MODIFICATIONS TO THE MOPRA ANTENNA TO ENHANCE THE MM WAVE CAPABILITY

J. M Payne

March 1995

Summary

This memorandum outlines several changes that can be made to the MOPRA antenna in order to improve its performance and potential as a stand-alone millimeter-wave instrument. These changes are as follows:

1) Extend the high accuracy surface to the full 22-meter diameter.

2) Unshape the antenna optics. This will result in good off-axis performance for beam switching and will make the adoption of focal plane arrays possible at mm wavelengths.

3) Arrange the optics so that a switch between low-frequency observations and mm wavelengths may be made easily in an hour or two. This is accomplished by having the mm wave receiver permanently mounted in the receiver cabin and also by having a permanently mounted small, nutating subreflector behind the large cm wave subreflector. To change from cm wave to mm wave operation, all that is necessary is to remove the large subreflector and install a 45° flat in the receiver room.

4) Incorporate a nutating subreflector that will permit beam switching in a square wave manner of a few arc minutes at a 5 Hz rate.

5) Make the final f/d ratio the same as the 12m antenna so enabling feed designs to be interchangeable between the two instruments. This will facilitate the common development of array receivers also.

Fairly detailed design information is given for these changes, but obviously the ideas presented here are just a start.

1.0 Introduction

The 70-115 GHz receiver built by G. Moorey and his group works well, and there is enthusiasm for increasing the capability of the MOPRA antenna for mm-wave radio

astronomy. During a recent visit, I had a chance to talk to many people and visit the antenna. This memo is the result of contributions from many people with good ideas but, of course, any mistakes are my own.

2.0 The Proposed Optics

2.1 The Antenna

The unshaped antenna arrangement is shown in Figure 1. The inner two rings of panels may be retained and the two outer rings replaced with solid panels. The difference in shape between the shaped and unshaped surface is small enough that accommodating the new outer panels will not be a problem (1).

The optics has been arranged such that the receivers and feeds for cm wave operation remain unchanged. By unshaping the main reflector, the diameter of the secondary has changed slightly (2589 mm) compared with 2750 mm for the shaped case). The focal length of the main reflector is set at 7.04 m.

2.2 The cm-wave subreflector

The feeds and feed positions for cm-wave operation are unchanged from the present arrangement. The secondary half angle is unchanged at 14°. The design of the subreflector is outlined in Figure 2 and the following approximate constants result.

EQUIVALENT FOCAL LENGTH	44.86 m
MAGNIFICATION	6.36
PLATE SCALE AT CASS FOCUS	4.6 arcsec/mm
POINTING CHANGE WITH LATERAL SUBREFLECTOR CHANGES	29 arcsec/mm

2.3 The mm-wave receiver mount

The mounting for the mm-wave receiver is shown in Figure 3. The mm-wave receiver is mounted off the main rotating mount and may be kept cold and cabled up at all times. To couple the receiver into the optical path, the feed assembly from a cm-wave receiver is removed and a 45° reflector is substituted as shown.

2.4 The mm-wave subreflector

The design of the subreflector is shown in Figure 4. A diameter of 498 mm will result in a simple nutation mechanism and with the receiver positioned as shown will give a subtended total subreflector angle of 4.1°; the same as the NRAO 12m telescope.

The relevant optical constants are given below.

EQUIVALENT FOCAL LENGTH	307.44 m
MAGNIFICATION	43.67
PLATE SCALE AT CASS FOCUS	0.66 arcsec/mm
POINTING CHANGES WITH LATERAL SUBREFLECTOR MOVEMENT	29 arcsec/mm

The high magnification results in the Cassegrain feed positions being very non critical both in displacements along the optical axis and perpendicular to it.

2.5 The Nutating Mechanism

Figure 5 shows the relationship between the subreflectors. The distance along the optical axis between the two subreflectors is 592 mm, which should be adequate to install the small mm-wave subreflector permanently behind the cm subreflector.

The nutating mechanism could be a direct copy of the NRAO mechanism (2). An article describing this is attached to this memo. This has been at use at the 36-ft and 12-m for over 20 years with no significant failures.

