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WIDEBAND FEED SYSTEMS FOR RADIO TELESCOPES

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ABSTRACT

While reflector-type antennas commonly used for radio telescopes are inherently capable of extremely wide bandwidth performance, they are severely limited by the behaviour of the feed system. An overview is given of wideband feed systems for radio astronomy purposes developed at the CSIRO Division of Radiophysics. This work encompasses the feed antenna, the orthomode transducer, and the waveguide polarizer.

INTRODUCTION

A wide variety of antennas have been used over the years for radio telescopes with the most commonly used type being that based on reflector-antenna technology. There are good reasons for this. Reflector antennas can be readily designed to track a source or region of the sky, they are generally cost effective, and are capable of working over an extremely wide band. If properly designed, reflector antennas can operate over frequency ratios of at least 100:1 — the lower limit being determined by the onset of excessive diffraction losses, and the upper limit by surface profile errors.

Reflector antennas can come in a variety of configurations (e.g. single or multiple, symmetrical or offset, Cassegrain or Gregorian), but with a common need to have an appropriate feed system at the focus. That part of the feed system addressed here is the passive section before the LNA. This is composed of relatively few elements, the most essential of which is the feed antenna. For dual-polarization reception, an orthomode transducer (OMT) is necessary. To detect circular polarized signals, a 90° phase polarizer is needed somewhere in the signal path. This can be in the RF stage before or following the LNA, or it can be in the IF stage, whichever is the more convenient and operationally satisfactory. All of these components will be considered here, namely the feed antenna, the OMT and the waveguide polarizer.

The choice of feed antenna is a crucial factor in designing any reflector antenna configuration. For example, the VLA design[1] uses a relatively large number of narrowband feed-horn antennas which are accommodated within the structure in an array, offset from the axis, and with a tilting subreflector to access the required feed. The Australia Telescope (AT) on the other hand, in a move to provide good dual-polarization characteristics, brings the operating wideband feed horn on axis by means of a rotating turret system[2]. This approach provided restricted space to house the necessary feed horns and was a major driving force in developing wideband components. As well as reducing the number of feed horns needed to cover the required frequency bands, wideband systems open up the possibility of simultaneous widely spaced frequency operation. This not only increases the speed of the instrument but it can also have specific scientific advantages. Over the past few years considerable effort has gone into developing wideband feed systems at the CSIRO Division of Radiophysics, for both satellite communication and radio astronomy purposes, especially in the microwave region. This paper gives a brief overview of this work.

PERFORMANCE CRITERIA

At the outset we need to establish performance criteria for the individual devices within the feed system, since the bandwidth over which a device is said to operate is directly dependent on the performance criteria that can be accepted for a given application. For example, a claim may be made for a device which can operate over very wide bandwidths, such as some commercially available 2-18 GHz quad-ridged horns. However, the actual performance over much of this bandwidth may be totally unacceptable for radio astronomy applications, where stringent demands are placed on the performance criteria of feed systems, particularly where dual-polarization is required. Consequently, the resultant operational bandwidth can be quite restrictive.

With the now widespread demand in radio astronomy for polarization-dependent measurements, there are five main criteria applicable to all radio-telescope feed-system designs. First, an overall *return loss* of at least 15 dB is necessary to minimize losses, with a figure closer to 20 dB or better being more desirable over the operating band. Second, *insertion loss* must be kept to a minimum to maximize the overall G/T of the system. In the lower GHz region, the insertion loss of the feed system is expected to be typically about 0.7 dB. Third, the majority of reflector antenna designs now use the dual-reflector configuration, which allows the reflector profiles to be specially shaped in order to provide the best overall *efficiency* by maximizing the G/T.

Fourth, in dual-polarization applications, the *isolation* between the two senses of polarization throughout the feed system is an important consideration and a figure of at least 20 dB of isolation is commonly required across the band. Finally, *cross-polarization* energy radiated by the feed must be kept to acceptable levels within the telescope's field of view, and a peak level of less than -20 dB is commonly required. Cross polarization is not only a result of the inherent performance of the feed horn itself, but is also a manifestation of the feed system generating unwanted high-order modes. In a wideband system some high-order modes are inevitably excited to some degree at the higher frequencies and it is necessary to limit their excitation to an acceptable level.

