

# Single-band Series Absorptive Common-mode Noise Filter

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**Abstract** – A Single-band Series Absorptive Common Mode Noise Filter (ACMF) is proposed. The ACMF is embedded in a four-layer printed circuit board (PCB) and consists of three parts: a Reflective Common Mode Noise Filter (RCMF), a matching circuit, and an absorber. The RCMF is designed using mushroom-type resonators. The matching circuit is designed using meander lines to reduce the size of the filter dimensions. The absorber of the Common Mode noise (CM) is a series resistor. The designed operating frequency is 2.45 GHz. The simulation results are as follows: the insertion loss of CM ( $S_{cc21}$ ) is  $-22.49$  dB at the frequency of 2.61 GHz, the return loss of CM ( $S_{cc11}$ ) is  $-18.62$  dB at the frequency of 2.5 GHz, while the integrity of the Differential Mode signals (DM) can be maintained with a very small insertion loss ( $S_{dd21}$ ) of  $-1$  dB at the frequency range of 0–8 GHz, and the achieved Absorption Efficiency (AE) is 93% at the frequency of 2.54 GHz. The proposed ACMF dimension is 10.3 x 4.6 mm. The fractional bandwidth is 19%. The measurement results of the fabricated ACMF do not deviate significantly the simulation results. They are as follows:  $S_{cc21}$  is  $-17.87$  dB at the frequency of 2.31 GHz,  $S_{cc11}$  is  $-20.87$  dB at the frequency of 2.38 GHz,  $S_{dd21}$  is  $-2.8$  dB at the frequency range of 0–8 GHz, the Absorption Efficiency is 97% at the frequency of 2.32 GHz, and the fractional bandwidth is 17%. Therefore, the results of the ACMF design carried out by simulation can be implemented into a fabricated ACMF with measurement results similar to the calculation results in the design.

**Index Terms** – absorptive common-mode filter (ACMF), absorption efficiency (AE), common-mode filter (CMF).

## I. INTRODUCTION

Today, high-speed data transmission is used in many electronic systems, including Universal Serial

Bus (USB) and High Definition Multimedia Interface (HDMI). The signals used are Differential Mode (DM) signals because of their high immunity to noise. However, some of these DM signals can turn into Common Mode (CM) signals as a result of the time skew and asymmetrical circuit structure. The CM signals will degrade the performance of electronic devices surrounding it, as they can cause the problem of radiated Electromagnetic Interference (EMI) noises [1, 2]. Therefore, the CM signals are considered as noise which is commonly referred to as CM noise [3–5]. To overcome this, a Common Mode noise Filter (CMF) is needed which is expected to reduce the CM noise at a certain frequency needed while maintaining the integrity of the DM signals.

In the past, many types of CMFs were proposed to overcome CM noise [6–8]. One of them is the use of a ferrite core with winding lines. This results in a large input impedance for CM noise [9], while the DM signals can still pass without significant attenuation. The disadvantage is that its bandwidth at high frequencies is limited due to decreased permeability. The next type of CMF proposed is the use of mushroom-like resonators in multilayer PCBs [10]. Next, RCMFs are made of Pattern Ground Structure (PGS). This structure provides a resonator in the reference ground plane to block the flow of CM noise [11]. The above-mentioned CMFs can prevent the transmission of CM noise to the next stage, because the CM noise is reflected to the front-end circuit by the filter. As a result, interference by CM noise is still sensed by the front-end and surrounding circuits. To overcome this problem, a filter type that can absorb CM noise energy is proposed.

There are two types of CMFs, namely: Reflective Common Mode Noise Filter (RCMF) and Absorptive Common Mode Noise Filter (ACMF). RCMF reflects CM noise to circuits in the previous stage. ACMF absorbs or dampens CM noise at certain frequencies so

it does not continue to transmit to the next stages of the circuits and also does not bounce back to the previous stages of the circuits. The reflective CM noise will degrade the performance of the previous stages of the electronic circuits. Therefore, ACMF is better than RCMF. An ACMF can be made by adding absorber circuits in the form of resistive materials to an RCMF to absorb the reflected CM noise [12].

