Novel Synthesizing Technique for Interference Rejection in Future Integrated Base Station

Jessada KONPANG Muhammad SANDHU Nutapong SOMJIT and Ian HUNTER

Institute of Microwaves and Photonics, School of Electronic and Electrical Engineering, University of Leeds,
Leeds, LS2 9JT, UK

Abstract A novel technique minimizing signal loss while enhancing isolation between transmitter and receiver is introduced in this paper by using four-port diplexer topology. Three and four-port networks are intensively analysed and synthesized for solving S-parameter equations. From the analytical solution verified by 3D fullwave simulations, the four-port diplexer can be designed by using two diplexers with 180° different phase. This technique offers the signal isolation of 68.46 dB between transmitter and receiver module, which is the best figure ever reported to date. The four-port network exploits both high and low-Q factor filters for the cost reduction while still offering superior figure-of-merits.

Keyword Three-port, Four-port, Diplexer, Isolation

1. INTRODUCTION

Generally speaking, the recent 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 configurations, 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] which conventional diplexers offer low cost (microstrip structure) but give poor isolation performance (worse than 20dB) and high losses. Consequently, a new technique to improve signal isolation while keeping low signal losses 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 (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 synthesizing technique for interference rejection in future integrated base station is introduced as a superior design technique for the high-isolation at lower cost compared to the state-of-the-art diplexer devices. The proposed four-port network combines bandpass filters with high and low-Q factor for the cost reduction and device miniaturization while offering superior RF performance.

2. ANALYSIS OF FOUR-PORT NETWORKS

The block diagram of four-port network is shown in Fig. 1.

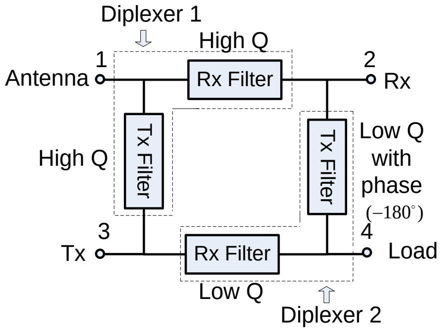

Fig.1. A diagram of four-port network.

From Fig.1, In case of high Q in both paths, we can 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 realized that the best signal isolation at Tx and Rx can be obtained from 180° different phase.

Again, we consider from Fig.1, the four-port network is based on the design of two diplexer bandpass filters combined together; one of them meeting the desired High-Q and the other desired Low-Q in order to reduce cost in mass production and keep low losses. We can also consider the difference of insertion between two paths (3-1-2 and 3-4-2 paths). From $\sin\theta - A\sin(\theta)$, where A is the attenuation of Low-Q path, the comparison between attenuation and the isolation is shown in Fig. 3. It can be seen that the signal isolation performance at Tx and Rx gives poor isolation when the high attenuation is increased. However there always exists a trade-off between size and energy loss. Therefore, the combination of High and Low-Q is still considered to reduce cost and size reduction and also keep low losses.

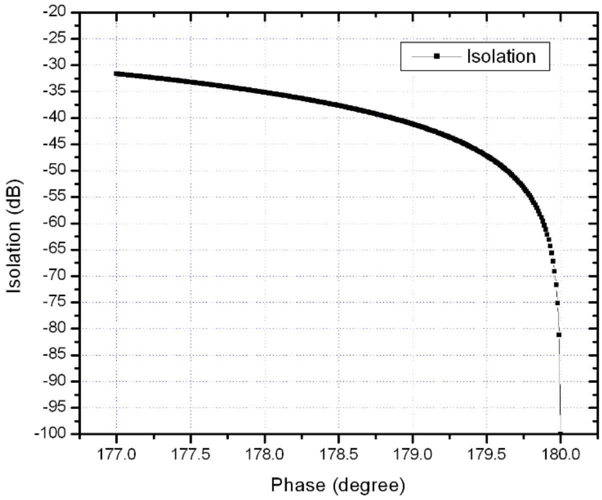

Fig.2. Comparison of isolation response and phase differences.

