EMC filter based on complementary split-ring resonators for audio applications

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Abstract — **Filters based on complementary split-ring resonators present a large notch attenuation at the resonant frequency. An application of these very low cost filters to an audio system interfered by a mobile phone is presented in this paper.**

1. INTRODUCTION

Low frequency analogue and digital electronic circuits can be disturbed very often by high frequency RF signals. This out of frequency band EMC issue is produced when the coupled RF signal is rectified by the non-linear behaviour of the semiconductors used in the electronic systems.

This susceptibility issue is known as *audio rectification* [1] because of the usual nuisance, or even an upset noise, generated in the audio equipments analogue stages. We can find easily *old* examples of this problem like hearing AM radio broadcast on the telephone sets, but also *new* unpleasant situations when, for example, we listen our mobile phone handshake signals on the car radio loudspeakers o even in an auditorium.

The main problem of this EMC issue is that, after the rectification is produced, the interference signal and the useful signal cannot be distinguished. This produces an offset in a DC circuit, an audible interference in an audio system or a right pulse input in a digital system.

To solve this problem, an effective filtering has to be introduced at the very first stages of the perturbed system, before the RF signal reaches any semiconductor, to avoid the non-desired rectification. Usually the connectors of the input and output cables are the best location for the filters.

The attenuation characteristic of the filter must be carefully designed because the frequency spectrum of the useful and the interference signals are usually very distant (consider for example a mobile phone in the GHz band interfering an audio system in the KHz band). Since most of the times the high frequency filter has to be implemented in a relative low frequency electronic circuit, special care must be taken when choosing the filter components and the PCB layout. On the other hand, when a system has a lot of input and output ports, this filtering can result in an extra cost, both in size and economically.

In this paper a filter developed by means of effective media metamaterials based on sub-wavelength resonators is used to reduce the interference produced in a personal computer audio system by an interference located in the mobile phones frequency band. Specifically, complementary split-ring resonators (CSRR) [2], have been implemented in order to obtain a rejection band centred at the frequency of interest.

The large and sharp attenuation of this kind of filters makes them very suitable in those situations where the interference is produced by a narrow RF communication system like mobile phones. Moreover, in systems with many inputs and output signals the filters are very promising due to their low implementation cost.

2. FILTER SYNTHESIS AND CHARACTERIZATION

CSRRs are the dual counterparts of the more known SRRs which consist of a pair of metal rings etched on a dielectric slab with apertures in opposite sides [3]. CSRRs (see Figure 1) are mainly excited by means of an electric field along the ring's axis. The key aspect of such resonators is the fact that they are electrically small and exhibit an effective permittivity which is negative in a narrow band above their resonant frequency. Therefore, CSRRs are able to inhibit signal propagation in the vicinity of the resonance frequency which satisfies the condition of a negative effective permitivitty ($\varepsilon<0$).

Therefore, by etching CSRRs in the ground plane underneath of a microstrip line (victim line) it is possible to reject EMI signals which frequency corresponds to the particles resonance frequency. This effect is basically carried out by means of a significant electrical coupling between the host victim line and the resonators.

Since these resonators present dimensions significantly smaller than signal wavelength at their resonance frequency, they allow reducing circuit area keeping unaltered the top metal layer. Also they add no extra cost to the implementation, since CSRRs are etched by using a conventional drilling machine [4].

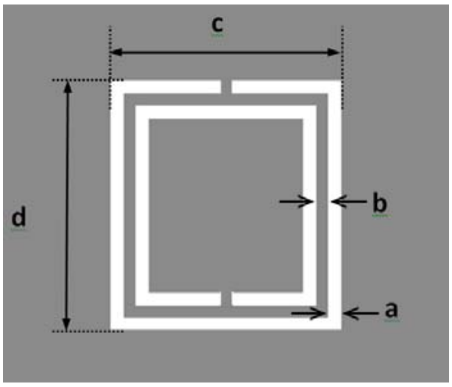

Fig. 1. Topology of the square shaped CSRR with its relevant dimensions. Grey zone corresponds to ground plane metal.

The synthesis of the filter is performed by using the equivalent model of CSRRs. In fact, these resonators behave as LC tank coupled by means of a capacitor (which value is slightly different to the corresponding to the capacitance of the transmission line) with the host line. Lumped equivalent parameters can of the transmission line and CSRRs can be extracted by comparing electromagnetic simulations and electrical simulations. The proposed EMI filter is depicted in Figure 2. It consists of 4-stage CSRRs coupled to a victim microstrip transmission line at their resonance frequency. The dimensions of the CSRRs are slightly modified in several stages in order to achieve slightly different resonance frequency operation and, thus, a wider stopband response.