In this paper, a series ACMF is proposed. The ACMF consists of three stages. The first stage is the RCMF, the second stage is the matching circuit, and the third stage is the absorber in the form of a series resistive material. The RCMF type that is designed is a mushroom type. The matching circuit function is to bring a short circuit in the middle of the RCMF to the absorber which is located on the front port. Therefore the length of the matching circuit is half wavelength ( $\lambda/2$ ) of the resonant frequency so that the short circuit condition reaches the absorber. The matching circuit is designed using meander lines to make the filter dimensions as small as possible. The absorber that is used is a Surface Mounted Device (SMD) resistor. The advantage of a series ACMF over another type of filter is its simpler implementation. The other type of ACMF filter is parallel ACMF. A series ACMF is implemented on a four-layer Printed Circuit Board (PCB).

An ACMF is said to be useful only if it is able to absorb as much CM noise as possible. This occurs when the insertion loss of CM ( $S_{cc21}$ ) is minimum and the return loss of CM ( $S_{cc11}$ ) is also minimum. This is expressed in terms of Absorption Efficiency (AE) as shown in (1) [13]. Therefore, the larger the AE the better the ACMF.

$$AE(\%) = 100 \times (1 - |S_{cc21}|^2 - |S_{cc11}|^2). \quad (1)$$

## II. PROPOSED STRUCTURE

The structure of the proposed ACMF is shown in Fig. 1. This series ACMF uses four Layers PCB with detail dimensions and materials can be seen in Fig. 2. Layer 1 is used for differential mode signal traces. Layer 2 is used for the mushroom pad and reference ground of the matching circuit. While Layer 3 is used for local ground. Layer 4 is used for system ground and the location where the serial Surface Mounted Device (SMD) Resistor is attached.

The series ACMF is shown in Fig. 3. The RCMF that we use in stage 1 is a mushroom-type RCMF. Therefore, the mushroom pad acts as an auxiliary ground for DM signals on stage 1. The mushroom pad is connected to the local ground at Layer 3 through a via and meandering path as shown in Fig. 1. This meandering path serves as an inductor that determines the resonant frequency. This is the frequency when transmission zero occurs for CM noise. The resonant frequency that we

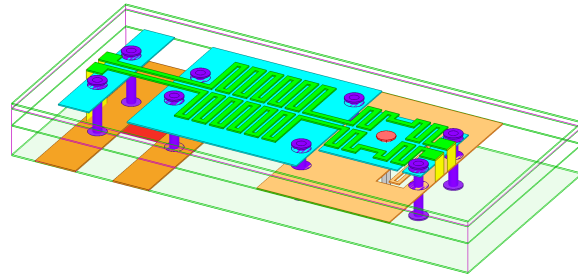


Fig. 1. The structure of proposed ACMF, trimetric view.

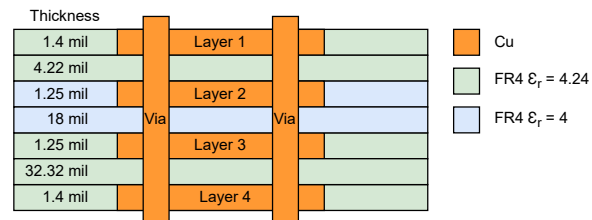


Fig. 2. PCB layers of proposed ACMF.

use is 2.45 GHz. This frequency was deliberately chosen according to the Wi-Fi frequency standard [14], so that our proposed ACMF can be used to secure the Wi-Fi transceiver module from the interference of CM noise.

Transmission Zero or short circuit load occurs in the middle of the mushroom pad. The matching circuit in stage 2 has a function as a short circuit load shifter from the middle of the mushroom pad to the resistor absorber on stage 3. This is achieved by adjusting the length of the matching circuit to  $\lambda/2$ , where  $\lambda$  is the wavelength of the resonant frequency. To reduce the physical dimensions of the filter, this matching circuit is made in meander form. This results in the proposed ACMF dimensions of 10.3x4.6 mm. Thus, at stage 3, the CM noise will go through a short circuit and an absorbent resistor that is mounted serially towards the ground. This is a new concept of our research, which is to use an absorbent resistor in series rather than parallel. The advantage of this concept is its simplicity in implementation. The absorbent resistor is drawn in red as shown in Fig. 1 and Fig. 3. This is how the CM noise is dissipated into heat by an absorbent resistor that has a resistance of 25  $\Omega$ .

