A New RF Interference Cancellation using A Novel 3-Pole Bandstop Resonator designed using Tapped CRLH T-Line Model

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***Abstract*—Wideband interference signals appearing at 20 MHz, 15 MHz and even 10 MHz away from the edge of the mobile received signal can now be suppressed by more than 30 dB by following the new RF interference cancellation technique introduced in this paper using bandstop resonators. Furthermore, a new methodology for designing a 3-pole bandstop resonator with very sharp rejection is presented. The resonators are implemented using a power splitter and different number of cells from the composite right/left handed transmission (CRLH-T) line circuit model. Two resonators are fabricated and measured: using two cells; and three cells, showing an insertion loss of less than 1.2 dB. An interference cancellation test bench is set using two 9 MHz LTE modulated signals with equal average peak power (40 dBm). The power spectrum measurements show more than 30 dB cancellation for the interferer injected at 20 MHz separation from the desired signal using the two-cell resonator. More than 45 dB and 30 dB cancellation are also achieved for interferers with only 15 MHz and 10 MHz frequency separation using the three-cell resonator. The tests are repeated with high power interferers (e.g. 20 dB above the received signal level) and the same cancellation performance is maintained without retuning any of the components used.**

***Index Terms*—interference cancellation, right/left handed transmission line, bandstop resonator**

I. Introduction

The unique properties of metamaterials and in particular composite right left handed transmission (CRLH-T) lines are offering many new solutions serving modern wireless communication systems. Over the past few years, many novel microwave devices were developed using CRLH-T lines. Examples include: Wideband tunable phase shifters for distortion cancellation in power amplifiers [1]; compact antennas; filters; and tunable large delay lines [2].

This paper is introducing a new design for a bandstop resonator targeting the interference issues in the upper 700 MHz LTE band. A common example for interference signals at these frequencies is the Digital TV broadcasting and public safety signals (Trans-European Trunk-ed Radio, TETRA) which can appear at a frequency separation of less than 20 MHz away from the received mobile signal. Moreover, they can reach the receiver with high power levels causing severe impairments to its components.

In Section II, the block diagram of the proposed interference cancellation technique is presented together with the design requirements for the stopband resonator. In Section III, the design methodology of the new sharp bandstop resonator is presented and discussed. Starting with the basic equivalent circuit model and followed by an analysis on the applied circuit simulations. In Section IV, the microstrip implementation and measurements for the fabricated microstrip resonator are also presented and discussed. In Section V, a test bench is set to experimentally evaluate the performance of the new solution proposed for suppressing interference signals at 20 MHz, 15 MHz and 10 MHz away from the receiver edge with different power levels.

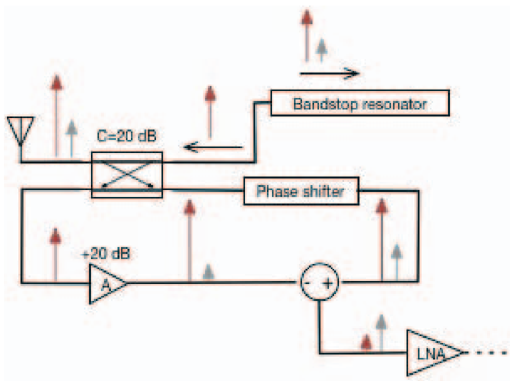

Fig. 1. The block diagram for the setup proposed for RF interference cancellation using bandstop resonators.

II. System Overview

Fig. 1 shows the block diagram proposed in this paper to suppress the interference signals. The bandstop resonator is used to separate the close interferer from the desired received signal. This can be done by reflecting one of the two signals and shorting the other to ground. In the diagram, the interference signal is reflected back from the stopband resonator, injected back to the bi-directional coupler, then amplified and subtracted from the total received signal. Given that the interferer can appear at a frequency separation of less than 20 MHz away from the receiver edge, it is required to design a very sharp bandstop resonator with high roll off in order to separate the two signals. Moreover, to successfully eliminate the interferer while keeping the distortion levels for the received signal at minimum, the stop band must be wide

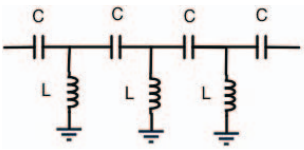

Fig. 2. The equivalent circuit model of an LH transmission line using three cells (three inductors).