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FEED ANTENNA

While there is potentially a wide variety of antenna types that can be used as feeds, very few are capable of meeting the modern demands of combining wideband behaviour with dual-polarization capability and low noise characteristics. The hybrid-mode waveguide radiator, usually in the form of a corrugated horn, is one such feed antenna[3]. The radiation characteristics of a hybrid-mode feed are almost ideal, with pattern symmetry (enabling high-efficiency, shaped dual-reflector antenna designs), low cross-polarization levels (providing excellent dual-polarization discrimination) and very low sidelobe levels (which lead to low antenna noise levels).

Most hybrid-mode feeds are in the form of a corrugated horn shown in Fig. 1. Aside from the desirable characteristics of hybrid-mode radiators, corrugated horns exhibit low-loss behaviour. Over the past 20 years considerable research has been devoted to these horns and designs are now available which provide exceptionally high performance over bandwidth ratios of up to 2.4:1[4],[5]. (Note, however, that this is still well short of matching, within a single feed horn, the bandwidth capabilities of the reflector antenna itself.)

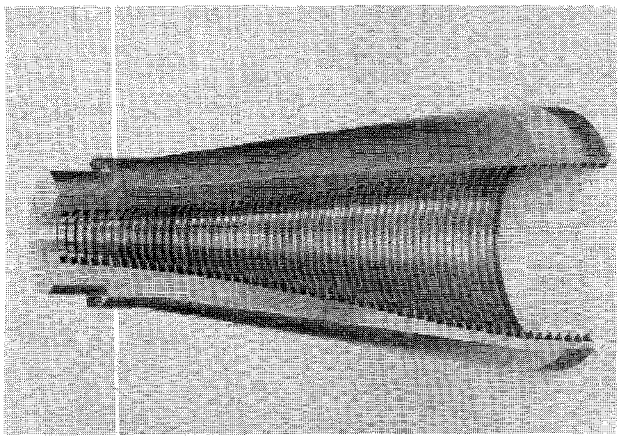

Fig. 1: Cut-away view of a corrugated hybrid-mode horn

High-performance, octave-bandwidth corrugated horns require ring-loaded slots [6] in the throat region to realize this bandwidth, and this, given the practical difficulties in manufacture, probably limits their application to frequencies up to about 50 GHz. At higher frequencies therefore, it may be necessary to use conventional variable-depth slots to match the horn in place of the ring-loaded slots. This would restrict the bandwidth performance to a frequency of 1.5:1.

As an alternative to the corrugated horn, there has, in recent years, been a great deal of interest in dielectrically loaded hybrid-mode horns [7],[8]. These horns, in principle, offer the advantages of wider bandwidth and lower manufacturing costs than corrugated horns. Of concern to radio astronomers is the additional noise contribution from losses in the dielectric. However, if low-density foam were used this may not be a problem except for the tendency of this material to absorb moisture over time. In practice, dielectric hybrid-mode horns developed to date have not quite lived up to their promise. The main problem appears to be inhomogeneities within the dielectric. When better dielectrics become available, this type of horn may find increasing application.

While most radio astronomy work is undertaken at frequencies above 1 GHz, there is some interest in frequencies down to the deuterium line at 327 MHz. For frequencies below 1 GHz, however, horn radiators can become too large to be practical and simpler feed antennas, such as dipole feeds, cavity-backed antennas etc., are sometimes used These antennas are usually quite narrowband and while it may be possible in some instances to consider using traditional wideband or 'frequency-independent' antennas such as log-periodic arrays, these structures do have the disadvantages of a shifting phase centre, relatively poor dual polarization and noise performance, and are cumbersome.

ORTHOMODE TRANSDUCERS

With the realization of the wideband corrugated feed horns, came the need to develop an OMT of similar bandwidth performance. This gave rise to a largely experimental investigation into a wideband OMT capable of separating two orthogonal, linearly polarized signals. The results are summarized in [9] with the best performance achieved by a quad-ridged waveguide design, illustrated in Fig. 2. Bandwidth ratios up to 2.2:1 and a maximum cross-polar level (when used in conjunction with a wideband corrugated horn) of -20 dB or less were achieved. Aside from the problems of matching the device over such a bandwidth, unwanted high-order modes can often be the major cause in limiting the bandwidth performance. As a result, the final designs were quite long — of the order of four wavelengths at the lowest operating frequency. Any attempt to reduce this length significantly resulted in limited bandwidth performance. (Full details are given in [9].) Thus the OMT to cover the 1.25 - 2.50 GHz band on the Australia Telescope is about a metre in length. To reduce losses this is cooled to about 75 K in a dewar, which in itself presented a considerable technological challenge[10]. Fig. 3 shows the large feed horn for this band with the OMT in the room below (not shown). Beside it is the smaller 4.4-10.6 GHz horn with the dewar containing the OMT and the LNAs to cover the bands required over this frequency range.

