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Microstrip Diplexers with Double-Stub Bandpass Filters

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Abstract – *This paper presents a microstrip diplexer using two Double-Stub Band-Pass Filters (DS-BPFs), composed of several double-stubs connected to a main microstrip line. Each DS-BPF has a null at the center frequency of the other. Therefore, these types of filters are suitable for diplexers with two near frequencies. A diplexer at frequencies 5.875 and 6.225 GHz is designed, fabricated and measured. Measured results of the fabricated diplexer have a good agreement with the calculated results.* ***Copyright © 2011 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Diplexers, Double-Stubs, Microstrip Transmission Lines*

I. Introduction

Diplexers are one of the important components in microwave circuits for channel separation in communication systems. They are commonly using two Band-Pass Filters (BPFs) with a common input [1]. Some of microstrip BPFs reported in the literature are based on using parallel-coupled transmission lines [2]-[4], symmetric EBG structure [5], dual behavior resonators [6], periodic stubs [7], and coupled open-loop resonators [8]-[11].

In some applications, two frequencies of diplexer are very near to each other, necessitating the use of two high-order BPFs. A novel idea in these applications may be the use of two low order BPFs that have a null at center frequency of one another. In this article, a new structure is proposed for these types of BPFs. The proposed structure contains some microstrip double-stubs composed of two parallel non-equal length open-ended stubs. A diplexer can be created by simply connecting two Double-Stub BPFs (DS-BPFs) at their inputs through two quarter-wavelength transmission lines.

Despite the simplicity of the proposed diplexer, good transmission performances and high isolation between the output ports are achieved. A microstrip diplexer at two near frequencies of 5.875 and 6.225 GHz has been designed, fabricated and measured to verify the usefulness of the proposed diplexer.

II. Diplexer with DS-BPFs

Fig. 1 depicts the proposed microstrip diplexer consisting of two DS-BPFs with center frequencies f_1 and f_2, whose corresponding null frequencies are f_2 and f_1, respectively.

As explained in the next section, the output of the DS-BPFs is zero and their input impedance becomes short circuit at null frequency.

Therefore, according to presence of two quarter-wavelength transmission lines in a crossed way in diplexer shown in Fig. 1, neither of two filters have effect around the centerfrequency of the other one.

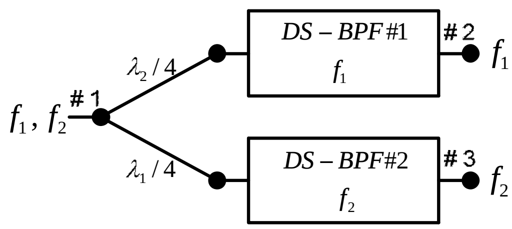

Fig. 1. The proposed diplexer consisting of two DS-BPFs

Assuming the diplexer is lossless and is connected to real load Z_0 at its three ports, the scattering parameters can be determined as follows:

$$S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{1}$$

$$|S_{21}| = \sqrt{\frac{P_{L2}}{P_A}} = \sqrt{\frac{P_{in,2}}{P_A}} = = 2\sqrt{Z_0\, Re\left(Z_{in,2}^{-1}\right)}\left|\frac{Z_{in}}{Z_{in} + Z_0}\right| \tag{2}$$

$$|S_{31}| = \sqrt{\frac{P_{L3}}{P_A}} = \sqrt{\frac{P_{in,3}}{P_A}} = = 2\sqrt{Z_0\, Re\left(Z_{in,3}^{-1}\right)}\left|\frac{Z_{in}}{Z_{in} + Z_0}\right| \tag{3}$$

where, $Z_{in,2}$, $Z_{in,3}$ and Z_{in} are impedances at the input (after two quarter-wavelength lines) of the upper filter, lower filter and both filters, respectively.

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III. Double-Stub BPFs

In this section, an *n*-th order BPF is introduced at center frequency f_p, which has a zero at frequency f_s. Figure 2 shows the structure of a BPF consisting of *n* double-stubs connected to the main transmission line. Each double-stub is composed of two parallel open-ended stubs of lengths $(2N+1)\lambda_s/4$ and $[2K-(2N+1)f_p/f_s]\lambda_p/4$, where *N* is an arbitrary positive integer for over-sizing, *K* is a positive integer number to avoid negative length and λ_p and λ_s are the wavelength at frequencies f_s and f_p, respectively. The distance between two adjacent double-stub is $\lambda_p/4$ on the main line whose characteristic impedance is $Z_0 = 1/Y_0$. The characteristic impedance of the *i*-th double-stub (i = 1, 2, …, n) is $Z_i = 1/Y_i$, so the input impedance of the *i*-th double-stub is as follows:

$$Y_{in}^{(i)} = Y_s + Y_p = jB_i \quad (4)$$

in which:

$$Y_s = jY_i \tan\left((2N+1)\frac{\pi}{2}\frac{f}{f_s} \right) \quad (5)$$

$$Y_p = jY_i \tan\left(\frac{\pi}{2}\frac{f}{f_p}\left(2K - (2N+1)\frac{f_p}{f_s} \right) \right) \quad (6)$$

