PLANAR INTEGRATED WAVEGUIDE DIPLEXER FOR LOW-LOSS MILLIMETER-WAVE APPLICATIONS

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ABSTRACT

Low-loss H-plane waveguide filters for planar integrated assemblies are described showing high attenuation near the pass-band due to a special modification of the outer inverter circuits. The outer irises are replaced by short-circuited T-junctions resulting in at least one pole above or below the pass-band. Such filters favorably can be combined to low-loss diplexer circuits for mm-wave applications. Examples of a single filter as well as of diplexers in the 28 GHz and 38 GHz frequency range are given.

INTRODUCTION

Modern mm-wave communication front-ends for LANs, tie lines etc. require high performance but low cost production. To this end, a combination of planar transmission line circuits (coplanar or microstrip lines) with metal waveguide for low loss filters and diplexers is used. If possible, tuning of components should be avoided or at least kept to a minimum effort. Integrated metal waveguide front-end equipment is usually fabricated in either E-plane or H-plane technology. Whereas E-plane circuits are preferably employed in applications involving standard satellite bands [1], the 'planar' H-plane design has demonstrated its advantage in the millimeter-wave range, e.g., [2] - [5]. Modern communication systems create a demand for more complex filter configurations, which produce transmission zeros and thus reduce losses by requiring fewer resonators than comparable standard filter designs. However, specific input-output-port locations are often difficult to meet due to complicated resonator arrangements which are dictated by the coupling matrix of the elliptic-function filter design. Therefore, this paper presents an alternative approach to low-loss millimeter-wave H-plane diplexers.

FILTER CONFIGURATION

Standard H-plane filters consist of a number of resonators separated by inductive irises. By replacing inductive irises with short-circuited T-junctions as inverter circuits, stop band poles in the frequency response are created and can be placed at either side of the filter pass-band. For a given out-of-band attenuation, especially if this is required close to the filter pass-band, this allows the number of physical resonators to be reduced and, therefore, leads to lower insertion loss compared to standard filter designs. Consequently, such a filter or diplexer arrangement achieves the specified attenuation levels with a minimum number of physical resonators. In addition, by a proper choice and optimization of the geometry, the complexity and effort to fabricate the filter or diplexer are reduced.

While the initial design of the filters is done applying standard filter design, the circuits itself are analyzed and optimized using the well-known mode matching technique [1] - [3], [6]. The inverter circuits realized as T-junctions with short-circuited stubs have to provide, on the one hand, the required filter coupling factors, and on the other hand, prescribed attenuation pole positions. The stub lengths are determined by the pole positions, and some additional degree of freedom is found in modifying the waveguide widths of either stubs or connecting waveguide; if necessary, even an additional iris can be combined with the junction. For a proper design it turned out that the stub lengths had to be at least one wavelength long. Another item to be considered was a design as insensitive against fabrication tolerances as possible, leading to a optimum waveguide width for each structure.

SINGLE FILTER

As a first example, a test filter in Ku-Band (Fig. 1, left side) was designed, fabricated, and tested. It is based on a Chebishev filter of order four. The iris on top of Fig. 1 is replaced by a combination of stub and modified iris (in this case, the required coupling coefficient could be achieved only in this way); the iris at the bottom simply is replaced by a T-junction and a short-circuited stub. Theoretical as well as experimental results are plotted in Fig. 1, right side, indicating an excellent agreement. An attenuation of better than 60 dB close below the pass band and a pass band insertion loss of less than 0.4 dB were achieved.