### A. Reflective common mode noise filter (RCMF)

The first stage of our proposed ACMF is an RCMF. Its structure is shown in Fig. 4. It is a mushroom-type RCMF. Its working frequency is 2.45 GHz. The transmission zero of the mushroom-type RCMF happens in the middle of the structure. The simulation results of the mushroom type RCMF is shown in Fig. 5. The dimension of this RCMF is 3x2.5 mm.

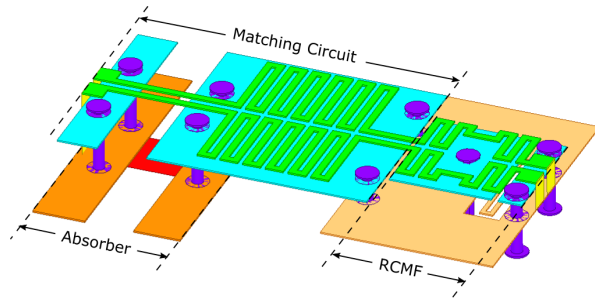


Fig. 3. The structure of proposed ACMF.

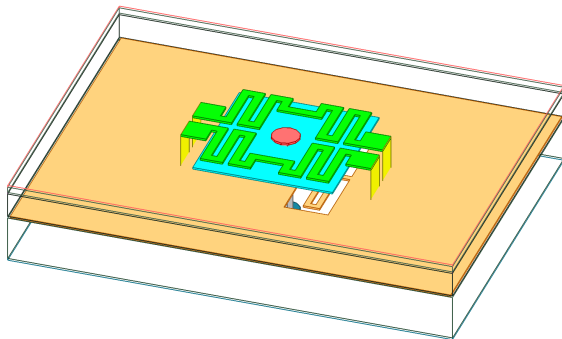


Fig. 4. The structure of proposed RCMF.

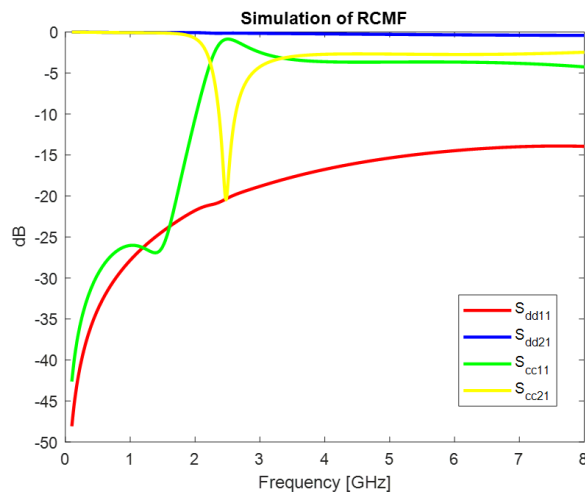


Fig. 5. The simulation results of RCMF.

It is seen in Fig. 5 that  $S_{dd21}$  only decreased slightly (less than  $-1$  dB) for the frequency range of 0–8 GHz. This shows that the integrity of the differential signals is well maintained. We also see that the insertion loss of CM  $S_{cc21}$  reached its lowest value of around  $-20$  dB at 2.45 GHz. Meanwhile, the return loss of CM  $S_{cc11}$  reached its highest value (less than  $-1$  dB) at a frequency

of 2.45 GHz. This means that at a frequency of 2.45 GHz the common mode noise is not transmitted to the next device but is reflected back to the previous device. This proves that this filter is an RCMF.

### B. Matching circuit

The function of the Matching Circuit is to bring the short circuit impedance from the center of the RCMF to the input port of the series-type absorber. The goal is that as much of the reflected common mode noise energy that occurs in the center of the RCMF is channeled to the absorber to be dissipated into heat so that it does not flow to the device located at the ACMF input. This matching circuit is implemented using a transmission line with a length of  $\lambda/2$ , where  $\lambda$  is the electromagnetic wavelength with a frequency of 2.45 GHz, which is the ACMF working frequency. To reduce the dimensions, the matching circuit transmission line is made in the form of a meander.

