A 4, 6, 20 AND 30 GHz BAND BRANCHING NETWORK USING A MULTILAYER DIELECTRIC FILTER FOR A SATELLITE COMMUNICATION EARTH STATION

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Abstract

A four frequency broadband branching network has been designed for transferring microwave (4 and 6 GHz) and millimeter-wave (20 and 30 GHz) band signals between an antenna and transmitter-receivers in a satellite communication earth station. Measurements show that its insertion loss, VSWR and axial ratio are less than 1.2 dB, 1.2 and 2.1 dB, respectively.

Introduction

A Japanese domestic satellite communication system has been proposed by NTT[1]. This system is characterized by the simultaneous use of four frequency bands, 4, 6, 20 and 30 GHz. The use of microwave bands (4 and 6 GHz) as well as of millimeter-wave bands (20 and 30 GHz) increases the feasibility of the communication system.

The ratio of the lowest to the highest frequency is about 8 for the system under consideration. On the other hand, the ratio is 2 or 3 at most for conventional microwave communication systems (4 - 6 GHz) and millimeter-wave communication systems (40 - 120 GHz). This fact indicates that hardware of antenna and branching network is extremely difficult. Especially, the conventional waveguide branching network is not likely to be applicable, because many higher-order modes of the millimeter-wave bands will propagate in the branching network and degrade transmission quality.

An early paper reported the feasibility of using the dielectric filter for satellite communication earth station[2]. In this paper, strict specification of a four frequency band branching network, required for application in practical system, is considered in the operational bandwidths of 0.5 GHz for 4 and 6 GHz bands, and of 3.5 GHz for 20 and 30 GHz bands. This antenna and branching network is combined with a feed system and is composed of the usual Cassegrain antenna, several beam reflectors, a wide-band dielectric filter and exclusively designed micro- and millimeter-wave primary horns and band-diplexers. This antenna and branching network is: (1) free from unwanted higher-modes, (2) has low loss and is ultra-broadband and (3) is flexible in system fabrications.

This paper describes construction, design and experimental results of the four frequency band branching network.

Construction and Design of a Branching Network

Figure 1 shows construction of antenna and four frequency band branching network combined with feed system. The primary antenna feed system is composed of well-known beam waveguide with three ellipsoidal reflectors and two corrugated horns for the microwave and the millimeter-wave bands. The dielectric filter is loacted at the common focal point of three beam reflectors and the corrugated horns are placed at the other focal points. First, the frequency band 4 - 6 GHz is separated from 20 - 30 GHz by the dielectric filter. Then, using second stage band-diplexers, 4 GHz is separated from 6 GHz and 20 GHz is separated from 30 GHz.

The wide-band dielectric filter described here is composed of multilayered dielectric stacks and is installed obliquely with respect to the incident wave. This dielecrtic filter is designed so that a millimeter wave is reflected obliquely from its surface and a microwave is transmitted through it. Thus, the microwave and millimeter-wave bands are independently fed by each corrugated horn. The band diplexers are composed of transmit-receive filters, to separate transmitted signals (6 and 30 GHz) from received ones (4 and 20 GHz), circular-polarizers to convert a linear-polarized wave to a circular one and TM_{01} mode coupler to track a satellite. The transmit-receive filter for each band is constructed by a slot coupled type coupler with reflecting metal plate.

For the design of the branching network, following four points are particularly taken into consideration.

(1) A beam waveguide composed of two ellipsoidal reflectors is designed for micro- and millimeter-wave bands, such that the radiation patterns of 30 GHz from 4 GHz have the same beamwidths.
(2) Dielectric materials of the filter are carefully selected to operate for the high power transmitted signals for the up link (6 and 30 GHz).
(3) Since the dielectric filter is installed obliquely, the two orthogonally polarized waves have different reflection and transmission coefficients. Therefore, deterioration of the desired circular polarization can occur. To avoid this effect, the optimum incident angle has been chosen. Moreover, it was attempted to reduce the phase difference between the two orthogonally polarized waves.
(4) The dielectric filter has matching sections in order to reduce undesired reflection of the microwave bands.

Figures 2 and 3 show the structure and theoretical transmission characteristics of the multilayered dielectric filter. Incident angle θ of the dielectric filter is 20 degrees. This filter consists of a five-layer main section with center frequency of 24 GHz, in stop band, and of two-layer matching sections with a center frequency of 5.5 GHz, in pass band. Alumina plates and quartz-spacers are piled up alternately in the main section, and solid quartz and foamed quartz are stacked in the main section. No change in dielectric constants of these materials was observed over a temperature range of up to 500°C. Theoretical curves were calculated from the conventional F-matrix method. The main section is designed to satisfy the stop band attenuation of over 25 dB and the matching transformer sections to give equal-ripple characteristics in the pass band.