28 GHZ AND 38 GHZ DIPLEXER

In a next step, diplexer prototypes for the 28 and 38 GHz communication band were investigated. The waveguide structure of the 28 GHz diplexer is displayed in Fig. 2. For this diplexer, the structures around ports 2 and 3 were folded. This configuration originally was chosen to achieve an output port separation of 40 mm; at the same time, however, this gives a chance - if the stubs close to port 1 were folded in the same manner - to reduce the required space for this diplexer. Theoretical and experimental results of the diplexer are plotted in the diagram of Fig. 2. Apart from a slight shift in frequency (70 MHz or 0.25 %) and minor deviations of the in-band return loss, a good agreement can be stated.
The 38 GHz diplexer has a very similar form compared to the 28 GHz structure (Fig. 3). It was designed for an attenuation of better than 60 dB in the adjacent pass bands and for a return loss of 25 dB; a final value of better than 17 dB was required. Fig. 4 shows computed and experimental results of this diplexer. It can be seen that, in addition to some slight frequency shift, the in-band return loss is deteriorated. A thorough analysis of hardware as well as of the computational results revealed that these deviations between theory and experiment are due to fabrication tolerances. Concerning the degradation of the return loss, especially the dimensions of the center resonators have a strong influence. Although this diplexer had been designed for minimum tolerance sensitivity, dimensions should be kept within $\pm 10\ \mu m$. With regard to the sensitivity of the center resonators, one tuning screw for each filter was added to the respective center resonator, resulting in a very simple tuning procedure. As can be seen in Fig. 5, a rather good performance can be achieved. The maximum insertion loss is in the range of 0.8 dB. Isolation specifications of 60 dB in the adjacent band and a return loss of better 20 dB after the easy tuning procedure are also met.

CONCLUSION

It can be stated that the new concept for planar integrated waveguide filters and diplexers has shown to have the following advantages:

- By replacing inductive irises with shorted T-junction inverters, the filter pass band characteristic of a standard inductive-iris filter is preserved.
- The two short-circuited T-junctions per filter structure produce at least one stop band pole each, the locations of which can be (partly) independently controlled.
- Due to the creation of stop band poles, the number of physical resonators is reduced which results in a low-loss design suitable for millimeter-wave applications.

The prototype diplexers at 28 and 38 GHz achieve more than 60 dB isolation with only three-pole filters and less than 1 dB insertion loss within the specified frequency bands.

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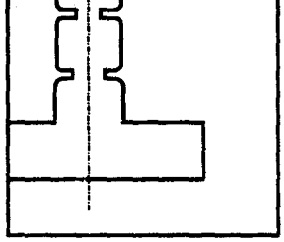

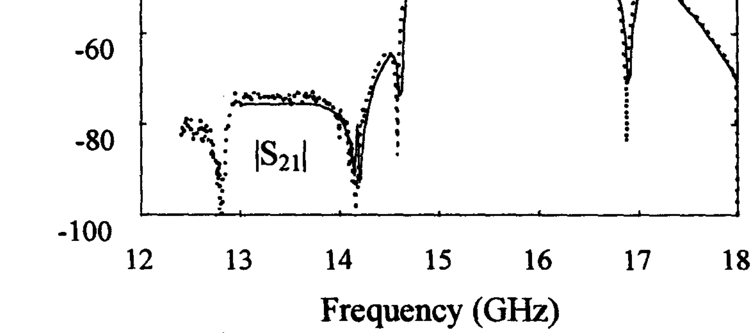

Fig. 1: Waveguide layout and theoretical (—) and experimental (....) results of Ku-band test filter.

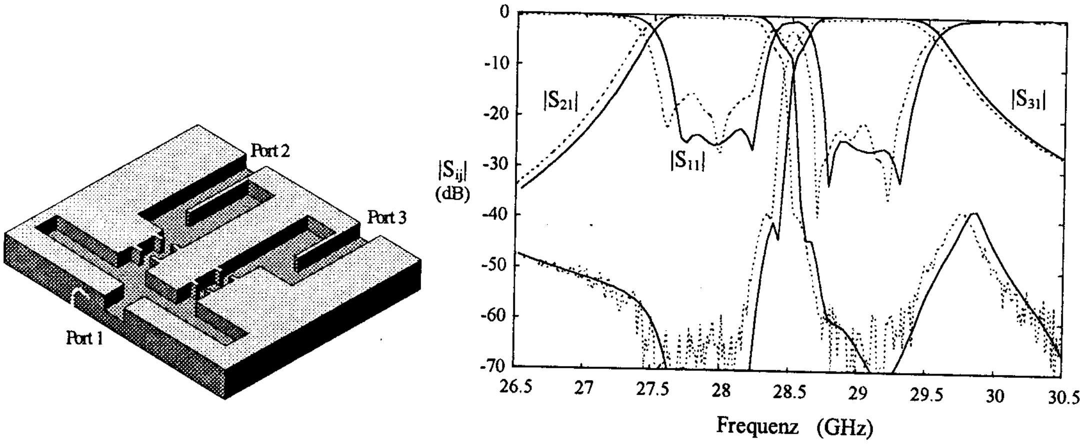

Fig. 2: Waveguide structure and theoretical (—) and experimental (....) results of 28 GHz diplexer.

