NCRA Technical Report *** NTR – (07/93) ***

FEEDS FOR GMRT ANTENNA – Part: I

G.Sankar

Keywords : Design & Construction, Radiation - Principal & Cross-polar patterns(PRIMARY), Measurements of Bandwidth, VSWR, Aperture efficiencies

---

Abstract

Choice criteria of feeds for radio-astronomical purposes are outlined;The design aspects of 327 MHz, 610 MHz & 233 MHz are summarised. Results of important measurements are furnished and construction details are sketched.

---

1 Introduction

Metre-wave radio astronomy being the pioneering area of research during yester-years has been relegated in developed countries because of man-made radio interferences. For the same reason it is quite an attractive field for developing countries like ours. The Giant Metre-wave Radio Telescope (GMRT) has been designed and being constructed as a major new instrument to fulfill this objective with potential to tread unexplored territories of astrophysics and cosmology.

The GMRT is an array of 30 numbers of fully steerable parabolic dish antennas, each of 45 metre diameter and willbe operating as an aperture synthesis radio telescope. The 30 antennas will form 435 possible interferometric pairs with their projected baselines continuously changing with the diurnal motion of Earth.

For the versatility of the radio telescope, it should exhibit high angular resolution and wide frequency coverage. Hence the reason for a large collecting area of each antenna and provision of multi-frequency feeds (plus receiver electronics). The chosen frequencies in the metre-wave band are six separate ones, centering at 50,150,233,327,610 and 1420 MHz. All the feeds at these frequencies will provide dual,circularly-polarized outputs.

Elaborate details about the novel design of the GMRT antenna can be found in references [1] and [2].This report describes the feeds of 233 MHz, 327 MHz and 610 MHz .

The feed system is a prime focus one for the parabolic dish and the feeds for various frequencies will be mounted on the four faces of a cubic shaped, rotating turret. The observing frequency will be changed from one band to the other by rotating the turret and positioning under computer control. This leads to a constraint that at least two faces of the turret should support multi-frequency capability . The coaxial waveguide feed design chosen for operation at 610 MHz and 233 MHz (simultaneously) and a combination of 38 MHz dipoles with 1420 MHz horn is the current solution to the above constraint.

An ideal feed for radio astronomy applications would have very low sidelobes, axially symmetric radiation patterns, a well-defined phase centre , a good VSWR over the required bandwidth and low internal losses. With special reference to GMRT objectives, the design specifications for the feeds can be postulated as follows :

1. The main lobe of the radiation patterns should exhibit axial symmetry and have a taper of less than or equal to -10 dB (at the edge of the reflector) excluding space attenuation.

2. The principal plane patterns (i.e. E and H) should match well, at least within the rim-angles of the parabolic dish — so as to provide a polarization efficiency of not less 0.99 (or in otherwords, the cross-polar response for any one of the linear polarized element must be the order of -25 dB or less).

3. The sidelobes of the feed's pattern should be less than -20 dB with respect to the peak of the main lobe.

4. The bandwidth of the feed must be approximately 10% for a VSWR of less than 1.2 (i.e. return loss of -20 dB or less.).

5. Overall aperture efficiency of the feed in conjunction with the parabolic dish should be maximised.

The 45 m. parabolic dish has a f/D value of 0.411 (the semi rim- angle works out to be 62.6 degrees) .

2 327 MHz. feed

Conventional dipoles with reflector would suffice most of the above requirements except for the fact that it will not be able deliver the required polarization purity. This condition arises because of its H-plane pattern being broader than the E-plane pattern. Two dipoles can be arranged as a parallel array with half wavelength spacing on a ground reflector [3] to yield nearly identical E and H plane patterns.

An alternative solution, much simpler to construct will be to incorporate a beam forming ring (BFR) above the dipole as discovered by P.S.Kildal [4]. The conducting ring is placed above the dipole in a plane parallel to the reflector and supported by dielectric rods. The beam forming ring compresses the H-plane pattern while it has no significant effect on the E-plane. Certain other positive features when compared to dipole and reflector are :

1. improvement in the overall antenna efficiency.
2. spillover losses are reduced and thus a lower noise temperature of the antenna.
3. enhancement in the cross-polarization level.

The optimum dimensions of the dipole, BFR and reflector were arrived at by careful measurements done on a scaled-up version (i.e. at 610 MHz.) The values arrived at are :

- Reflector diameter : 2.2λ.
- Height of dipole above reflector : 0.26λ.
- BFR diameter : 1.22λ.
- BFR height above reflector : 0.51λ.

Comparison of these values with the optimum estimated by theoretical means [4] shows that all the dimensions are well within the tolerance limit.

The final configuration of the feed designed for 327 MHz is shown in Figure 1. A prototype was fabricated and all its radiation and electrical characteristics were studied. The dipoles were constructed in Copper and the BFR was in Aluminium. The reflector was made out of stainless steel frame and a stainless steel wire mesh of 10 mm. square. The mesh was stretched and then spot-welded to the frame-work. Crossed dipoles are employed for dual polarization. To achieve pattern symmetry the colinearity of the centres of the reflector,BFR and the crossed dipoles is ensured.

A small deviation from the Kildal's design is done on our feed— incorporating sleeves over the dipole. Sleeves increases the bandwidth of the dipoles [5]. The feeding arrangement is the standard $\lambda/4$ balun (1:1) type.Care has been exercised in minimising the reflection losses within the coaxial transmission line portion of the dipoles: Simple dielectric beads are used generally to ensure the concentricity of the inner conductor to the outer one, yet these beads introduce high reflection losses if not properly designed and placed [6],[7]. We have used teflon bushes of computed thickness and inter-bead spacing to minimise those reflection losses at 327 MHz.

Figure 3 is a plot of VSWR against frequency ; The VSWR is less than 1.2 for 300 to 367 MHz. Though the lowest occurs at 340 MHz it is seen that a bandwidth of 20 % for a centre-frequency of 334 MHz has been realised. The measurement shown is for one of the routinely produced feeds. A fairly high degree of repeatability of this measurement has been achieved in all such units. The feed-points are covered with an epoxy resin to make it waterproof and the connector port is fitted with a vinyl rubber O-ring.

The principal plane patterns measured for the optimised feed is given in Figure 2. Pattern taper (at the rim of parabola - 62.6 deg.) is -12.2 ± 1 dB. Figure 4 depicts the 45 deg. cross-polar pattern measured as per standard procedures suggested in [8].The power level shown is with respect to a co-polar maximum of 0 dB. It is seen that a cross-polar maximum of -27.5 dB (mean value) has been achieved.

From the measured E and H patterns, one can estimate the antenna sub-efficiencies for an ideal parabolic reflector, i.e. with no surface errors,and no aperture blockage by feed and feed support frames [9],[10]. Table 1 lists the feed sub-efficiencies computed for GMRT antenna at 327 MHz.

