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Coplanar and Proximity Radio Frequency Noise and Interference Rejection Using Transmission-Line Met material Devices

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***Abstract*— with the advent of modern telecommunication systems with several devices integrated on the same circuit board, the noise and interference related issues have become more critical than ever. In recent years, metamaterials have been utilized in different ways to mitigate the coplanar noise and unwanted signal interference. This paper investigates suppression of harmonic and coplanar interference in circuit boards that utilize metamaterial devices. It has been shown in a simulation study that by using metamaterial based devices, the noise and harmonic effects can be significantly reduced. This leads to signal propagation with lesser mutual interference and cleaner pulse propagation.**

***Index Terms*—Noise and Interference suppression, mutual coupling, metamaterials, maximally flat filter, rat-race coupler.**

I. INTRODUCTION

With the advent of modern communication gadgets such as smart phones and tablets, multi device integration has become an inevitable necessity. Several communication systems that occupy a wide frequency spectrum share the same circuit board and back plane. In such a wideband noisy environment which includes devices such as mobile phone, GPS, and Wifi antennas in close proximity, the radio frequency (RF) designer has to deal with issues such as harmonic interference, co- and adjacent channel noise, and higher order radiations. In recent years, metamaterial based devices and backplane designs have been effectively applied in noisy RF environments [1-7]. The metamaterial based circuit boards and substrates [1,3,4] are very effective in the noise and interference reduction. But for large backplanes, this method is expensive. The unwanted noise and radiation can also be mitigated by employing metamaterial unit cells at selective locations on the circuit board [2,7]. In such cases, the unwanted signals are blocked in a certain direction only. Another effective approach is utilizing metamaterial based devices which are designed to eliminate the frequency-selective noise and interference by exploiting the inherent dispersive properties of metamaterials [5,6]. The unwanted signals in such devices are eliminated by employing components that demonstrate band-pass characteristics. Hence they effectively absorb the interfering signals so that they are blocked in all directions. Moreover, since the metamaterial cells are applied to the device only, the existing circuit boards can still be employed, thus making the method economical.

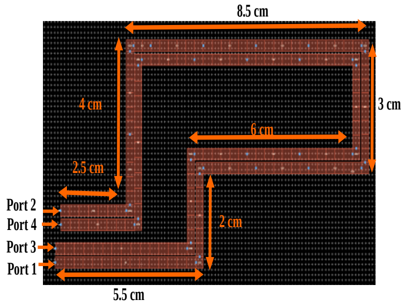

Fig 1. Schematic diagram of the two adjacent signal traces that are separated by a 100 □ m distance, as simulated in the Agilent Momentum.

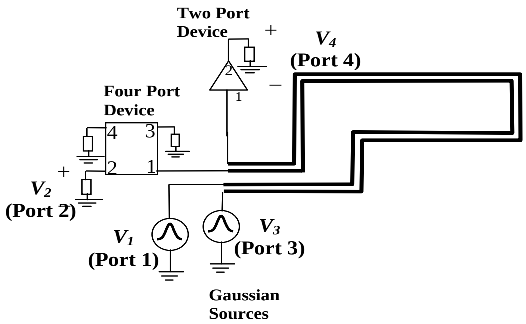

Fig 2. Coplanar four port and two port devices connected to adjacent signal traces

To demonstrate the interference and noise reduction in the coplanar circuit applications using metamaterials, a numerical study is performed by employing two microwave devices on adjacent signal traces. The schematic diagram of the two traces which are separated by 100μm is shown in Fig. 1. The four port trace is first simulated in the electromagnetic full-wave design package Agilent Momentum and then the S-parameters are imported in Agilent ADS for a co-simulation. A four port dual-band device and a two port single board device are connected to the two signal traces to investigate the interference in the 2.5 GHz band. The two devices are connected according to the schematics given in Fig. 2. The input ports are excited by spectrum-limited modulated Gaussian signals. The outline of this paper is as follows. Section II presents the design of the two port device

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which is a 2.5 GHz maximally-flat bandpass filter. In Section III, the four-port device which is a 0.75 GHz rat-race coupler is designed by using traditional and metamaterial microwave elements. To show the noise and interference mitigation using metamaterial devices, the two four-port devices re sequentially connected to the port 4 of the signal trace (as shown in Fig 2). The frequency domain results of this configuration are presented in Section IV. In Section V, it is shown that by time-domain simulations that the metamaterial based device not only suppresses the signal in unwanted band, it also guarantees cleaner propagation with reduced inter-symbol interference.

