IMPROVEMENT OF THE HIGH-RESOLUTION INTERFEROMETER AT 9.4 GC/S

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Abstract

The Toyokawa compound interferometer at 9.4 Gc/s has been improved in three ways for increasing sensitivity. (1) 16 dishes of 1.2 meters in diameter were replaced by 2-meter dishes. The difficulty arising from the sharpness of the beam has been overcome by applying a special step-drive system. (2) Low loss circular waveguides have been used for branch lines longer than 10 meters. The transmission loss has not increased though a simple branch line system is used instead of using 2 preamplifiers. The single output terminal thus obtained has enabled us (3) to use an elaborate low-noise preamplifier. T. W. T. is being used for routine observations of the sun, and a maser amplifier is prepared for the reception of cosmic radio emission. The explanation is given of the method of observing circularly polarized components, and finally a future plan of extending base line is briefly described.

1. Introduction

A compound interferometer at 9.4 Gc/s consisting of 16+2 dishes[1] was constructed in December 1962 and continuous observations of the brightness distribution and the distribution of polarized components across the solar disk had been made until January 1964, when the aerial was disassembled for increasing the sensitivity.

The 16-element interferometer with 1.2-meter dishes, which was a part of the compound interferometer, seemed to have a sufficient sensitivity for the observation of the brightness distribution across the sun, but it was not quite satisfactory for the observation of a polarized component as weak as several percent of flux density. When used as a compound interferometer by multiplying the output with that of two 3-meter dishes, the lack of sensitivity became more serious for the following reasons. The output signal coming from an extended active region decreases in proportion to the sharpness of the beam whereas the effective collecting area remains almost the same, and in addition, for the observation of the sun, most of the output of the 2-element interferometer coming from outside the main beam of the 16-element interferometer to be multiplied, is an incoherent background noise which further spoils the signal to noise ratio.

In these circumstances, we have looked for the possibility of increasing sensitivity and finally we have found three different ways to approach this requirement. The first is to expand the size of 16 dishes by introducing a special driving system, the second is to use a low-loss waveguide and the last is to use a low-noise receiver. These improvements which we are going to describe in more detail were completed in June 1964, and the continuous observations started again.

The interferometer of increased sensitivity is now available also for the observation of discrete sources as is described in a separate paper in this volume (p. 35).

2. Increasing the size of dishes

The size of 16 dishes, which was 1.2 meters in diameter, was formerly determined by considering the sharpness of the beam. It is clear that the drift curve of an adding-type multiple-element interferometer is the convolution of an interference pattern with a signal source multiplied by a directive pattern of each antenna which is fixed to the source. Thus the directive pattern of each antenna is the weighting function of the source distribution so that it should not be too sharp compared with the size of the source to be observed. If we confine the weighting value at the solar limb to 95 percent, the half-power width of the beam should be about 2 degrees. This value corresponds to the size of a dish of 1.2 meters in diameter when the dish is fed by a circular waveguide end. This limitation conflicts with the requirement of increasing sensitivity by increasing the size of dishes.

However, we found that this limitation can be partly taken off by using a special method of driving antennas. This is based on the principle that if we stop the antennas at a peak of the interference pattern, the solar disk is scanned uniformly in the east-west direction. Therefore a successive uniform scan is possible when we drive the antennas intermittently at each valley of the drift curves as shown in Fig. 1.

To our regret, this step-drive system does not give solution to being weighted in the north-south direction of the sun. But if we give up the precise discussion on the quiet sun, the size of each antenna may be allowed to be doubled because most active regions avoid the polar regions of the sun.

On the other hand, there is another limitation on the size of the dish, i.e. the diameter should considerably be less than a unit spacing. For a four-hour observation around local noon, the diameter should be less than about 2 meters for the spacing of 2.74 meters. Thus we have decided to increase the diameter of 16 dishes from 1.2 to 2 meters.

For the two-element interferometer to be combined with the 16-element one, the

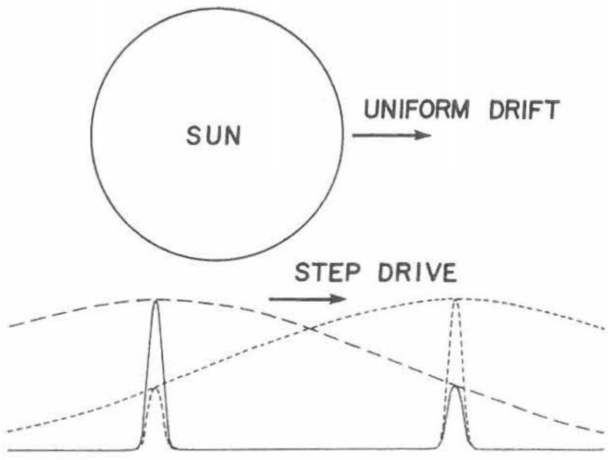

Fig. 1. Principle of step-drive system.

diameter of 3 meters was determined mainly from the requirement of sensitivity becase our modified configuration of the compound interferometer does not allow us from the beginning to observe the quiet sun. Indeed it would be possible to expand the size of dishes if the antennas were correctly aimed at an active region to be observed. But in practice, this procedure is too complicated for routine observations. Therefore, the 3 meters in diameter is considered to be maximum at this frequency, which corresponds to the weighting value of 90 percent at ± 8 minutes of arc from the disk center.

