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TRIPLE-MODE TRUE ELLIPTIC-FUNCTION FILTER REALIZATION FOR SATELLITE TRANSPONDERS

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Abstract

A six-pole, triple mode filter with true elliptic-function response has been synthesized and experimentally realized. This was done by using a new inter-cavity iris structure that can control three inter-cavity mode couplings simultaneously.

Introduction

High capacity communication satellite transponders usually require many receive and transmit channelizing filters. These channelizing filters went through a series of advancement between 1968 and 1974. In 1969 Comsat Laboratories began an active search for a waveguide structure which would enable real transmission zeros to be generated. The geometry which realized this objective was the dual-mode waveguide filters first introduced in 1970 [1] and generalized in 1972 [2]. To realize the frequency selectivity of the INTELSAT IV channelizing filter, the dual-mode filter required only eight poles or four physical cavities. Consequently, weight and volume savings were achieved.

Between 1974 and 1982 the communications satellite industry started to use the dual-mode waveguide filter extensively. However, no more advancement has been made during this period to further improve the multi-mode waveguide filter structures. In this paper multi-mode concepts have been utilized to design a triple-mode waveguide filter (6 poles - 2 cavities) capable of realizing true elliptic response. This waveguide structure will allow a further reduction of size and weight in communication satellite waveguide channelizing filters.

Multi-Mode Filters

Design of multi-mode filters, using degenerate modes with identical natural frequency in a single cavity, was first suggested by Lin [3]. He demonstrated the possibility of exciting and controlling up to five degenerate modes in a single cylindrical or spherical cavity. In 1969 the first multi-mode cavity filter, a longitudinal dual-mode waveguide filter was patented [4]. This filter used two orthogonal TE_{011} modes in a rectangular cavity or TE_{111} modes in a cylindrical cavity. Coupling between the electric cavities was achieved by using a direct coupling method [5]. Although this dual-mode longitudinal filter represents a major advancement in filter design, it is not capable of realizing a true elliptic response for filter higher than 4th order [6]. In 1971 canonical dual-mode structures that enabled the realization of any even order elliptic-function response in a dual-mode configuration was presented [6]. In the same paper the use of two orthogonal TE_{111} modes and a TM_{010} mode to construct a sixth order two cavity elliptic filter was demonstrated. However, the measured results indicated that they were unable to control all inter-cavity couplings simultaneously, and, therefore, failed to achieve a true elliptic-function response.

In the case of two cavity triple-mode filters, one requires three inter-cavity couplings between six electrical cavities. The coupling mechanism is provided by placing a metal plate with slots (iris) between the two cavities. However, the iris can only provide a two dimensional independence for inter-cavity couplings. Therefore, in order to construct a two cavity six-pole elliptic filter, one must first find an iris structure that can control three inter-cavity couplings simultaneously.

In the following, a new iris structure that is capable of providing three independent inter-cavity couplings is designed. The experimental performance of a sixth order triple mode filter using this new coupling iris is presented.

Inter-Cavity Aperture Design

In the current filter design, electrical cavities 1, 2 and 3 are excited in the physical cavity-1, and the electrical cavities 4, 5 and 6 are excited in physical cavity-2. Electrical cavities 1, 3, 4 and 6 were chosen to be TE_{111} modes (1 and 6 orthogonal to 3 and 4), and cavities 2 and 5 were taken to be TM_{010} modes. (This choice of cavity-mode sequencing avoids some problems encountered in [6]). To achieve true elliptic function response, the required coupling matrix for the prototype network is as shown in Fig. 1. In this coupling matrix, elements M_{16}, M_{25}, and M_{34} involve energy coupling between two physical cavities, and therefore has to be realized with an appropriate inter-cavity aperture.

