Low-loss filters in rectangular waveguide with rigorous control of spurious responses through a smart modal filter

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Abstract **Low-loss performance is one of the main drivers in the design of microwave input filters and diplexer, used on satellite communication transponders. In addition, a careful control of spurious responses is also required in order to guarantee an adequate protection from high-level input interfering signals, which may degrade the performance of the receiver. Both these requirements can be accomplished by a simple and cost-effective design approach, based on rectangular waveguide resonator. Fast and accurate simulation and measured response of a specific design are also compared, demonstrating that the proposed solution is practical and reliable.**

I. INTRODUCTION

Modern rectangular waveguide filters are been designed by using the so-called "inductive windows" technology [1], which has replaced the "inductive post" implementation, proposed since the early sixty [2]. Inductive apertures are used to form impedance inverters separating sections of rectangular waveguides, acting as microwave resonators. The prime reason for the popularity of this design approach is the availability of fast computers and the development of efficient computing algorithms, which can accurately predict the in-band and out-of-band response of such filters. Thanks to the uniformity of the geometry and inductive nature of the inside electromagnetic field only $TE_{m,0}$ are excited, resulting in a dramatic simplification of the computing algorithms, which can be conceived even faster and reliable. Secondly, the manufacturing process is easy and economic, since it basically consists of the machining of a single block of metal (typically aluminum) to obtain the required geometry and a flat cover. No expensive fabrication process is usually needed, as deep brazing or spark erosion.

One important field of application is the input filtering and diplexing function for communication satellite transponders, where low-loss performance is typically the main driver, as it directly impacts the system noise figure. Recently [3], the rectangular waveguide approach has been demonstrated suitable for very low-loss application, in that the height B of the resonator can be increased in order to reduce losses, without any adverse effect on the other filter characteristics. Doubling the height B, from the standard value of 0.5, results in a unloaded quality factor Q_u which is twice the figure achievable with conventional WR waveguide filters. Assuming the same percentage bandwidth and number of resonators, the insertion loss is therefore halved, thus giving a considerable improvement over the conventional waveguide approach. In real applications, however, the filter must be connected to input and output waveguides of standard dimensions. This task can be conveniently accomplished by using a E-plane step transformer, which has the not negligible advantage of increasing the overall filter length by only $\lambda_g/2$ ($\lambda_g/4$ for each side). However, the presence of E-plane discontinuities causes the excitation and possible transmission of high order modes, generating spurious responses, which can typically degrade the out-of-band performance of the filter. Therefore it can happen that the attractive low-loss behavior of such a design approach is vanished by the presence of spurious responses, which can eventually require, in some cases, a low pass filter to be attenuated.

In this context, we demonstrate in this paper how to control spurious responses in low-loss square cross-section waveguide filters, having input and output step transformers, by incorporating a dedicated modal filter. A specific example is discussed, including measured and simulated performances.

II. EFFECT OF THE E-PLANE TRANSFORMER

By inserting the E-plane transformers the filter structure becomes three dimensional and all the higher order modes ($TE_{m,n}$, $TM_{m,n}$) must be taken in account in order to compute accurately the response of the filter. An E-plane symmetrical transformer has been first considered to reduce the higher order mode effects. Considering the symmetry of the structure in both the E and the H planes, only modes with odd values for *m* and even values for *n* are excited. The cut-off frequencies of such higher order modes are given in Table 1.

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Modes	Cut-off Freq. (GHz)
TE_{12},TM_{12}	17.59
TE_{30}	22.25

Table 1. Cut-off frequencies of the higher order modes

As confirmed by the simulation shown in Fig.1, the filter has a spurious response rising just above 17.6 GHz, caused by the TE_{12} and TM_{12} modes excitation. In order to eliminate such a spike, a dedicated modal filter has been designed inside the step transformer (see Fig.3).