Though the step-drive mechanism is not yet completed, the antennas are intermittently driven by hand near the meridian passage of the sun. The effect of stopping antennas is illustrated in Fig. 2, where the interferometer is switch on to the 16-element one. The area under the drift curve of the quiet sun decreases by 4 percent

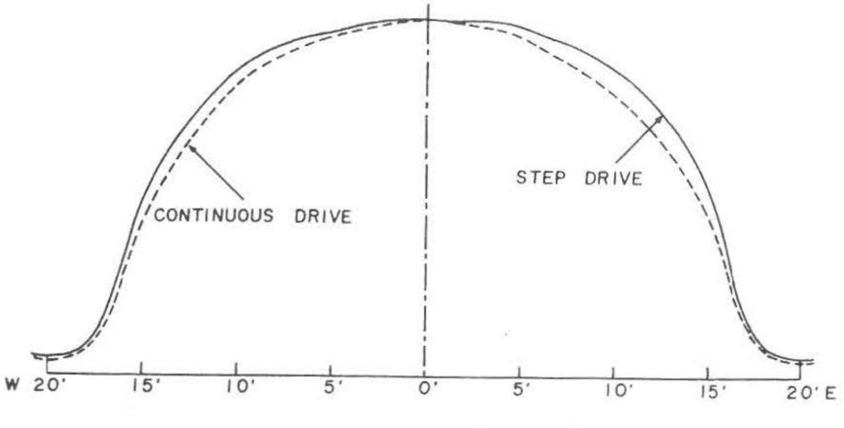

Fig. 2. Drift curves taken on the 26th November 1964.

when the antennas are driven continuously. Similarly, when the total flux of the sun is compared with the flux of a small radio source from the areas under the drift curves taken by a continuous drive of the 16-element interferometer, the area for the quiet sun should be multiplied by approximately 1.08.

It should be noted here that the tracking accuracy of antennas is quite severe when they are driven continuously, and 5 seconds' error in the hour angle results in a considerable deformation of the drift curves of the quiet sun.

3. Low loss waveguide

Since it is quite difficult to get a satisfactory amount of collecting area of antennas, the loss in transmission lines seriously controls the sensitivity of aerial system. Fortunately, a low-loss circular waveguide has been developed in the microwave communication engineering and is readily available at a comparatively low cost. So we have decided to introduce this technique in our interferometer. This waveguide has a diameter of 51 millimeters and transmits H_{11}-mode waves with a loss of 0.02 db/m. The loss in the transition units, i.e. from rectangular to circular and circular to rectangular waveguides, is 0.3 db including the loss of a mode filter.

In relation to the use of a low-noise receiver, it is quite desirable to collect the outputs of the antennas into a single output terminal instead of using two preamplifiers as had been the case in our previous interferometer. The use of a simple branch line system means the increase of transmission losses, though inevitable, and cancels out considerably the merit of using circular waveguides. However, from a different point of view, we could not imagine the use of a simple branch line system until the low-loss waveguide had become available.

The actual configuration of the equipment is shown in Fig. 3. Table 1 gives the estimated values of transmission losses where 3 cases are compared; the previous

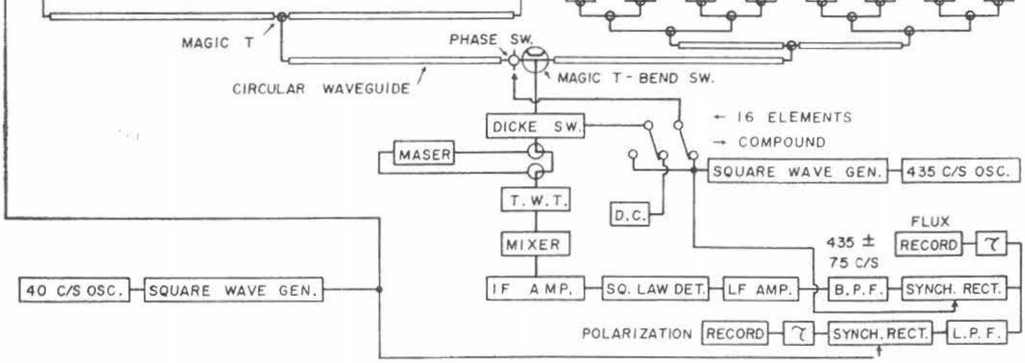

Fig. 3 Block diagram of the 16-element / compound interferometer.

