NOVEL S AND C BAND TT AND C ANTENNAS FOR SATELLITE APPLICATIONS

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ABSTRACT

Full spherical coverage from a single antenna cannot be provided at microwave frequencies on a normal satellite because of blockage by the satellite itself. However, cardioid coverage is sufficient. Achieving such coverage from a single antenna minimises the complexity of the on-board TT and C subsystem and so optimises both cost and reliability. Accordingly, investigations have been made into the feasibility of such an antenna in both S and C band versions.

The design is a cylindrical waveguide, propagating a rotating TE mode, terminated in a circumferential array of axial slots and a short-circuiting plate into which an aperture is cut. A short metallic skirt can be added to the outside of the antenna if it is desired to reduce the coverage from the maximum achievable. The design has the advantage of being ‘dual mode’, i.e. it has two isolated Rf connectors providing identical pattern coverage. Thus two separate transponders can be ‘hard-wired’ on for reliability.

The paper deals with the design, main development stages, an performance - including environmental testing results - of the antenna, and includes the results of investigations into a ‘fill in’ antenna intended to complete the spherical coverage if desired.

INTRODUCTION

Analysis of telemetry and telecommand antenna requirements indicates that for most missions, the coverage requirements may be met by a single antenna with cardoid shaped pattern. With this type of pattern, the influence of the satellite body is inherently minimal, a feature which enhances the application of such a standard antenna to a variety of spacecraft bodies. Typically the antenna would be mounted on a boom projecting from the satellite structure.

Two versions of such antennas - one for S band and one for C band - have been developed and tested, including full environment testing for the S band version. The antenna designs, development problems, the final resultant configurations, and their performances are discussed in detail.

S BAND ANTENNA

The essential performance parameters for the S band TT and C antenna have been established as follows:

Operating Frequency band:	2.0 - 2.3 GHz
Total Power Gain (when boom mounted):	>-5 dBi for $\theta < 0 < \alpha^\circ$, $(0^\circ < \emptyset, < 360^\circ)$ where $\alpha = 140^\circ$ for TM band and $\alpha = 120^\circ$ for TC band
Maximum Azimuthal Ripple:	1 dB
VSWR:	1.5:1
Channel Isolation:	10 dB minimum
Back Radiation:	-10 dBi maximum
Rf Power:	10 watts under all conditions

The spherical coordinate system adopted is shown in figure 1.

To meet these requirements the antenna design shown in Figure 2 was initially developed. The cylindrical waveguide carries a rotating TE_{11} mode which is set up by the two probes excited in phase quadrature by means of a hybrid. The isolated port of the hybrid gives the ‘dual mode’ capability. The radiation takes place through the equispaced axial slots placed at the end of the waveguide. For this position of the slots and a rotating TE_{11} mode in the waveguide, the axial slots radiate a circularly polarized field towards boresight. In the opposite direction towards the satellite, the radiation will be circularly polarized but of the opposite sense and of low intensity. In other directions, the antenna will be essentially horizontally polarized which is desirable. A conducting ring is placed inside the waveguide near the centre of the slots to match the slots to the field in the waveguide.

Such a configuration was analysed theoretically and shown to be promising. However, the mutual coupling phenomena, between the probes resulted in the requirement of an asymmetric (-2.5 dB) excitation. Furthermore, the VSWR, the bandwidth and the azimuthal ripple performances were found to be inadequate.

The essential undesirable feature, namely the requirement of an asymmetric excitation was investigated in detail. Of the various alternative feeder configurations like two crossed loops, planar crossed dipoles, crossed dipoles in log periodic arrangement, the last-named showed the most promise. Tests performed with a breadboard incorporating such a feed exhibited good VSWR characteristics but the ellipticity of the rotating TE_{11} mode in the waveguide and hence the azimuth ripple proved to be difficult to maintain over the bandwidth. Further examination identified the apex of the feeder to be the problem area. A special printed circuit was manufactured and assembled, with satisfactory results.

In order to obtain a high radiation efficiency, the slotted waveguide section should be matched to the incident TE_{11} mode. Numerical analysis indicates that the slots act as a shunt conductance to the incident TE_{11} mode and may be matched by a shunt capacitance which can be realised by means of a conducting ring. The diameter and the position of such a ring was empirically established. This matching ring has a significant adverse effect on the radiation patterns because of reduced coupling through the end plate. An increase in the size of the hole, however, in the end plate restored the radiation performance.