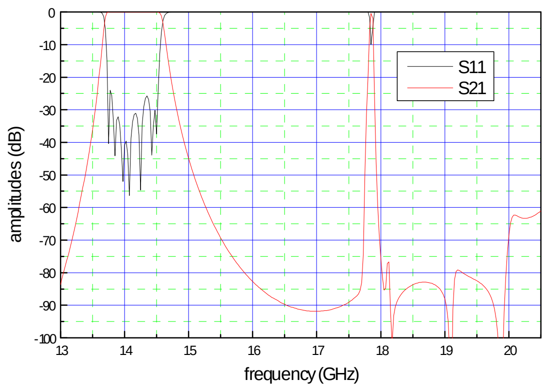

Fig. 1. Simulation response with symmetrical transformer

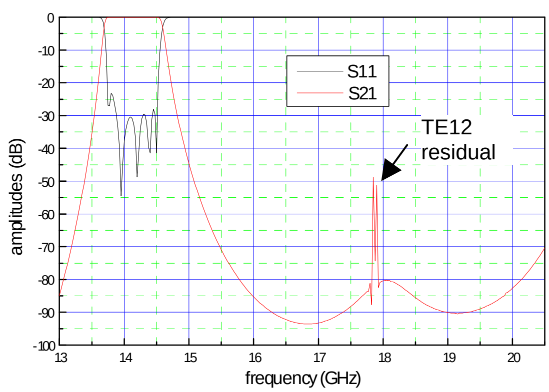

Fig. 2. Simulation response with modified transformer

The section of the central guide has been split by using a metallic septum. Due to the symmetry of the structure, the symmetry plane acts as a metallic plane, allowing for the m-even modes not to be excited, as in the case of the first transformer.

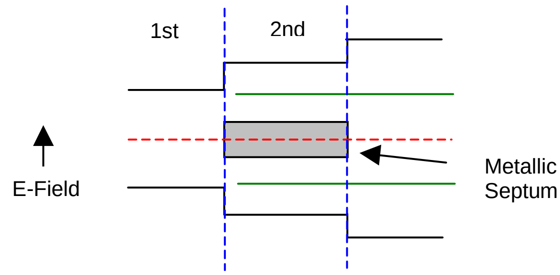

Fig. 3. E-plane section of the transformer

The septum splits the waveguide in two sections having reduced height, where the TE_{12} and TM_{12} modes are strongly attenuated, because they are below their cut-off frequency. Besides, the septum is dimensioned in such a way to create a further E-plane symmetry, starting from the second junction, not allowing for the TE_{12} and TM_{12} modes to be excited again.

The net result is a considerable attenuation of the above spurious responses. The simulation of the filter with the modified transformer is shown in Fig.2, indicating that all spurious responses have been controlled below -50 dB.

III. Application

The filter has been fabricated by machining a single aluminum block to obtain the required windows and cavities geometry. The resonator has a square cross-section 19.05x19.05mm wide and approximately $\lambda_g/2$ long at the central frequency. The input and output step transformers, realizing the WR75 interfaces, are machined from the same piece as the filter body, while a flat cover is screwed on the top, restoring the waveguide cross section. Tuning screws are used to recover manufacturing tolerances and optimize the return loss.

They enter each resonator cavity right in the middle, having the same direction of the E field. As discussed above, they are also doubled in order to maintain the symmetry of the structure in the E-plane. In-band measured performance (Fig. 4) shows that the insertion loss is 0.2dB, resulting in Q_u factor of 5000, about two times the Q_u as evaluated for a standard waveguide height (9.525mm). The out-of-band behavior (Fig. 5) is well under control below 50dBc, in good agreement with simulation response. The higher peak, situated at 16.5Ghz, is due to the residual asymmetry of the structure associated with the double-sided tuning screws, which causes a small excitation of the TE_{11} mode. The second pass-band, generated by the fundamental mode TE_{10} is located at 21 GHz, as for the waveguide filter having conventional height. Therefore it can be stated that the filter meets both the major requirements for this class of applications: superior insertion loss and good control of spurious responses.

Eight filters of this kind have been designed, space qualified and produced by Alenia Spazio for on-board communication transponders in Ku band (Fig. 6).

