OBSERVATIONS OF EXTENDED RADIO SOURCES USING A MULTIPLE-BEAM TECHNIQUE

D.T. Emerson and U. Klein
Max-Planck-Institut für Radioastronomie, Bonn, F.R.G.

1. INTRODUCTION

The limiting sensitivity for conventional single-dish radio continuum observations of extended objects at wavelengths of a few cm is set mainly by weather; for much of the time a varying component of atmospheric attenuation, and hence thermal emission, causes deviations in the response of the receiver far in excess of any deviations due to receiver noise or receiver instabilities.

A dual-beam technique, where only the difference in power received by the two beams pointing at slightly separated points in the sky is recorded, has been used for many years for observations of small sources; atmospheric emission from within the near-field zone affects both beams equally, and so cancels. It has often however been stated that this technique is only suitable where the angular size of the radio source is less than the separation of the two beams.

This paper presents a dual-beam technique suitable for observations of sources many times greater in angular extent than the separation of the two beams. A consideration of the spatial frequency response of a dual-beam system and the effect of noise on the observations shows that such sources may be mapped and restored to the equivalent perfect-weather single-beam observation without degradation in signal-to-noise ratio, and with a complete sampling of spatial frequencies.

2. DUAL-BEAM OBSERVATIONS

An observation made with a dual-beam system is equivalent to a single-beam observation, but convolved additionally with the 2-beam function shown in Fig. 1(a). An example of such an observation is given in Fig. 2, which shows the source 3C 10 (diameter $\sim$ 9') observed at λ2.8 cm with the 100-m Effelsberg telescope using an angular separation of $5\overset{'}{.}5$ between the two beams, each of which has a full-width to half-power of 70". The effects of bad weather have been removed by the dual-beam system — compare Fig. 2 with the single-beam map observed at

C. van Schooneveld (ed.), Image Formation from Coherence Functions in Astronomy, 293–298.
Copyright © 1979 by D. Reidel Publishing Company

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press

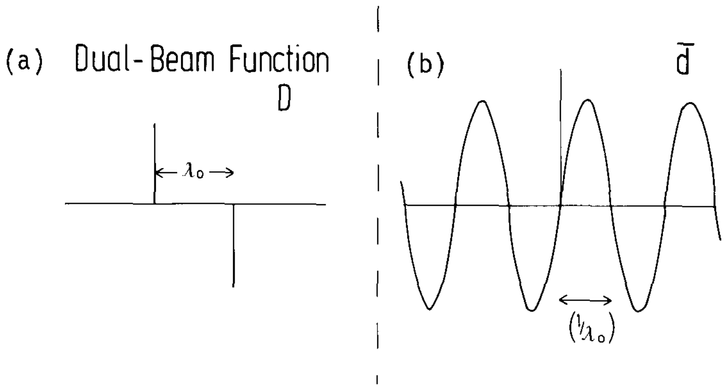

Fig. 1. (a) The dual-beam function, and (b) a representation of its Fourier transform. λ_o is the angular separation of the 2 far-field beams.

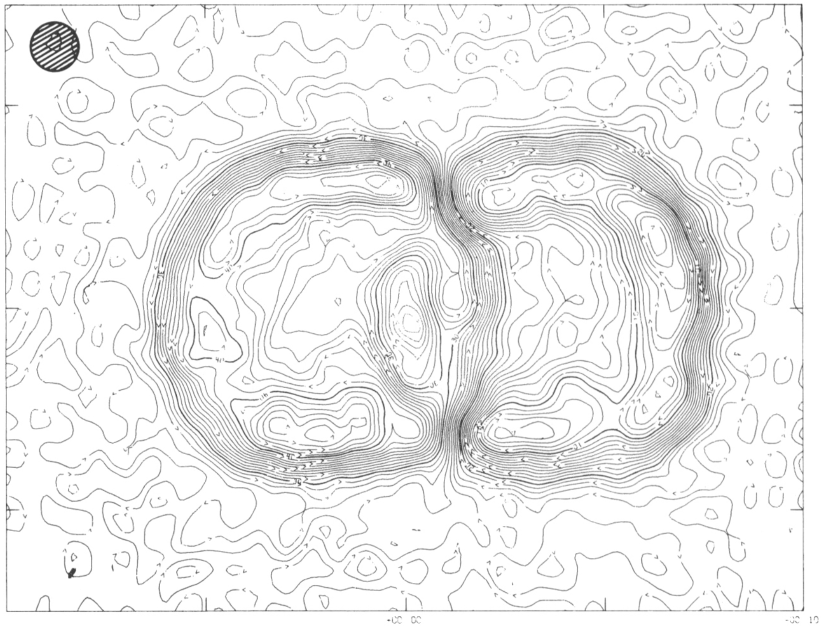

Fig. 2. A dual-beam observation of 3C 10 made at λ 2.8 cm with the 100-m Effelsberg telescope.

the same time, which is shown in Fig. 3 — but in the centre region of the map emission is detected by both beams simultaneously, giving a confused representation of the true emission.