The ratio of subreflector rotation to beam movement on the sky depends on the distance from the subreflector vertex to the mechanical rotation point. Taking reasonable values, the ratio between beam movement on the sky to subreflector tilt is around 0.1. The beamwidth of the antenna at 100 GHz will be around 30 arc seconds, so a tilt of around 15 arc minutes will give a 3 BW beam shift in the sky.

References PARSONS

Barry ~~Parsius~~ and Mike Kestevan (Private Conversation)

J. M. Payne, "Switching Subreflector for Millimeter Wave Radio Astronomy," *Rev. Sci. Instrum.* Vol 47, No. 2, February 1976

DIMENSION	cm λ	mm λ
D	22 m	22 m
f	7.04m	7.04m
f/D	0.32	0.32
θ_P	76°	76°
θ_S	14°	2.05°
d	2589mm	498mm
L	749mm	157.4mm

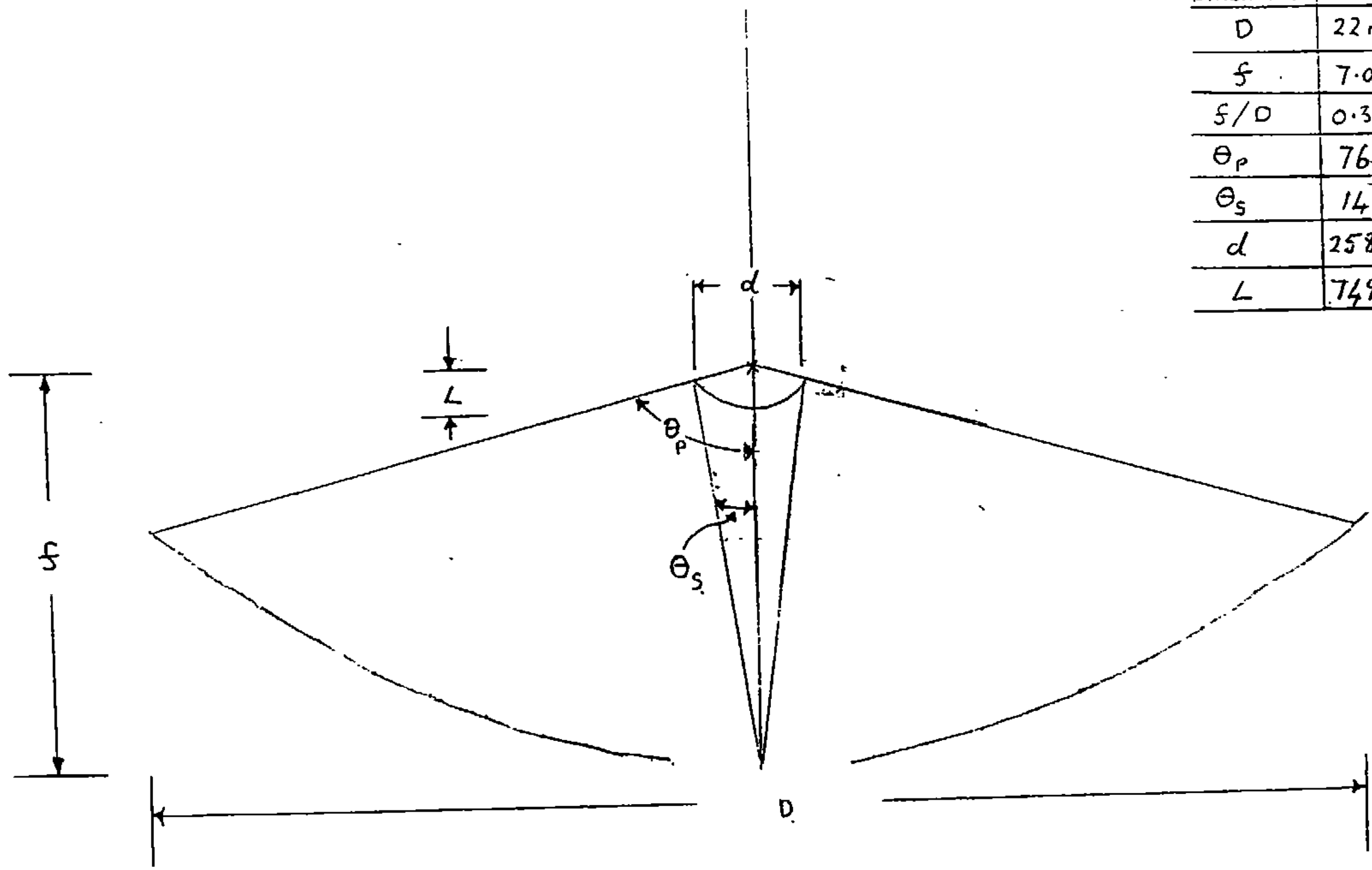


FIGURE I

OPTICS – MOPRA ANTENNA
UNSHAPED
PAYNE MARCH 75

REQUIREMENTS

① MAIN REFLECTOR UNSHAPED
$D = 22\,m$

② CM FEED POSITION UNCHANGED

③ FEEDS THE SAME ($\theta_s = 14°$)

④ FOCAL LENGTH $7.04\,m = f$

$$\tan\tfrac{1}{2}\theta_p = \frac{1}{4}\frac{D}{f}$$