II. THE TWO PORT DEAVICE DESIGN AND S-PARAMATERS

A five stage maximally flat band pass filter centered at approximately 2.5 GHz with a 10% bandwidth is designed by applying the standard filter design procedures [8]. The inductive and capacitive component value for the nth series stage, which replaces the series low-pass inductor, is given by:

Table 1: Maximally Flat Filter Design

Stage (n)	g_n (Low-pass Prototype)	Band-pass transformations
1	0.618	L_1 = 12.3nH, C_1 = 0.3pF
2	1.618	L_2 = 0.3nH, C_2= 12.9pF
3	2.00	L_3 = 39.8nH, C_3= 0.09pF
4	1.618	L_4 = 0.3nH, C_4= 12.9pF
5	0.618	L_5 = 12.3nH, C_5 = 0.3pF

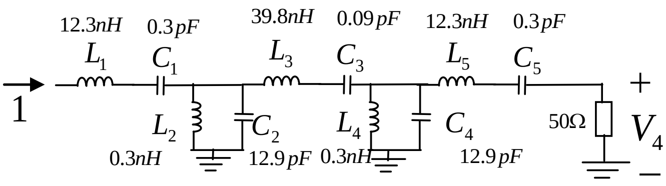


Fig. 3. Schematic diagram of a Maximally-flat five stage band pass filter

$$L_n = \frac{Z_o g_n}{\Delta \omega_c} \quad (1)$$

$$C_n = \frac{\Delta}{Z_o \omega_c g_n} \quad (2)$$

Where Δ is the percentage, ω_c is the center frequency, and Z_o is the system impedance. Bandwidth On the other hand, LC values for the nth shunt (low-pass capacitive) stage are obtained by the following transformations:

$$L_n = \frac{Z_o \Delta}{\omega_c g_n} \quad (3)$$

$$C_n = \frac{g_n}{Z_o \omega_c \Delta} \quad (4)$$

Table 1 provides the unit element values and the scaled lumped element values after the low pass to band pass transformations. The final filter prototype is given in Fig. 3. The transmission characteristics, plotted in Fig. 4, show desired 10% pass band centered at 2.5 GHz.

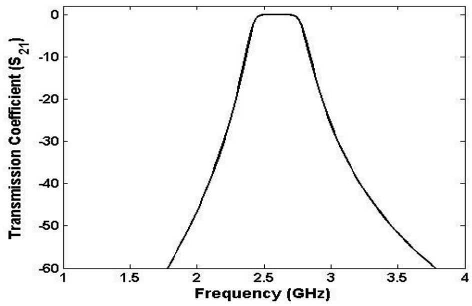


Fig. 4. The transmission characteristics of the maximally flat bandpass filter centered at 2.5 GHz

III. THE FOUR PORT DEVICE DESIGN AND S-PARAMETERS

The traditional coupler (Fig. 5a) consists of six transmission line segments, each having an electrical length of 90o at the design frequency (assumed to be 0.75 GHz in this paper). In the metamaterial coupler (Fig. 5b), the transmission line segments are replaced by four left-handed unit cells with a Bloch phase shift of 22.5o each. As shown in Fig. 6, the unit cell consists of transmission line segments loaded with series and shunt impedances given by:

$$Z_s = \frac{1}{j\omega C_s}$$

(5)

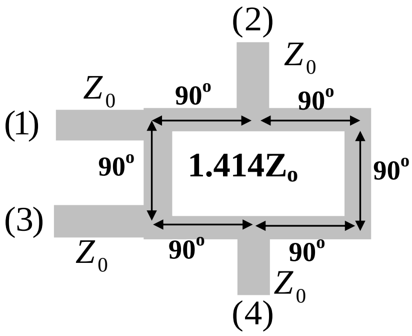
$$Z_{sh} = j\omega L_{sh} + \frac{1}{j\omega C_{sh}} \quad (6)$$

The design procedure is discussed in an earlier publications [5,6]. The final unit cell component values are provided in Table 2.