Table 1 : Antenna Feed sub-efficiencies for 327 MHz.

Efficiencies	*Value*
$\eta_{spillover}$	0.955
$\eta_{polarizn.}$	0.999
η_{taper}	0.779
$\eta_{meshleak}$	0.998

3 Dual-frequency Coaxial Waveguide Feed

The single most attractive feature of coaxial waveguide feed is its' multi-frequency launching capability. Simultaneous transmission or reception of diffrent frequencies without multiplexing is feasible. A coaxial feed covering three frequencies for a satellite on-board antenna has been reported [11]. Similar design and construction of a four band coaxial feed for telemetry antenna exists [12]. Apart from telecommunication it has found application in radio astronomy too. The Netherlands radio telescopes (Westerbork) are one such example; their prime focus feed system has two separate multi-frequency coaxial waveguides, covering 327 MHz, 2300 MHz in one and 610 MHz, 5000 MHz in another [13],[14].

Based on an exhaustive theoretical analysis of the design of coaxial waveguide feeds [15], we had carried out our design for 610 MHz and 233 MHz – as a dual frequency feed [16]. One constraint in such multi-frequency design of coaxial feed is that adjacent frequency bands should not overlap within an octave.This lead us to opt for either 150 MHz or 233 MHz to be included with 610 MHz. The former choice was rejected since it resulted in unwieldy dimensions of the feed.

The fundamental mode of propagation in coaxial structures being TEM, the radiated field component along the axis is zero everywhere; Obviously for a feed it is the most undesirable characteristic. So propagation by alternate mode (single or multiple) is the plausible solution. Coaxial waveguides must then be forced to radiate in TE_{11} mode – simply by exciting the probes in phase opposition. To achieve this, low loss baluns can be employed ; Probes – can be defined as transmission line to guide tranition devices as given in [7].

Figure 5 shows the construction of the dual frequency feed and Figure 9 depicts the geometry and placement of the probes inside the coaxial cavity. One pair of probes supports one-plane polarization while an orthogonal pair supports the normal to the first plane. Similar to the dipole feed discussed in the previous section, a quadrature hybrid at the back-end of the coaxial feed provides circular polarized outputs of both senses. In the dual frequency construction the outer conductor of the 610 MHz serves as the inner one for the 233 MHz. Quarter wavelength chokes are provided in both the frequency parts to cut down the surface currents on the outer conductor and thereby ensuring pattern symmetry. The rear-half of the 610 MHz feed,separated by a thick metal disc is utilised to mount the baluns, quadrature hybrids and low-noise amplifiers.

The impedance matching of the feed (at one chosen frequency) is done by measuring the return loss at balun output-port for various geometries of the probe and its placement, while the feed is radiating into a non-scattering environment. Figure 7 illustrates the final measurement of VSWR for the optimised probe geometry at 610 MHz. For frequencies from 604 MHz to 645 MHz the VSWR is less than 1.2 and for 598 to 702 MHz is less than 1.5.

The principal plane patterns measured at 610 MHz are shown in Figure 6. The mean value of edge taper is seen to be -9.8 dB with variation of ± 1 dB. Figure 8 gives the cross-polar pattern (at 45 deg.) of 610 MHz. The cross-polar maximum is -22.8 dB with respect to a co-polar peak of 0 dB. Figures 10 and 11 show the VSWR plot and the radiation patterns respectively for 233 MHz. The edge taper is -9 dB which conforms to the computed value of the design note [16]. The VSWR plot shows that the 233 MHz feed is a narrowly- tuned one and currently efforts are in way to improve the bandwidth.

The inter-coupling of radiated power between the two frequencies of the coaxial feed has been studied on the radiation patterns : The main lobe does not show any significant change when compared to the patterns of single-frequency feed of identical dimensions.

The dual frequency feed was fabricated in Aluminium ;To reduce the weight marginally ($\approx 7\%$) perforations were done on the following parts :

- Choke and outer conductor of the 233 MHz coaxial feed.
- Back-cover (annular shaped disc) of the 233 MHz feed.
- Choke and outer conductor of the 610 MHz coaxial feed.

This measure did not have any effect on the radiation patterns and impedance characteristics of the feed. Computed sub-efficiencies for 233 MHz and 610 MHz are given in Table.2

with identical presumptions as notified for Table.1.

Table 2: Antenna Feed sub-efficiencies for 233 & 610 MHz

Efficiencies	*233 MHz.*	*610 MHz.*
$\eta_{spillover}$	0.8	0.83
$\eta_{polarizn.}$	0.97	0.999
η_{taper}	0.894	0.847
$\eta_{meshleak}$	0.999	0.991

4 Conclusion

Summarising the performance measures of the three frequency-bands,viz.,233,327 & 610 MHz in lieu of the design objectives (pg.2-3),

327 MHz :

- Taper : -12.2 ± 1 dB.
- Cross-polar Peak : -27.5 dB.
- Sidelobe level : -22 ± 4 dB.
- Bandwidth (SWR < 1.2) : 67 MHz ; 20 %
- Aperture efficiency : 0.742

610 MHz :

- Taper : -9.8 ± 1 dB.
- Cross-polar Peak : -22.8 dB.
- Sidelobe level : -17 ± 3 dB.
- Bandwidth (SWR < 1.2) : 41 MHz ; 7 %
- Bandwidth (SWR < 1.5) : 104 MHz ; 16 %
- Aperture efficiency : 0.696

233 MHz :

- Taper : -9 ± 0.5 dB.

- Sidelobe level : -15 ± 1 dB.
- Bandwidth (SWR <**1.5**) : 10.0 MHz ; 4 %
- Aperture efficiency : 0.693

it is seen that the impedance characteristic of 233 MHz must be improved to a large extent and a marginal improvement of the similar property for 610 MHz must also be attempted. Part-II of this report describes about the 150 MHz and 38/50 MHz feeds.

****

5 References

1. Swarup,G., GMRT–Scientific objectives and design aspects, *Indian Jl. of Radio & Space Physics*, Vol.**19**,(1990).

2. Swarup,G.,Ananthakrishnan,S.,Kapahi,V.K.,Rao,A.P.,Subrahmanya, C.R.,and Kulkarni,V.K., The Giant Metre-wave Radio Telescope, *Current Science*, Vol.**60**, No.2, (1991).

3. Christiansen,W.N.,and Hogbom,J.A.,*Radio Telescopes*, Cambridge University Press, (1969) p.68.

4. Kildal,P-S.,and Skyttemyr,S.A., Dipole-Disk Antenna with Beam-Forming Ring,*IEEE Trans.on Ant. & Propg.*, Vol.**AP-30**, No.4, (1982).