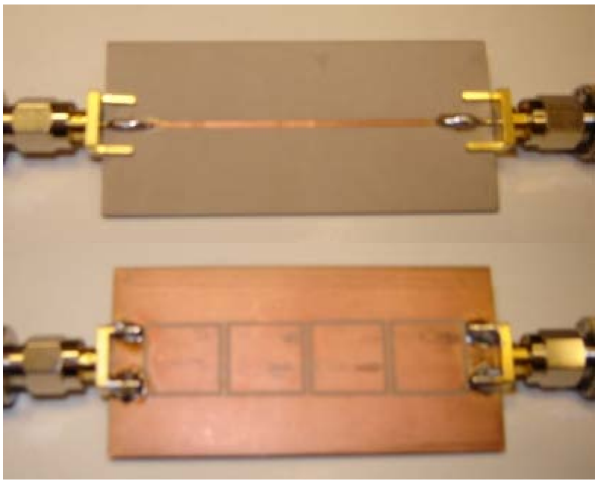

Fig. 2. Test prototype of the characterized 4-stage EMI CSRR filter (Top and bottom views). Dimensions are:
host victim line: width=1.18mm, length=59.5mm;
CSRRs: a=b=200µm; d=12mm; 1-stage c=11.8mm; 2-stage c=11.6mm; 3-stage c=11.4mm; 4-stage c=11.4mm.

The filter has been designed by using a Rogers RO3010 substrate (ε_r=10.2 and h=1.27mm), the 50Ω microstrip line has been designed by means of *Agilent Linecalc* calculator and the maximum attenuation of the filter has been designed at 800 MHz.

The experimental results (shown in Figure 3) have been measured by means of a *Rohde & Schwarz ZVRE* vector network analyzer. A notch attenuation of -55 dB is obtained at 800 MHz. The attenuation below 700 MHz, where the useful signals are located is negligible.

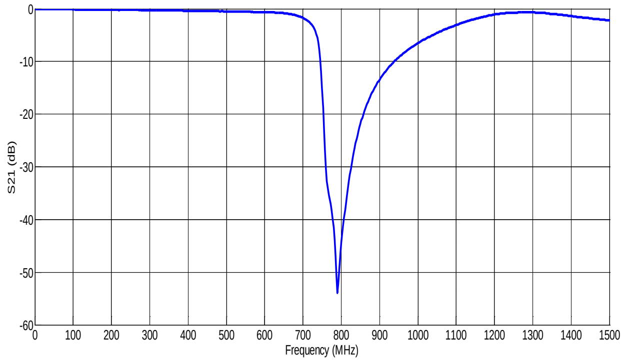

Fig. 3. Measured attenuation (S_{21}) of the CSSRs filter.

3. APPLICATION TO AN AUDIO SIGNAL

In this section, the previously developed filter is applied in an audio system consisting in a personal computer loudspeaker disturbed by a mobile phone. In this application we are considering the coupling to the power supply cable not to the audio signal cable.

To obtain some reference levels of the disturbances involved, an alone loudspeaker powered (12 V) by a 1 m long cable has been placed next to a mobile phone transmitting in the 900 MHz band. The mobile phone has been operated and approached to the power cable until the noise generated by the GSM handshaking signals was audible. This noise was recorded by an oscilloscope at the loudspeaker input (see Figure 4). The recorded signal shows the GSM RF signal modulated by a square wave. The measured level that produces an audible noise has a maximum of 80 mV.

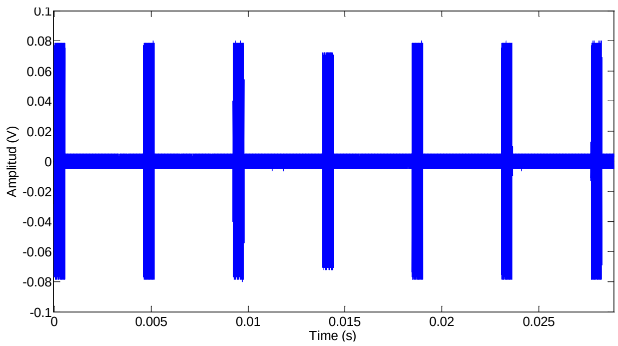

Fig. 4. Noise generated by the mobile phone recorded at the loudspeaker input that produces an audible disturbance.

In order to reproduce the EMC situation in the lab, a setup to inject a noise signal in the power supply cable and to measure the interference signal has been designed. Figure 5 shows the lab setup. An amplified 800 MHz signal produced by an RF signal generator is coupled to the loudspeaker power supply cable by means of a Lüthi electromagnetic injection clamp type EM101 with an operating frequency range between 0.15 and 1000MHz (see picture in Figure 6). The interference at the input is measured by an oscilloscope.

