Short Papers

Wide-Band Low-Loss High-Isolation Microstrip Periodic-Stub Diplexer for Multiple-Frequency Applications

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Abstract—**This paper introduces a three-port microstrip multifrequency diplexer used in a phased-array transceiver system that employs band-stop filters with open-circuited stubs for band selection and separation. The diplexer is designed to take 10, 12, 19, and 21 GHz into port 1 and to separate 10 and 19 GHz to port 2 and 12 and 21 GHz to port 3 with minimal dispersion. The insertion loss for each frequency varies from 0.4 to 3.4 dB and the return loss is better than 10 dB. The isolation between channels at the four frequencies is greater than 50 dB. Each passband created between adjacent stopbands has a bandwidth over 1 GHz. The microstrip diplexer is designed using periodic stubs that collectively have the advantages of low insertion loss, high isolation and rejection, wide-band performance on each channel, and easy fabrication. This type of diplexer has many applications in multifrequency transceivers for communication systems.**

Index Terms—**Diplexer, multiplexer, periodic filters.**

I. Introduction

Diplexers are three terminal devices that take two or more frequencies into one input port and separate them to two output ports. They are commonly used behind wide-band or multifrequency antennas in transciever applications. Diplexers became widely studied in the early 1960's by Matthaei *et al.* [1], [2] and Wendel [3]. They studied microstrip diplexers that used bandpass/band-stop configurations as well as waveguide diplexers. In the late 1960's, waveguides became widely used due to their very low insertion loss and high isolation. However, waveguides generally entail much more manufacturing complexity than planar etched microstrip diplexers. For this reason, microstrip diplexers have remained an active area of research. In the 1990's, microstrip diplexers such as low-pass/bandpass [4] and ring diplexers [5] have gained notice [6].

The diplexer presented in this paper uses balanced open-circuited periodic stubs as band-stop networks to provide both low loss and high isolation between the channels. The periodic stub geometry requires no gaps making the etching very reliable. The design provides the advantages of low loss and high isolation between channels and wide-band channel performance without the etching uncertainty found in gap-coupled filters. In 1996, Sheta *et al.* [7] used spurious harmonic modes for passbands in order to reduce the number of filters. The diplexer in this paper utilizes passbands formed between adjacent harmonic stopbands for size reduction and matching simplicity.

II. Simulated and Measured Data

The diplexer schematic, as well as its individual filters shown in Fig. 1, was simulated using the full-wave electromagnetics simulator IE3D.[1] The diplexer consists of two filters. Each filter has ten sections

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[1]IE3D release 6.1, Zeland Software Inc., Freemont, CA, Aug. 1998.

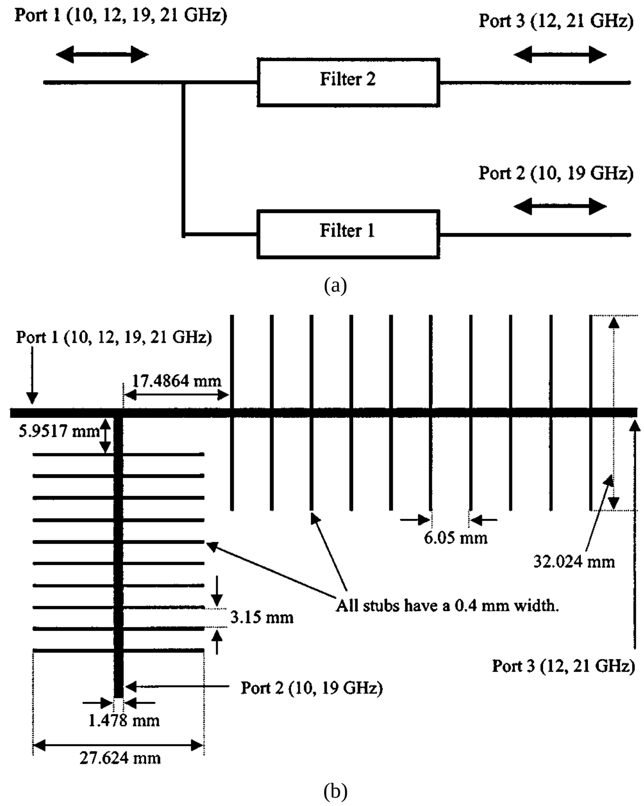

Fig. 1. (a) General diplexer schematic. (b) Diplexer layout.

of shunt stubs. The filter was designed and fabricated on 20-mil Duroid 5870 with a dielectric constant of 2.3. All of the ports are terminated into 50 Ω. The input signals at port 1 (10, 12, 19, 21 GHz) are separated by the diplexer into two channels (10, 19 GHz and 12, 21 GHz). The highest frequency in the IE3D simulation was chosen to be 23 GHz and the gridding was set at 15 cells per wavelength. The measured data was acquired from the HP 8510 network analyzer measurement system.