5. Stutzmann,W.L.,and Thiele,G.A.,*Antenna Theory & Design*, John Wiley & Sons. Inc., (1981) pp.280–282.

6. Sankar,G., Coaxial Transmission Lines – Bead supported. NCRA Tech. Note : N00108. (1991).

7. Ragan,G.L.,(Ed.),*Microwave Transmission Circuits*, Dover Publication.Inc.,New York., (1965) pp.155–170.

8. Clarricoats,P.J.B.,and Olver,A.D.,*Corrugated horns for Micro wave Antennas*, Peter Peregrinus Ltd.,London, (1984) pp.177–79.

9. Kildal,P-S., Factorization of the Feed Efficiency of Paraboloids and Cassegrain Antennas,*IEEE Trans.on Ant. & Propg.*, Vol.**AP-33**,No.8, (1985).

10. Sankar,G., Antenna Feed Efficiencies Computation - Steps showing Computation. NCRA Tech. Note : N00109, (1990).

11. Figlia,G.,Klooster,K.v.,Savini,D., A three-frequency feed for Quasat antenna,*CSELT Tech. reports*, Vol.**XVI**,No.4, (June,1988).

12. Livingston,M.L., Multi-frequency Coaxial Cavity Apex Feeds,*Microwave Journal*, (Oct.1979) pp.51–54.

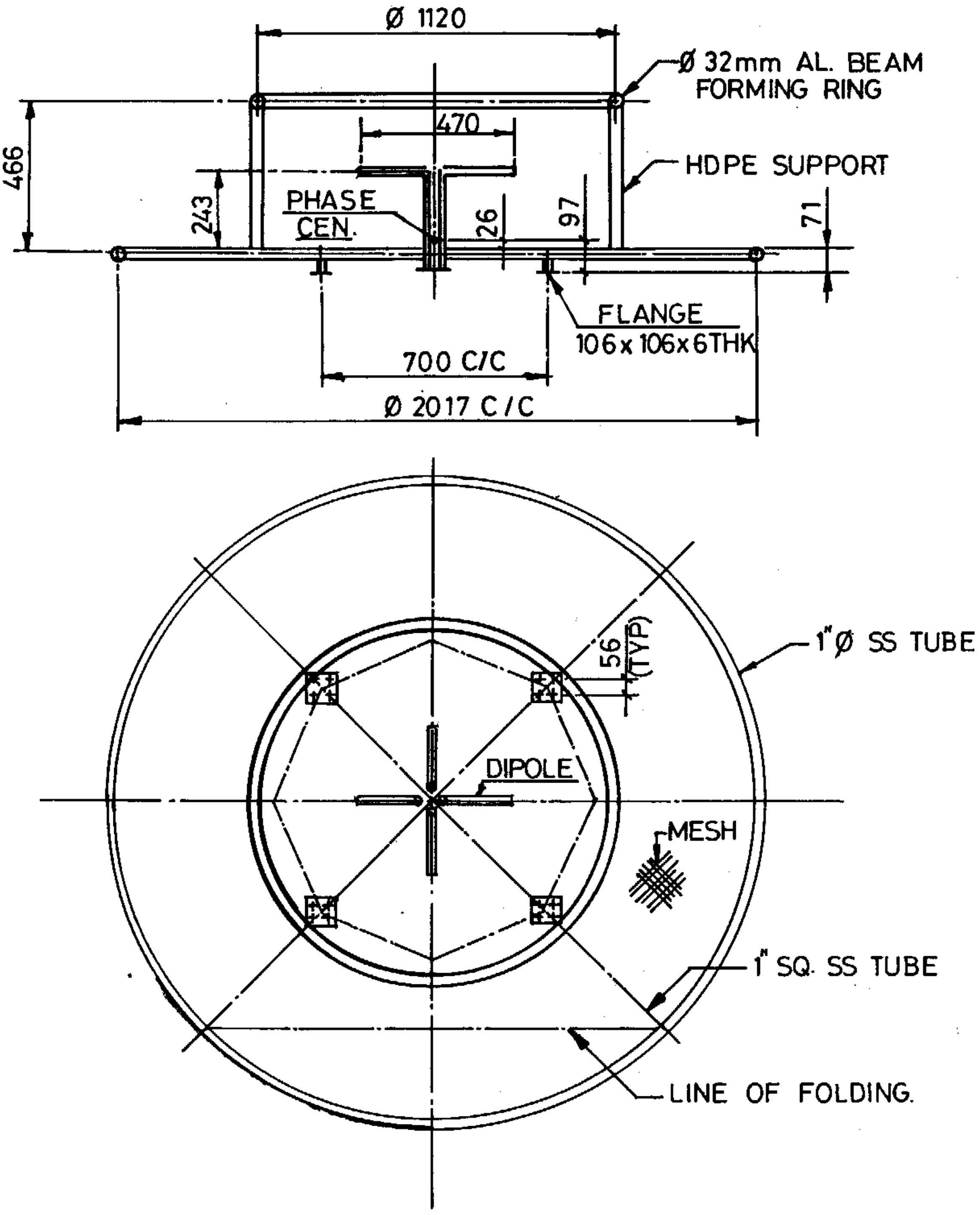
13. Van Ardanne,A.,Bregman,J.D.,Sondaar,L.H.,Knoben,M.H.M., A Compact Dual Polarized Coaxial Feed at 327 MHz.,*Electronics Letters*, Vol.**20**,No.18, (1984) pp.723–724.

14. Jeuken,M.E.J.,Knoben,M.H.M, and Wellington,K.J., A Dual Frequency, Dual Polarized Feed for Radioastronomical Applications,*Rechnernetze und Nachrichtenverkehrstheorie*,NTZ, Heft:**8**, (1972) pp.374–376.

15. Shafai,L. and Kishk,A.A., Coaxial Waveguides as Primary Feeds for Reflector Antennas and comparison with Circular Waveguides,*AEÜ*,Band:bf 39, Heft 1, (1985) pp.8–14.