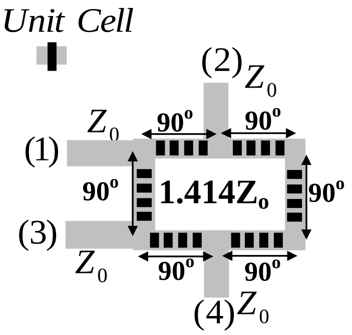
Table 2: Metamaterial Unit Cell Design

d	4.6mm
Z_d	29.4Ω
C_s	28.4pF
C_{sh}	0.5 pF
L_{sh}	20.4nH

The rat-race can be operated in many ways but here equal power split in-phase response is considered. In this application, the input power that is fed at port (1) splits into half at ports 2 and 3 with an equal phase of 90^o. The transmission coefficients (S_{21}) for the two couplers are determined by the Microwave circuit simulator Agilent's ADS and the plot is shown in Fig. 7. The 3dB transmission responses at the design frequency of 0.75 GHz for both plots indicate the equal power split. However, additional 3dB mode is obtained for the traditional coupler at three times the design frequency i.e. 2.25 GHz because of the inherent periodic response of a transmission line. The metamaterial unit cell blocks the higher harmonics on accounts of its dispersion properties. The higher order mode is suppressed by almost 15 dB by the metamaterial coupler.



(a) Traditional coupler



(b) Metamaterial Coupler

Fig. 5. The schematic diagram of (a) a traditional rate-race coupler and (b) its implementation using metamaterial unit cells of Fig 6.

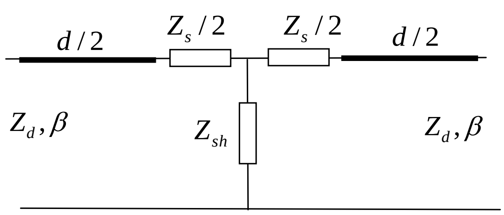


Fig. 6. The metamaterial unit cell used to implement the rate-race coupler. The design has been performed in [6]

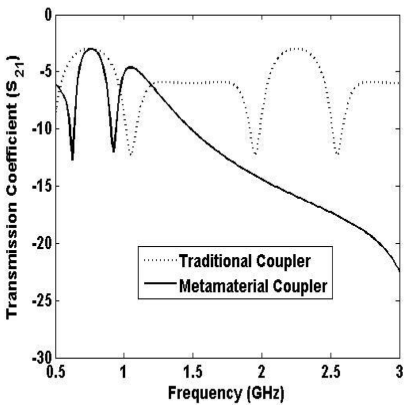


Fig. 7. The transmission response of the traditional and metamaterial couplers when the input is provided at port 1 and output is determined at port 2. The same response is observed at port 3.

IV. THE S-PARAMETER FREQUENCY DOMAIN SIMULATIONS ON THE CO-PLANAR SIGNAL TRACES

To compare the behavior of the two couplers in the co-planar environment, they are connected sequentially at the output of one of the signal traces of Fig. 2, while the maximally flat filter is connected to the adjacent trace. The transmission coefficient S_{21} corresponds to the power transferred to the output port 2 of the coupler and S_{34} is the power transferred to output of the filter. With the traditional coupler in the circuit, the two transmission coefficients are depicted in Fig. 8. The mutual interference due to the second harmonic leakage at 2.5 GHz causes obvious signal deterioration at the center of the filter's pass band. When the traditional coupler is replaced by the metamatarial coupler, the second harmonic of the coupler is well suppressed, as depicted in Fig. 9. Consequently, the pass band filter characteristics are much improved. Hence placing the metamaterial components in the circuit serves two purposes in this application. It suppresses the second harmonic which can be used for other applications. Moreover, it reduces the co-planar interference which can otherwise cause severe signal degradation.