The diplexer uses two periodic filter structures with open-circuited stubs to achieve the required stopbands. The centers of the stopbands occur when the lengths of the open-circuited stubs are at odd multiples of a quarter-wavelength creating shunt short circuits at the middle of the main line. Low-loss passbands are formed between the adjacent stopbands. Each filter must be designed individually with IE3D to yield the desired stopbands before combining the two as a diplexer. Stopbands can be shifted in frequency by changing the stub lengths. Making the stubs longer will shift the stopbands toward lower frequencies, as well as shorten the passbands. Making the stubs shorter will shift the stopbands toward higher frequencies and lengthen the passbands. The filter should be designed such that the lowest possible harmonic stopbands are used to create the desired passbands since higher order harmonics will have more loss. The vertical filter (Filter 1) of Fig. 1(b) passes 10 GHz between the first and second harmonic stopbands. Similarly, Filter 1 passes 19 GHz between the second and third stopbands. The horizontal filter (Filter 2) of Fig. 1(b) passes 12 GHz between the second and third harmonic stopbands. Likewise, Filter 2 passes 21 GHz between the third and fourth harmonic stopbands. Both filters use the second and third stopbands for rejecting the desired frequency.

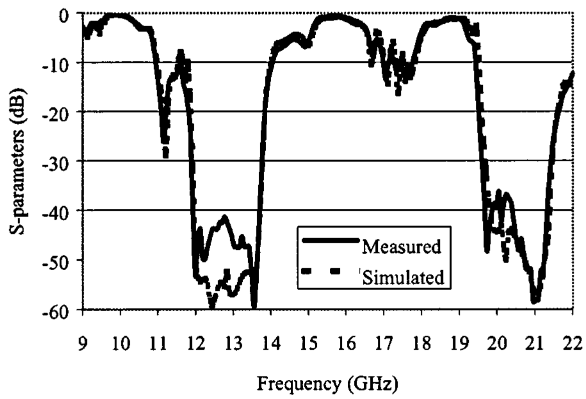

Fig. 2. S_{21} and S_{12} insertion loss of the diplexer.

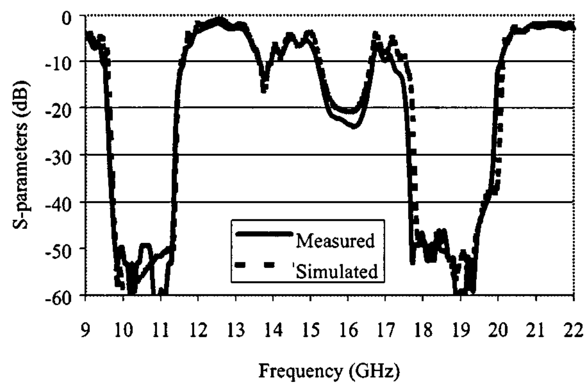

Fig. 3. S_{31} and S_{13} insertion loss of the diplexer.

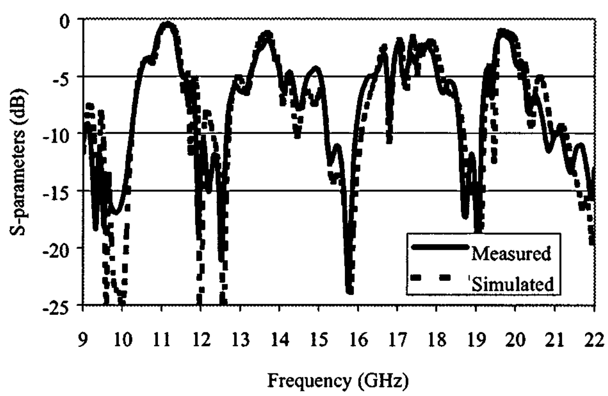

Fig. 4. S_{11} return loss of the diplexer.

