Novel Channelization Multiplexer using Metamaterial Filters

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Abstract

This paper describes a novel channelization multiplexer for multi-band front-ends (B3G 450, GSM 900, GSM 1800 and W-CDMA 2100). This subsystem eliminates harmonic resonances by using Metamaterial (MTM) directional filters. The proposed configuration is simple to implement and is highly miniaturized.

1. Introduction

Modern communication systems require multi-band operation. For such systems the separation of different frequency channels in the *RF* Front-End becomes an essential characteristic. For example, for mobile telephony, newer system configurations will require the usage of the existing 2G, 3G frequencies plus the newly B3G allocation. Since these three different generations require frequencies that are significantly separated in the spectrum, conventional multiplexers would require filters with additional Low Pass (*LP*) or High Pass (*HP*) filtering to nullify harmonic resonances [1, 2]. For example, for the f_0 = 450 MHz B3G band, conventional resonators would have harmonics at $nX f_0$, which would interfere the GSM 900, 3G 1800, and B3G 3200 bands [3].

A good alternative to conventional *LP* and *HP* filtering in wireless systems is the usage of Metamaterial (*MTM*) filters based on closed loop zeroth-order resonators with harmonic resonance suppression [6, 7]. Moreover, *MTM* allow filter miniaturization, particularly useful at the lower frequency spectrum (i.e. 450 MHz, 900 MHz).

Directional filters are excellent candidates for channel separation since they can be cascaded to form a multiplexing network [4]. In order to suppress harmonic resonances and to miniaturize the structure, *MTM* closed loop resonators can be incorporated to the Directional Filter [7].

In this paper a novel multiplexer using *MTM* directional filters is presented for mobile multi-band transceiver front-ends. The proposed system operates at the B3G 450, GSM 900, GSM 1800, and W-CDMA 2100 bands for geographical Region 4 [3].

The rest of the paper is organized as follows: Section 2 shows the architecture and characteristics of a *MTM* directional filter; Section 3 presents the proposed Front-End design using the *MTM* filters; and finally conclusions are presented in Section 4.

2. MTM Directional Filter

2.1 Directional Filters

Directional Filters are four-port structures having a bandpass response between ports 1 and 4 and its complementary rejectband response between ports 1 and 2. Ideally, at the center frequency, no power is transmitted to port 3 and none is reflected to port 1. The principle of operation of these filters is the constructive-destructive interference effect produced by the electrical distance between the resonator-coupling points [4]. Figure 1 shows a conventional planar directional filter composed by two $\lambda_g/2$ resonators, where λ_g represents a guided wavelength.

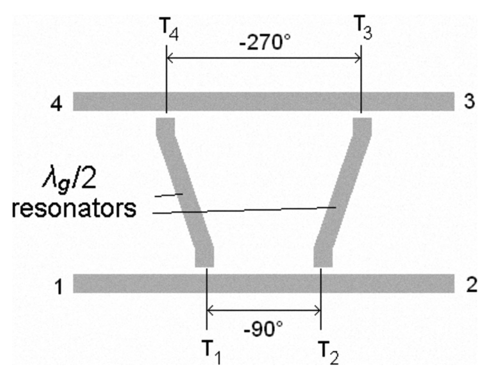

Figure 1. Conventional planar directional filter.

An example of a multiplexing network composed by four directional filters is displayed in Figure 2, where the input frequencies f_a, f_b, f_c, f_d and f_e are split into 5 different

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channels. However this network can also act as a combiner if all the arrows are reversed.

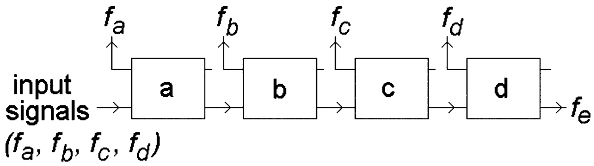

Figure 2. Multiplexing network with directional filters.