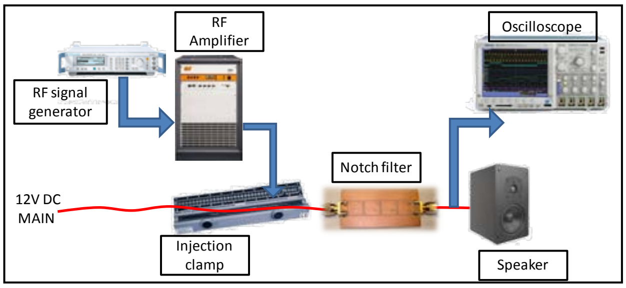

Fig. 5. Test setup in the lab to generate and inject the interference and to measure the loudspeaker power supply input.

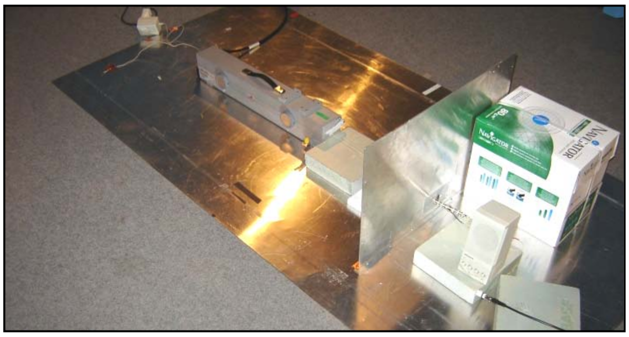

Fig. 6. Interference coupling by an injection clamp detail.

With the previous setup, an 800 MHz RF signal modulated in amplitude by a 1 kHz sinusoid is injected to the cable. In this first step the CSRR filter is removed. The output level of the RF generator is adjusted to obtain an 80 mV signal at the loudspeaker power supply input; this signal is plotted in Figure 7. This is the level stated before with the actual mobile phone to produce an audible nuisance. Therefore, due to the rectification, a 1 kHz tone is audible in the audio system.

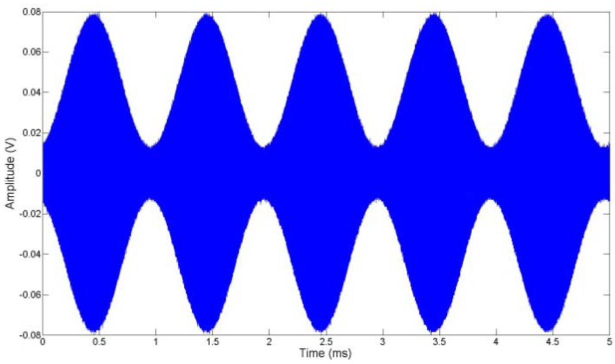

Fig. 7. Injected modulated RF signal (800 MHz - 1 kHz) injected in the lab to reproduce the interference from a mobile phone.

By inserting the CSSR designed filter at the loudspeaker power supply input the audible noise is eliminated. In this situation the oscilloscope does not have enough sensibility to acquire the filtered interference.

In order to measure the effective attenuation introduced by the filter, a higher level signal (0.5 V) is injected in the system. Input and output signals of the filter are plotted in Figure 8, showing the actual attenuation of 28 dB.

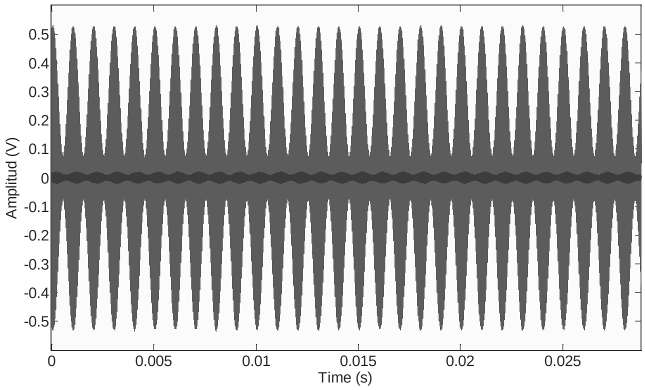

Fig. 8. Interference measured at the loudspeaker power supply input. In red without the filter, in blue using the CSRR filter.

4. CONCLUSION

Audio rectification is a common EMC problem that is usually solved by filtering. In this paper, a filter developed by means of effective media metamaterials based on sub-wavelength resonators has demonstrated its ability to attenuate the interference produced by a mobile phone in an audio system. The non component and low cost characteristics of this kind of filters make them a very promising solution for these EMC problems.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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