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Four-port Microstrip Diplexer For RF Interference Rejection

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***Abstract*—A novel four-port microstrip diplexer for RF interference rejection is presented in this paper by combining two diplexers together. This technique offers the signal isolation of 62.9 dB between transmitter and receiver module, which is the best figure ever reported. The four-port network exploits microstrip structure for the cost reduction, while still offering superior figure-of-merit compared to the existing state-of-the-art diplexers. Finally, four-port microstrip diplexer for RF interference rejection can be used in IMT-2000 applications whereas device miniaturization and low infrastructure cost are required.**

Keywords—four-port network; lumped-element; microstirp diplexer; high isolation

I. INTRODUCTION

Nowadays, the advance of radio frequency (RF) and microwave technology has stimulated the rapid development of modern wireless communication systems. For the last few decades, a variety of techniques used to design bandpass filters were developed e.g. lumped-elements (LC Circuit), microstrip technology, coaxial configurations, dielectric filters, cavity resonator and high temperature superconductors [1, 2]. In microwave system, it is challenging to design a device at low cost and high performance. The design of different filters and diplexers was discussed in [3-4] in which conventional diplexers offer low cost (microstrip structure) but offer poor signal isolation (worse than 20dB) and high signal losses. Consequently, a new technique to improve signal isolation while keeping low costs is required. Diplexers are three-port network and commonly used to combine or separate different signal frequencies which they are usually set in the form of filters. RF front-end of a cellular radio base station uses bandpass filters to discriminate two different frequency bands for transmitting (Tx) and receiving (Rx) channels using a single antenna. Generally, relatively high power signals, in an order of 30 W, are generated by Tx channel. Consequently, the Tx filter should have high capability of power handling and the receiver Rx channel has to detect very weak signals [5].

Therefore, in order to protect the low-noise amplifier in the receiver channel from the transmitter channel with high power signals (higher than 30 W), the Rx filter is designed to have high signal isolation between the two channels because transmit power amplifier produces out-of-band intermodulation products and harmonics [5]. In the transmitting band, Tx filter also has a high level of stopband attenuation to reject the noise generated at the output of the power amplifier. For this reason, diplexer with high isolation between Tx and Rx channels is required.

In this paper, a novel four-port microstrip diplexer for RF interference rejection is introduced as a superior design technique for the high-isolation at low cost. The proposed four-port network combines two diplexers together in order to obtain the best isolation while offering low complexity.

II. ANALYSIS OF FOUR-PORT NETWORKS

Block diagram presenting component topology of the four-port network is shown in Fig. 1.

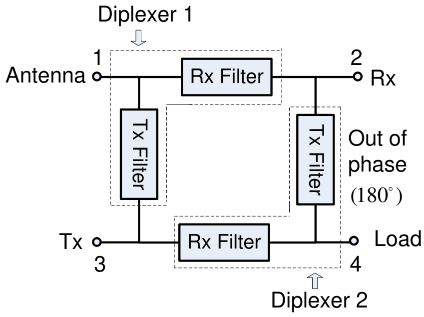

Fig. 1. A diagram of four-port network.

Fig.1, we can also consider the difference of signal isolation between two paths (3-1-2 and 3-4-2 paths). We can investigate the combination of sine waves as $\sin\theta + \sin(\theta + \Delta)$. Let Δ is phase difference. The comparison between phase and the isolation is shown in Fig. 2. It can be seen that the phase between port 2 and 4 must be out of phase (180° different) to obtain the best signal isolation.

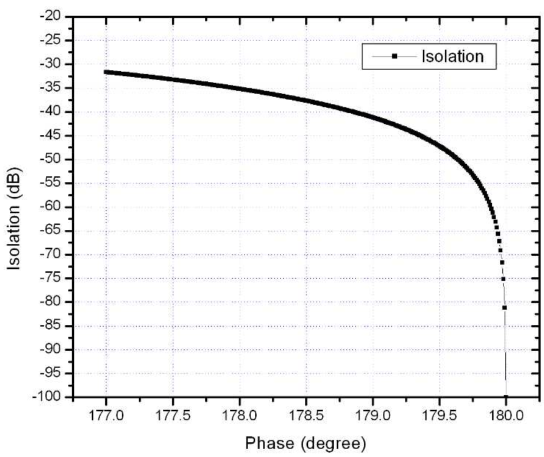

Fig. 2. Comparison of isolation response and phase differences.

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III. SECOND ORDER CHEBYSHEV FILTER FOR DIPLEXER AND FOUR-PORT DIPLEXER

The key design parameters of lumped-element Chebyshev bandpass filter are shown in table I.