The capacitive nature of the resonant ring makes it susceptible to charge to high potential on account of the secondary emissions from the surface of the spacecraft. To prevent breakdown and possible transmission of noise associated with such discharge to the command receiver, a D.C. bonding from the ring to the waveguide wall, having a high inductance per unit length at 2 GHz was incorporated.

A refined breadboard antenna incorporating the promising modifications was manufactured and tested. The coverage performance achieved is summarised in Table I.

	Antenna with skirt		Antenna without skirt	
	TM	TC	TM	TC
Minimum Gain ($0° < \theta < 40°$), dBi	-3.0	-2.2	-3.2	-3.7
Minimum Gain ($40° < \theta < 12°$), dBi	-2.5	-3.2	-1.7	-1.9
Minimum Gain ($120° < \theta < 140°$), dBi	NA	NA	-4.5	-3.6
Equatorial Ripple ($\theta = 90°$), dB	<1	<1	<1	<1

Table I . Coverage performance of the S band antenna.

It may be noted that the basic pattern is nearly toroidal. The addition of the skirt provides a means of further control over the radiation pattern. Alteration in the skirt dimensions (angle, slant length) affect the total pattern while sliding the skirt along the waveguide provides the desirable control of coverage in the region from $\theta° = 90°$ to $\theta = 180°$. Figure 3 shows EØ polarisation patterns for the basic antenna as well as the antenna fitted with skirt.

The performance characteristics discussed above are applicable to an isolated antenna, while in practice the antenna will be mounted on a boom attached to the spacecraft. It is essential therefore to verify the 'in-situ' performance. The influence of the satellite body on the radiation patterns was computed using GTD and verified experimentally for variable boom-lengths (up to 1 meter) when mounted on a representative satellite body. From these measurements it was concluded that the effect of the spacecraft body is to introduce a ripple, as shown in Figure 4, in the region $0° < \theta < 40°$ and a somewhat steeper fall near the limit angle. No significant changes were observed when the metallic boom was replaced by a dielectric one.

For those missions for which full omnidirectional coverage is required, a fill-in antenna is necessary. The fill-in antenna must have conical coverage and adjustable polarisation in order to minimise the interference over the crossover region. One suitable antenna configuration identified and verified experimentally is the open-ended waveguide with a ring termination, to provide d symmetric pattern.

Subsequent to the developmental effort in which the feasibility of a cardoid antenna was established, effort was concentrated on the space application aspects. A refined lightweight model (0.8 kg), incorporating space qualified materials and processes was therefore constructed and space qualified through the normal environmental testing.

C BAND ANTENNA

TT and C systems for a range of application satellites in particular, operate at C band (4/6 GHz). In principle, to meet the coverage requirements, a C band antenna could be scaled from the S band antenna developed; however the frequency gap between the uplink and downlink bands is too large, and warrants an alternative approach.

The principle performance requirements for the C band antenna have been established as follows:

Operating Frequency Bands:	3.943 - 3.957 (TM)
	6.168 - 6.182 (TC)
Total Power Gain	
TM: (on-station):	>-4 dBi over $-20^\circ < \theta < 20^\circ$ (RHCP)
TM (transfer orbit):	>-2.5 dBi over $70^\circ < \theta$ 110° linear ($E\theta$)
TC (on-station):	>-4 dBi over $-30^\circ < \theta < 30^\circ$ (LHCP)
TC (transfer orbit):	>-2.5 dBi over $55^\circ < \theta < 125^\circ$ (EØ)
Maximum Azimuth Ripple:	2 dB
VSWR:	1.3:1
Channel Isolation:	15 dB
Back Radiation:	<10 dBi maximum
Rf Power:	10 watts under all conditions

The performance requirements indicated that at least two radiating elements will have to be provided to comply with the polarisation specifications. The slotted waveguide antenna developed for the S band would radiate orthognal circular polarisations towards the axial directions as required for the on station coverage but only horizontal polarisation for the transfer orbit coverage. Hence, for this coverage the slotted waveguide antenna can only be used for either telemetry or telecommand, and the other operation must be carried out from another antenna with vertical polarisation.