2.2 MTM directional filter

To design a closed loop *MTM* resonator, a Composite-Right-Left-Handed Transmission Line (*CRLH TL*) is designed by cascading a conventional Right-Handed (*RH*) *TL* and symmetrical *LH* cells, and then looping the entire structure. In a *LH* cell, the phase gives a positive phase shift, while in conventional *RH* lines the phase lags in the direction of the group velocity incurring in a negative phase shift [5]. The total phase shift of a cascaded *CRLH TL* (Φ_{CRLH}) can be calculated using (1) [6]:

$$\phi_{CRLH} = \phi_{RH} + \phi_{LH} = \\ = \frac{-2\pi f l_{MS}\sqrt{\varepsilon_{eff}}}{c} + \frac{N}{2\pi f\sqrt{L_L C_L}}, \qquad (1)$$

where Φ_{LH} and Φ_{RH} are the *LH* and *RH* phase shift respectively, N is the number of *LH* cells, ε_{eff} is the substrate effective permittivity coefficient, l_{MS} is the length of the microstrip line, and f is the design frequency. L_L and C_L are the *LH* inductor and capacitor values respectively. Here c is the speed of light in vacuum.

A *MTM* directional filter was designed at the GSM 900 Up-Link (*UL*) band using zeroth-order closed loop resonators [7]. Each *MTM LH* cell is composed by *SMD* (Surface-Mounted Device) series capacitors and an *SMD* shunt inductor in a "*T*" configuration circuit. Each *LH* unit cell was designed to give a phase shift of +50° and the conventional *RH* cell line generates the complementary shift of -50°, thus generating a zero phase shift along the overall circumference of the structure at the central frequency. The zeroth-order resonator was designed at 900 MHz using an RT/DUROID substrate, with ε_r = 2.2 and thickness h = 1.575 mm. The capacitances and inductances were implemented using *SMD*'s of values 8.2 pF and 10 nH respectively. This *MTM* resonator occupies an area of about 528 mm^2, which represents an 85 % miniaturization compared to a conventional closed loop resonator. Figure 3(a) presents the designed *MTM* resonator, while its simulated and experimental responses are shown in Figure 3(b).

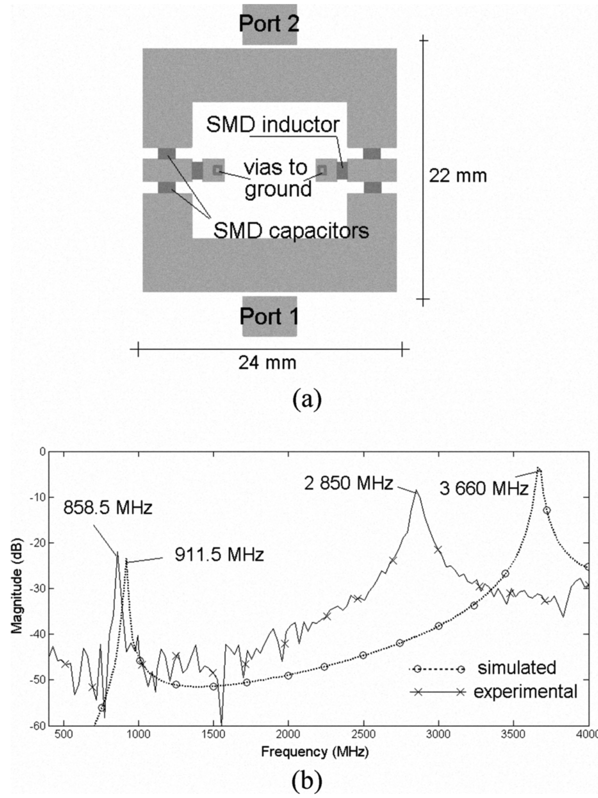

Figure 3. (a) *MTM* closed loop resonator, and (b) simulated and experimental responses.

From Figure 3(b), the elimination of harmonic resonances is noticeable. Spurious resonances appear at 3660 MHz and 2850 MHz for the simulated and experimental responses respectively, and are generated by a 360° phase shift along the loop [6]. The differences between the simulated and experimental responses are because the *SMD* element dimensions are not taken into account in the simulator, so in the real circuit the length of the loop is slightly increased generating a lower resonance [7].