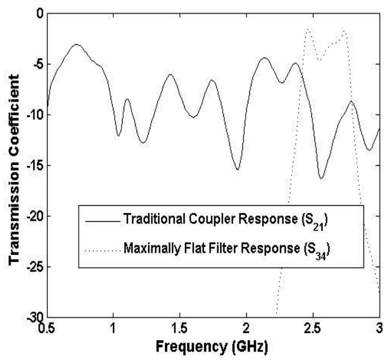


Fig. 8. The transmission response of a traditional coupler and a maximally flat filter when connected in a coplanar circuit environment to adjacent signal traces.

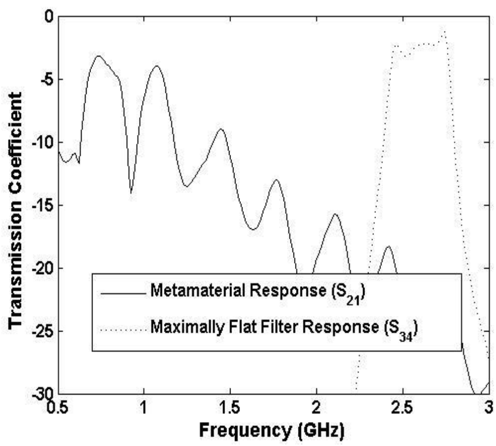


Fig. 9. The transmission response of a metamaterial coupler and a maximally flat filter when connected in a coplanar circuit environment to adjacent signal traces.

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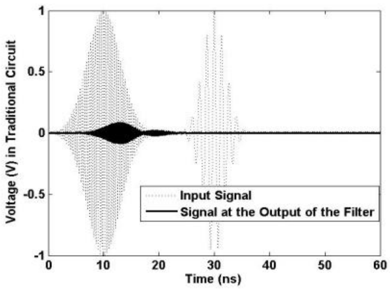
V. TIME-DOMAIN GAUSSIAN PULSE SIMULATIONS ON THE CO-PLANAR SIGNAL TRACES

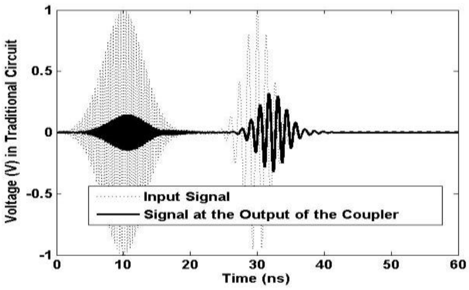
Consider the schematic diagram given in Fig. 2. The adjacent signal traces are excited by the Gaussian pulses modulated at 0.75 GHz and 2.5 GHz, given by the following equation:

$$v_1(t) = v_3(t) = e^{-\frac{(t-t_1)^2}{2\sigma_1^2}} \cos(2\pi f_1 t) + e^{-\frac{(t-t_2)^2}{2\sigma_2^2}} \cos(2\pi f_2 t) \quad (7)$$

Where σ_1 and σ_2 are the standard deviations of the Gaussian pulses that are modulated on f1 = 2.5GHz and f2 = 0.75 GHz respectively. Here σ_1 and σ_2 are assumed to be 1ns and 3ns respectively. The times t1 and t2 are the delays in the 2.5 GHz and 0.75 GHz pulses and are given by 10 and 30 ns respectively. First consider the case when a traditional coupler is connected to the port 2. The Gaussian pulses that appear at the output of the coupler and filter are depicted in Fig. 10. Since the Maximally flat bandpass filter does not let the 0.75 GHz pulse pass through it, only the higher frequency pulse appears at its output. At the coupler's output, on the other hand, both pulses appear. Note that the harmonic interference from the coupler affects the signal at the filter's output which results in the signal deterioration. Consequently, this can also cause inter-symbol interference if multiple pulses are transmitted.



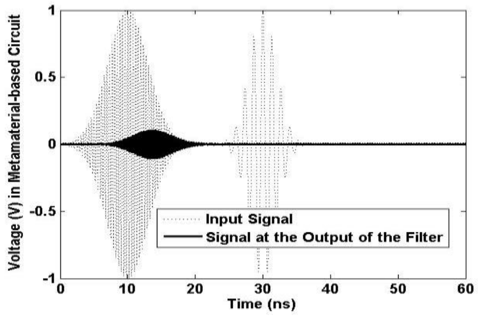
(a) Filter Output



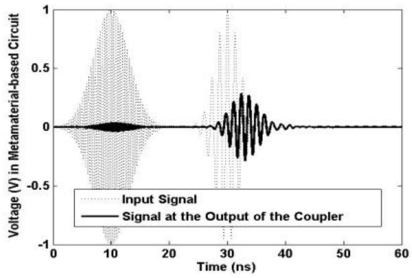
(b) Traditional Coupler Output

Fig. 10. The 2.5 and 0.75 GHz Gaussian pulses as they appear at the output of (a) the traditional coupler and (b) the maximally flat filter centered at 0.75 GHz. at the filter's output, single deterioration is visible