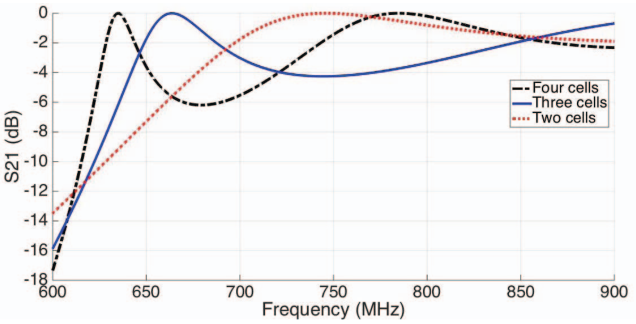

Fig. 3. Circuit simulations for the circuit model of LH-T line constructed using two cells, three cells and four cells.

enough to cover the total bandwidth of the desired signal and a minimum rejection of 20 dB is also required.

III. Circuit Design and Simulation

Several studies were conducted for analyzing the behavior of EM propagation in LH-T lines, defining the Bragg cutoff frequency of the line as a function of the equivalent series capacitance and shunt inductance in a unit cell used to construct the line circuit model as given in Eqn. 1. However, the cutoff frequency is still not only a function of L and C, as it also varies depending on the number of cells used to model the LH-T line. By applying circuit simulation on three LH-T lines modeled using different number of cells: two cells; three cells (Fig. 2); and four cells, this variation can be noticed as shown in Fig. 3.

$$f_{Bragg} = \frac{1}{4\pi\sqrt{LC}} \tag{1}$$

Furthermore, it is known that the EM wave experiences an anti-parallel phase and group velocities at the Bragg cutoff which allows it to convey energy leading to a significant rise in the group delay [3]. Fig. 4 shows the simulated group delays for the same three circuits, where they are all terminated by a short circuit at one end. It again demonstrates how the position of the peaks changes as a result of the shifts in the cutoff frequency of the lines. In this work, this variation has become advantageous as it is used to successfully design a stopband resonator with three poles, which is explained in details as follows.

Starting with Fig. 5, which shows the equivalent circuit model of the new stopband resonator proposed in this paper. It consists of a wilkinson RF power splitter/combiner whose output ports are connected to two pure left handed transmission (LH-T) lines with different number of cells. The first line is

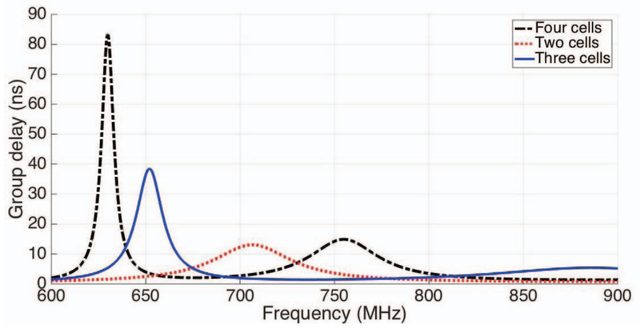

Fig. 4. The simulated group delay of the reflection coefficient for the circuit model of pure LH-T lines constructed using different number of cells, given that each circuit is terminated by a short circuit at one end.