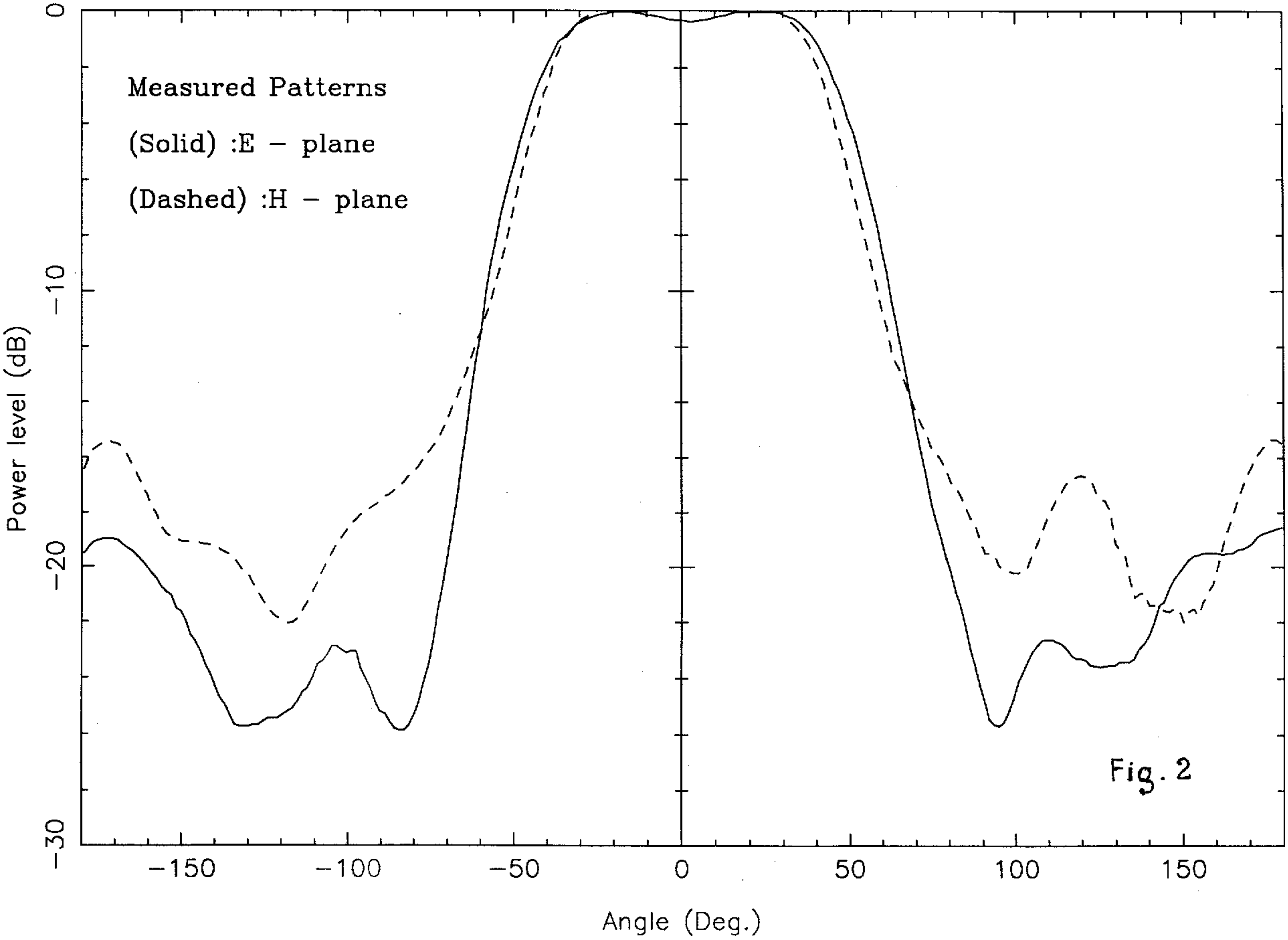
16. Sankarasubramanian,G. and Praveenkumar,A., Dual Frequency Coaxial Waveguide Feed - Design calculations,*Int.Tech.Report*, **AG-02/90**, GMRT–TIFR, Pune.

****



1) U O S ALL DIMENSIONS ARE IN mm.

FIG. 1 **327 MHz FEED FOR G.M.R.T. PROJECT**



KILDAL FEED – 327 MHz.