### C. Series-type absorber

The absorber is used to absorb the CM noise energy reflected by the RCMF by passing it through a resistor so that the energy turns into heat. By dissipating the CM noise energy into heat, the CM noise energy no longer interferes with RF (Radio Frequency) devices around it. This absorber is implemented using a 0805 SMD resistor and is installed in serial position with the system ground through which common mode energy passes. Technically, we cut the system ground plane immediately after the input port of the ACMF so that there is a gap in the system ground. Into this gap an SMD resistor is serially installed in such a way that the SMD resistor connects the two planes of the cut off system ground. This SMD resistor is safe and suitable for use in ACMF because the maximum power that can be applied to this SMD resistor is 0.5 W and its size is  $2.00 \times 1.25 \times 0.50$  mm [13]. The resistance used for this SMD resistor is  $25 \Omega$ . This absorber resistance is chosen according to the input impedance of the CM noise so that the transfer of CM noise energy to the absorber is maximum.

## III. SIMULATED AND FABRICATED ACMF

This section presents measurement results both in simulation and fabricated of designed ACMF. The simulation was made by using HFSS software from Ansys and the real ACMF was made at the factory based on this simulation. We named it the fabricated ACMF and it is shown in Fig. 6 and Fig. 7, which are the fabricated ACMF top view and bottom view, respectively.

The measurement results of the simulated ACMF are shown in Figs. 8-11 in green line, meanwhile the measurement results of the fabricated ACMF are shown in red line. The comparison between them is shown in Table 1.

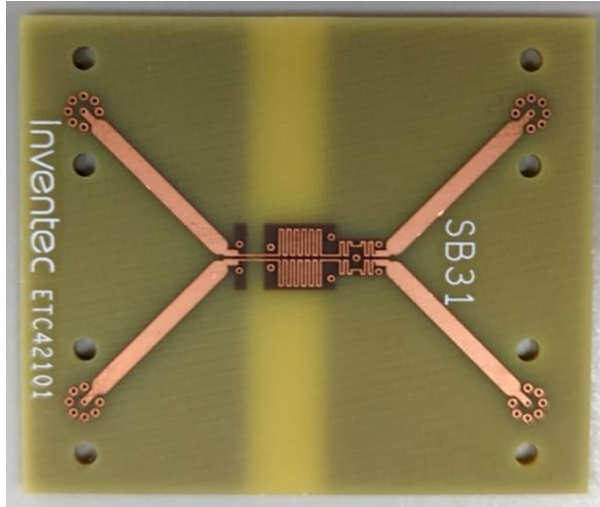


Fig. 6. Fabricated ACMF, top view.

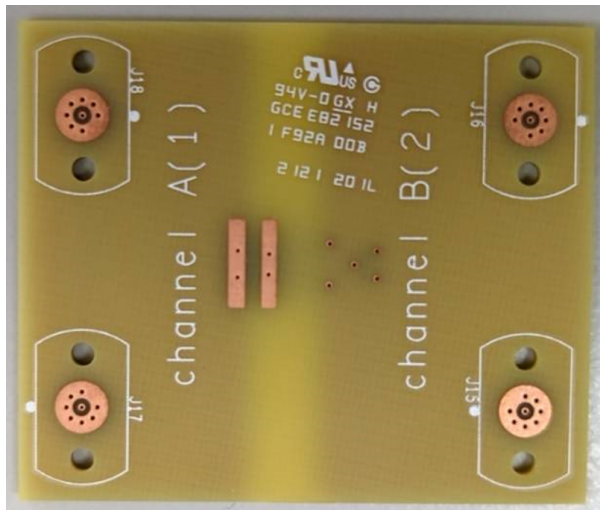


Fig. 7. Fabricated ACMF, bottom view.

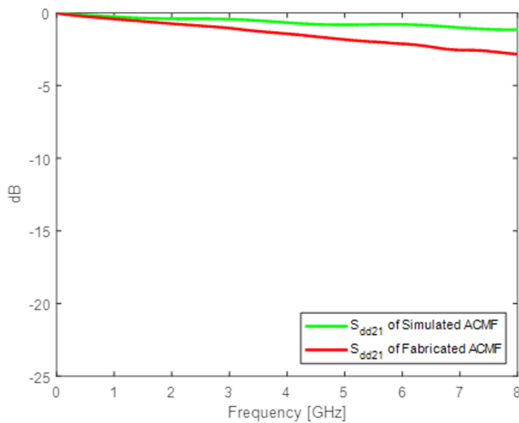


Fig. 8. The comparison between the  $S_{dd21}$  of the simulated and fabricated ACMF.