In view of the frequency gap between the telemetry and telecommand bands the initial concept developed was to use the axially slotted waveguide for TM transmissions, and an arrangement of ring slots on the top plate for telecommand radiation. In the latter case, the ring slots would be excited in TM_{01}, mode. Experiments however confirmed that while the axially slotted antenna would adequately meet the requirements for on station and transfer orbit telemetry case, the ring slots proved to be poorly coupled for effective radiation. The ring slot concept was therefore abandoned, and an alternative approach was introduced for the telecommand case.

For telecommand case, the configuration adopted consisted of separate radiators for the transfer orbit and on station requirements.

For the transfer orbit phase, the coverage is obtained by means of a monopole placed on top of the waveguide antenna which is provided with a choke to decouple the monopole from the waveguide. The on station coverage can be obtained with two crossed dipoles in a self-phasing turnstile arrangement placed on the waveguide antenna top plate or with a helical antenna. The crossed dipole arrangement, being mechanically more attractive, was investigated experimentally. The tests indicated that the cross polarisation component is rather high and that the performance is very sensitive on account of dimensional criticality of the self-phasing circuitry. Though the crossed dipole arrangement can be improved with further development work, an alternative in the form of a five turn helix was designed and tested with satisfactory results.

The final version of the overall antenna assembly is shown in Figure 5. The helical antenna is excited via a coaxial coupler with the same cable exciting the monopole. Both the telecommand antennas are fed via the waveguide using a TM_{01}, mode excited by means of an axial probe. The waveguide telemetry antenna is excited by means of a self-phasing crossed dipole with sheath balun arrangement (instead of a log periodic arrangement for the S band version). The axial slots are coupled to the waveguide by means of a resonant ring placed at 10 mm from the top plate. Since the top plate now supports the telecommand antennas, the straight slots have taken ‘I’ form to compensate for the lack of radiation through the hole in the top.

Tests performed on this antenna assembly have confirmed predictions and met the requirements. Like its S band counterpart, this antenna will be space qualified in the near future.

CONCLUSIONS

Two separate TT and C antennas (one each for S band and C frequency bands) have been developed to comply with the coverage requirements of most missions. The antennas are structurally simple, and can be boom-deployed from a satellite body or mounted on top of tower supporting feed elements of reflector antennas. While the requirements at S band have been met from a single slotted waveguide antenna, the wide frequency separation at C band necessitated addition of separate radiators for the telecommand function. The radiators however are structurally integral.

In view of the performance requirements achieved it is expected that these antennas will be standard components for most European satellites.

REFERENCES

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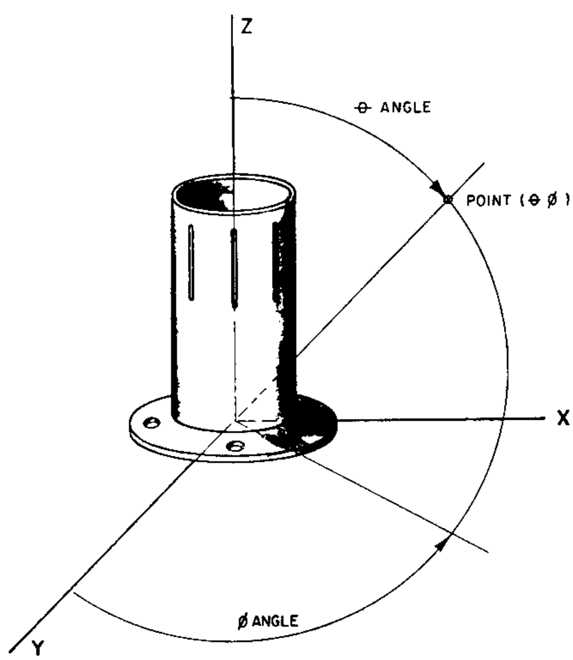

Figure 1. Reference coordinate system.