Two *MTM* closed loop resonators were coupled to form the directional structure. Each one was symmetrically coupled to generate a 3 dB frequency bandwidth of 9.4 % at a center frequency of 900 MHz, and connected by 270° and 90° lines at each coupling point, thus generating the constructive interference at the output port 4 and the destructive interference at the isolated port 3 [7]. The designed *MTM* directional filter is shown in Figure 4.

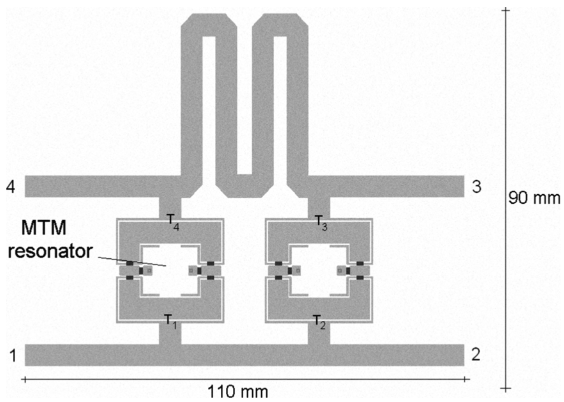

Figure 4. *MTM* Directional Filter.

From Figure 4 it is noticeable that the size of the upper (T_3 – T_4) line is rather large compared to the overall dimension of the filter. In order to obtain further miniaturization, a second prototype was designed by replacing the conventional –270° line with a *MTM TL* composed of two +45° unit cells. The values of the series capacitors and the strip-line shunt inductors are 4.7 pF and 6.4 nH respectively. Figure 5 shows the miniaturized directional filter.

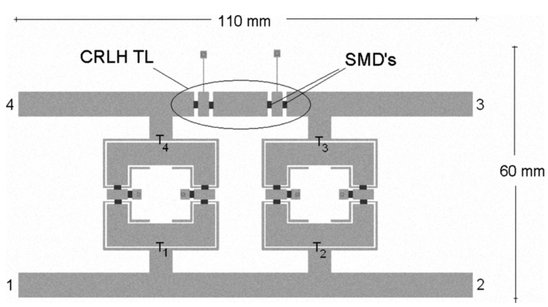

Figure 5. Miniaturized *MTM* directional filter.

The simulated and experimental responses of the miniaturized filter of Figure 5 are plotted in Figure 6.

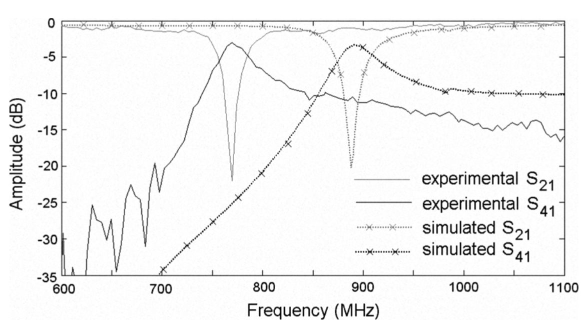

Figure 6. Simulated and experimental responses of the filter of Figure 5.

The measured curve shows a central frequency of 770 MHz and the simulated 892 MHz. The simulated S_{41} bandwidth is 5.9 % and the experimental bandwidth is of 4.7 %. S_{21} gives the complementary band-reject filter response. Transmission losses at port 4 are around 2.8 dB in the passband for simulation and measurement. The differences between simulated and experimental results are due to manufacturing tolerances and the inclusion of *SMD* components as discussed previously. This filter occupies an area of about 6600 mm^2, 76 % smaller than a conventional one with $\lambda_g/2$ resonators.

3. Front-End with MTM Directional Filters

A multiplexing network is shown in Figure 7 with *MTM* Directional Filters. Each filter was designed and simulated to operate at the Up-Link (*UL)* channel of each frequency band (B3G 450, GSM 900, GSM 1800 and W-CDMA 2100). Table 1 shows the frequency allocation of the *UL* and Down-Link (*DL*) channels of the mentioned bands for the geographical region 4 [3]. Port 3 of each *MTM* Directional Filter is grounded using a 50 Ω load.