When the traditional coupler is replaced by the metamaterial coupler, the mutual interference is suppressed at the output of the filter, as depicted in Fig. 11a. Hence the output Gaussian pulse is much cleaner and no inter-symbol interference can result. This is due to the ability of the metamaterial coupler to effectively suppress the higher frequency modes as depicted in Fig. 11b.



(a) Filter Output



(b) Metamaterial Coupler Output

Fig. 11. The 2.5 and 0.75 GHz Gaussian pulses as they appear at the output of (a) the metamaterial coupler and (b) the maximally flat filter centered at 0.75 GHz. The output pulse at the filter's output is much cleaner. The second harmonic at the output of the coupler is suppressed.

VI. CONCLUSION

Metamaterial microwave components can be employed to significantly reduce mutual interference and noise in printed circuit boards with multiple devices. In this paper, behaviors of traditional and metamaterial microwave components in a coplanar noisy printed circuit environment have been compared via full-wave numerical simulations. The metamaterial devices have been shown to demonstrate excellent noise and interference suppression compared to their traditional counterparts. In particular, the signal propagation at 0.75 and 2.5 GHz is shown to take place with much reduced harmonic and inter-symbol interferences.

REFERENCES

[1] H.-M. Lee and H.-S. Lee, "A dual band absorber based with resonant-magnetic structures," Progress In Electromagnetic Research Letters, Vol. 33, pp. 1-12, 2012

[2] A. Ruaro, J. Thaysen, and K. Jakobsen, "Mitigation of Unwanted Forward Narrow-band Radiation from PCBs with a Metamaterial Unit Cell," in Proc. of European Microwave Conference (EuMC), pp. 939-942, Oct. 2013.

[3] A. I. Gila and R. Fernández-Garcíaa, "Electromagnetic interference reduction in printed circuit boards by using metamaterials: a conduction and radiation impact analysis,"

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ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 10, April 2015
Journal of Electromagnetic Waves and Applications, vol. 28, pp. 378-388, 2014.

[4] S. Shahparnia, O. Ramahi, "Electromagnetic Interference (EMI) Reduction from Printed Circuit Boards (PCB) Using Electromagnetic Bandgap Structures," IEEE Transactions on Electromagnetic Compatibility, Vol. 46, Issue 4, pp. 580-587, Nov, 2004.

[5] O. Siddiqui, O., A. Mohra, "A Harmonic-Suppressed Micro strip Antenna Using a Metamaterial-Inspired Compact Shunt-Capacitor Loaded Feed line", Progress In Electromagnetic Research C, vol. 5, pp. 151 – 162, 2013

[6] O. Siddiqui, "Numerical Investigation of Phase and Group Propagation of Time-Domain Signals in a Novel Band-Reject Metamaterial Ring Hybrid", accepted for publication in Journal of Computer and Communications, April 2015

[7] M. Bait-Suwailam, O. Siddiqui and O. M. Ramahi, "Mutual Coupling Reduction between Micro strip Patch Antennas using Slotted Complementary Split-Ring Resonators," IEEE Antennas and Wireless Propagation Letters, Vol. 9, pp. 876 – 878, 2010

[8] D. Pozar, Microwave Engineering. 3rd Edition, John Wiley & Sons, pp. 352-357.

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Omar Siddiqui graduated with PhD from University of Toronto in 2006. He has worked as Radio Frequency Design Engineer in various Telecommunication Companies worldwide. Currently, Dr Siddiqui is associated with College of Engineering at Taibah University in Madinah, Saudi Arabia. He has several publications and on going research projects in the fields of Microwave Engineering and Electromagnetic.