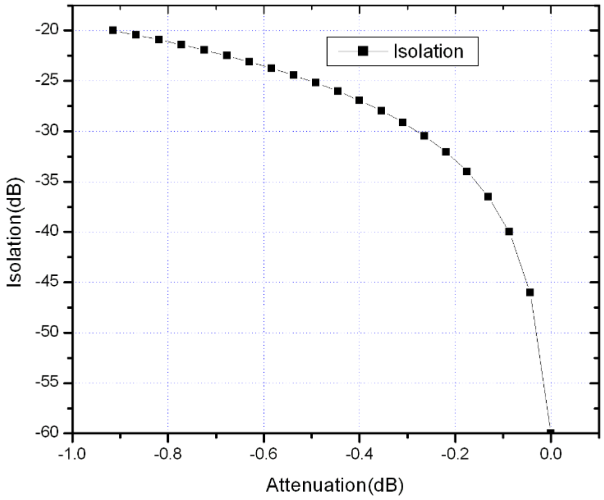

Fig.3. Comparison of isolation response and attenuation.

3. LUMPED-ELEMENT FILTER DESIGN FOR DIPLEXER AND FOUR-PORT NETWORKS

The key design parameters of lumped-element Chebyshev bandpass filter is shown in table 1.

TABLE I. SPECIFCATONS OF BANDPASS FILTERS DESIGN

Centre frequency	Tx=1.73 GHz and Rx=2.13 GHz
Passband Bandwidth	50 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].

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

Where

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

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

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

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

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

The ripple level ε is

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

$$=0.1005$$

Hence

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

$$=2.1213$$

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

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

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. 4.

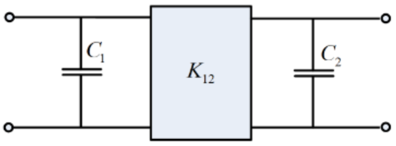

Fig.4. Equivalent circuit of impedance inverter.

At the centre frequency of 1.73 GHz and 2.13 GHz and Z=50 ohm

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

at 1.73 GHz = 10.87x10^9 and at 2.13 GHz = 13.38x10^9

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

at 1.73 GHz =34.6 and at 2.13 GHz=42.6

The element values of a lowpass to bandpass frequency and impedance scaled capacitively coupled network shown in Fig. 5 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=1.73 GHz	Rx=2.13 GHz
C_{01}= C_{23}	0.32 pF	0.23 pF
C_{12}	0.06 pF	0.04 pF
C_{11}= C_{22}	0.86 pF	0.73 pF
L_{11}= L_{22}	6.9 nH	5.6 nH

4. DESIGN EXAMPLE AND RESULTS

4.1. DIPLEXER DESIGN

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 1.73 GHz with 50 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).

The circuit of the capacitively coupled filter network is shown in Fig. 5.

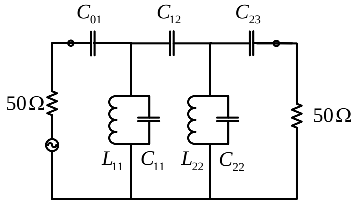

Fig.5. Capacitively coupled filter layout.

The capacitively coupled filter at 1.73 GHz simulated response by AWR microwave office is portrayed in Fig. 6. The 20-dB bandwidth is 50 MHz. The passband IL in Tx band is less than 0.218 dB. The RL is better than 20 dB in the passband.

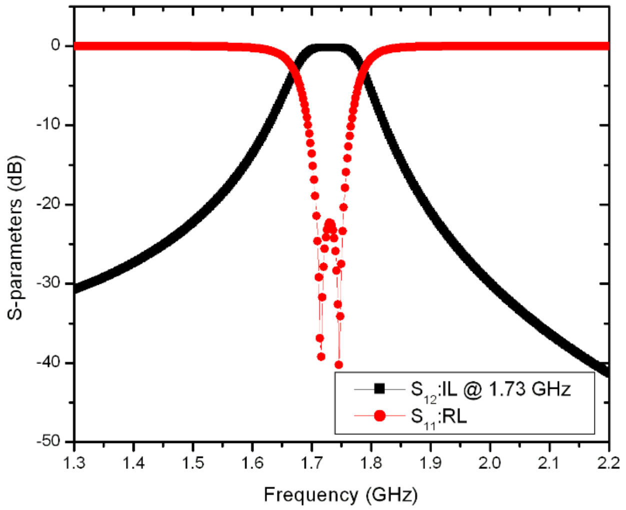

Fig.6. Capacitively coupled lumped element filter response at 1.73 GHz.

Step 4: design filter in Rx at centre frequency of 2.13 GHz with 50 MHz bandwidth which is the same steps as in Tx. The capacitively coupled filter at 2.13 GHz simulated response by AWR microwave office is portrayed in Fig. 7. The 20-dB bandwidth is 50 MHz. The passband IL in Tx band is less than 0.3075 dB. The RL is better than 20 dB in the passband.