Fig. 2

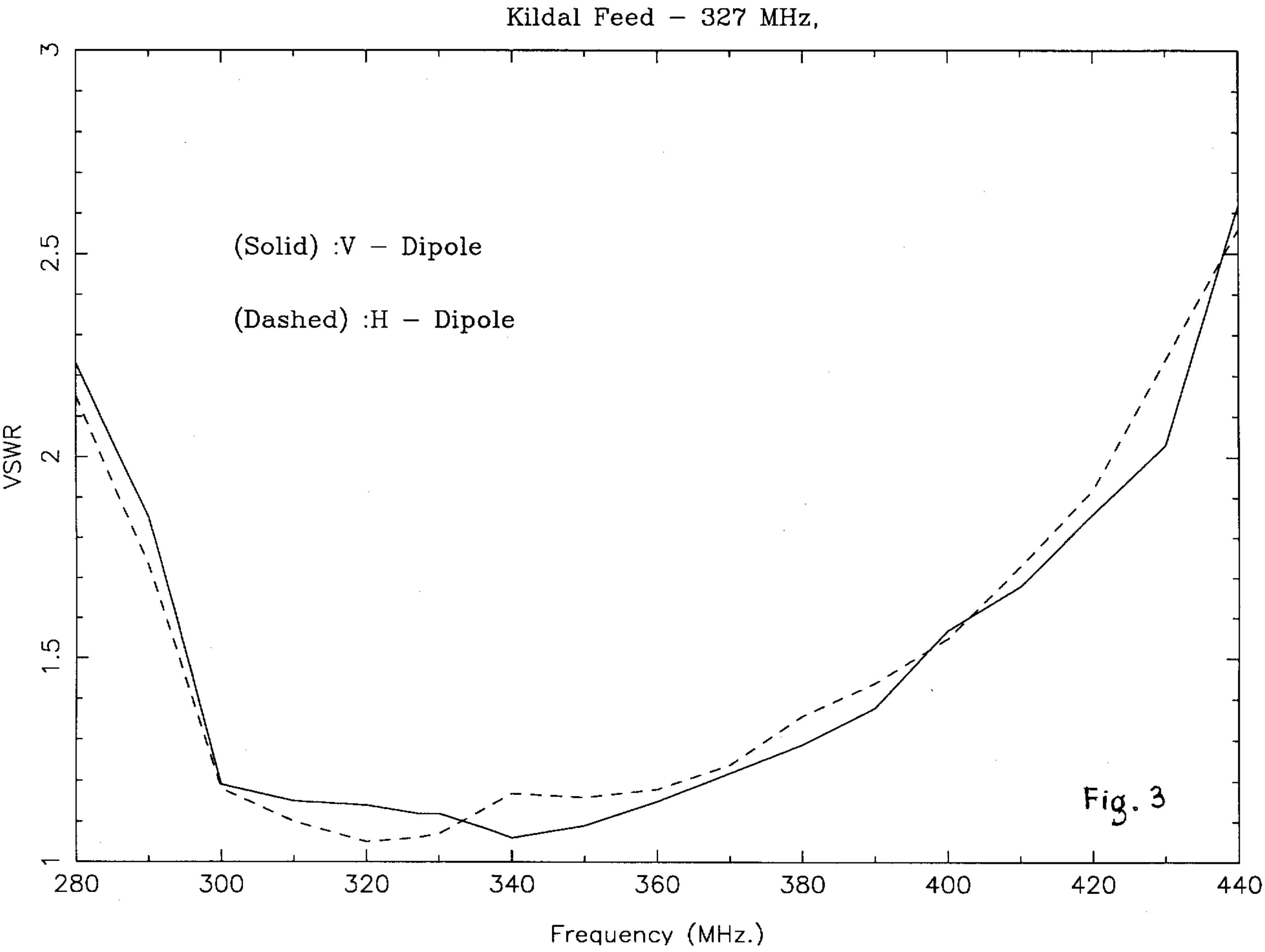
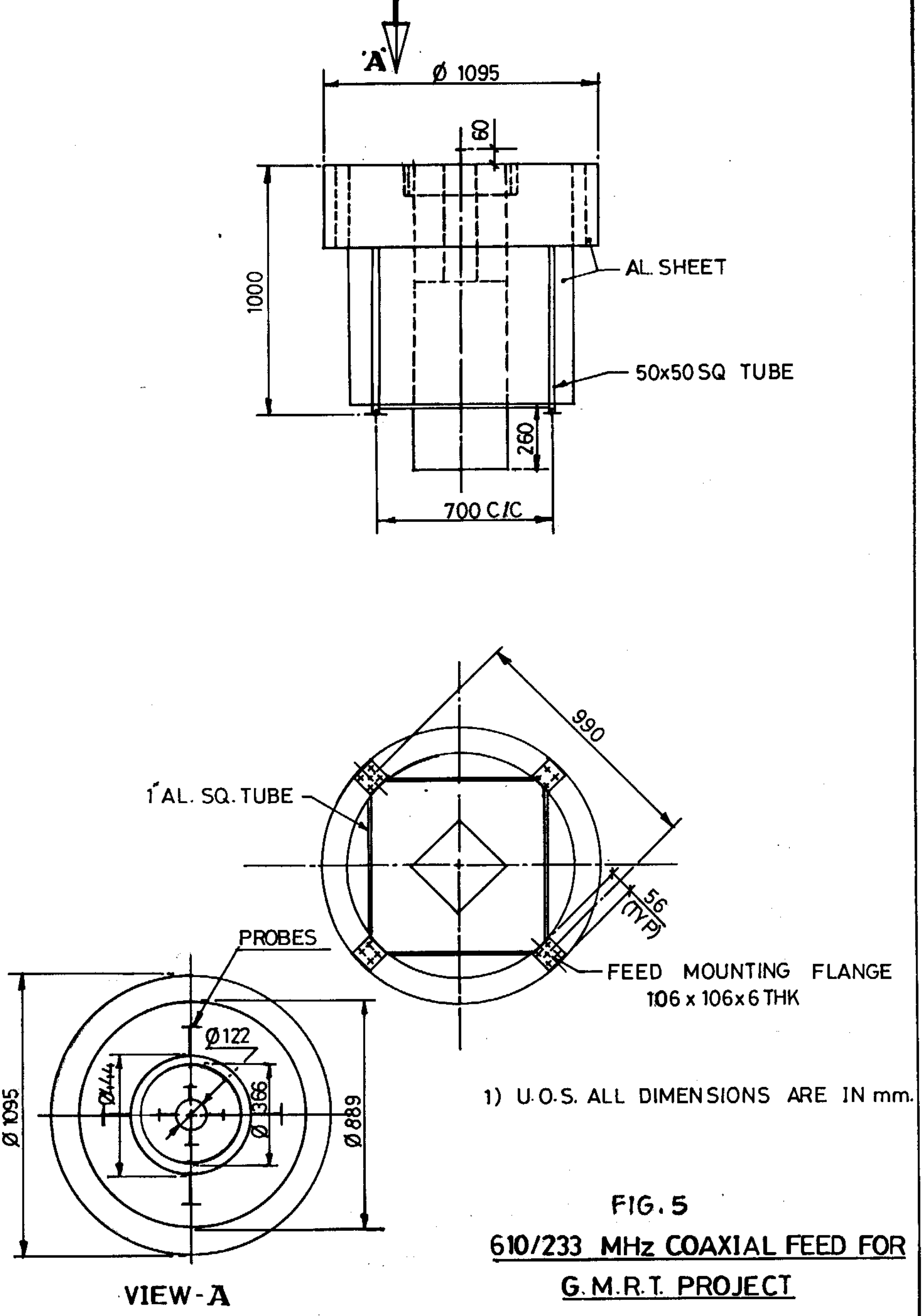

Kildal Feed – 327 MHz,
(Solid) :V – Dipole
(Dashed) :H – Dipole
VSWR
1
1.5
2
2.5
3
280
300
320
340
360
380
400
420
440
Frequency (MHz.)

Fig. 3



1) U.O.S. ALL DIMENSIONS ARE IN mm.