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press

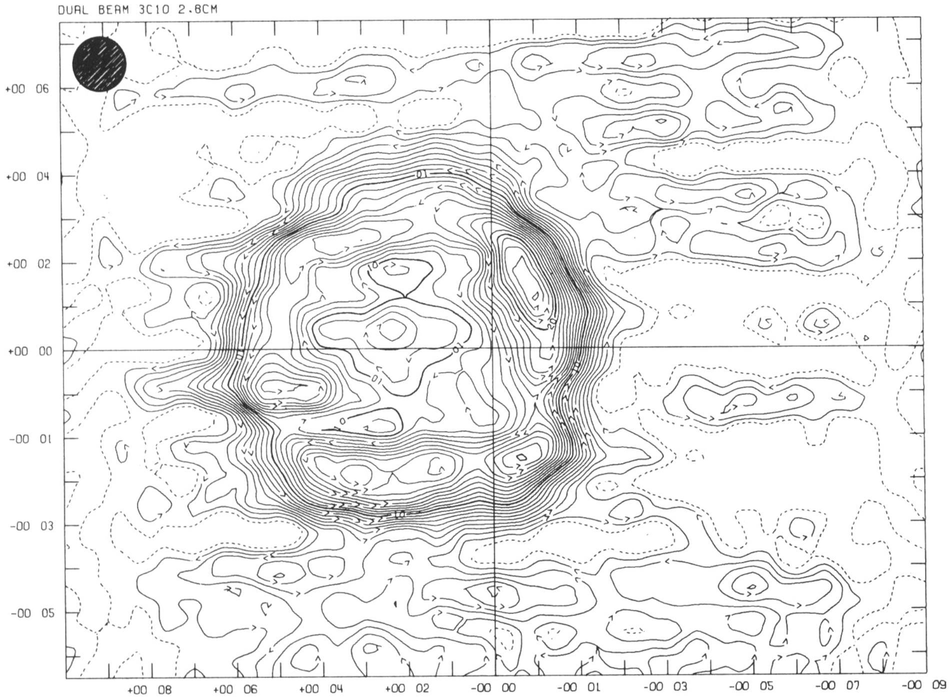

Fig. 3. A single-beam map of 3C 10, observed at the same time as Fig. 2.

The convolution with the dual-beam function of Fig. 1(a) is equivalent to multiplying the spatial frequency $(1/\lambda)$ distribution of the data with the sine wave $\sin (\lambda_0/\lambda \cdot \pi)$ illustrated in Fig. 1(b). In principle it might be possible to reweight spatial frequencies by $\operatorname{cosec} (\lambda_0/\lambda \cdot \pi)$, but clearly spatial frequencies close to the zero-crossing points are undefined. However for a source of finite extent x it is only necessary to sample at finite intervals 1/x in spatial frequency, and these sample points can be arranged to avoid the undefined spatial frequencies. This is illustrated in Fig. 4; for a map of extent $3\lambda_0$, where λ_0 is the angular separation of the 2 beams, no spatial frequency needs to be sampled which has been attenuated by more than a factor of 2 by the convolution with the dual-beam function.

It may be computationally convenient to perform the reweighting and sampling of the spatial frequencies present in the original data by a 1-dimensional convolution with a function having the required spatial frequency response. This function is illustrated in Fig. 5. The result of applying the procedure to the data of Fig. 2 is shown in Fig. 6, which should be compared with the single-beam data recorded directly at the same time, shown in Fig. 3.

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press

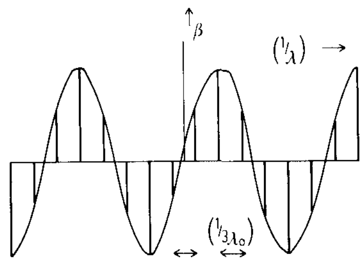

Fig. 4. The required spatial frequency sample points for a source of extent $3\lambda_o$ are illustrated.

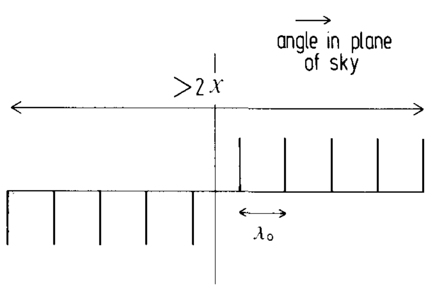

Fig. 5. The convolution function with the required spatial frequency response to restore a dual-beam observation to the equivalent single-beam observation.