Therefore, it can be seen that the input impedance of each double-stub is zero and infinite at frequencies f_s and f_p, respectively. Also, the known slop of susceptance parameter of the *i*-th double-stub can be obtained as follows:

$$b_i = \frac{f_p}{2}\frac{dB_i}{df}\bigg|_{f=f_p} = \frac{K\pi}{2}Y_i\left(1 + \tan^2\left(\frac{\pi}{2}(2N+1)\frac{f_p}{f_s} \right) \right) \quad (7)$$

From (7), it is seen that over-sizing, i.e. $N > 0$, help to move away the argument of tangent function from $\pi/2$ and so to avoid high values for characteristic impedances. From theory of microwave filters [1], each double-stub acts as a resonator at center frequency f_p and each segment of the main line between two adjacent double-stub acts as an admittance inverter with constant $Y_0 = 1/Z_0$.

Figure 3, shows the equivalent model of a BPF utilizing resonators and admittance inverters. The relationships between the slop of scuceptance parameter of resonators and the characteristic admittance of the inverters are given as follows [1]:

$$J_{0,1} = \sqrt{\frac{Bb_1}{g_0 g_1}Y_0} \quad (8)$$

$$J_{i,i+1} = B\sqrt{\frac{b_i b_{i+1}}{g_i g_{i+1}}} \quad \text{for } i = 1,2,...,n-1 \quad (9)$$

$$J_{n,n+1} = \sqrt{\frac{Bb_n}{g_n g_{n+1}}Y_0} \quad (10)$$

in which *B* is the fractional bandwidth and g_i (i = 0, 1, 2, …, n+1) are the element values of the prototype lowpass filter. Equating the parameter of all inverters to Y_0, yields the following required parameters for double-stub resonators:

$$b_1 = \frac{g_0 g_1}{B}Y_0 \quad (11)$$

$$b_{i+1} = \frac{g_i g_{i+1}}{b_i B^2}Y_0^2 \quad \text{for } i = 1,2,...,n-1 \quad (12)$$

$$b_n = \frac{g_n g_{n+1}}{B}Y_0 \quad (13)$$

Finally, the characteristic impedance of all double-stubs can be determined using (7) and (11)-(13).

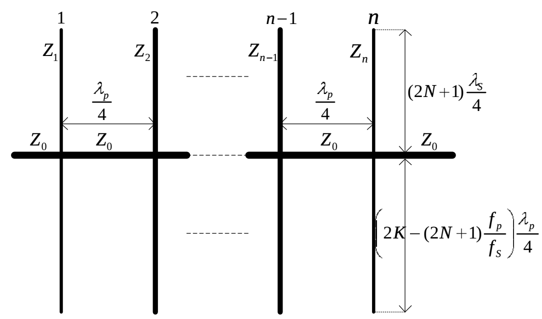

Fig. 2. The structure of a DS-BPF consisting of *n* double-stubs

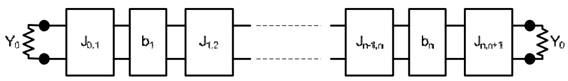

Fig. 3. The equivalent model of a BPF utilizing resonators and admittance inverters

IV. Example and Results

In this section a diplexer is designed and fabricated in frequencies f_1 = 5.875 GHz and f_2 = 6.225 GHz with 270 MHz bandwidth in each frequency, considering Z_0 = 50 Ω. Therefore, the specifications of two required filters have to be as the following:

1. BPF-1: f_p = 5.875 GHz, f_s = 6.225 GHz, B = 270 MHz.
2. BPF-2: f_p = 6.225 GHz, f_s = 5.875 GHz, B = 270 MHz.

For both filters, we use DS-BPF structure with a third order chebychev response of passband ripple 0.1 dB, considering $N = 1$ and $K = 2$.

Table I shows the required characteristic impedance of stubs of two filters. If we don't use over-sizing, i.e. $N = 0$, the characteristic impedance of stubs become too high for fabrication.

TABLE I
THE REQUIRED CHARACTERISTIC IMPEDANCE OF STUBS OF TWO DS-BPFS

BPF	Z_1 [Ω]	Z_2 [Ω]	Z_3 [Ω]
No. 1	102.05	91.75	102.05
No. 2	96.31	86.59	96.31

Fig. 4 shows the amplitude of the scattering parameters of designed diplexer. It is seen that although the order of two BPFs is low, the results can be acceptable.

