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Compact Highly Selective Passive Notch filter for 3.1-5 GHz UWB Receiver System

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Abstract—This paper deals with the design of highly selective passive notch filter working at 2.4 GHz for 3.1-5 GHz UWB receiver system. The proposed filter aims to enable IEEE 802.11 b/g and UWB standard coexistence in the same terminal device. The filter topology is composed of two paths: the first path contains an all-pass function while the second path contains a band-pass one. By this way, the signal is divided at the circuit input and is combined at its output forming a notch response that exhibits a high rejection at the center frequency of the band-pass filter function. Experimental prototype implemented on Rogers4003 multilayer substrate is built in order to show the benefit of this concept design.

Keywords—Notch filter, high rejection, division and combination signal techniques, coexistence problem, IEEE 802.11 b/g, UWB receiver system.

I. INTRODUCTION

Ultra Wideband (UWB) communication is an emerging wireless technology suitable for short-range applications (< 10m). This Radio Frequency communication technique uses the approved unlicensed frequency band from 3.1 GHz to 10.6 GHz to emit its signals [1]. An UWB signal is characterized by its very low power level and its wide frequency bandwidth that allows it to offer very high speed data. The maximum power level of these signals is imposed by the Federal Communications Commission (FCC) depending on where these signals are used, e.g. indoor or outdoor [1], [2]. On the other hand, IEEE 802.11b/g WLAN (Wireless Local Area Network) is a popular standard suitable for long range application used to connect wireless devices in a local area space such as home, coffee shop, library, etc... The operating frequency of this standard is 2.4 GHz which is relatively close to the UWB frequency band.

With the increasing demand for multi-standard devices, many wireless technologies are implemented in the same terminal as depicted in Fig. 1. The coexistence of these technologies leads to interference issues due to the proximity of the concerned radio frequency bands and the high emission power level emitted by the jammer and received by the victim. As for instance, the output signal power of IEEE 802.11 b/g is high (about +24 dBm) in comparison to the UWB receiver

sensitivity [3]. Moreover, as the IEEE 802.11 b/g emitter and the UWB receiver are both integrated in the same device terminal, the free-space loss attenuation is weak. Thus, the UWB receiver antenna collects the unwanted signal with a relatively high power level that depends on the decoupling ability of the antennas. The power level of this undesirable signal exceeds the linearity limit of the low-noise amplifier and can be out of the dynamic range of the Analog to Digital Conversion (ADC) and thus degrades the quality of the digitalized baseband signal. To overcome this issue, it's necessary that the multi-standard device includes a highly selective notch filter solution to relax the receiver linearity requirement and improve the quality of the digitalized receiver signal. The highly selective notch filter should be placed next to the antenna to cancel the interferer signal while having a compact size for optimal integration and cost. Another important parameter from the system point of view is the insertion loss in the passband of the filter. Indeed, as the filter is the first element of the receiver chain, its insertion loss has a direct impact on the equivalent noise figure of the receiver chain. Thus, the proposed filtering solution should be attractive from all the point of views cited above.



Fig. 1. Example of a Multi-standard handheld terminal device.

In this paper, the UWB receiver is considered as a victim and the IEEE 802.11 b/g as a jammer. So, to ensure their coexistence, a highly selective passive filtering solution is proposed. The filter topology is composed of two paths, the first path contains an all-pass function while the second path contains a band-pass one. The filter shows high rejection at the

center frequency while featuring very low insertion losses in the filter passband. The prototype is fully simulated, fabricated and measured and the obtained results show the benefit of this proof-of-concept design. The filter concept is suitable to be implemented in a UWB receiver system that uses the 3.1-5GHz sub-band.

This paper is organized as follows: Section II presents the filter concept. An example of this filter is then presented in section III. The measurement results are compared to the simulation ones and presented in section IV.