FIG. 5

610/233 MHz COAXIAL FEED FOR G.M.R.T. PROJECT

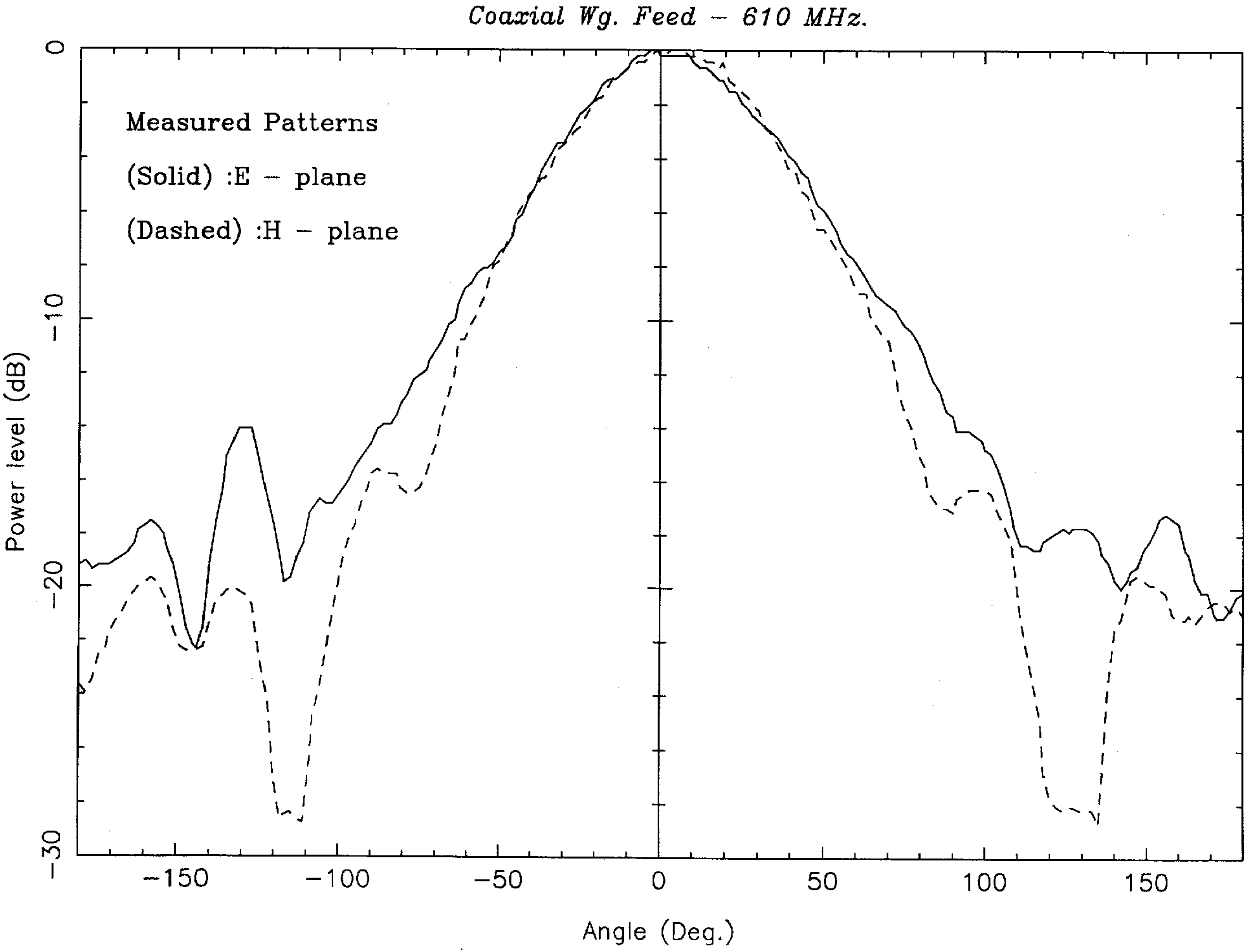

Coaxial Wg. Feed – 610 MHz.
Measured Patterns
(Solid) :E – plane
(Dashed) :H – plane
Power level (dB)
0
−10
−20
−30
−150
−100
−50
0
50
100
150
Angle (Deg.)

FIG. 6

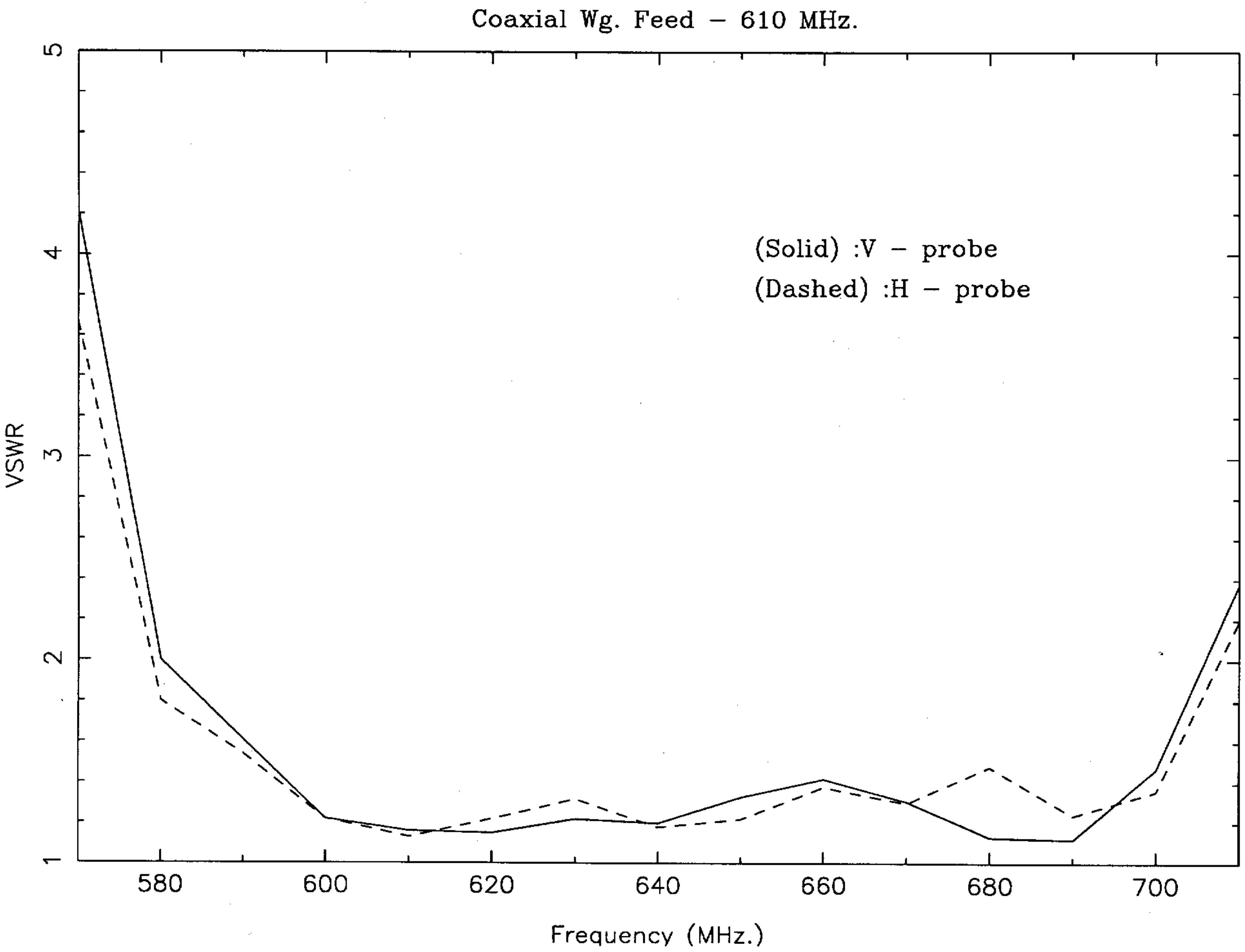

Coaxial Wg. Feed – 610 MHz.
(Solid) :V – probe
(Dashed) :H – probe
VSWR
1
2
3
4
5
580
600
620
640
660
680
700
Frequency (MHz.)

