. He pointed out that various types of noise sources have been used to calibrate radio receivers used in astronomy; noise diodes, gas discharge tubes, heated resistive loads, etc. It is believed that eventually all workers will refer back to a heated (or cooled) resistive load as the primary noise power standard.

The difficult problem of antenna gain calibration for radio telescopes has not yet been solved. Eventually the radio emission spectrum of the brightest radio sources will be measured accurately over the radio spectrum. Then they will be the primarily standards for antenna gain measurements.

14. The session then turned to the somewhat neglected topic of data recording, processing, and storage. Mr. Rochester started the discussion with a brief description of the capabilities and limitations of punched card and tape recording systems. Subsequent to the meeting, he has sent a letter, the text of which is attached hereto as Appendix A-14-1. Reference is made also to a post-session letter from Dr. Nash, that is also attached as Appendix A-14-2.

The discussion turned to the specific problems of processing the observational data from a Mills Cross. Dr. Bolton, Fano, Nash, Rochester, and Spencer contributed comments. Dr. Spencer stressed the tremendous ability of an observer to recognize a pattern, that is not found in machine capabilities, and Prof. Fano suggested the use of an optical device to speed-up the machine analysis of Mills Cross data. He also suggested that geophysical seismic surveying has similar complex data analysis problems and that techniques which had been successfully employed there might also be applicable to radio astronomy problems.

The consensus was that in most radio astronomy experiments, involving large quantities of numerical values, there could be significantly large saving of time and effort if the basic data were developed in a form that could be directly introduced into an automatic computer system. It was clear that the very large, high-speed computers now available have more capacity than is needed for radio astronomy. A combination of smaller units should be able to handle most radio astronomy problems.

List of Appendices