The designed diplexer is fabricated on a substrate with $\varepsilon_r = 2.2$ and $h = 20$ mil = 508 μm (RT/Duroid 5880 from Rogers) as shown in Fig. 5.

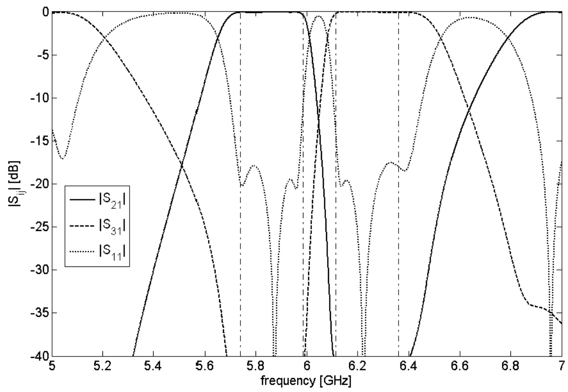

Fig. 4. The theoretical scattering parameters of designed diplexer

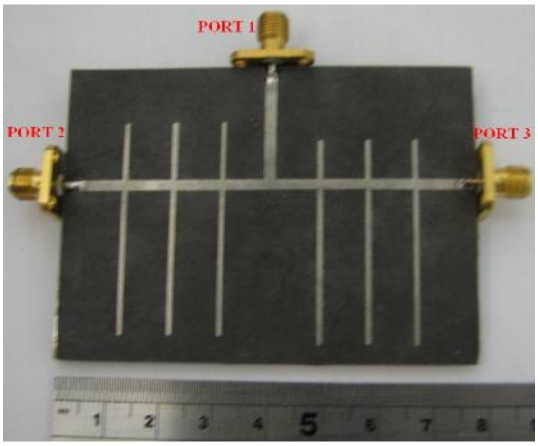

Fig. 5. The photo of the fabricated diplexer

Fig. 6 shows the measured amplitude of the scattering parameters of the fabricated diplexer. It is seen from Figs. 4 and 6 that the agreement between theoretical and measurement results is good except a minus shift frequency less than 300 MHz which may be related to the effect of microstrip discontinuities at the cross points.

The insertion loss of the fabricated diplexer is 2.3 dB and 2.2 dB at frequencies 5.875 and 6.225 GHz, respectively, which is due to the losses of substrate, conducting strips and connectors. Finally, Fig. 7 shows the measured reflection parameters of the output ports along with the isolation between them. It is seen that the return loss of all ports is more than 10 dB at passband frequencies. In addition, the isolation between two output ports is more than 40 dB at two center frequencies.

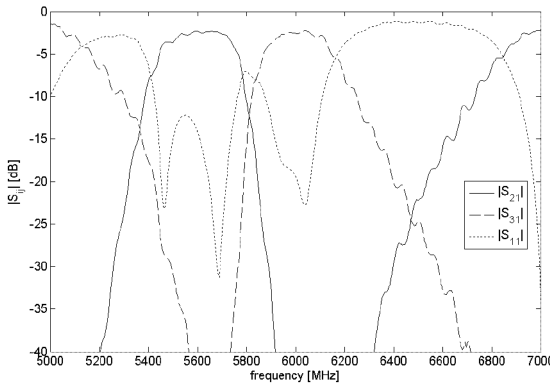

Fig. 6. The measured scattering parameters of the fabricated diplexer

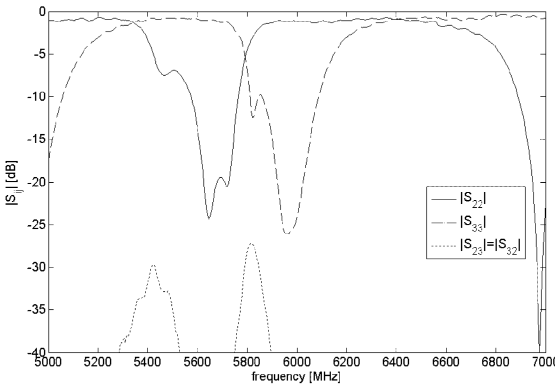

Fig. 7. The measured reflection parameters of fabricated diplexer

V. Conclusion

A new microstrip diplexer using two Double-Stub Band-Pass Filters (DS-BPFs), composed of several double-stubs connected to a main microstrip line was proposed. A diplexer at frequencies 5.875 and 6.225 GHz is designed, fabricated and measured. An excellent agreement between the theoretical and practical results is observed. The insertion loss of the fabricated diplexer is about 2.25 dB and the isolation between two output ports is more than 40 dB. Also, the return loss of all ports is more than 10 dB at passband frequencies. So, the proposed diplexer can be used as de-diplexer (two frequency combiner) too.

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