TABLE I. SPECIFICATONS OF DIPLEXER DESIGN

Centre frequency	Tx=1.95 GHz and Rx=2.14 GHz
Passband Bandwidth	60 MHz
Stopband Attenuation	>40 dB
Passband Return Loss	> 20 dB
Passband Insertion Loss	< 0.4 dB
System Impedance	50 Ω

Firstly, the order of the filter can be calculated in [5].

$$N \geq \frac{L_A+L_R+6}{20\, log_{10}[S+(S^2-1)^{1/2}]} \quad (1)$$

Where

$$L_A=40 \text{ and } L_R=20 \quad (2)$$

S is the selectivity and is the ratio of stopband to passband bandwidth. Hence

$$S=40 \quad (3)$$

$$N\geq =1.734 \quad (4)$$

That is, a degree 2 transfer function at least must be used.

The ripple level ε is

$$\varepsilon = (10^{L_R/10}-1)^{-1/2} \quad (5)$$

$$=0.1005$$

Hence

$$\eta = \sinh[\frac{1}{N} sinh^{-1}(1/\varepsilon) \quad (6)$$

$$=2.1213$$

And the shunt capacitive element value of the capacitive element Chebyshev low pass prototype is

$$C_r = \frac{2}{\eta}\sin[\frac{(2r-1)\pi}{2N}] \quad (7)$$

Where r=1,…, N

$$C_1 = C_2 = 0.6667$$

The element value of the normalised inverter coupled Chebyshev low pass prototype is

$$K_{r,r+1} = \frac{[\eta^2+sin^2(r\pi/N)]^{1/2}}{\eta} \quad (8)$$

Where r=1,…, N-1

Therefore the inverter value is

$$K_{12} = 1.1055$$

The normalized Chebyshev inverter coupled low pass prototype is represented in Fig. 3.

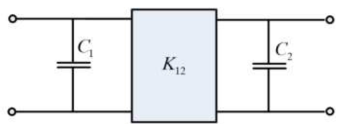


Fig. 3. Capacitive coupled normalised low pass inverter.

At the centre frequency of 1.95 GHz and 2.14 GHz and Z=50 ohm

$$\omega = 2\pi f \quad (9)$$

at 1.95 GHz = 12.252x10^9 and at 2.14 GHz = 13.446x10^9

and
$$\alpha = \frac{f}{\mathrm{BW}} \quad (10)$$

at 1.95 GHz =65 and at 2.14 GHz=71.33

The element values of a lowpass to bandpass frequency and impedance scaled capacitive coupled network shown in Fig. 4 can be calculated as

$$C_{01} = C_{N,N+1} = \frac{1}{\omega Z(\alpha-1)^{1/2}} \quad (11)$$

and

$$C_{r,r+1} = \frac{Kr,r+1}{Z\alpha\omega} \quad (12)$$

Where r=1,…, N-1

The shunt element values can be calculated as

And

$$C_{11} = \frac{\left[\frac{C_1}{\omega}-\frac{(\alpha-1)^{\frac{1}{2}}}{\omega\alpha}-C_{12}\right]}{Z} \quad (13)$$

And

$$C_{NN} = \frac{\left[\frac{C_N}{\omega}-\frac{(\alpha-1)^{\frac{1}{2}}}{\omega\alpha}-C_{N-1,N}\right]}{Z} \quad (14)$$

And

$$C_{rr} = \frac{\left[\frac{C_r}{\omega}-\frac{(\alpha-1)^{\frac{1}{2}}}{\omega\alpha}-C_{r-1,r}-C_{r,r+1}\right]}{Z} \quad (15)$$

Where r=2,…, N-1

$$L_{r,r} = \frac{Z}{C_r\omega} \quad (16)$$

Where r=1,…, N

The element values of second order Chebyshev diplexer are shown in table II.

TABLE II. DIPLEXER DESIGN

Elements	Tx=1.95 GHz	Rx=2.14 GHz
$C_{01}= C_{23}$	0.204 pF	0.177 pF
C_{12}	0.0278 pF	0.0231 pF
$C_{11}= C_{22}$	0.8596 pF	0.7937 pF
$L_{11}= L_{22}$	6.121 nH	5.599 nH

IV. DESIGN EXAMPLE AND RESULTS

The diplexer (three-port) design is based on the independent design of two bandpass filters as following steps.

Step 1: design filter in Tx at centre frequency of 1.95 GHz with 60 MHz bandwidth.