	1	2	3	4	5	6
1		M_{12}				M_{16}
2	M_{12}		M_{23}		M_{25}	
3		M_{23}		M_{34}		
4			M_{34}		M_{45}	
5		M_{25}		M_{45}		M_{56}
6	M_{16}				M_{56}	

Fig. 1 Coupling Matrix Structure for Six-Pole Elliptic Filter

Since M_{16} and M_{34} provide coupling between TE_{111} modes, they are usually achieved by placing iris or cross at the centre of the inter-cavity aperture (see Fig. 2a). From the analysis of the mode pattern of TE_{111} mode it can be shown that these couplings are obtained through the magnetic fields at the slot opening. On the other hand, the element M_{25}, which represents the coupling between the TM_{010} modes in two physical cavities, is achieved with both the magnetic and axial electric fields at the aperture opening. Thus, in Fig. 2a once the lengths of the slots (ℓ_1 and ℓ_2) are fixed (W has to be small compared to the wavelength) to give proper susceptances corresponding to M_{16} and M_{34}, the susceptance providing the coupling between TM_{010} modes cannot be controlled. In fact, since the axial electric field of TM_{010} is maximum at the centre, the structure of Fig. 2a inherently yields a large value for M_{25}, whereas for a true elliptic-function realization, typical value of M_{25} is quite small. It has been observed that the coupling M_{25} determines the inner transmission zeros (nearest to the pass band) and M_{16} gives the outer transmission zeros. Thus, if proper value for M_{25} is not obtained, a true elliptic-function response cannot be realized.

The aperture structure shown in Fig. 2b can alleviate the above problem, since it can satisfy all three (M_{16}, M_{25}, M_{34}) coupling requirements simultaneously. This structure provides 3 parameters; namely, R(R_1 and R_2), L(L_1 and L_2) and W for controlling the inter-cavity mode couplings. Due to the difference in field patterns of TE_{111} and TM_{010}, it is possible to find a combination of R, L and W which satisfies all 3 coupling values simultaneously. For a given filter specification, a graphical method, using the values of magnetic and electric polarizability of slots [7,8] and variational formulas [9] for TE_{111} and TM_{010} mode susceptances, has been developed for designing the required inter-cavity aperture of Fig. 2b [10].

Theoretical and experimental studies of the new inter-cavity aperture suggest that only a range of susceptance values can be realized simultaneously by this structure (limited by range of R and L determined by the cavity radius). This limitation in susceptance realization will limit the realizable bandwidth and/or notch level of a practical filter. However, as the experimental results presented in the next section indicate, the specification of a typical satellite channelizing filter can be easily met with this aperture structure.

Experimental Results

The experimental realization of a 6-pole, triple-mode, true elliptic-function response filter shown in Fig. 3 is presented in Fig. 4. The filter was synthesized to have a centre frequency of 3.93 GHz with a BW of 32 MHz. Other specifications of this filter were as follows:

Notch level = 40 dB

VSWR = 1 : 1.15

The measured return loss of this filter is shown in Fig. 4a. From an inspection of the variation of the return loss in the pass-band it is clear that all six modes have been controlled and excited properly. The measured insertion loss characteristic of this filter is shown in Fig. 4. The isolation characteristic given in Fig. 4b clearly shows the two transmission zeros in the stop-band, which is a typical feature of a true elliptic-function response. The wide band isolation characteristic of the filter shows the spurious response of the filter between 3 GHz and 5 GHz range. These are, of course, due to the propagating higher order modes.

An interesting observation made during the experimental phase of this work is that the measured Q of the filter was found to be approximately 13 k. This value is much larger than the Q obtained in normal production of a six-pole dual mode filter, which is typically around 11 k. This large difference in Q is attributed to the fact that in triple-mode filter only one inter-cavity aperture, as opposed to two in dual-mode filter, is required.

Conclusions

By using a new inter-cavity aperture structure and proper mode sequencing, a six-pole, triple-mode, true elliptic-function response filter has been realized. The experimental results have indicated that an excellent control of the degenerate mode excitation and inter-cavity mode coupling is possible. In addition to the reduction in size and weight, this filter provides a much larger Q than the corresponding dual mode counter part.