$$\theta_p = 76°$$

F_c = DISTANCE BETWEEN PRIMARY AND SECONDARY FOCI = 5515 mm

$$\frac{1}{\tan\theta_p} + \frac{1}{\tan\theta_s} = \frac{2F_c}{d}$$

d = DIAMETER OF SUBREFLECTOR

= 2589 mm

L = DISTANCE FROM PF TO SUBREFLECTOR VERTEX

$$1 - \frac{\sin\frac{1}{2}(\theta_p - \theta_s)}{\sin\frac{1}{2}(\theta_p + \theta_s)} = \frac{2L}{F_c}$$

$L = 749$ mm

HYPERBOLIC PARAMETERS FOR CM λ SUBREFLECTOR

ECCENTRICITY, $e = \dfrac{\sin\frac{1}{2}(\theta_p + \theta_s)}{\sin\frac{1}{2}(\theta_p - \theta_s)}$

= 1.37292

HALF TRANSVERSE AXIS, $a = \dfrac{F_c}{2e}$

$a = 2008.50$

HALF CONJUGATE AXIS, $b = a\sqrt{e^2 - 1}$

$b = 1889.4$

$2C$ = DISTANCE BETWEEN PRIM + SEC FOCUS

$C = \sqrt{a^2 + b^2}$

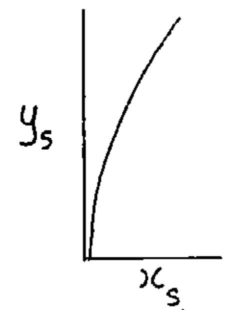
$2C = 5515$ ✓

FIGURE 2

EQUATION FOR SUBREFLECTOR

$$x_s = a\left[\sqrt{1+\left(\frac{y_s}{b}\right)^2} - 1\right]$$

y_s	x_s
100	2.8
200	11.2
300	25.2
400	44.5
500	69.2
600	99.0
700	133.5
800	172.7
900	216.3
1000	264.1
1200	371.0
1295	426.7



