Nonradiative Dielectric (NRD) Waveguide Diplexer for Millimeter-Wave Applications

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Abstract — **In this paper, a T junction and a right angle elbow in Nonradiative dielectric (NRD) guide technology are carefully analyzed. This analysis is based on our mode-matching program combined with a cascading procedure that allows formulating generalized admittance and then generalized scattering matrices. These structures are optimized to reach the maximum power transfer from LSM to LSE mode. Putting these together, a splitter from LSM to LSM mode is created. Two LSM bandpass filters are then designed and added to the previous structure to obtain a diplexer. This diplexer presents two kinds of isolation. The first one can be easily minimized by increasing the order of filters. The second one is defined as a coupling isolation. A new physical topology is then presented to minimize this isolation. Our simulations are compared with HFSS software simulations and results are in very good agreement.**

I. INTRODUCTION

Millimeter wave research is challenging and it becomes more and more attractive for broadband systems. Planar structures are widely and successfully used for RF and microwaves circuits and systems and are naturally become the principal driving force for millimeter circuits and systems. Such structures allow designer to achieve various kinds of circuits using hybrid or monolithic integration. However, since high Q components cannot be realized by planar structures, due to their important and inherent losses, waveguide techniques are still used in the design of passive components such as filter or diplexers, leading to a combination of planar and non-planar structures. In the scheme of planar and non-planar integration, the non-radiative dielectric (NRD) guide [1] appears to be an inescapable solution and a credible alternative to the bulky rectangular waveguide. In addition to its low loss and potentially low cost properties, the NRD guide can be integrated with a planar structure, as it has been successfully shown in [2,3]. This hybrid integration allows one to combine advantageous features of each structure and at the same time to overcome their drawbacks.

The modeling and characterization of NRD-guide are increasingly well documented and various components have been developed such as filters, couplers, leaky-wave millimeter-wave antenna, unidirectional dielectric radiators (UDR's), magic tee junction [4-8]. With the aim of doing a full receiver for an LMCS/LMDS application using hybrid integration, the design of an NRD guide diplexer is now reported in this paper. A general description of the proposed diplexer is shown in figure 1. This diplexer can be fed either by a horn antenna with rectangular waveguide to NRD guide transition, or directly by an NRD guide antenna. The two outputs of the diplexer can be followed by two NRD guides to microstrip transitions in order to connect a low noise amplifier stage for the receiver branch and a power amplifier stage for the transmitter branch.

The diplexer design can be made step by step. First, two LSM filters are designed for LMCS application using a mode-matching program. Then the design of the splitter is carefully described. Finally, S-parameters of the overall structure can be obtained by a cascading procedure.

Results bring to the fore a coupling isolation. The source of this isolation is clearly identified and a solution is proposed to drastically reduce this isolation.

In this paper, the height of NRD guide is 5.00 mm, its width is 3.556 mm and a dielectric constant of 2.56 is used.

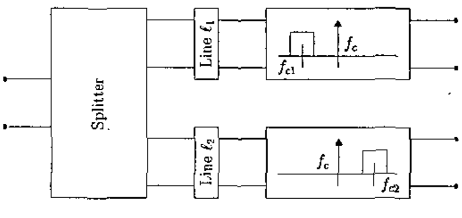


Fig. 1. Diplexer block diagram.

II. Design Considerations

A. LSM or LSE Filters Design

The design of NRD filters is well documented. It can be described as follows. First, the mode matching method is used to calculate the generalized S matrix of a coupling structure. This coupling structure can be of various kinds but, in the present paper, the focus is on an air gap coupling structure. In this case, a performance analysis on electrical characteristics can be made, allowing one to establish an equivalent model of the air gap coupling structure. This model and the design procedure allow one to use the conventional K-inverter technique [9] to design and simulate any bandpass filter. Two important points must be emphasized here. First, the choice of fundamental mode is critical in the equivalent model: the LSE_{10} fundamental mode leads to an LSE bandpass filter, the LSM_{10} fundamental mode leads to an LSM bandpass filter. Second, the design is only done at the central frequency. A powerful iterative optimization procedure [10] is used to complete the design and to meet filter requirement in terms of bandwidth. Then a very good agreement between our mode-matching results and HFSS results for an LSM bandpass filter is obtained, as shown in figure 2.

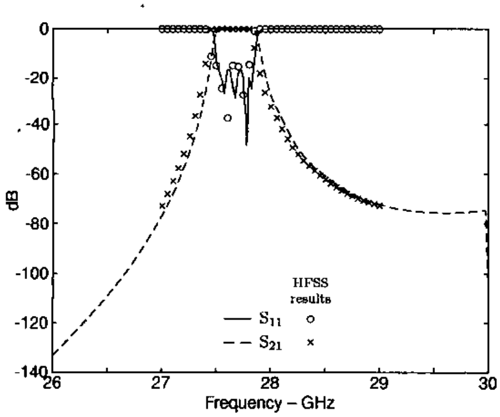


Fig. 2. Comparison between our mode matching program and HFSS software for a LSM five order bandpass filter.