II. HIGHLY SELECTIVE PASSIVE TWO-PATHS FILTER CONCEPT

A simple and known approach to design a notch filter is based on the theory of the coupled lines. Indeed, by coupling a half-wavelength line or a grounded quarter-wavelength one to a main transmission line, a notch filter response occurs [4]. Although this approach is simple, it suffers from a major drawback which is related to its rejection capability. Indeed, the relatively high losses of the used substrate degrade drastically the notch filter rejection. For instance, the rejection depth of a notch filter using this approach at 700 MHz implemented on FR4 substrate, do not exceed 3 dB at the center frequency. This low rejection is obviously not sufficient to protect a disturbed system when a physically close jammer with relatively high power is emitting. To overcome this problem, some active components, e.g. active capacitor, negative resistor circuits could be used to compensate for the losses of the passive filters [5], [6]. Although the technique of associating the active components to the passive filters is very useful and allows the filter losses to be compensated, it suffers from linearity problems associated with transistors. In [7], [8], pre-distortion techniques can be used to improve significantly the notch filter rejection. However, this improvement is obtained at the expense of increasing the passband insertion loss.

The notch filter design considered in this paper is presented in Fig. 2. It is constituted on two paths: path n°1 contains an all-pass network which in this case is a transmission line and path n°2 that contains a band-pass network designed at center frequency f_0 . Assuming a lossless all-pass network (path n°1), if a frequency sweep signal is applied at the input of the notch filter design, the output signal is equal to the input one. This behavior is true until the frequency of the input signal is equal to the center frequency f_0 of the band-pass filter network (path n°2). Indeed, far from the center frequency of the band-pass network, all the power injected at the input is directly coupled to the output port. However, at the center frequency f_0 of the band-pass network, the power is divided between two paths and is combined at the output port as shown in Fig. 2. If one assumes that the signals derived from the both paths are combined at the output with the same amplitudes ($A_1 = A_2$ in Fig. 2) but with a phase difference of 180° (corresponding to the term βx in Fig. 2, where β is the phase constant and x is the physical length of the line in path n°1), the signal is canceled at f_0 . The obtained filter is then a notch filter that resonates at the band-pass (path n°2) resonance frequency.

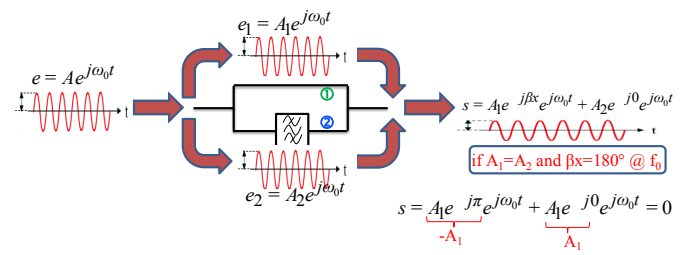


Fig. 2. Time-Domain behavior at the center frequency of the highly selective passive notch filter.

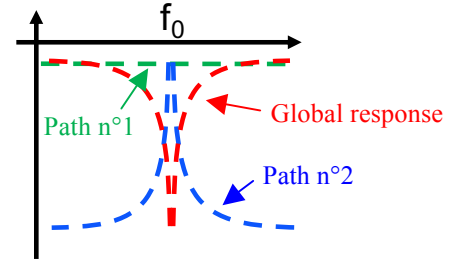


Fig. 3. Frequency behavior of the highly selective passive notch filter.

III. DESIGN EXEMPLE OF A 2.4 GHZ FOR 3.1-5 GHZ UWB SYSTEM

In this section, the design of a highly selective passive notch filter using the previous concept is presented. The filter aims to reject the IEEE 802.11 b/g signals that are received at the input of UWB receiver. The band-pass filter (path n°2) must have a center frequency of 2.4 GHz with a fractional bandwidth (FBW) of 8.3% ($F_{3dB} = F_c \pm 100$ MHz). Moreover, a minimum attenuation of 15 dB is required in order to release constraint on the dynamic performance of the UWB receiver chain.