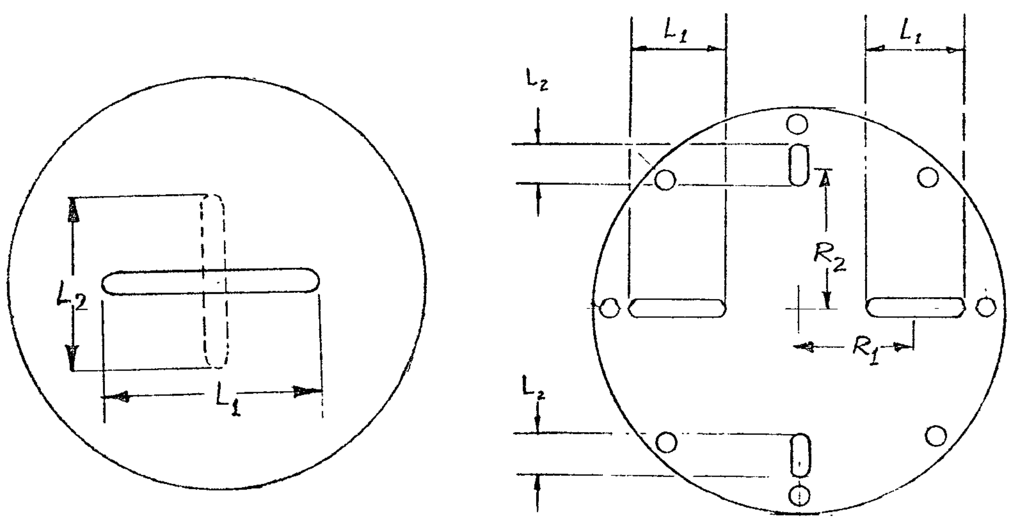

Fig. 2 Inter-Cavity Aperture Structure; (a) As Used In [6], (b) As Used In Present Paper.

Acknowledgment

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References

[1] A.E. Williams, "A Four-Cavity Elliptic Waveguide filters," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-18, pp 1109-1114, Dec. 1970.

[2] A.E. Atia and A.E. Williams, "Narrow-Bandpass Waveguide Filters," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-20, pp 258-265, Apr. 1972.

[3] W-G Lin, "Microwave Filters Employing a Single Cavity Excited in More Than One Mode," Journal of Applied Physics, Vol-22, pp 989-1001, Aug. 1951.

[4] B.L. Blachier and A.R. Champeau, "Plural-Cavity Band Pass Waveguide Filter," United States Patent No. 3697898, Oct. 10, 1972.

[5] S.B. Cohn, "Direct-coupled-resonator filters," Proc. IRE, Vol-45, pp 187-197, Feb. 1957.

[6] A.E. Atia and A.E. Williams, "New Types of Waveguide Bandpass Filters for Satellite Transponders," COMSAT Technical Review, Vol-1, pp 21-42, Fall 1971.

[7] S.B. Cohn, "Determination of Aperture Parameters by Electrolytic Tank Measurements," Proc. IRE, Vol-39, pp 1416-1421, Nov. 1951.

[8] S.B. Cohn, "The Electric Polarizability of Apertures of Arbitrary Shape," Proc. IRE, Vol-40, pp 1069-1071, Sept. 1952.

[9] N. Marcuvitz, Waveguide Handbook, Radiation Lab. Series, Vol-10, McGraw-Hill Book Co., 1951.

[10] W-C Tang, "Multi-Cavity Triple-Mode Filter Realization for Satellite Transponders," M.A.Sc. Thesis, Faculty of Graduate Studies, University of Waterloo, Waterloo, Ontario, April, 1983.