CM-λ SUBREFLECTOR.
MOPRA ANTENNA – UNSHAPED

PAYNE MARCH 95

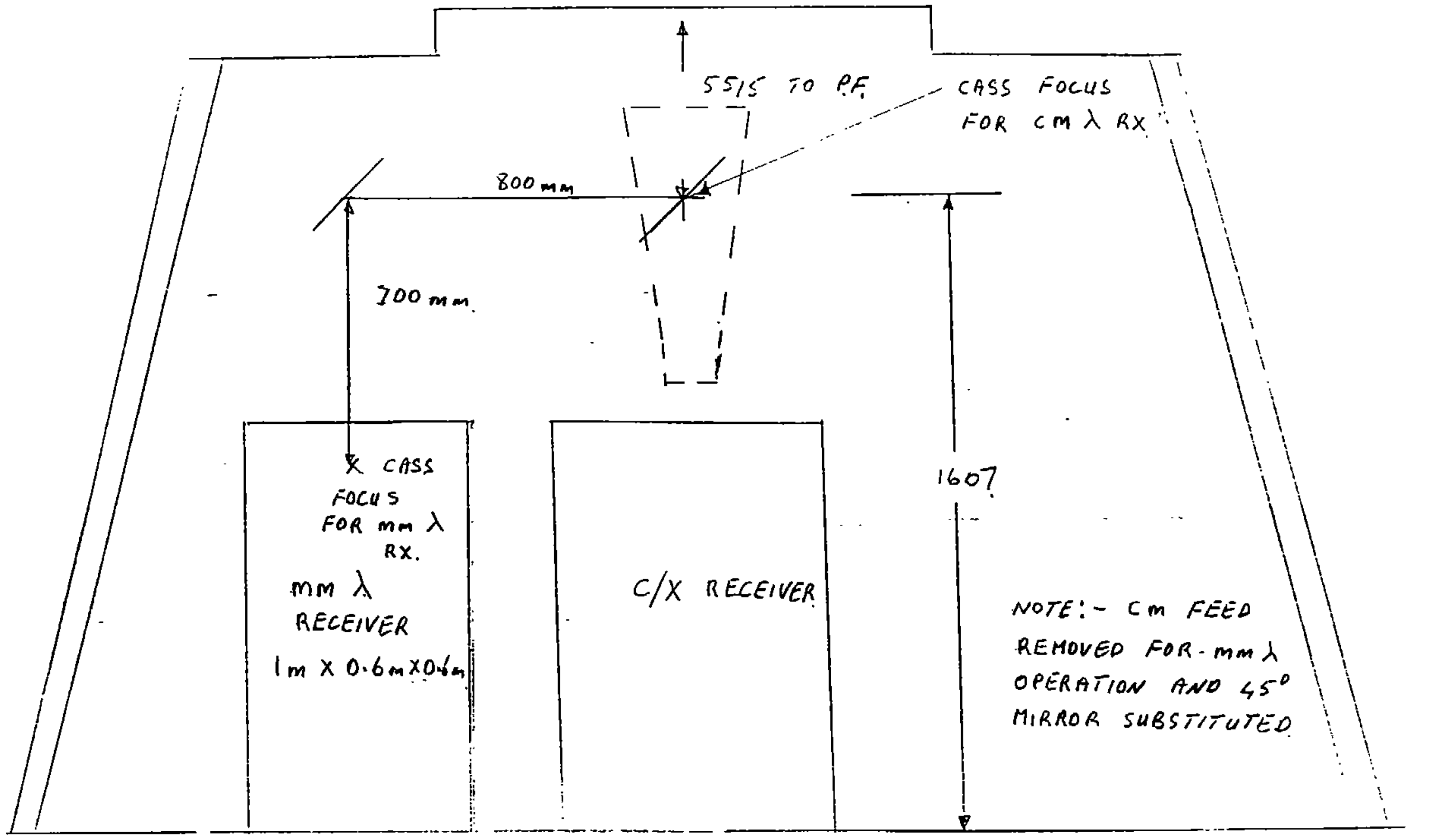


FIGURE 3

MOPRA ANTENNA
mm λ RECEIVER
INSTALLATION
P.F.YNE MARCH.

REQUIREMENTS

① mm-λ RECEIVER MOUNTED OFF TO THE SIDE

$F_c = 5515 + 800 + 700$

$= 7015\,mm$

② MAKE FEEDS THE SAME AS NRAO 12 m.

$\Theta_s = 2.05^\circ$

$$\frac{1}{\tan\Theta_p} + \frac{1}{\tan\Theta_s} = \frac{2F_c}{d}$$

DIAMETER OF SR, $d = 498\,mm$.

$$1 - \frac{\sin\frac{1}{2}(\Theta_p - \Theta_s)}{\sin\frac{1}{2}(\Theta_p + \Theta_s)} = \frac{2L}{F_c}$$

DISTANCE FROM VERTEX OF S.R. TO P.F., L

$L = 157.1\,mm$

HYPERBOLIC PARAMETERS FOR mm λ SUBREFLECTOR

ECCENTRICITY, $e = \dfrac{\sin\frac{1}{2}(\Theta_p + \Theta_s)}{\sin\frac{1}{2}(\Theta_p - \Theta_s)}$

$= 1.04687$

$a = \dfrac{F_c}{2e} = 3351\,mm$.

$b = a\sqrt{e^2 - 1} = 1038\,mm$.