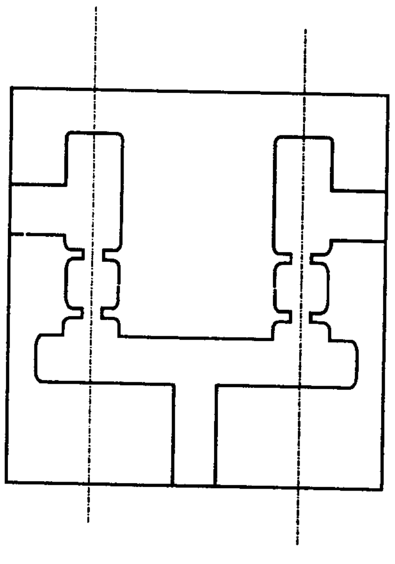

Fig. 3: Waveguide layout of 38 GHz diplexer.

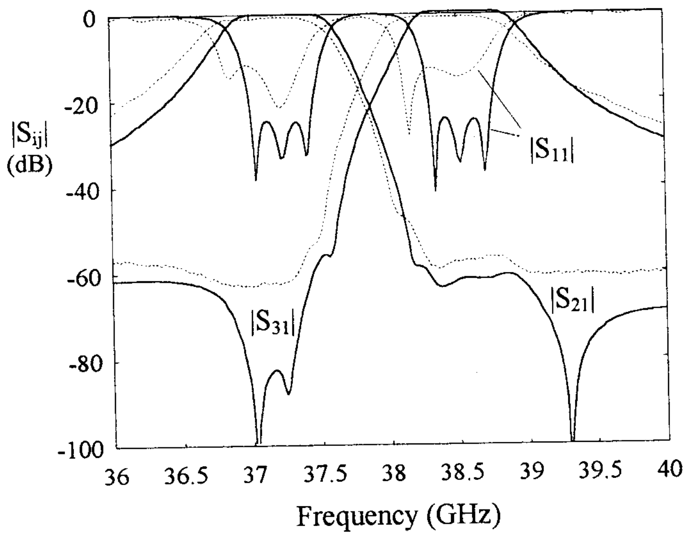

Fig. 4: Theoretical (—) and experimental (....) results of 38 GHz diplexer .

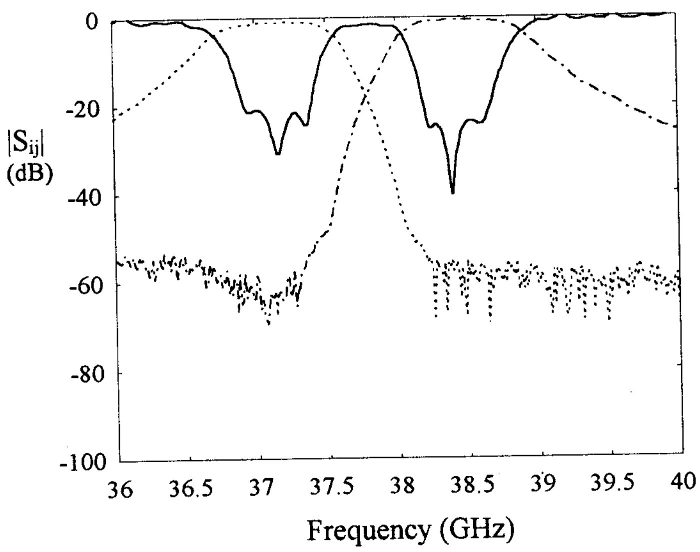

Fig. 5: Measured results of 38 GHz diplexer after tuning of the center resonators.