The multifrequency diplexer is formed by connecting the two aforementioned filters with the T-junction shown in Fig. 1(b). The positioning of the filters from the T-junction was determined using IE3D. These distances greatly affect the return loss or matching of the system, as well as the insertion loss. However, the isolations do not fluctuate much ($<$5 dB) with the variations of filter placement since the isolation created by the stopbands depends on the lengths of the open-circuited stubs. Each filter uses ten stubs to achieve more than 50 dB in isolation. All of the main lines have a width of 1.478 mm corresponding to a characteristic impedance of 50 Ω. The diplexer's performance is plotted in Figs. 2–4. The simulated IE3D data and measured data agree very well. The results at 10, 12, 19, and 21 GHz are summarized in Table I. The diplexer has very good passband insertion-loss performance due

TABLE I
SIMULATED AND MEASURED RESULTS FOR THE DIPLEXER

	10 GHz	12 GHz	19 GHz	21 GHz
S_{11} Simulated (dB)	-25.3	-35.2	-14.7	-10
S_{11} Measured (dB)	-15.5	-12.7	-18.3	-10
S_{21} Simulated (dB)	-0.42	-50	-1.1	-56.1
S_{21} Measured (dB)	-0.4	-53.3	-1.25	-57.9
S_{31} Simulated (dB)	-62.2	-1.8	-52.1	-1.9
S_{31} Measured (dB)	-51	-3.4	-60.1	-2.4

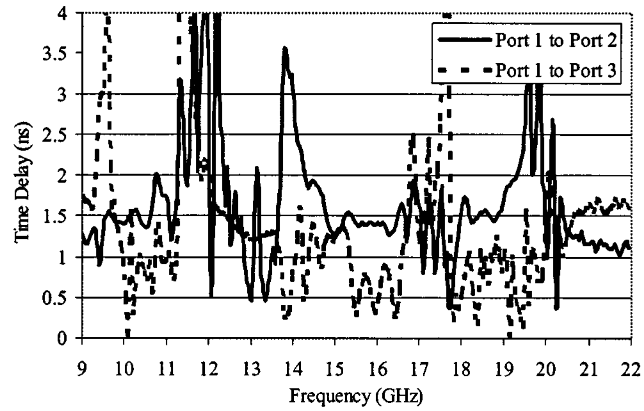

Fig. 5. Time delay for both diplexer channels.

to the inherent low loss in the periodic filters. The measured insertion loss varies from 0.4 to 3.4 dB for the four frequencies. The isolation is extremely good and exceeds 50 dB for all four frequencies. Each of the passbands has very good bandwidth of around 1 GHz, as shown in Figs. 2–4. The return loss is better than 10 dB.

In order to minimize dispersion, the signal time delay of the frequencies of interest must be equal [8]. The energy at 10 and 19 GHz must flow from port 1 and reach port 2 at approximately the same time. Likewise, the energy at 12 and 21 GHz must flow from port 1 and reach port 3 at about the same time. The signal time delay (τ), sometimes referred to as the group delay from port 1 to port 2, is

$$\tau = -\frac{\partial \angle S_{21}}{\partial \omega} \tag{1}$$

where $\angle S_{21}$ is the insertion phase and ω is the frequency in radians per second. Fig. 5 shows the time delay for both channels of the diplexer. From port 1 to 2, 10 and 19 GHz have time delays of 1.41 and 1.72 ns, respectively. Similarly, from ports 1 to 3, 12 and 21 GHz have time delays of 1.78 and 1.64 ns, respectively. The passbands containing 10, 12, 19, and 21 GHz have uniform time delay varying from around 1.3 to 1.8 ns. This constant time delay for the passbands is caused by the imaginary portion of the propagation constant being an almost linear function of frequency. This results in minimal dispersion.

III. CONCLUSIONS

The simulated and measured data matches extremely well. IE3D predicts the diplexer's behavior very well. The use of the periodic stub architecture allows many resonant sections to be used to achieve high isolation while maintaining low-loss performance and minimal dispersion. This diplexer is used for transmitting 10 and 19 GHz and receiving 12 and 21 GHz or vise versa. The filter could be built on a higher dielectric substrate for size reduction. The diplexer is very easy to manufacture and results are extremely reproducible because no coupling gaps are required.

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