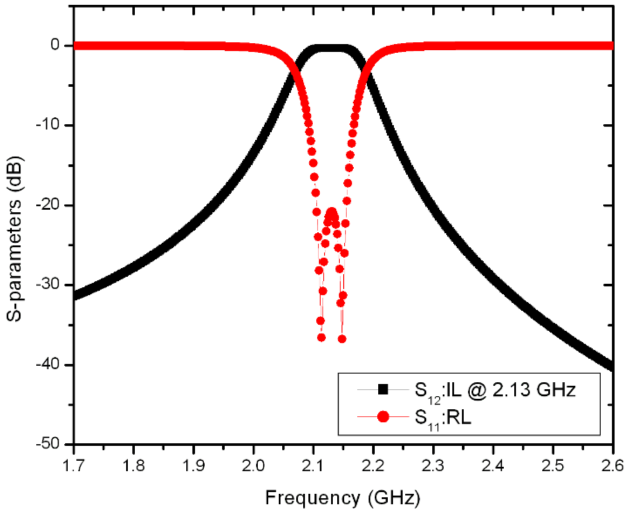

Fig.7. Capacitively coupled lumped element filter response at 2.13 GHz.

Then, the T-junction is connected the two independent bandpass filters together. The circuit of the capacitively coupled diplexer network is shown in Fig. 8. The capacitively coupled three-port network simulated response by AWR microwave office is portrayed in Fig. 9. The 20-dB bandwidth is 50 MHz. The passband IL in Tx band is less than 0.22 dB and Rx band 0.31 dB. The RL in both channels is better than 20 dB in the passband.

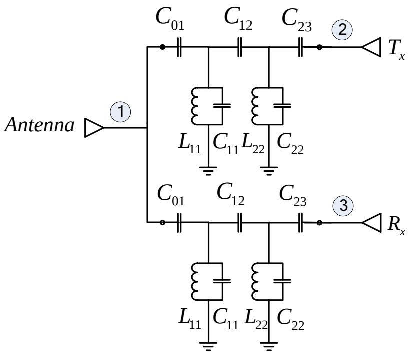

Fig.8. Capacitively coupled diplexer layout.

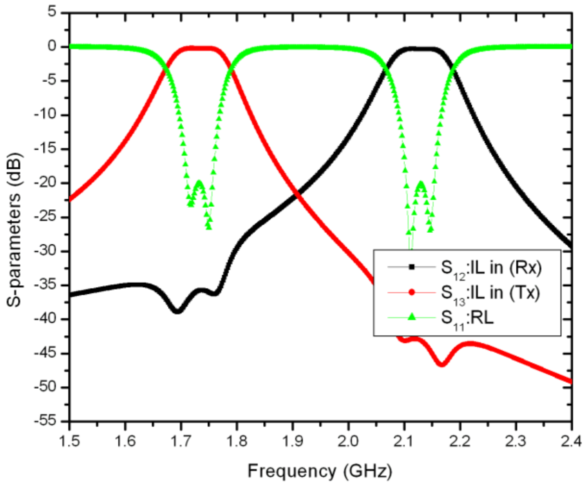

Fig.9. Capacitively coupled lumped element diplexer network response.

4.2. FOUR-PORT DESIGN

From Fig.1, two diplexer filters (diplexer 1 and 2) are combined together in order to obtain the best isolation. The first diplexer (No. 1, 2 and 3) is designed with High-Q factor (Q=1000). The second diplexer (No. 2, 3 and 4) is designed with Low-Q factor (Q=500). The circuit of the capacitively coupled four-port network is shown in Fig. 10. The capacitively coupled four-port network simulated response is portrayed in Fig. 11. The RL in both channels is better than 20 dB in the passband. The passband IL in Tx band is less than 0.23 dB and Rx band 0.32 dB. It can be seen that both three-port and four port network are almost the same insertion loss. The comparison isolation (S_{32}) of three-port and four-port is shown in Fig. 12. The simulated isolation of diplexer network is 35.66 dB and 68.46 dB in four-port. From Fig. 12, it can be realized that the phase shift between 180° and 183° of four-port network still has signal isolation (S_{32}) better than the existing diplexer [6-7].

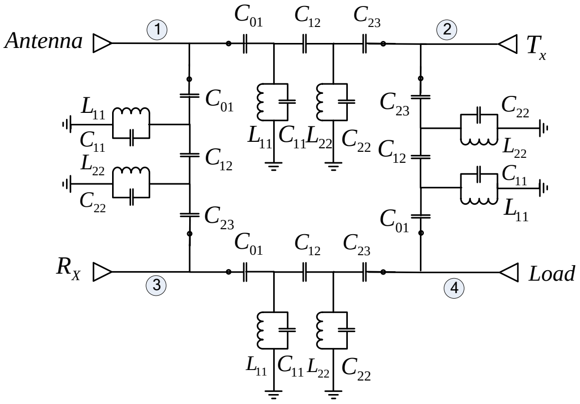

Fig.10. Capacitively coupled four-port layout.

