Int. J. Electron. Commun. (AEÜ) xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

Common-mode noise mitigation using ring resonator patterned ground plane for WiMAX and TD-LTE applications

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ARTICLE INFO

Article history:
Received 30 March 2016
Accepted 4 July 2016
Available online xxxx

Keywords:
Common mode noise
Differential signal
Defected ground structure
Ring resonator

ABSTRACT

This paper proposes a novel miniature bandstop filter for common-mode noise suppression in WiMAX and TD-LTE devices using ring resonator patterned defected ground structure (DGS). The proposed filter consists of two layers; coupled microstrip lines on the top layer, ring resonator based DGS on the bottom layer and the two layers are separated by FR4 dielectric substrate. Due to asymmetry in the PCB layout, the differential signal is converted to common-mode signal. The common-mode signal is considered as a noise in differential signaling systems and it must be suppressed to preserve the differential signal integrity. The filter provides differential insertion loss of less than −2 dB for frequencies up to 5 GHz. A peak insertion loss of −34 dB is observed for the common-mode signal at 3.5 GHz and a −20 dB stop bandwidth of 580 MHz from 3.14 to 3.72 GHz. The common-mode to differential mode conversion is below −70 dB for frequencies up to 5 GHz. The common-mode noise suppression is improved by 72% in the time domain. The fractional bandwidth is 17%. The size of the filter is 0.41λg × 0.2λg. From the eye-diagram, the values of MEO and MEW are 0.93 V, 0.58 ns. The proposed filter is fabricated and the measured results have good correlation with the simulated results.

1. Introduction

In high speed printed circuit boards, the communication link between the driver and the receiver is established by means of a Bus. Buses are a group of parallel transmission lines; each line carries single-bit from driver to the receiver, called as single-ended signaling. Single-ended signaling supports data rate up to 1–2 Gb/s. As the data rate increases, it is very difficult to maintain the signal integrity because digital systems are disgracefully noisy [1]. For example, simultaneous switching of multiple I/O devices at higher data rate induces noise between the power/ground planes, called as Simultaneous Switching Noise (SSN). The other sources of noise that severely distort the signal integrity of the digital signals are crosstalk and non-ideal return paths.

One of the techniques to reduce the impact of system noise at higher data rate is to employ differential signaling, where a dedicated pair of transmission lines is used to transmit single-bit data. The two lines are driven by 180° out of phase (odd-mode) and the differences between the voltage levels are used to recover the signal at the receiver by using a differential amplifier. If the two lines are driven by an in-phase signal, then it is called as a common-mode signal. Due to the EMI from nearby devices, common-mode noise is induced on the differential pair. Differential signaling is one of the effective methods in reducing the common-mode noise when the two lines are in close proximity to each other. This will ensure that the induced noise magnitude is equal on both the lines of the differential pair and it is easily removed by the differential amplifier available at the receiver end.

Two major causes of common-mode noise are phase deviation between the two lines of a differential pair and asymmetry in the differential pair layout. Ideally, the 180° phase difference between the two lines keeps the energy to be propagated in the odd-mode. However, phase deviation may occur during the signal propagation and it could convert a portion of the energy from odd-mode to even-mode. This is called as mode-conversion (or) differential to common-mode conversion. In addition, the asymmetry in the differential pair layout such as length differences, etching differences, proximity effects, coupling differences, termination differences, 90° bends could also cause mode-conversion.

The common-mode noise will affect the performance of high-speed system above the gigahertz frequency range. Furthermore, in most of the high-speed system applications, long cables were used for differential signal transmission from one PCB to another. Sometimes the induced common-mode noise may cause radiation through I/O cables could be a major problem. These kinds of issues

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http://dx.doi.org/10.1016/j.aeue.2016.07.003
1434-8411/

will drive the researchers to bring novel design methodologies for common-mode noise suppression and maintain the signal integrity over the desired frequency band for high-speed digital system applications.

Several methodologies were reported earlier to suppress the common-mode noise from the differential pair. Earlier, the high permeability ferrite core-based common-mode choke was used to suppress the common-mode noise [2–4]. The major drawbacks of this approach are large in size and it is valid up to MHz frequency range only. A compact common-mode filter fabricated using LTCC technology was reported in [5]. The filter provides noise suppression around 1 GHz, but the cost of fabrication is very high. The common-mode filters based on DGS were reported in [6–9]. The filter design based on periodic DGS for common-mode noise suppression over the particular frequency band was reported in [6,7]. The drawback of this approach is that the number of DGS unit-cells must be increased for broadband noise suppression. This will increase the layout dimension of the common-mode filter. In the non-periodic DGS-based filter, the combination of UH-slots and C-slot were introduced in the ground plane to obtain the broadband noise suppression [8,9]. To improve the capacitance effect, common-mode filters were built using multilayer technology [10–12]. The feasibility and implementation of multilayer common-mode filter are very difficult.

This present work proposes a novel ring resonator based defected ground structure to suppress common-mode noise in TD-LTE and WiMAX operating frequency bands. The paper is organized as follows: Section 2 discusses the design concept of the proposed common-mode filter. The significance of virtual reference plane in the odd-mode excitation is discussed in Section 3. Common-mode filter characterization using mixed-mode S-parameters is discussed in Section 4. The simulated and fabricated common-mode filter performances are analyzed in Section 5. Finally, conclusions are drawn in Section 6.