Table 1. Estimated values of the transmission loss and collecting area.

	Rectangular w. g. with magic T's bends and rotary joints		Circular w. g. with transition units and mode filter		Polarization switch	Total	Collecting area in m²		
	length in m	loss in db	length in m	loss in db	loss in db	loss in db	Geometrical	with loss	as compound
16 elements	16.3	3.14	30.6	1.21	0.6	4.95	50.3	16.1	19.7
2 elements	8.4	1.68	40.8	1.42	0.6	3.70	14.1	6.0	
Old 16 elements	25.0	4.5	—	—	0.6	5.1	18.1	5.6	9.9
Old 2 elements	26.9	4.5	—	—	0.6	5.1	14.1	4.4	
Future 32 elements	19.5	3.66	73.3	2.36	0.3	6.32	100.5	23.5	20.6
Future 2 elements	13.4	2.43	82.0	2.24	0.3	4.97	14.1	4.5	

interferometer, the present one and the future 32+2-element interferometer to be mentioned later.

4. Low-noise preamplifiers

Though the equivalent antenna temperature due to the transmission loss is as high as about 200 °K, the noise of preamplifier still greatly controls the overall sensitivity. For the observation of the sun, however, the equivalent antenna temperature rises to about 700 and 1300 °K at the center of each scan for the 16-element and compound interferometer respectively. Therefore the receiver noise of the order of 1000 °K would be tolerable for this purpose. For daily observations, we are using a low-noise travelling-wave tube NEC LD-571A which has an equivalent noise temperature of 1200 °K. The rated value is 950-1600 °K. For the observation of weak radio sources, a maser amplifier is prepared which is described in a separate paper in this volume (p. 35).

5. Polarization measurement

In connection with Fig. 3, it would be necessary to explain how to observe polarized components, which we have dropped out in the previous report.[1]

In the case of an adding-type interferometer, flux density and polarized components can be separated by using two phase sensitive detectors in parallel, the one corresponding to the frequency of Dicke switch, and the other to that of polarization switches. For the phase-switch system, on the other hand, a band-pass filter must be inserted in the audio frebuency amplifier, and the phase sensitive detector for polarization must be placed after the phase sensitive detector for the flux measurement.

Let the voltage responses coming from two antenna systems be

$$\left.\begin{aligned} v_{a1} &= A_1(\theta)\exp[j(-\pi D\sin\theta/\lambda)] \\ v_{b1} &= B_1(\theta)\exp[j(\pi D\sin\theta/\lambda)] \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where D is the distance between the two antenna systems and θ is the angle between the normal to the east-west line and the incoming ray. The output voltage is then,

$$v_1 = (v_{a1} + v_{b1})/\sqrt{2}. \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

The output power is,[2]

$$p = \frac{v_1 \cdot \bar{v}_1}{2} = \frac{1}{2}\left[\frac{A_1^2(\theta)+B_1^2(\theta)}{2} + A_1(\theta)B_1(\theta)\cos f(\theta)\right],$$
$$f(\theta) = 2\pi D\sin\theta/\lambda. \quad \cdots\cdots\cdots\cdots \quad (3)$$

When the phase of v_{a1} or v_{b1} is reversed, the positive sign of the last term in Eq. (3) becomes negative.

Let us suppose that suffix '1' corresponds to the right-handed circularly polarized component and suffix '2' for the left-handed one, and that each signal comes alternately at a lower speed than that of phase switching. The output will then become as shown in Fig. 4. If the output of this waveform were synchronously rectified as was the case in the adding-type interferometer, the output will contain a component which is proportional to

$$(A_1^2 - A_2^2) + (B_2^2 - B_1^2),$$

which is the sum of the polarized components produced by two separate antennas. Actually we want only the difference of A_1 B_1 cos f(θ) and A_2 B_2 cos f(θ), and this purpose can be attained by using a band-pass filter of Dicke-switch frequency as mentioned far above. Since the output of this filter is amplitude-modulated at a