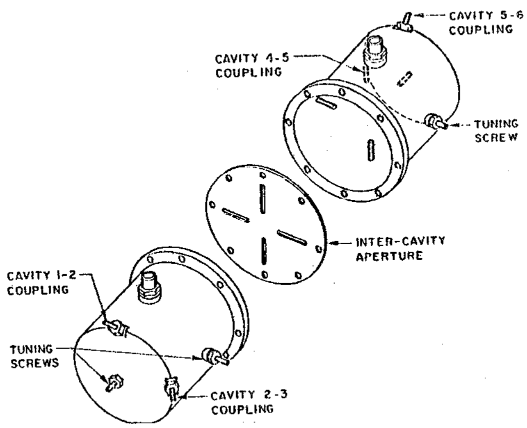

Fig. 3 Schematic Diagram of the Two-Cavity Six-Pole Elliptic Filter

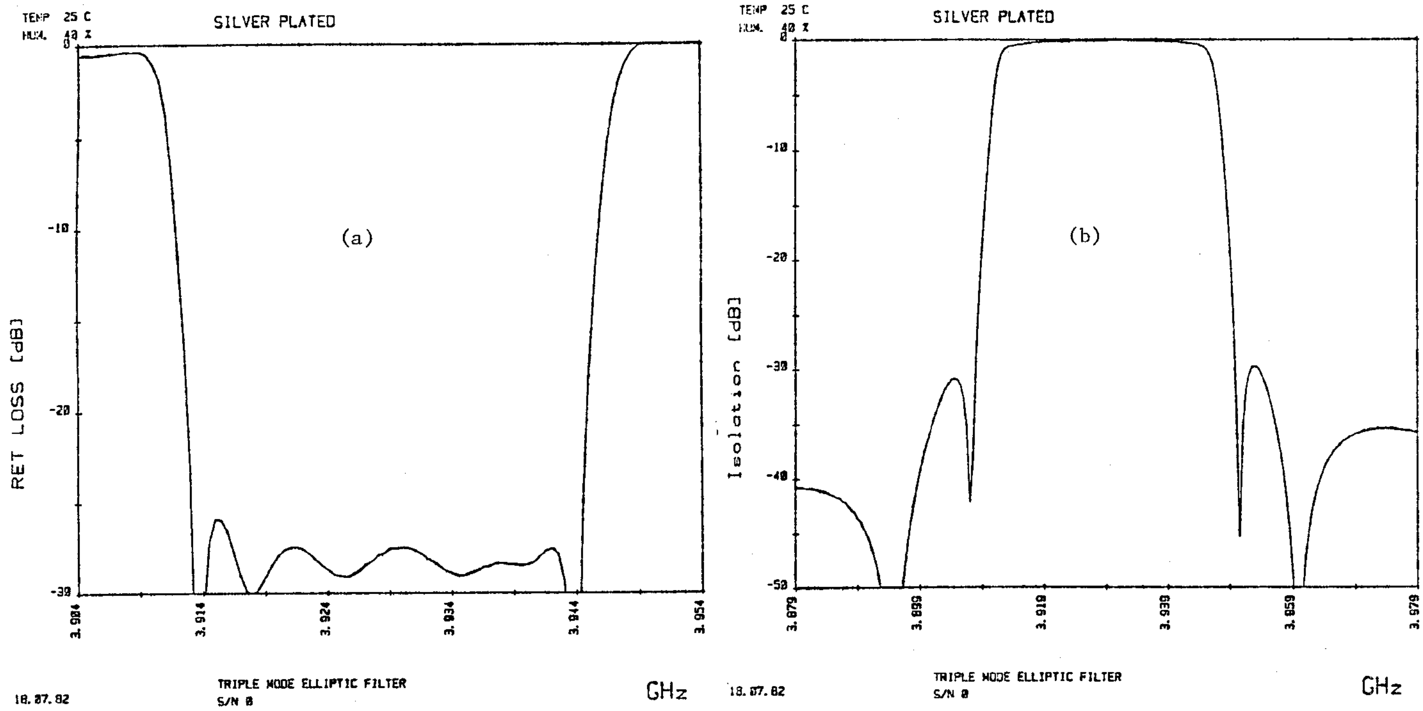

Fig. 4 Measured Response of the Designed Filter;
(a) Return Loss, (b) Isolation Characteristic.