2. Design concept

The proposed common mode filter is shown in Fig. 1. It is a two layer PCB structure. A coupled microstrip line is present in the top layer; DGS is present in the bottom layer; two layers are separated by an FR4 dielectric medium of thickness 0.8 mm, $\varepsilon r = 4.3$, $\tan\delta = 0.025$. The coupled microstrip lines are designed for the differential impedance of 100 Ω. The length and width of the individual lines are L = 12.5 mm, W = 1.2 mm. The gap between the two lines is G = 1 mm. The thickness of the top and bottom copper layer is 17 μm. A portion of the ground plane is etched away to create the desired defected ground structure. The DGS layout configuration and its design parameters are shown in Fig. 2. The area of the DGS is $21.5 \times 10.5\ mm^2$. The combination of Double Split Rectangular Ring Resonator and the connecting bridges formed the defected ground structure. The dimensions of the DSRR are S1 = 7.45 mm, S2 = 3 mm, S3 = 0.5 mm, S4 = 19.5 mm and

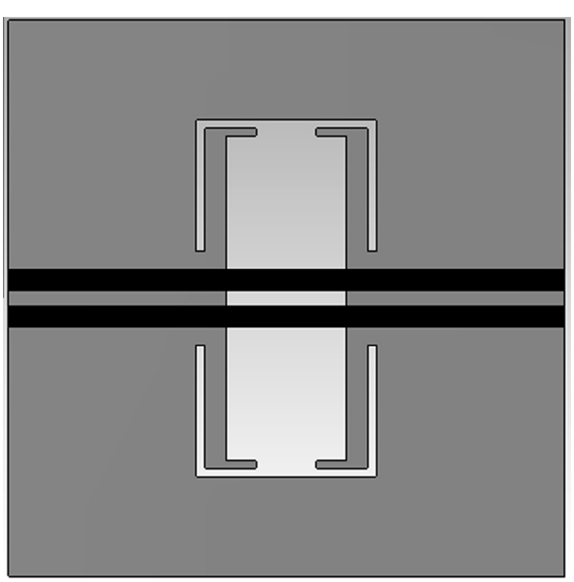

Fig. 1. Proposed common-mode filter based on defected ground structure.

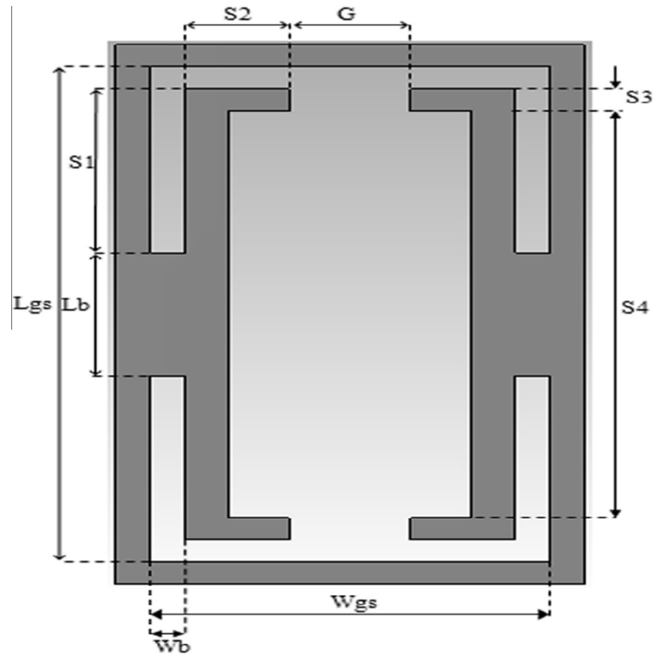

Fig. 2. Layout of Double Split Rectangular Ring Resonator patterned defected ground structure.

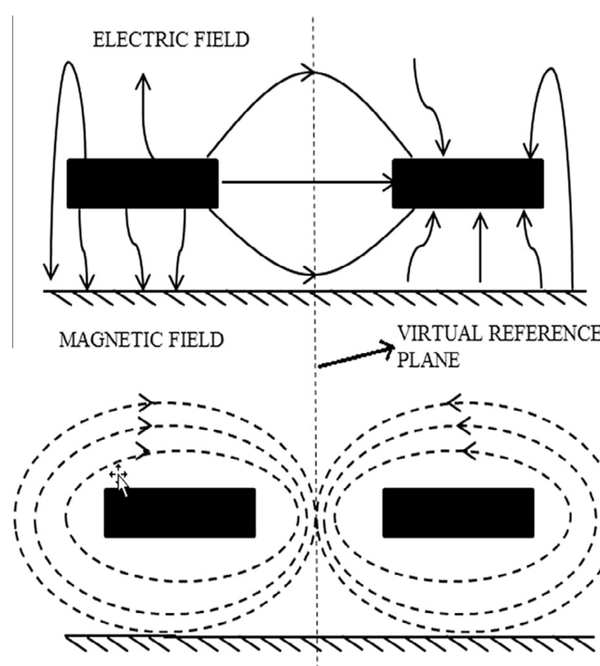

Fig. 3. Odd-mode excited electromagnetic field orientation in a coupled microstrip line.