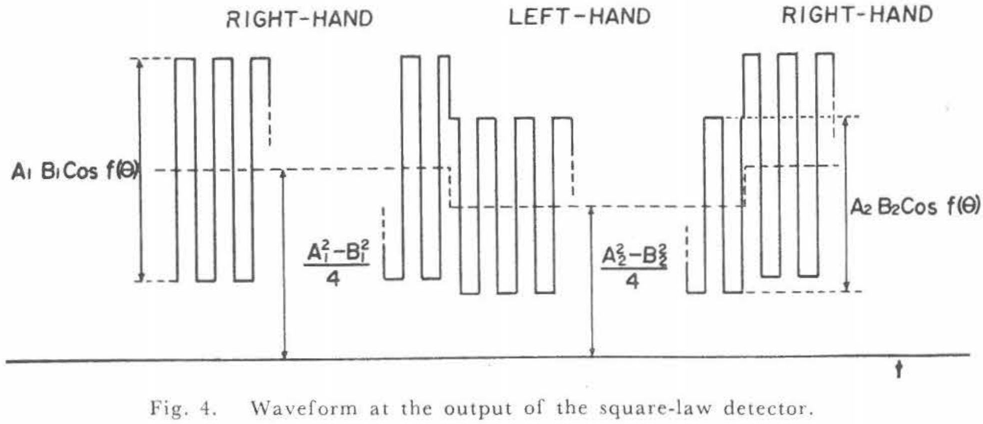

Fig. 4. Waveform at the output of the square-law detector.

frequency of polarization switch, the bandwidth of the filter should be sufficiently wide to pass the first sidebands. In addition, the switching frequencies should be arranged so that the harmonics of the lower frequency do not fall close to the higher frequency.

6. Future plan

Being encouraged by the successful use of a low-loss circular waveguide, we have started construction of increasing the dishes, 32+2 in the east-west direction and 16 dishes in the north-south direction. The 16 dishes will be used with the 32 east-west elements to form a 2 dimensional T antenna. The foundations for the east-west elements are being built on a new base line to improve the accuracy of setting. When we first constructed an 8-element interferometer(3) at this frequency, the antennas were placed on a common concrete basis, expecting a linear expansion and contraction of the base line. When the other 8 elements were added one year later,(4) the basis was simply expanded for the same reason. However, since 2 antennas were added on separate bases and the beam produced by each antenna became sharp, an irregular motion of the basis due to the weather conditions has become a little more than negligible. For this reason, the new foundations are built separately on the land and they are waiting for settlement until the antennas will be set several months later.

7. Acknowledgement

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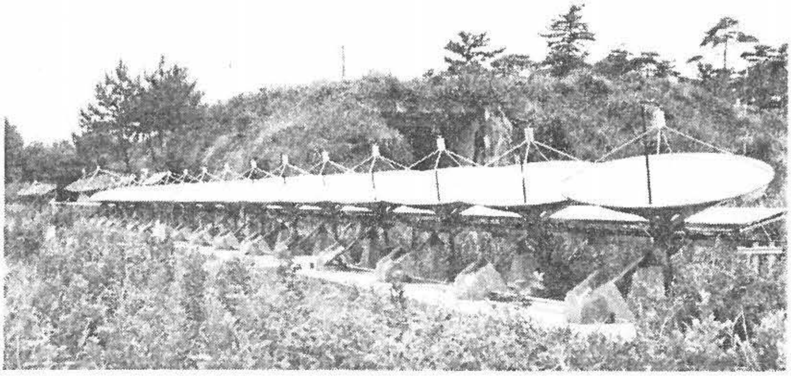

Fig. 5. General view of the compound interferometer at 9.4 Gc/s.

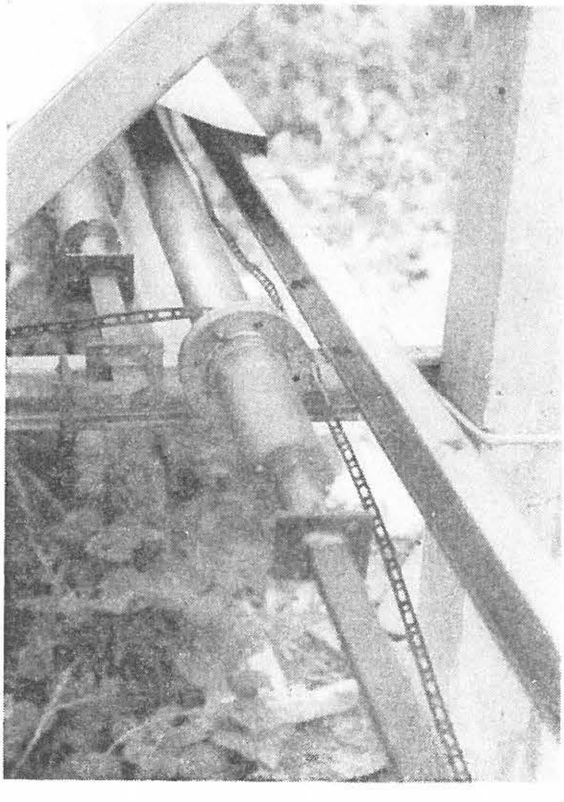

Fig. 6. Transition from rectangular to circular waveguides.