EQUATION FOR SUBREFLECTOR

$$x_s = a\left[\sqrt{1 + \left(\frac{y_s}{b}\right)^2} - 1\right]$$

y_s mm	x_s mm.
0	0
20	0.62
40	2.49
60	5.59
80	9.94
100	15.51
120	22.32
140	30.34
160	39.58
180	50.01
200	61.64
220	74.44
240	88.41
249	95.07

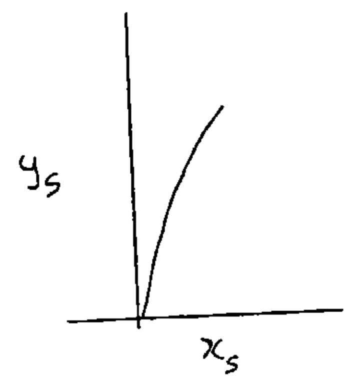


FIGURE 4

mm λ SUBREFLECTOR – MOPRA ANTENNA

PAYNE MARCH 95

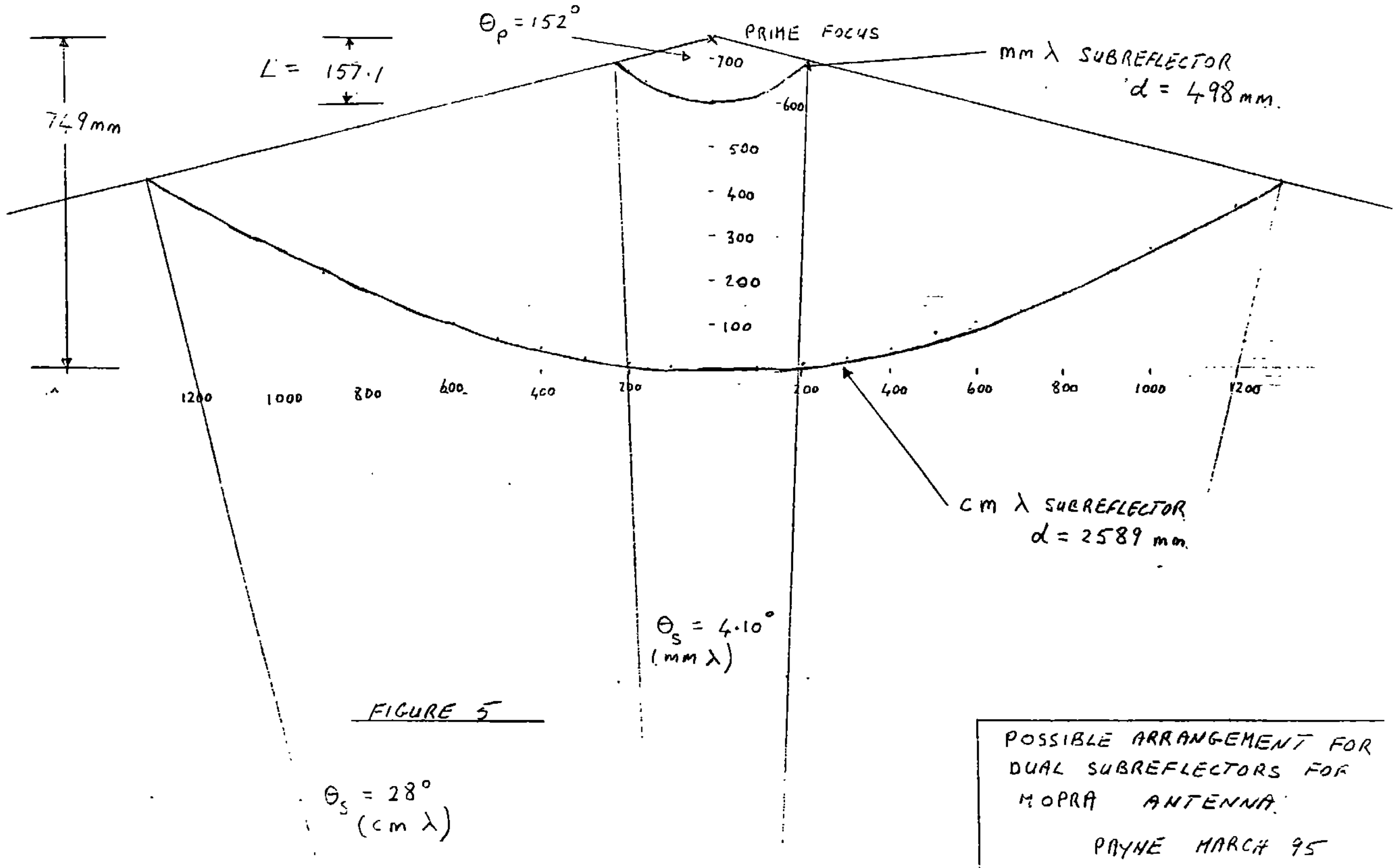


FIGURE 5

POSSIBLE ARRANGEMENT FOR DUAL SUBREFLECTORS FOR MOPRA ANTENNA.