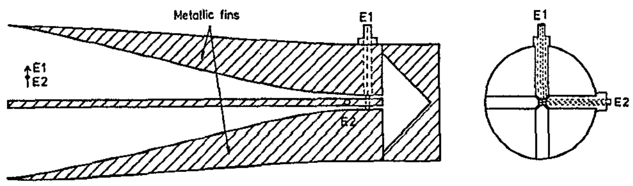

Fig. 2: Cross-sectional and end view of the quad-ridged OMT

POLARIZER

For dual circular-polarization operation a polarizer between the horn and the OMT can be used to convert the two senses of circularly polarized signals into linearly polarized components which can be subsequently detected by the OMT. A number of waveguide polarizer designs abound, including the quarter-wave plate placed at 45° inside the waveguide (to provide the necessary 90° phase shift to one of the field components), the pin polarizer, dielectrically loaded waveguides, and corrugated waveguides. Many designs are narrowband (typically 10%) with the widest bandwidth published to date about 35% [11]. A design based around a square waveguide, where some or all of the interior walls are corrugated (or alternatively dielectrically loaded), would appear to offer the best means of obtaining wideband performance. It has the advantage of being readily amenable to

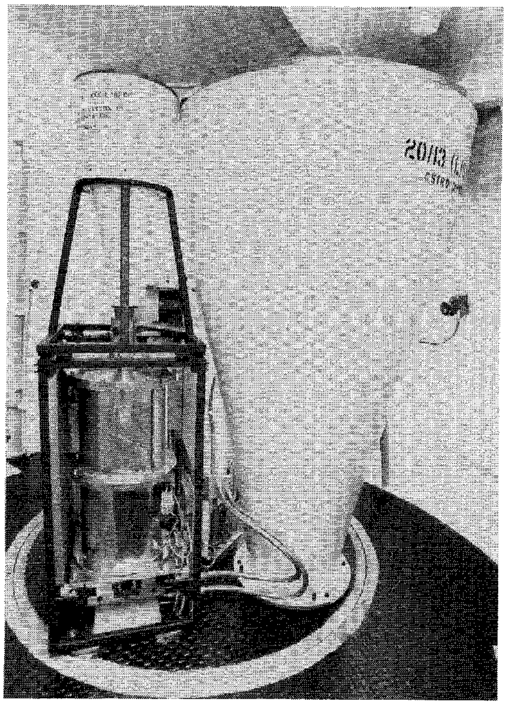

Fig. 3: View of the feed horns in the cone of one of the antennas in the Australia Telescope array. On the left is the 4.4-10.6 GHz feed horn connected to the dewar containing the wideband OMT and LNA system. On the right is the large 1.25-2.50 GHz feed horn. The base of this horn is also connected to its own dewar (not shown) of over a metre in length housed in the room below.

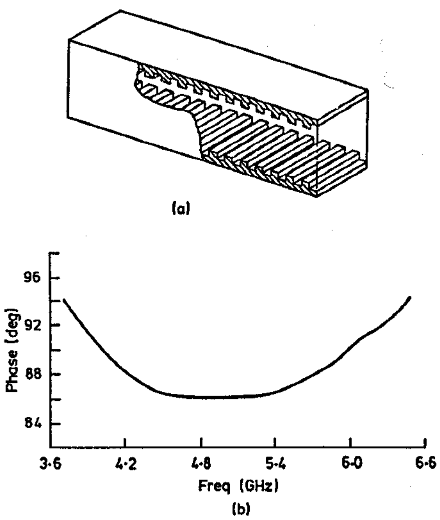

Fig. 4: Square waveguide wideband polarizer
(a) general view
(b) an example of the predicted performance

theoretical analysis and we are currently investigating the type of polarizer shown in Fig. 4 for wideband applications. If one is prepared to accept an on-axis cross-polar level down to 20 dB (which is usually quite adequate for radio astronomy observations) then our investigations indicate that this type of waveguide polarizer is capable of achieving a similar bandwidth performance to that of the corrugated horn.

CONCLUSION

A brief survey of the work undertaken at the CSIRO Division of Radiophysics on developing wideband feed systems for radio astronomy has been given. This work includes developing wideband feed horns, OMTs, and polarizers capable of high-performance operation over at least an octave bandwidth.

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