As the bandwidth of the highly selective notch filter is narrow, the bandwidth of the band-pass network (path n°2 in Fig. 2) should be narrow too. The degree of low-pass prototype is then chosen to be the lowest one namely 1. The prototype element values for 1st order Butterworth low-pass filter are given as follows: $g_0 = g_1 = 1$ and $g_2 = 2$.

The band-pass filter network is designed using a parallel coupled microstrip half-wavelength lines. The impedance inverter parameters are then determined to be: $J_{01} = J_{02} = 0.0051$. The even-mode and odd-mode characteristic impedances are determined as: $Z_{(even)0,1} = Z_{(even)1,2} = 66 \Omega$ and $Z_{(odd)0,1} = Z_{(odd)1,2} = 40.5 \Omega$. Assuming that the band-pass microstrip filter is constructed on a Rogers4003 substrate with a constant relative dielectric of 3.48 and a thickness of 0.203 mm, the width and the spacing of the coupled lines are given respectively to $w = 0.35$ mm and $s = 110 \mu\text{m}$.

The all-pass filter network (path n°1 in Fig. 2) is designed as a microstrip transmission line. This latter is calculated to be half-wavelength at 2.4 GHz and is equal to 38 mm using Rogers4003 substrate.

The schematic of the highly selective notch filter is presented in Fig. 4. Time-Domain analysis is firstly investigated on this circuit using Agilent ADS software tools, by applying at its input a sine wave at 2.4 GHz with 2 volts peak to peak. The simulated results are presented in Fig. 5 where: the blue graph represents the output signal of the band-pass filter alone (path n°2), the red graph represents the output signal of the transmission line alone (path n°1) and the black one represents the output signal of the highly selective notch structure. As it can be noticed from Fig. 5, the output signal of the transmission line and of the band-pass network one, have almost the same amplitude but a 180° of phase difference. Thus, the combination of these two signals (black graph) leads to a low amplitude output signal at the center frequency of the band-pass network. The frequency behavior of the circuit is presented in Fig. 6. As depicted in this figure, the global response of the filter (red graph) is a notch filter response with a relatively high rejection almost 19 dB at the needed center frequency 2.4 GHz.

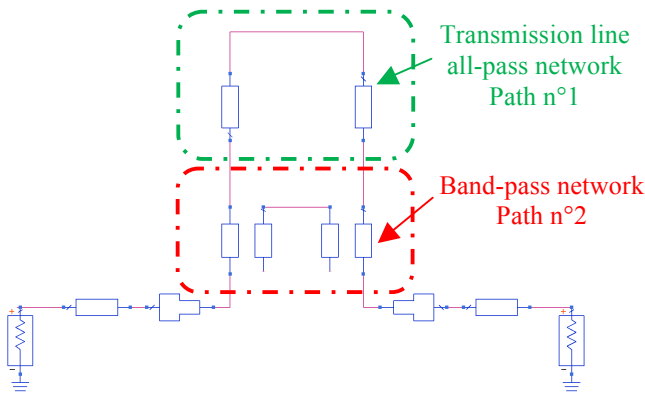


Fig. 4. Schematic of the highly selective passive notch filter.

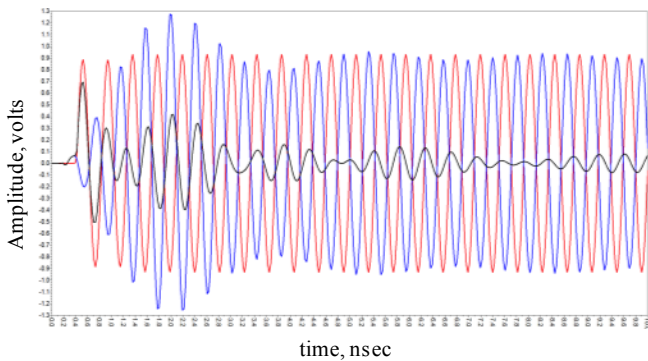


Fig. 5. Time-domain response of the highly selective notch filter.