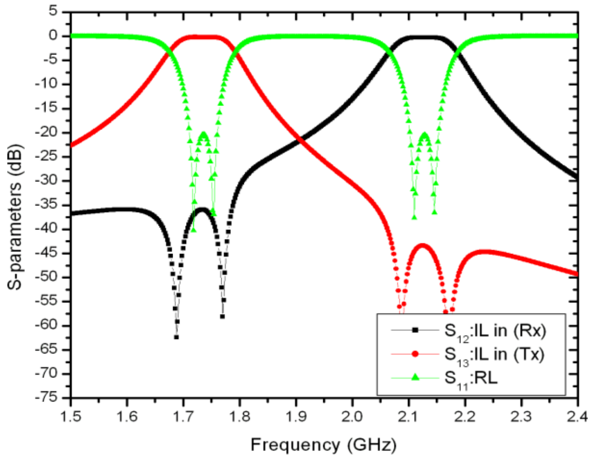

Fig.11. Capacitively coupled lumped element four-port network response.

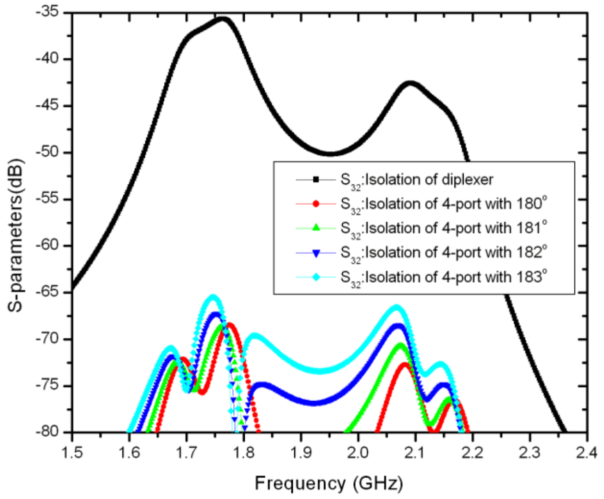

Fig.12. Comparison of isolation (S_{32}) response of diplexer and four-port network.

5. CONCLUSIONS

The novel synthesizing technique for interference rejection in future integrated base station is proposed here. The concept is very attractive since the four-port network is based on the design of two independent diplexer bandpass filters, (Tx at 1.73 GHz, Rx at 2.13 GHz, BW=50MHz): one of them meeting the desired High-Q (Q=1000) and the other desired Low-Q (Q=500). The new technique design can enhance the isolation (S32) from (35.66 dB) to (68.46 dB). Finally, RF interference rejection technique can be used in wireless communication systems whereas small size, low losses and low complexity are required.

References

[1]J.-S. G. Hong and M. J. Lancaster, Microstrip filters for RF/microwave applications vol. 167: John Wiley & Sons, 2004.

[2] I. C. Hunter, L. Billonet, B. Jarry, and P. Guillon, "*Microwave filters-applications and technology*," Microwave Theory and Techniques, IEEE Transactions on, vol. 50, pp. 794-805, 2002.

[3]Han-Sam Peng and Yi-Chyun Chiang, "*Microstrip Diplexer Constructed With New Types of Dual-Mode Ring Filters*," IEEE Microwave and Wireless Components Letter, vol. 25, pp. 7-9, 2015.

[4]Q. Xue and J.-X. Chen, "*Compact diplexer based on double-sided parallel-strip line*," Electronics Letter, vol. 44, pp. 123-124, 2008.

[5]I. Hunter, Theory and design of microwave filters: IET, 2001.

[6]Yonggang Zhou, Hong-wei Deng, and Yongjiu Zhao *"Compact Balanced-to-Balanced Microstrip Diplexer With High Isolation and Common-Mode Suppression"* IEEE Microwave and Wireless Components Letter, vol. 24, No. 3, pp. 143-145, 2014.

[7]Dong Chen, Lei Zhu, Huizheng Bu, and Chonghu Cheng "*A Novel Planar Diplexer Using Slotline-Loaded Microstrip Ring Resonator*" IEEE Microwave and Wireless Components Letter, vol. 25, No. 11, pp. 706-708, 2015.