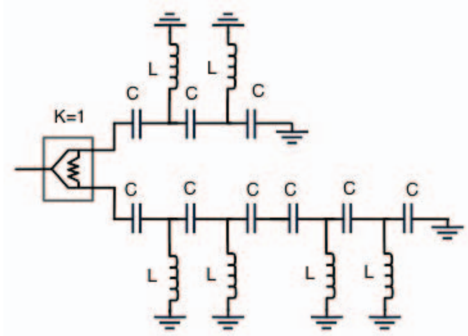

Fig. 5. The equivalent circuit model of the new stop band resonator constructed using two cells and their duplicates. All capacitors (C) are 3.0 pF, while inductors (L) are 5.95 nH.

composed of two cells; three capacitors and two inductors. The second line always duplicates the number of lumped elements in the first one. Each of the two is terminated by a short circuit. The input RF signal is now divided between the two chains where it encounters different group delay as well as different phase shift. The signal is then reflected at the short circuit termination and recombined back at the input. Ideally, the signal is perfectly reconstructed with zero insertion loss at the wilkinson combiner as long as the two inputs are in phase. As the phase difference increases, the insertion loss increases reaching infinity where a notch is created. This explains the role of the two LH-T lines which are designed such that the two signals are in phase through the whole frequency band of the interferer and out of phase in the full band of the desired signal. As the frequency separation between an interfering signal injected at f_1 and a desired received signal at f_2 decreases, larger group delay is required between the two LH-T lines to alternate the phase from 0^o at f_1 to 180^o at f_2. For example, a 20 MHz frequency separation requires more than 25 ns of group delay given that the signal is traveling though the lines and back. In fact a large variation is the group delay is always required to alternate the phase by 180^o over a narrow frequency band. And this is why the position of each of the three poles in the stopband can be identified as follows: the frequency at the peak group delay of the first line

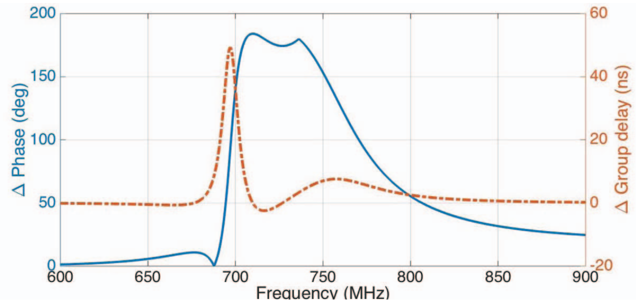

Fig. 6. The simulated phase and group delay difference between the two short terminated branches/ outputs of the power combiner of the resonator model in Fig. 5.

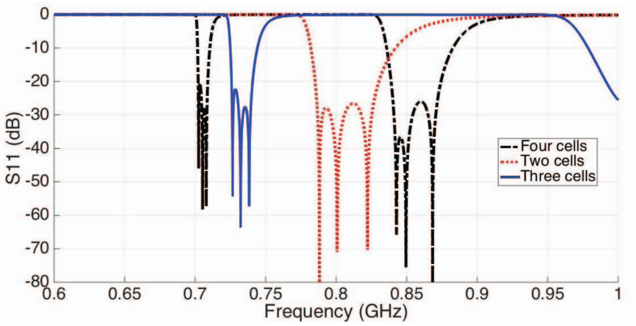

Fig. 7. Simulations for the magnitude of the reflection coefficient at the input of the new bandstop resonators constructed using different number of cells.

constructed with two cells; the frequency at the peak delay of the second line with more number of cells; and the frequency at the peak of the group delay difference between the two lines. The number of elements in the second line must be equal to twice that in the first line in order to keep the two reflected signals out of phase over the stop band region.

Fig. 6 shows the phase and group delay difference between the two cell in the first output of the power divider and their duplicate. It shows how a phase difference of approximately 180^o is maintained over the stop band region. Now, three resonators are constructed with different number of cells in the first line/ output of the power splitter and Fig. 7 shows the simulated s-parameters which illustrates how the position of the three poles changes with the number of cells. As the number of cells increases, the group delay difference between the two paths increase improving the quality factor of the resonator where a very sharp rejection can be achieved. On the other hand, the bandwidth of the three poles reduces as the number of cells is increased. This is because the cutoff frequency of each of the two lines start to converge back to the theoretical Bragg cutoff. Another advantage for using this new technique is the tuning capability, which can be obtained only by varying either of the series capacitance or shunt inductance of the circuit.