Experimental Results

Figure 4 shows an overall view of the four frequency band branching network, set up for indoor experiments. Four kinds of radiation patterns at an equivalent subreflector plane, are measured at a distance of about 6 meters from beam reflector #1. A measuring pick-up horn is moved along the x-axis and y-axis for H- and E-wave as shown in Fig.5. The H- and E-wave mean that the electric field is perpendicular to the incident plane and parallel to it, respectively. The radiation patterns of the E-wave are shown in Fig.5. They have nearly the same beamwidths from 4 GHz to 30 GHz. H-wave pattern is also in good agreement with the E-wave pattern at every frequency band.

Table 1 shows the overall characteristics of the branching network measured between reflector #1 and the band-diplexer. The overall insertion loss is below 1.2 dB for the microwave bands and 1.1 dB for the millimeter-wave bands, in agreement with the theoretical values. These measured values include the insertion losses of the dielectric filter, 0.7 dB for the microwave bands and 0.1 dB for the millimeter-wave bands. The latter loss was measured by replacing a metal plate at the same focal point.

A new waveguide phase shifter was constructed using multi-hole arrays in the axial direction of a circular waveguide, in order to compensate for the phase difference of the dielectric filter between the orthogonally polarized waves. This results in the axial ratio being below 0.8 dB for the microwave bands and 2.1 dB for the millimeter-wave bands. This shows that the phase difference is reduced to half of the value without the phase shifters.

Conclusion

The 4, 6, 20 and 30 GHz band branching network, using a multilayer dielectric filter, has successfully been constructed. It is concluded that this branching network can be applied to various antenna systems for use in future satellite communication systems. Because the microwave-band axial ratio is very low, this network can be applied to the two independently polarized waves to re-use the satellite communication frequency bands.

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References

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[2] M.Koyama and S.Shimada,"The Quasi-Optical Filters Used for the Domestic Satellite Communication System", Trans. IECE of Japan, vol. 56-B, No. 3, p. 115 (March 1973)

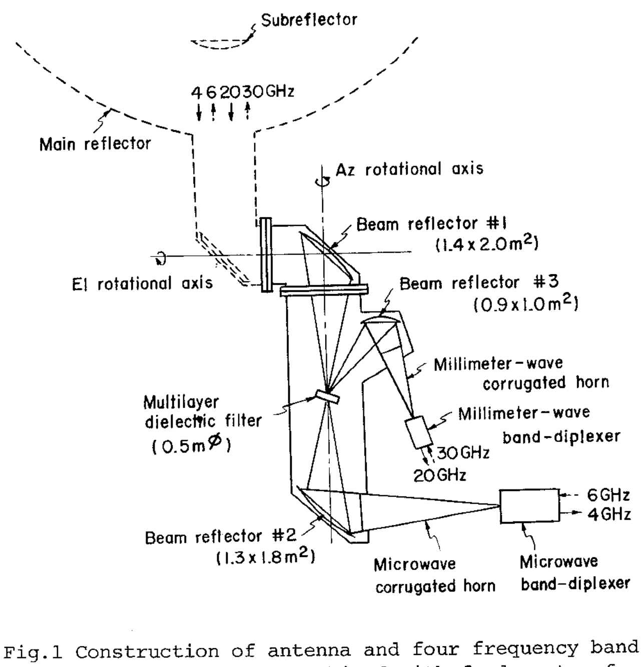
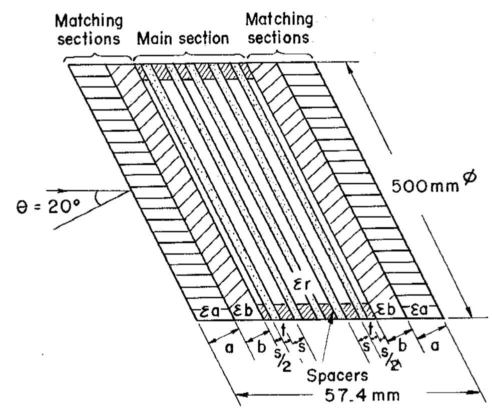


Fig.1 Construction of antenna and four frequency band branching network combined with feed system for satellite communication earth station.



Sections	Kinds of Dielectric	Relative Permittivities *	tan δ *	Thicknesses(mm)
Matching	Two foamed quartz plates **	$\varepsilon_a = 1.7$	5×10^{-4}	a = 10.83
	Two quartz plates	$\varepsilon_b = 3.8$	1×10^{-4}	b = 7.10
Main	Five alumina plates	$\varepsilon_r = 9.7$	1×10^{-4}	t = 0.99
	Six layers of air (quartz spacers)			s = 3.37

* Experimental values measured at 38.9 GHz.