PAYNE MARCH 95

Switching subreflector for millimeter wave radio astronomy

J. M. Payne

National Radio Astronomy Observatory, Suite 100, 2010 North Forbes Boulevard, Tucson, Arizona 85705*

(Received 18 September 1975; in final form, 28 October 1975)

A method of beam switching a Cassegrain antenna used for radio astronomy by tilting the hyperbolic secondary reflector is described. The system described has been in use for over a year at the 11-m millimeter-wave antenna operated by the National Radio Astronomy Observatory at Kitt Peak, Arizona.

INTRODUCTION

The purpose of switching the antenna beam during observations is to provide cancellation of atmospheric noise. By beam switching between the radio source of interest and a position some beam widths away from the source, the contribution of the source may be separated by the normal process of synchronous detection.

The advantages of beam switching by tilting the subreflector, rather than using a radio frequency switch coupled to an off-axis feed horn, are twofold. First of all, the switching system is virtually lossless and, secondly, switching for all frequencies is accomplished by one simple mechanism. Although this technique has been employed in the past,[1,2] the mechanism used to achieve the switching described here is novel and represents an improvement in both performance and reliability over previous methods.

A square-wave movement of the beam is desirable in order to provide an optimum signal-to-noise ratio. The frequency of the square wave should be >2 Hz and as high as 5 Hz, if possible, in order to cancel atmospheric effects and instabilities in the receiving system. To minimize time lost due to transition, a maximum of one-eighth of the cycle should be spent in moving from one position to the other; thus the transition time should be <31 msec and preferably <12 msec.

A suitable subreflector for the 11-m antenna is 45.7 cm in diameter, 0.635 cm thick, and, when manufactured from aluminum, weighs approximately 2.17 kg.

The required performance of the switching subreflector, in addition to the transition times already mentioned, are outlined below:

(1) For adequate beam switching at the lowest frequency at which the antenna will be used (33 GHz), a beam deviation of 10′ is required. This corresponds to an angular movement of the subreflector of 80′ or an edge movement of 5.4 mm.

(2) The tilt angle of the subreflector must be simply adjustable from the control room of the telescope, and the angle must be stable to within ±40″ after the reflector switches from one position to the other.

(3) The tilting mechanism must be reliable and not prone to wear. At a switching frequency of 5 Hz the reflector moves 864 000 times per day, so the absence of wear is an important consideration.

DESCRIPTION OF THE MECHANISM

A block diagram of the subreflector mechanism and the control electronics is shown in Fig. 1.

Two solenoids driven by a high-power transistor amplifier position the reflector. The torque required to switch the reflector through the required angle in less

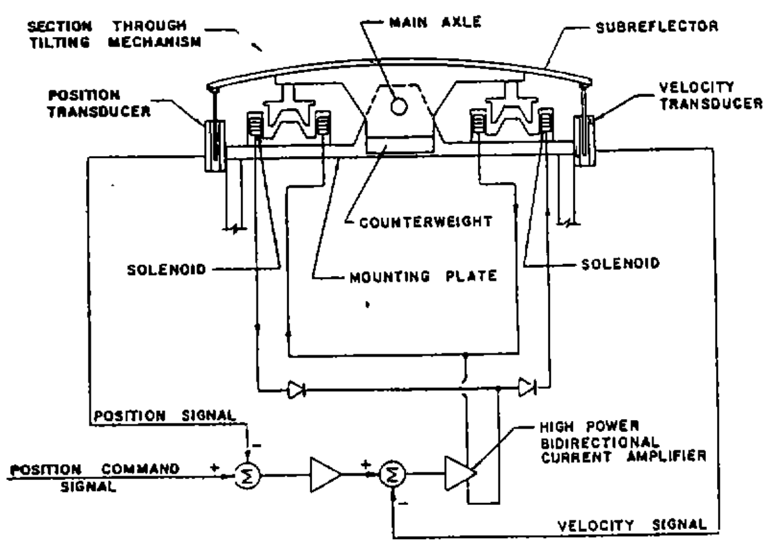


FIG. 1. Block diagram of switching subreflector.