IV. Microstrip Implementation and Measurements

It is known that the implementation of a pure LH-T line circuit is not practical since they require extra sections of right hand transmission lines to connect the series capacitors and shunt inductors. These extra sections create what is known as composite right left hand (CRLH-T) lines. They introduce extra parasitic capacitances and inductances whose effect can be reduced by increasing both the series capacitance and shunt inductance of the line. To facilitate the fabrication process, all lumped inductors are replaced by $50\,\Omega$ microstrip short circuited stubs. Standard FR4 substrate is used with a thickness of 1.6 mm. Fig.8-a shows a picture of the fabricated new microstrip bandstop resonator with two cells in the first line. The measured results in Fig. 10 agrees with the circuit simulation showing three poles with more than 20 dB rejection and less than 1.2 dB insertion loss at 20 MHz away from the rejection band.

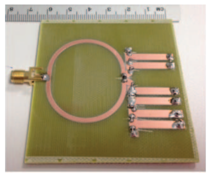

Fig. 8. The fabricated new microstrip bandstop resonator with two stubs in the first LH-T line (50 mm x 60 mm).

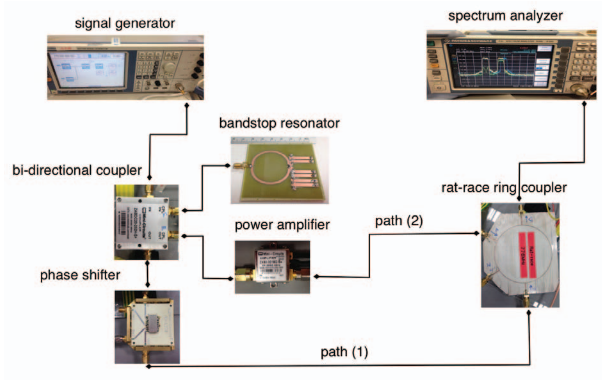

Fig. 9. The components used to build the interference cancellation test bench with the new bandstop resonators.

V. Test Results

Fig. 9 shows the setup used for testing the cancellation performance using the new bandstop resonator. Where the phase of path (1) and path (2) are matched at 680 MHz as shown in Fig. 10. Two LTE modulated signals are generated to represent both the desired received signal and the interferer. Each of the two signals occupy a bandwidth of 9 MHz. For the first case, the center frequency of the interferer is set to be located at 20 MHz away from the edge of the desired signal, and the two signals are injected with equal average peak power ($\simeq$40 dBm). Fig. 11 shows the measured power spectrum at the output of the antenna (before cancellation) together with that at the input of the LNA (after cancellation) where more than 30 dB cancellation is successfully achieved at the center of the interferer. For case II, the interferer is set to occupy higher power (>20 dB) compared to the desired signal and the

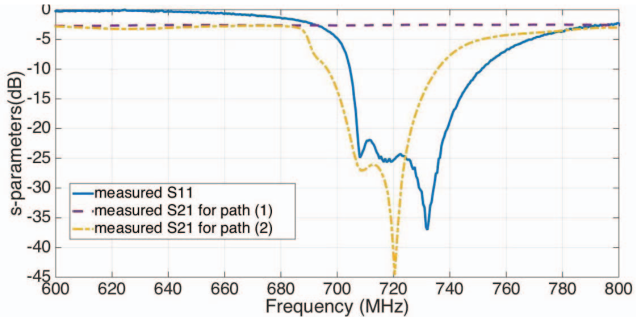

Fig. 10. The measured input reflection coefficient of the new bandstop resonator together with the transmission coefficient between the input of the 20 dB coupler and the two inputs of the rat-race ring coupler: path (1); and path (2).