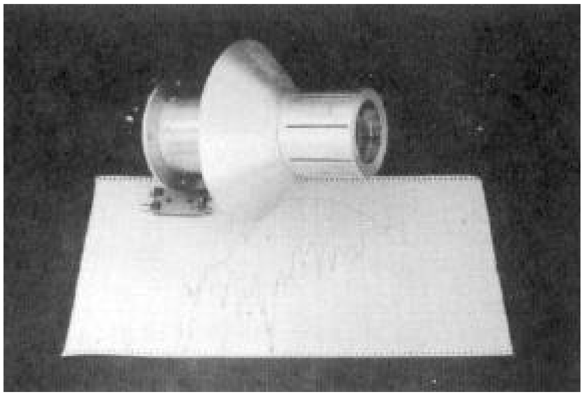

Figure 2. The S band slotted waveguide antenna (with skirt).

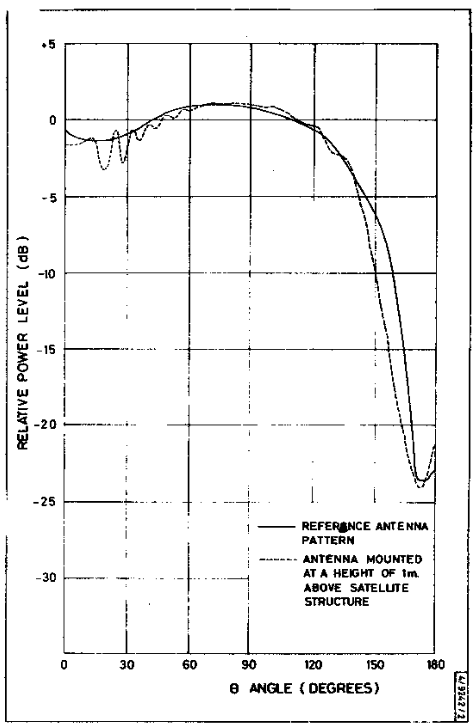

Figure 4. Antenna pattern comparison for ‘isolated’ and ‘satellite mounted’ configuration.

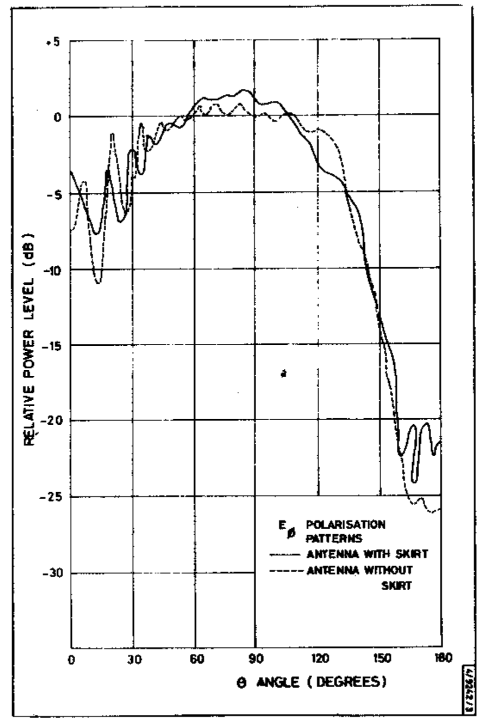

Figure 3. Influence of the skirt on antenna radiation pattern.

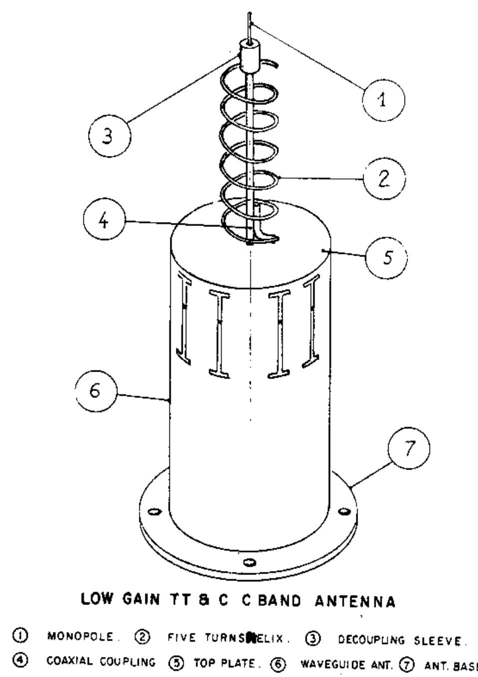

Figure 5. C band TT and C antenna assembly.