3. AN EXTENSION OF THE TECHNIQUE TO LARGER SOURCES

After restoration to the equivalent single-beam observation, the noise level dT of a dual-beam observation of a field n units of the beam separation λ_o in extent, is given by:

$$dT = \frac{\sqrt{n} \cdot T_{sys}}{\sqrt{B \cdot \tau}}$$

This may be derived from a consideration of the noise of each spatial frequency sample after reweighting, and indicates that a higher noise level is expected on dual-beam maps of very extended regions. Compare this with the conventional Dicke-switching receiver, whose noise dT is given by:

$$dT = \frac{2 \cdot T_{sys}}{\sqrt{B \cdot \tau}}$$

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press

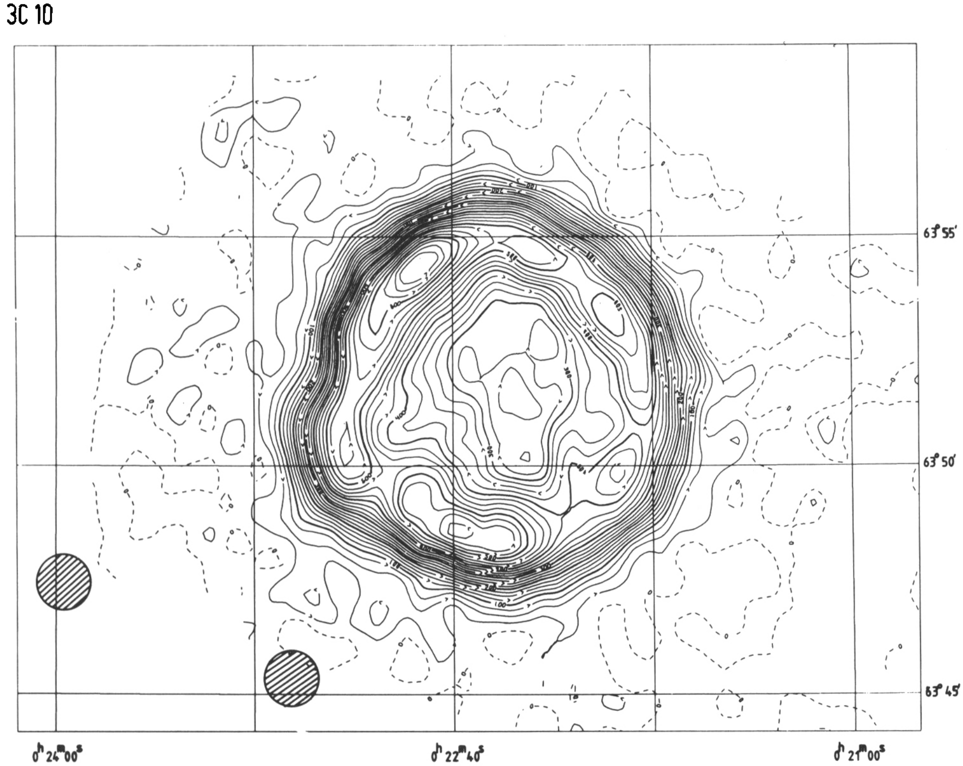

Fig. 6. The same data as Fig. 2, restored to the equivalent single-beam observation.

If additional dual-beam observations are made with a different beam separation λ_1, such that nulls in the respective spatial frequency distributions do not overlap, then all spatial frequencies except those close to zero will be well defined. This is illustrated in Fig. 7. All spatial frequencies except zero are now measured although the noise level of the very low frequency terms become worse closer to zero. The 2 sets of data are simply combined by weighting spatial frequencies from each dual-beam combination according to relative signal-to-noise ratio. With such a multiple-beam system, using for example 3 separated feeds, regions extending over many units of the larger far-field beam spacing may be mapped unambiguously without difficulty. Major continuum observing programs using this system at Effelsberg will begin towards the end of 1978.

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press

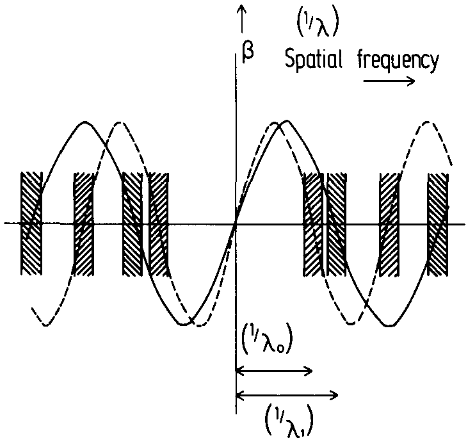

Fig. 7. Illustration of the complete spatial frequency coverage obtained by combining observations using 2 different beam spacings λ_o and λ_1.

DISCUSSION.

Comment T.W. COLE
1) How much blank sky do you need at the edge? 2) What is the noise degradation?
Reply D.T. EMERSON
1) It is necessary to scan far enough that both beams (& their sidelobes) are clear of the emission from the source at each end of the scan. A large "guard-ring" is not required. 2) For a source of ∿ 3 units of beam spacing in extent, this technique gives superior signal/noise ratio, even in the absence of atmospheric perturbations, compared to a Dicke-switching system. This is because a Dicke-switching system only sees the sky for ½ the observing time.

Comment U.J. SCHWARZ
One also could use different restoration techniques, such as CLEAN. Since the 'dirty beam' is non symmetric, one has to symmetrize it by a self-convolution and convolution of the data.
Reply D.T. EMERSON
Yes, one could use a version of CLEAN, but there is no need to. The technique I have presented gives a unique analytic solution, requiring no iteration and using negligible computing time.

https://doi.org/10.1017/S0252921100075011 Published online by Cambridge University Press