B. Splitter Design

The splitter is done in two parts. The first one is a T-junction where the LSM_{10} mode at the input port is converted to an LSE_{10} mode at the two output ports. The second part is a right angle elbow where an LSE_{10} mode at the input port is converted to an LSM_{10} mode at the output port. The design of such a junction is based on our mode-matching scheme combined with a cascading procedure that allows one to formulate generalized admittance and then generalized scattering matrices. Reference [11] gives all the details on theoretical development of this method.

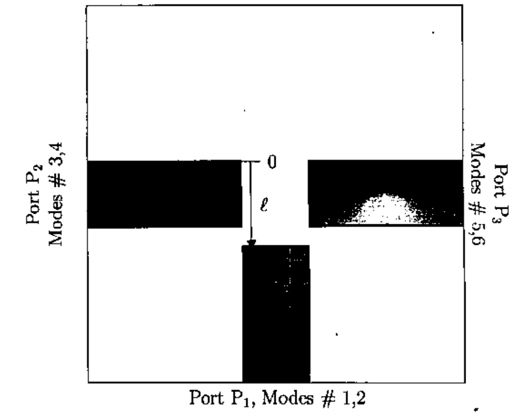
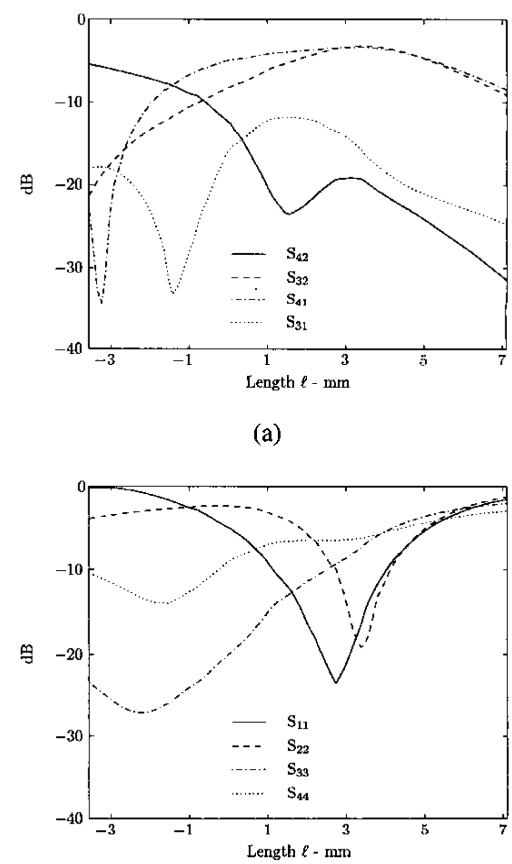


Fig. 3. Physical topology of the T-junction and definition of the length ℓ.



(a)

(b)

Fig. 4. S-parameters of T-junction: a) transmission parameters b) reflection parameters

To obtain a quasi-complete mode transfer from input to output, different analyses along dimension and frequency are done. The reasoning for the T-junction and right angle elbow is very similar and only results for T-junction are reported in this paper. Figure 3 defines the reference for the dimension ℓ and figure 4 shows S parameters of T-junction along this dimension at 28GHz.

Figure 4 shows that ℓ=3.556 mm is a critical point. For this dimension, the LSM_{10} mode at the input port P_1 is equally divided in amplitude in two LSE_{10} modes at port P_2 and P_3 with an attenuation of 3.18dB. The reflected power at port P_1 is then minimum (-17.8dB) and is only on mode LSM_{10}. For ℓ=3.556 mm, the behavior of the S parameters of the junction is investigated as a function of frequency, from 26 GHz to 30 GHz. The mode transfer from LSM_{10} at port P_1 to LSE_{10} mode at port P_2 and P_3 remains practically constant, from -3.69dB at 26Ghz to -3.15 dB at 30 GHz, as shown in figure 5.

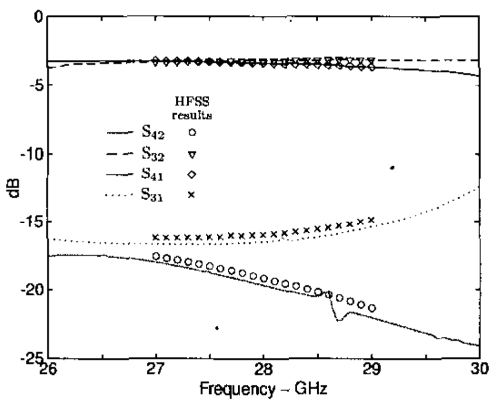


Fig. 5. Transfer parameters of T-junction along frequency: our results compared to HFSS results.