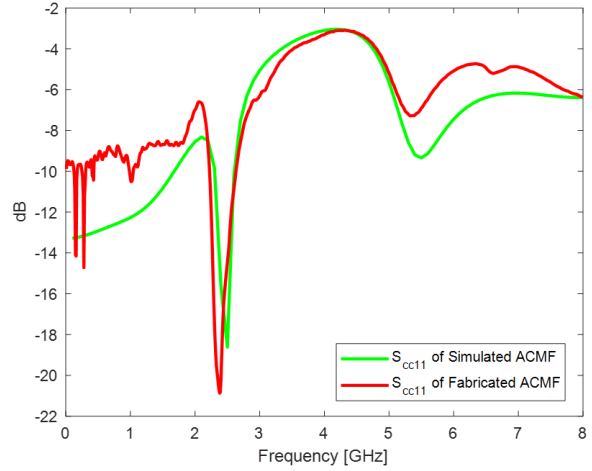


Fig. 9. The comparison between the  $S_{cc11}$  of the simulated and fabricated ACMF.

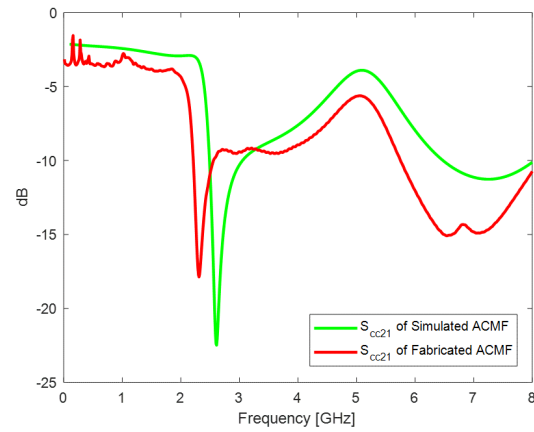


Fig. 10. The comparison between the  $S_{cc21}$  of the simulated and fabricated ACMF.

Table 1: Comparison between Simulation and Fabrication

	Simulation		Fabrication	
$S_{cc21}$	-22.49 dB	2.61 GHz	-17.87 dB	2.31 GHz
$S_{cc11}$	-18.62 dB	2.5 GHz	-20.87 dB	2.38 GHz
$S_{dd21}$	< -1 dB	8 GHz	< -2.8 dB	8 GHz
AE	92.8%	2.54 GHz	97%	2.32 GHz
Fract. BW	19%		17%	

#### IV. DISCUSSIONS

S parameter is used to analyze the characteristics of common mode filters. The ones that are often used are  $S_{dd21}$ ,  $S_{cc21}$ , and  $S_{cc11}$  [6, 8, 15–17].  $S_{dd21}$  is the insertion loss of DM which is ideally 0 dB.  $S_{cc21}$  is the insertion loss of CM which is ideally  $-\infty$  dB.  $S_{cc11}$  is the return loss of CM which is ideally  $-\infty$  dB for ACMF.

Table 2: Comparison between Series and Parallel ACMF

Parameter [Unit]	This Paper	Paper [18]	Paper [19]	Paper [20]
Absorption freq. [GHz]	2.32	2.25	3.55	2.45
Absorption efficiency [%]	97	96	97	97
Dimensions [mm]	10.3 x4.6	8.65x2.5	28.6x13.5	16x3.5

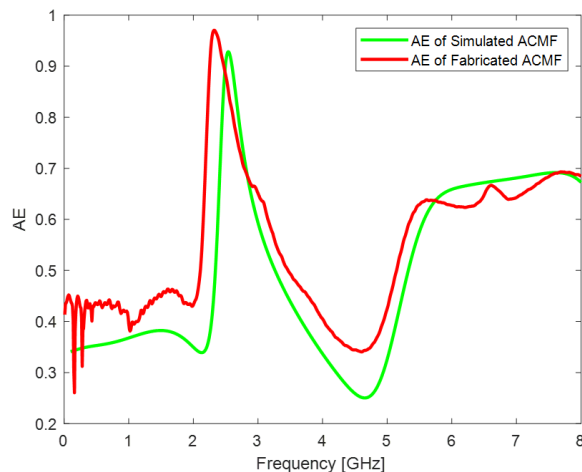


Fig. 11. The comparison between the Absorption Efficiency of the simulated and fabricated ACMF.