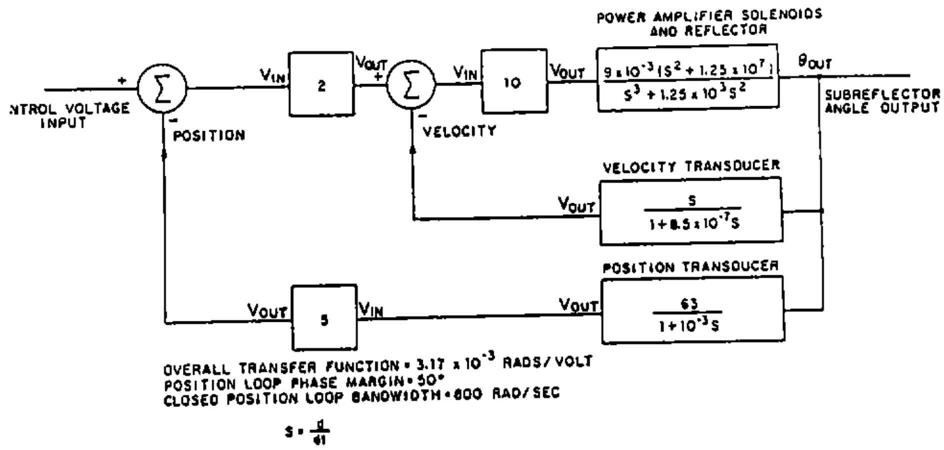


Fig. 2. Block diagram of servo system.

than 20 msec is approximately 1.5 kg m, an easily obtainable torque with the solenoids positioned as shown in Fig. 1. A type I position servo system is used to accurately position the subreflector. This type of servo should, in the absence of friction, give a zero static position error owing to the presence of one integrator in the loop. The integrator in this case consists of the secondary velocity loop: a constant voltage input results in a constant rate of change of output angle. Because of the nonlinearity associated with solenoid operation and also to provide damping, the position loop is closed around a high gain velocity loop. The subreflector may then be commanded to tilt any angle simply by means of a voltage applied to the position loop. When beam switching, this voltage is simply a square wave. A block diagram of the servo system, showing the various transfer functions, is shown in Fig. 2. This system is simply realized using operational amplifiers.

This system of switching is attractive in that no bearings are needed apart from those associated with the main shaft about which the subreflector rotates. The moving parts of the solenoids never come into contact with the stationary parts, so no wear takes place. Both the position and velocity transducers consist of noncontacting metallic cores moving within coils of wire; therefore, wear is again nonexistent. Suitable transducers are manufactured by Hewlett–Packard and Schaevitz Engineering.

The position waveform of the subreflector, together with the current through the solenoids, when switching the antenna beam 4′ is shown in Fig. 3.

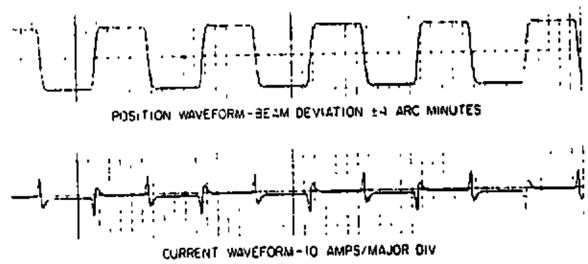


Fig. 3. Switching waveforms at 5 Hz.

* Operated by Associated Universities, Inc., under contract with the National Science Foundation.

[1] S. D. Slobin, "A Study of Asymmetrical Cassegrain Antenna Feed System Applications to Millimeter Wavelength Radio Astronomical Problems," USC EE Report 321, University of Southern California, Electrical Science Lab, Dec. 1968.

[2] National Aeronautic and Space Administration, US Patent no. 3,417,399, "Millimeter Wave Radiometer for Radio Astronomy" 17 Dec. 1968.