Step 2: calculate the order of filter and element value of the capacitive element Chebyshev inverter coupled low pass prototype from equation (1) to (8).

Step 3: calculate the element values of a lowpass to bandpass frequency and impedance scaled capacitive coupled network from equation (11) to (16).

Step 4: design filter in Rx between port 1 and 2 at centre frequency of 2.14 GHz with 60 MHz bandwidth which is the same steps as in Tx.

Then, the T-junction is connected the two independent bandpass filters together. The circuit of the inverter coupled diplexer network is shown in Fig. 4.

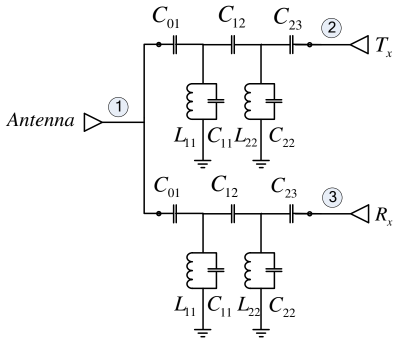
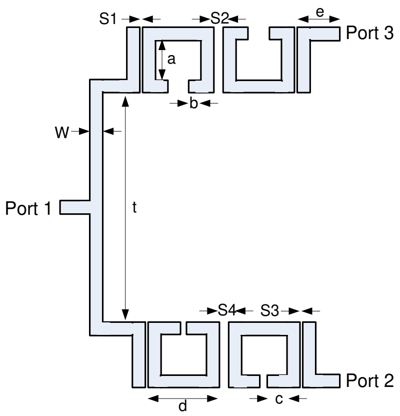


Fig. 4. Capacitively coupled diplexer layout.

The proposed microstrip diplexer is based upon square open-loop resonator as shown in Fig. 5. The diplexer is designed on a RT/Duroid substrate having a thickness h = 1.27mm with relative dielectric constant ε_r =6.15. The diplexer was simulated by AWR microwave office.



W = 1.87mm	t = 21.76mm	S1 =0.16mm	S2 =2.4mm
S3 =0.1mm	S4 =2.4mm	a = 7.8mm	b = 2mm
c = 3.75mm	d = 11.54mm	e = 6.87mm	

Fig. 5. The microstrip diplexer design and its optimised dimensions.

The comparison of capacitively coupled and microstrip diplexer simulated response by AWR microwave office is portrayed in Fig. 6. It can be seen that the capacitively coupled-circuit responses agree well with the microstrip diplexer responses. The 3-dB bandwidth of diplexer is 60 MHz. The passband insertion loss (IL) is less than 0.968 dB and 0.942 dB for Tx and Rx band, respectively. The return loss (RL) in both channels is better than 20 dB in the passband.

From Fig.1, two diplexers (diplexer 1 and 2) are combined together in order to obtain the best isolation. The circuit of the capacitively coupled four-port network is shown in Fig. 7. The four-port microstrip diplexer is depicted in Fig. 8.

The capacitively coupled four-port network simulated response is portrayed in Fig. 9. The RL in both channels is better than 20 dB in the passband. The passband IL in Tx band is less than 2.2 dB and Rx band 2.18 dB. It can be realizable that both four-port lumped element circuit and four-port microstrip diplexer agree well responses. The comparison isolation (S_{32}) of diplexer and four-port diplexer is shown in Fig. 10. The simulated isolation of microstrip diplexer is 29.52 dB and 62.9 dB in four-port microstrip diplexer. From Fig. 10, it can be seen that the four-port microstrip diplexer still has signal isolation (S_{32}) better than the existing state-of-the art diplexers [6-7].

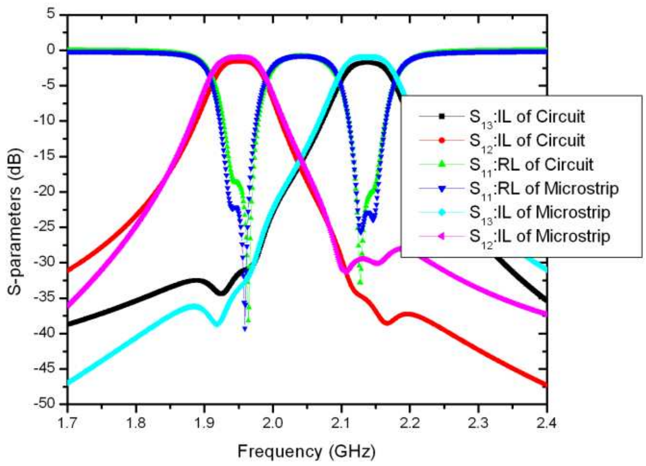


Fig. 6. Comparison of capacitively coupled lumped element and microstrip diplexer.