Although the passive structure allows high level of rejection at the center frequency, it suffers from one major drawback. Indeed, the half-wavelength lines at relatively low frequency may not be allowed from the system size point of view. To overcome this drawback and reduce the filter size, the highly selective passive notch filter is designed on a multilayer Roger4003 substrate. On the first layer, the band-pass filter network is implemented and its lines are folded for a compact size. On the bottom layer, the transmission line is

folded too and is connected to the band-pass network by via holes (Fig. 7). A common ground plane is placed at the middle of the multilayer substrate so that all the line widths and lengths are calculated in relation to this plan.

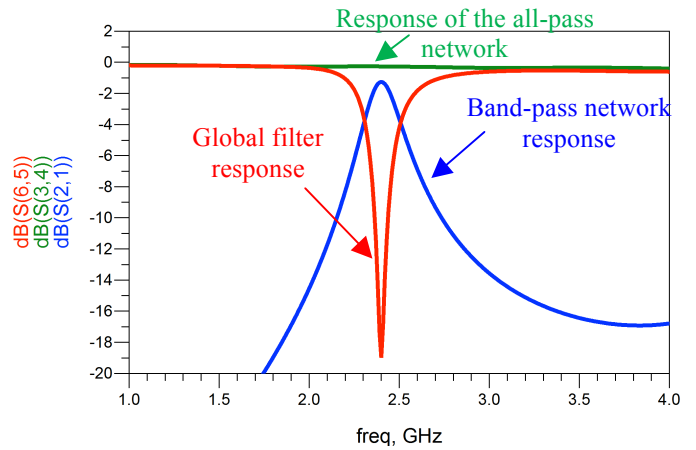


Fig. 6. Simulation results of the highly selective passive notch filter.

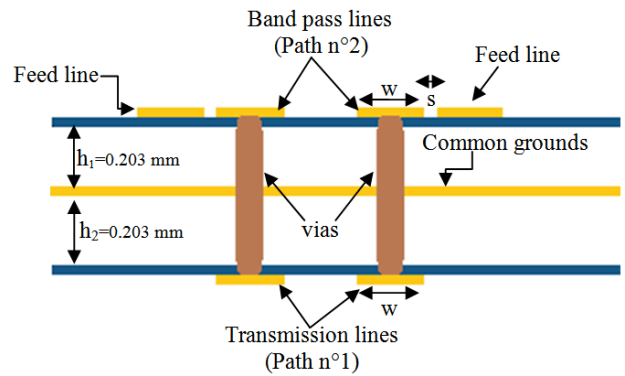


Fig. 7. Cross-section view of the highly selective passive notch filter.

The filter design is fully simulated using Ansoft HFSS simulation tools. The simulated transmission and reflection coefficients are presented in Fig. 8. As it can be noticed, the filter presents high rejection at 2.4 GHz (almost 20 dB) with 3-dB rejection bandwidth of 190 MHz while featuring very low insertion losses (less than 0.6 dB) far from its center frequency.

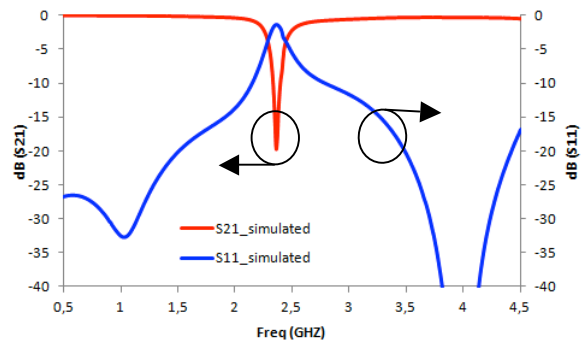


Fig. 8. S-parameters of the highly selective passive notch filter simulated using HFSS.