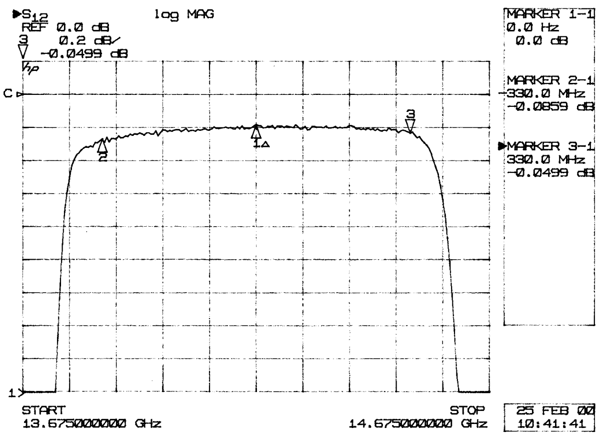

Fig. 4. In-band measured performance

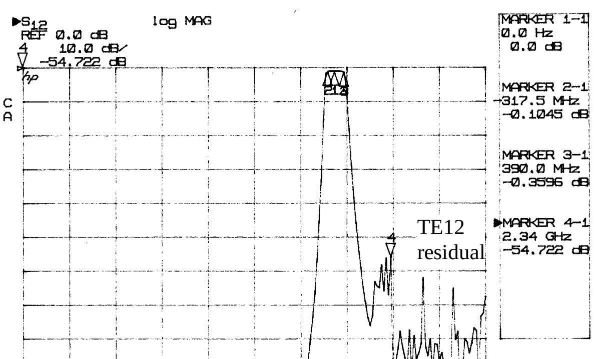

Fig. 5. Out-of-band measured performance

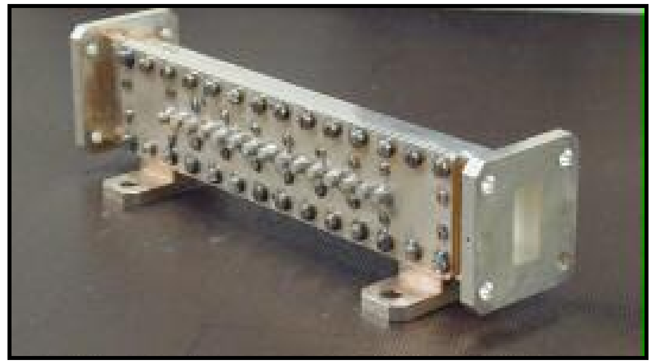

Fig. 6. Ku-Band Input Filter

IV. Conclusion

Rectangular waveguide filters, having increased height are an attractive solution when low-loss performance is required, because of the low-cost, easy manufacturing and straightforward design. However they are prone to generate spurious responses, which must be carefully considered for a number of applications. A method has been presented to control the out-of-band behavior, consisting of design recommendations, tuning (if necessary), precautions and a smart modal filter to suppress the transmission of TE12 mode. The effectiveness of the proposed approach is proved by comparing measured results of a specific filter, designed as input filter for space communication transponders.

References

[1] M.Guglielmi, G.Gheri, M.Calamia and G.Pelosi, "Rigourus Multimode Network Numerical Representation of Inductive Steps", IEEE Trans. on Microwave Theory and Techniques, vol.42, n.2, February 1994.

[2] G. Matthei, L. Young, and E.M.T. Jones “Microwave filters, impedance matching networks, and coupling structures”, Artech House, Dedham, MA, 1980

[3] Ferdinando Alessandri, Massimo Comparini, Marco Guglielmi, Dietmar Schmitt, and Francesco Vitulli, “Low-loss Filters in Rectangular Waveguides”, Microwave and Optical Technology Letters, vol.27, No.1, October 5 2000.

[4] R.Sorrentino, F.Alessandri, M.Mongiardo, G.Avitabile and L.Roselli, "Full-Wave Modeling of Via Hole Grounds in Microstrip by Three-Dimensional Mode Matching Technique", IEEE Trans. On Microwave Theory and Techniques, vol. MTT-40 No. 12, December 1992, p.2228-2234.

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