** Emerson & Cuming, Inc., ECCOFOAM Q-R.

Fig.2 Structure of the multilayer dielectric filter

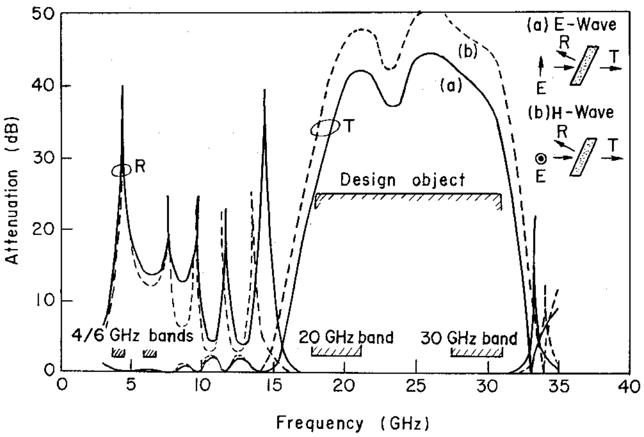


Fig.3 Theoretical characteristics of the multilayer dielectric filter with matching sections

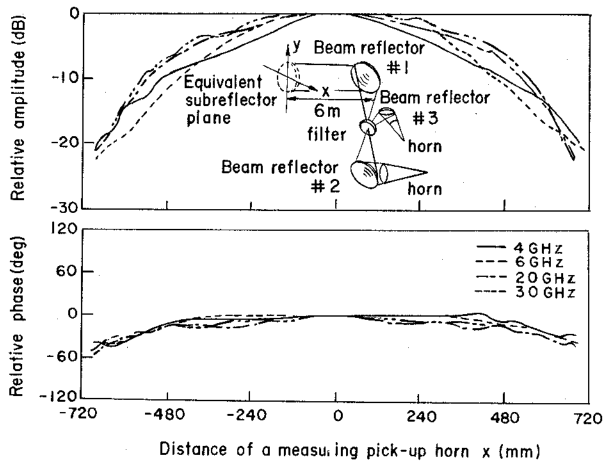


Fig.5 Frequency characteristic of radiation patterns at an equivalent subreflector plane (E-Wave)

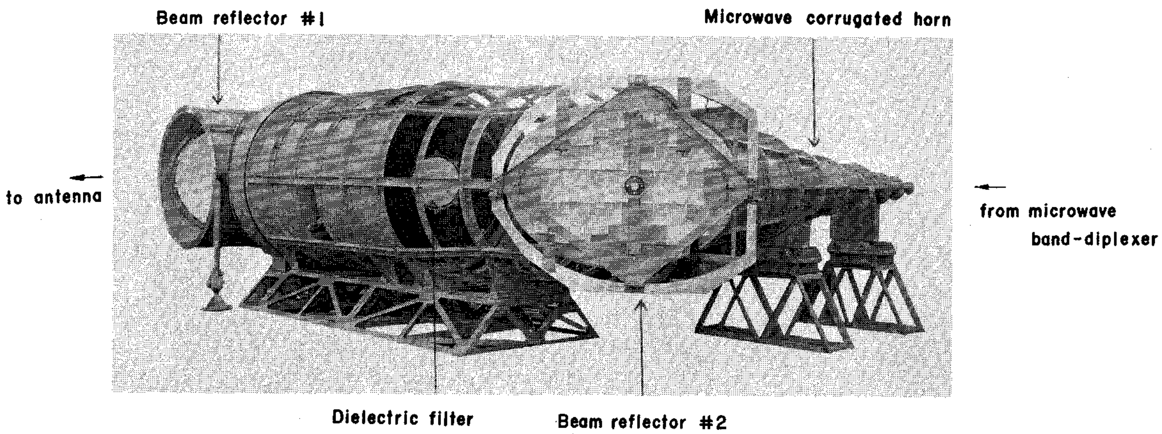


Fig.4 Overall view of the four frequency band branching network combined with feed system

Table 1 Overall transmission characteristics of the four frequency band branching network

FREQUENCY (GHz)	4	6	20	30
OPERATIONAL BANDWIDTH (GHz)	0.5 (3.7~4.2)	0.5 (5.925~6.425)	3.5 (17.7~21.2)	3.5 (27.5~31.0)
INSERTION LOSS (dB)				
BEAM WAVEGUIDE *	0.3	0.3	0.3	0.4
DIELECTRIC FILTER	0.7	0.6	0.1	0.1
BAND-DIPLEXER	0.2	0.2	0.7	0.5
(TOTAL)	1.2	1.1	1.1	1.0
VSWR OF INPUT PORT OF BAND-DIPLEXER	1.1	1.2	1.2	1.2
AXIAL RATIO (dB)	0.7	0.8	2.1	2.0

* Theoretical values include losses of corrugated horn, feedome, spill-over and surface roughness of beam reflectors