IV. REALIZATION OF THE HIGHLY SELECTIVE NOTCH FILTER AND DISCUSSION

A prototype based on this concept is realized on Rogers4003 multilayer substrate as depicted in Fig. 9-a. The effects of the input and output feeding lines are de-embedded using the through-reflect-line (TRL) calibration technique. Measurements are done using Rohde&Schwarz network analyzer and a probe station. The photograph of the highly selective passive notch filter under test is presented in Fig. 9-b.

In Fig. 10, the measured S-parameters are plotted for a large frequency sweep from 2 to 10 GHz of the filter topology where a quite good correlation can be highlighted in comparison to Fig. 8. The Discrepancy on the rejection depth of the measured filter at the center frequency is at around 5 dB in less. This behavior is explained by the fact that the signals traveling through the two paths of the filter are combined at its output with different amplitude levels (the term A_1 and A_2 in Fig. 2). Thus, the rejection at the center frequency is degraded as the signal is not perfectly cancelled. Otherwise, the filter shows the following performances: The 3 dB bandwidth is of 200 MHz with a notch depth of almost 15 dB at 2.4 GHz; the insertion loss is lower than 1 dB up to 7 GHz; the filter is well matched with a return loss of lower than -15 dB beyond $F_{\text{notch}} \pm 0.7$ GHz.

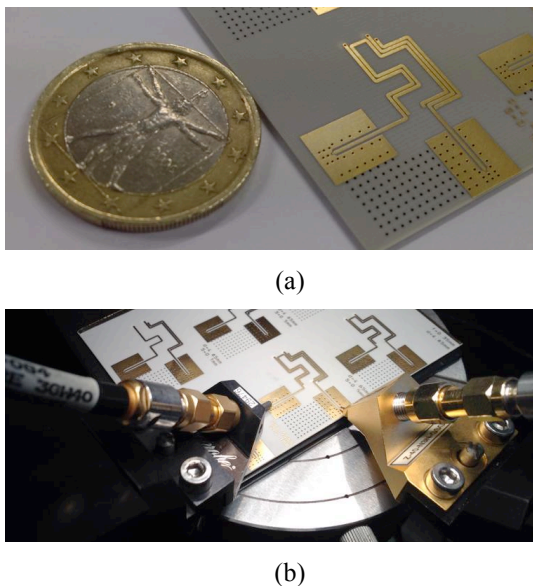


Fig. 9. Photo of the realized highly selective passive notch filter (a) and of the circuit under test (b).

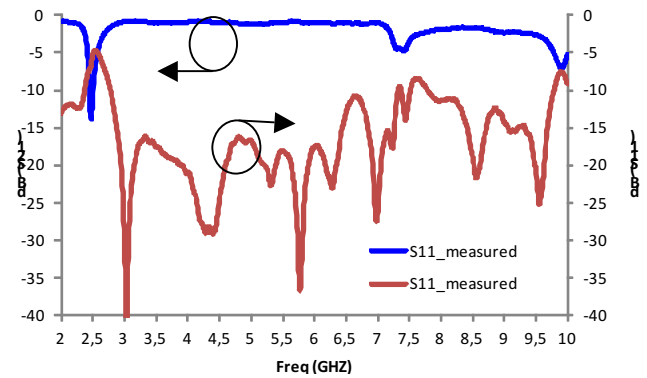


Fig. 10. Measured S-parameters of the highly selective passive notch filter.

V. CONCLUSION

In this paper a highly selective passive notch filter topology for 3.1-5 GHz UWB communication system is proposed. The filter contains two paths and uses a destructive technique to cancel the signal emitted by the IEEE 802.11 b/g standard. Experimental prototype implemented on Rogers4003 multilayer substrate is built and shows the benefit of this concept design. In further work some solutions to tune the frequency response of the notch filter will be addressed.

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