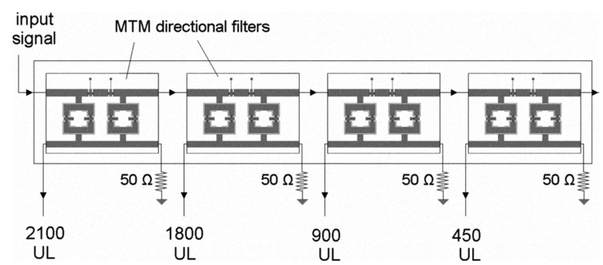

Figure 7. Proposed multiplexing network.

Table 1. Wireless Communication frequency bands [3].

	Up-link (MHz)		Down-link (MHz)	
B3G 450	452.5	457.475	462.5	467.475
GSM 900	880	915	925	960
GSM 1800	1710	1785	1805	1880
W-CDMA 2100	1920	1980	2110	2170

The proposed Front-End for the 450 MHz, 900 MHz, 1800 MHz and 2100 MHz frequency bands is shown in Figure 8. A common wideband antenna is used for transmission and reception. The *UL* channels are processed in a second stage with high-performance filters in order to improve selectivity (in our case we used a six pole Chebyshev filter). Due to the harmonic pre-filtering by the *MTM* multiplexer, conventional filters can be used. The *UL* channels are combined using a power splitter, which is connected to a Wideband Low-Noise Amplifier (*W-LNA*) [2] with gain G = 12 dB. Two microwave circulators are used to guide the *UL* signals down to the *BS*, and to pass the *DL* signals through to the multiplexer. The *UL* and *DL* signals share a single common coaxial cable between the Front-End and the *BS*.

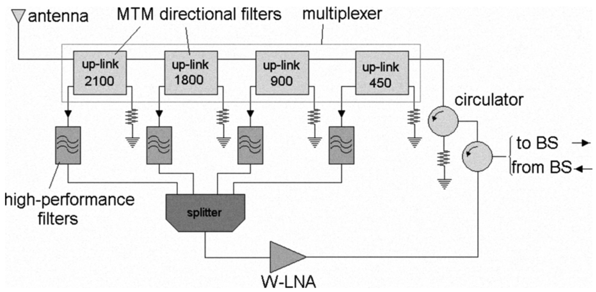

Figure 8. Proposed Front-End using *MTM* directional filters for multiplexing.

Figure 9 shows the simulated response of the multi-band (2G, 3G & B3G) Front-End using [8]. As it can be seen, the signals are well split without disturbance of higher harmonics.

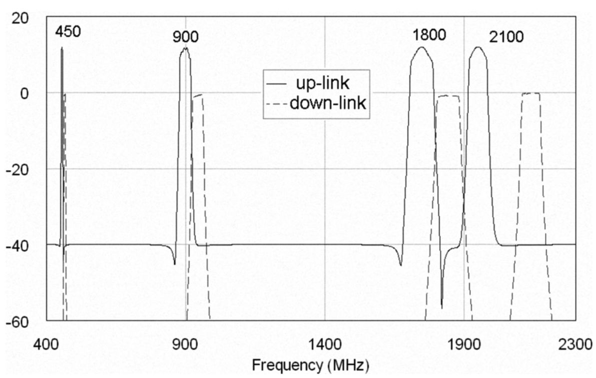

Figure 9. Simulated response of the full multiplexer for 2G, 3G and B3G bands.

4. Conclusions

A novel channelization multiplexer using *MTM* directional filters for Front-Ends was presented. This subsystem combines the B3G 450, GSM 900, GSM 1800 and W-CDMA 2100 frequency bands. The use of *MTM* Directional Filters allows suppression of harmonic bands without the use of additional *HP* or *LP* filters. The proposed Front-End offers a simple configuration and is highly miniaturized.

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