From simulation results, Fig. 8 shown that  $S_{dd21}$  is  $-0.4$  dB at frequency 2.45 GHz. Therefore, the insertion loss of DM signal in our simulation is very small, i.e. integrity of the DM signal that is passed in the proposed ACMF is well maintained. Figure 9 shown that  $S_{cc11}$  for the frequency of 2.45 GHz is about  $-19$  dB. This means that the reflected CM noise in our simulation has been reduced quite significantly. Figure 10 shown that the minimum for  $S_{cc21}$  with a level of  $-23$  dB occurs at a frequency slightly above 2.45 GHz. This means that the CM attenuation in our simulation is very large and occurs slightly above the expected frequency. In Figure 11, it can be seen that the maximum absorption efficiency of about 93% occurs at a frequency of around 2.5 GHz. As a result, at a frequency of around 2.5 GHz, our simulation succeeded in reducing and absorbing 93% of the CM noise that passes through it.

The real ACMF was fabricated at the factory based on this simulation as shown in Figs. 6 and 7. The comparison between the measurement results and the simulation results are shown in Figs. 8–11 in which we can clearly see that the S parameter measurements are slightly different from the measurement results in the simulation. These differences are caused by the addition of transmission lines, which are used to connect ACMF ports with measurement terminals as we can see in Fig. 6. However, these differences can be tolerated because they are

small and the overall results of these measurements show the same pattern and close similarity.

In addition, the absorption efficiency obtained from fabricated ACMF is also greater than that obtained from simulated ACMF. This AE, which is generated by a series ACMF, is also compared with the AE generated by a parallel ACMF and made by other researchers [18] as shown by Table 2.

Table 2 is a comparison of the data between the ACMF that we made and several ACMFs produced by other researchers as written in the papers [18–20]. Frequency absorption occurs at adjacent frequencies, namely: 2.32 GHz, 2.25 GHz, 3.55 GHz, and 2.45 GHz, so this comparison is valid because the ACMF works at adjacent frequencies. Although our ACMF dimension is larger than the ACMF dimension reported by the paper [18], the Absorption efficiency generated by our ACMF is greater than the ACMF absorption efficiency reported by the paper [18]. Papers [19, 20] reported absorption efficiencies similar to absorption efficiency produced by our ACMF, but our ACMF dimension is smaller than those reported in the same papers.

In addition, the fabricated series ACMF can maintain the integrity of differential signal well. As we can see in Fig. 8, it can be seen that at a frequency of around 2.5 GHz the DM insertion loss value of  $S_{dd21}$  is less than  $-1$  dB. Thus, we can conclude that the simulation of the series ACMF that we have designed has been successful and can be implemented on the PCB with good S parameter measurement results.

## V. CONCLUSIONS

The motivation of this research is to identify a technique to reduce CM noise at a frequency of 2.45 GHz so as not to interfere with RF devices operating in the vicinity of this frequency, such as Wi-Fi transceiver module. Our experiment solved this problem with the success of our simulated ACMF and fabricated ACMF to reduce CM noise at the frequency of near the 2.45 GHz. We use an SMD resistor in our ACMF to absorb CM noise. The absorption efficiency that we managed to achieve in the simulation was 93%, while our fabricated ACMF managed to achieve an absorption efficiency of 97%. In addition, our simulated ACMF and fabricated ACMF also managed to maintain the integrity of the DM signal that passes through it with a DM insertion loss of less than  $-0.5$  dB and less than  $-1$  dB respectively at

frequencies of around 2.45 GHz. The next thing, the dimension of our proposed ACMF is also small. For future development, the method used in our experiment can be further developed to achieve better characteristics and smaller dimensions.

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