Fig. 7

Fig. 8

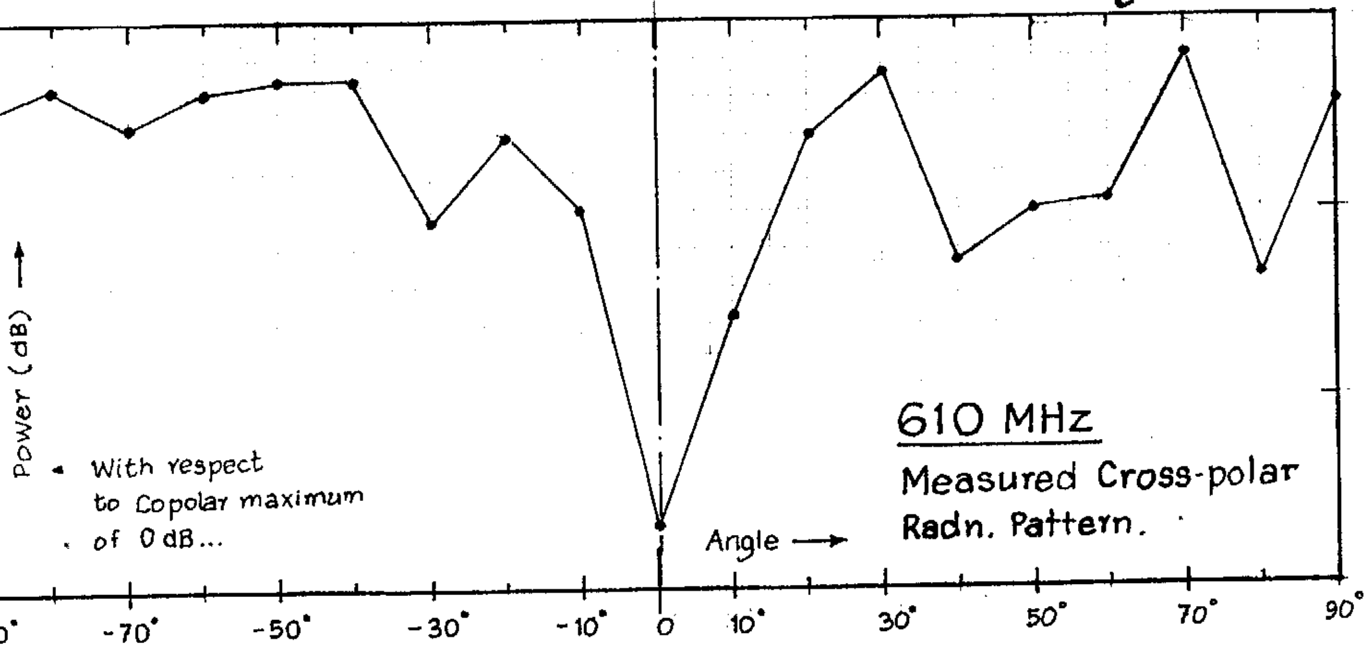

610 MHz
Measured Cross-polar Radn. Pattern.
Power (dB) →
With respect to Copolar maximum of 0 dB...
Angle →
-70°
-50°
-30°
-10°
0
10°
30°
50°
70°
90°

Fig.4

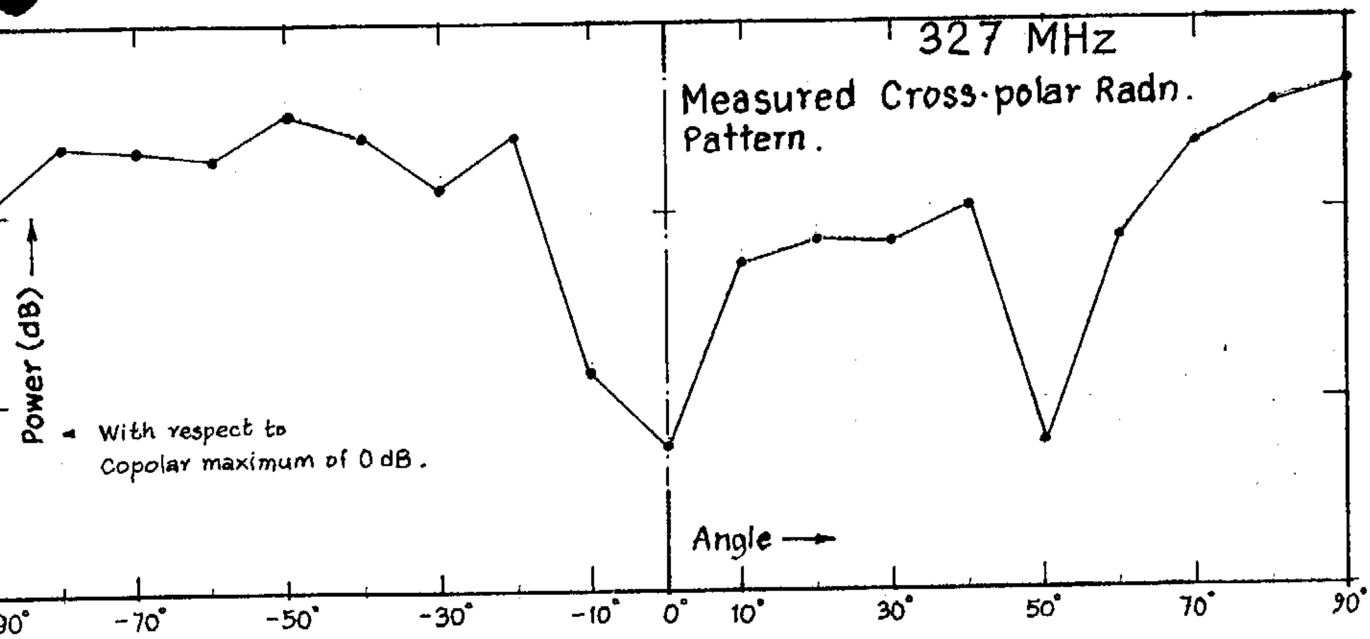
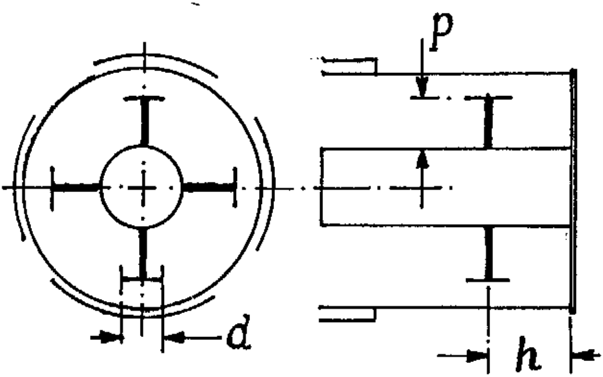

327 MHz
Measured Cross-polar Radn. Pattern.
Power (dB) →
With respect to Copolar maximum of 0 dB.
Angle →
90°
-70°
-50°
-30°
-10°
0°
10°
30°
50°
70°
90°