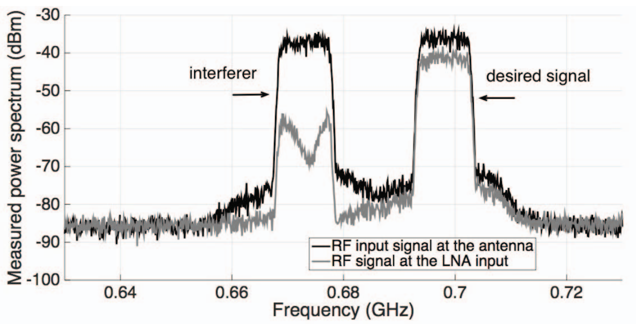

Fig. 11. Case 1 power spectrum measurements for the two signals before and after interference cancellation.

measurements are repeated with the same phase state as shown in Fig. 12, which indicates no degradation in the cancellation performance. Thus such a cancellation technique can handle interferers with any amplitude and retuning is not required.

For case III and IV, the separation between the two signals is reduced down to 15 MHz, followed by 10 MHz. This time a new resonator is designed and fabricated with more number of cells as shown in Fig. 13. Power spectrum measurements of these two cases are shown in Fig. 14 where 45 dB and 30 dB cancellation are achieved for the interferer with 15 MHz and 10 MHz separation, respectively. For the four cases, the desired signal is attenuated by approximately 3 dB. Given that the

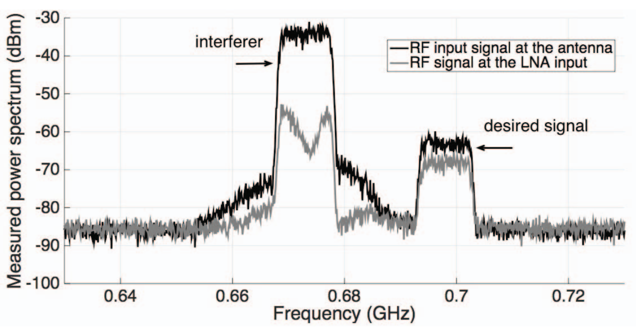

Fig. 12. Case 2 power spectrum measurements for the two signals before and after interference cancellation.

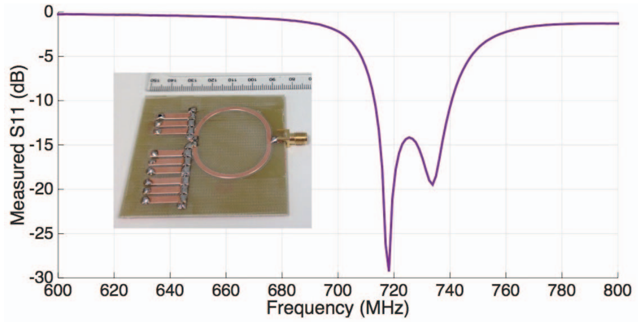

Fig. 13. The measured reflection coefficient for the fabricated bandstop resonator with three stubs for very close interfering signals (60 mm x 65 mm).

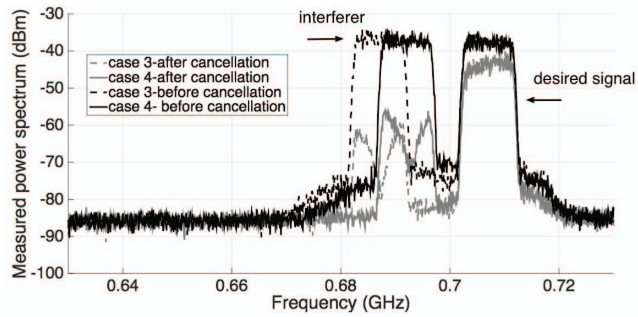

Fig. 14. Case 3 and case 4 power spectrum measurements for the two signals before and after interference cancellation.

insertion loss of the resonator is less than 1.2 dB, these extra losses can be further reduced by replacing the 20 dB coupler used in this experiment, which was optimized for frequencies above 800 MHz. As this coupler has added more than 1.5 dB losses to the two signal paths as noticed in Fig. 10.

VI. Conclusion

This paper presents a new passive interference cancellation technique using a new band stop resonator which is designed, fabricated and successfully tested to attenuate interferers at 20, 15 and 10 MHz offset by more than 30 dB.

Acknowledgment

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