III. Results

The diplexer is simulated by cascading an S matrix of splitter with two lines ℓ_1 and ℓ_2 and two S matrices of LSM five order bandpass filters, as shown in figure 1. An optimization is performed on the length ℓ_1 and ℓ_2 of lines between splitter and filters in order to guarantee the phase condition to get good performance of the diplexer. The result for S parameters after optimization is shown in figure 6.

From these results, we can note that the two pass bands are well defined and well centered, as expected. Since isolation between the two arms containing filters is a critical point for a diplexer, a careful analysis has to be done for our diplexer. Two kinds of isolation are underscored. The first one is the direct isolation and it affects the power transfer from the LSM_{10} mode at port P_2 to the LSM_{10} mode at port P_3. Increasing the order of the filters can drastically minimize this isolation. The second one is the coupling isolation and it affects the coupling between the LSM_{10} mode at port P_2 and the LSE_{10} mode at port P_3. This coupling isolation is possible since the LSM filter in the arm leading to port P_3 has a passband for the LSE_{10} mode exactly between 27.5GHz and 27.85GHz, which is the frequency passband of LSM filter in arm leading to port P_2. Then, an LSM_{10} mode excited at port P_2, pass through the filter contained in this arm and is converted to LSE_{10} by right angle elbow.

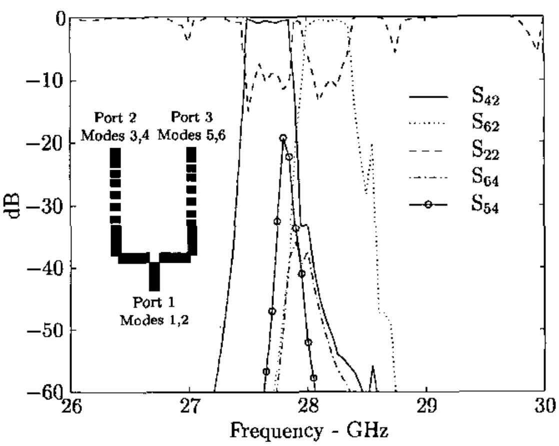


Fig 6: Results for the optimized diplexer using two five order filters.

At the second right angle elbow, this LSE_{10} mode is mainly converted to LSM_{10} mode but a small part (-16dB), is converted to LSE_{10} as shown in figure 5. This remaining LSE_{10} mode can propagate through the LSE passband of the LSM five order passband filters in the arm leading to port P_3. This coupling isolation is no longer valid from port P_3 to P_2 since the LSE passband of filter in arm 2 does not overlap the LSM passband of filter in arm 3.

Increasing the order of filters does not improve greatly this isolation since this does not lead to a frequency bandpass shift. So, a new topology is now presented to improve this isolation.

This new topology is made up of an LSE filter between the T-junction and the right angle elbow for the high frequency band of the diplexer. In the scheme of our hybrid integration, this right angle elbow can be replaced by an NRD/microstrip transition, using an LSE mode as the fundamental mode. The objective of the new topology is to force LSM filter in arm 2 and the LSE filter to have two different frequency passbands and above all no overlap. Then, coupling isolation is greatly improved as shown in figure 7. At 27.95 GHz, using two five orders filter for diplexer, direct isolation is equal to –35.6 dB and coupling isolation is equal to –44.6 dB.

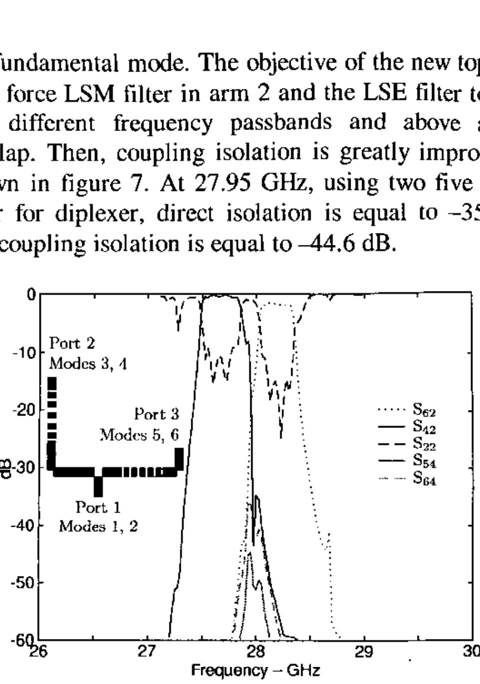


Fig. 7. Results for the proposed diplexer with two five order filters.

IV. Conclusion

An efficient program was developed using a mode matching technique, allowing us to design LSE or LSM mode filters with the NRD guide technology. Moreover, this program can analyze three port structures. Right angle elbow and T-junctions are then designed and optimized. Adding two five order filters designed for an LMCS application, a diplexer has been designed. The source of a coupling isolation has been clearly identified and explained. Then, a new topology has been introduced and a great improvement on coupling isolation has been achieved. This work shows that the NRD guide technology can be very useful in the development of high-performance millimeter-wave transmitter/receiver for communication systems.

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