Fig. 9



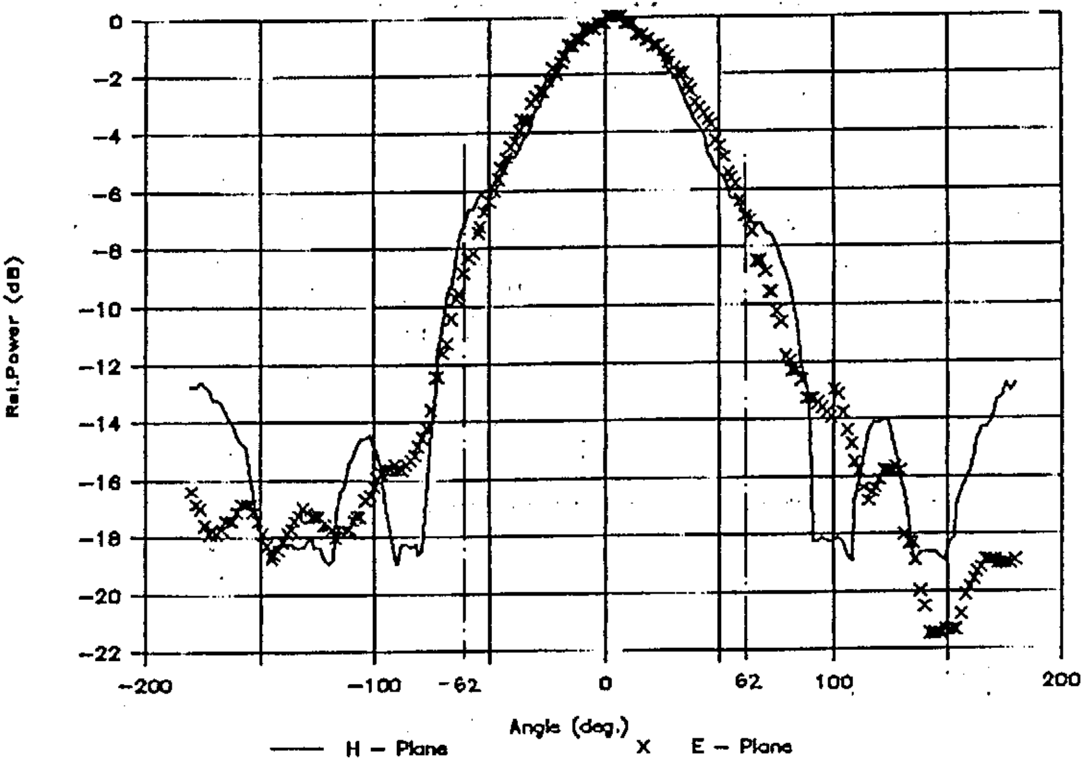
Probe Geometry

p : Probe height

h : Probe position from backplane

d : Probe disc diameter

Fig. 10. 233 MHz. Coax. Feed (2:1)



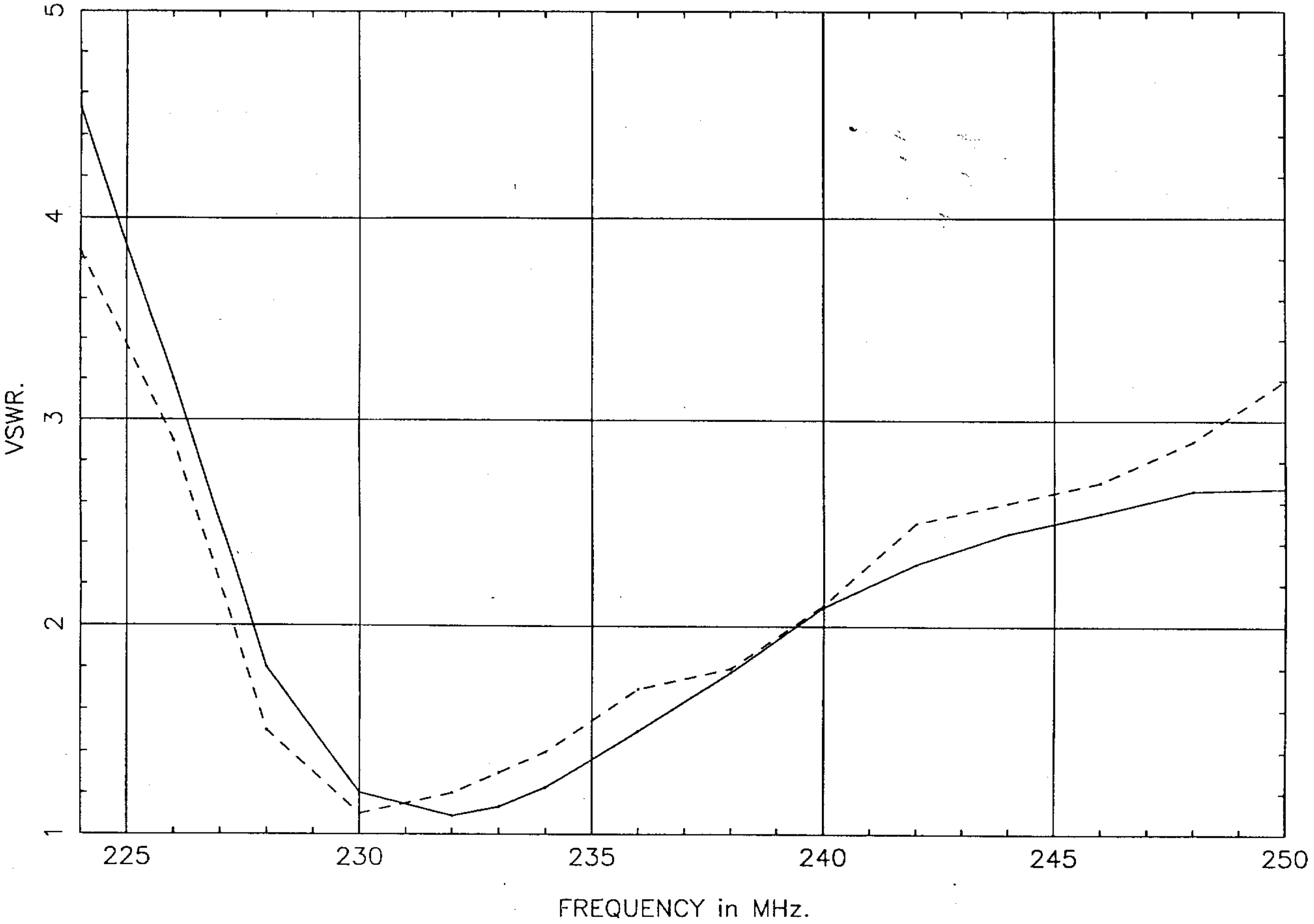


Fig.11