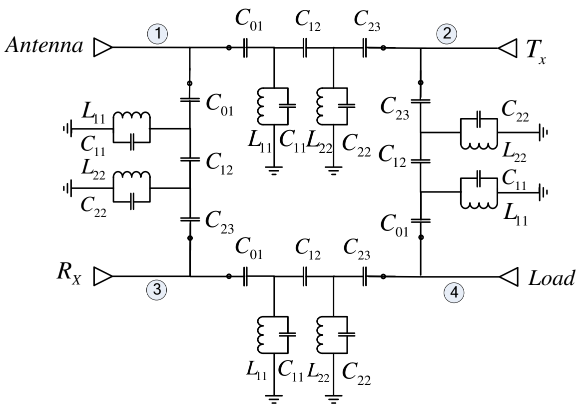
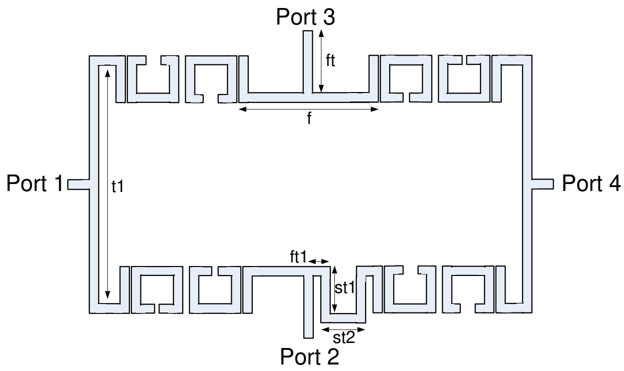


Fig. 7. Capacitively coupled four-port layout.



t1 = 37.75mm	ft = 20mm	f =44.62mm	ft1 =5.57mm
st1 =16.4mm	st2 = 7.415mm		

Fig. 8. The microstrip four-port diplexer design and its optimised dimensions.

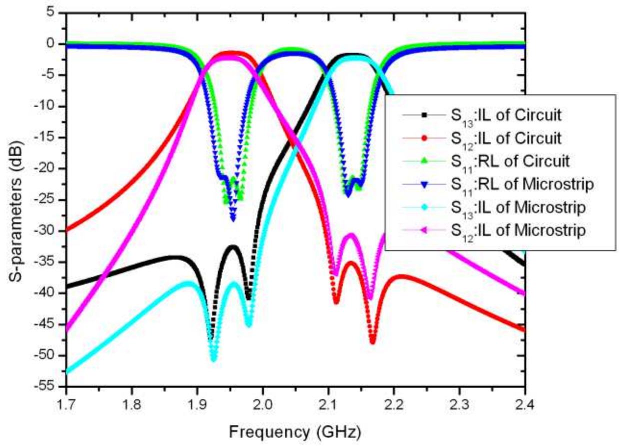


Fig. 9. Comparison of capacitively coupled lumped element four-port network and four-port microstrip diplexer.

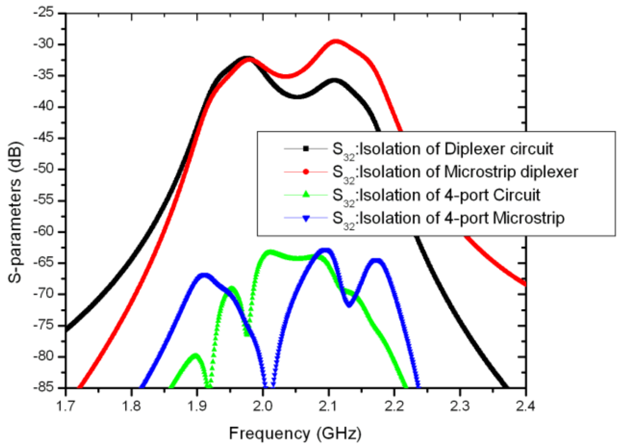


Fig. 10. Comparison of isolation (S_{32}) response of diplexer and four-port diplexer.

V. CONCLUSIONS

The novel four-port microstrip diplexer for RF rejection is proposed here. The four-port network is based on the design of two independent diplexers, (Tx at 1.95 GHz, Rx at 2.14 GHz, BW=60MHz). The new four-port microstrip diplexer structure can enhance the isolation (S_{32}) from (29.52 dB) to (62.9 dB), which can be used in IMT-2000 wireless systems.

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