Decoupling Method Between Digital Signals on FPCB and Mobile Handset Antenna

Joonchul Kim and Hyeongdong Kim

Digital harmonics, which may reduce the radio frequency sensitivity of a system, can be coupled with an antenna in a mobile handset. This letter presents a decoupling method for increasing the isolation between digital harmonics on a flexible printed circuit board (FPCB) and an antenna in terms of the ground mode current and the concept of reaction. We model the signal and ground lines in an FPCB as a loop circuit exciting a ground mode current and demonstrate a simple but efficient decoupling method for reducing the excited ground mode current.

Keywords: Ground mode, characteristic mode, digital noise coupling, reaction, FPCB.

I. Introduction

A variety of noises can couple with an antenna in mobile handsets. Specifically, digital signals on a flexible printed circuit board (FPCB) used to connect a liquid crystal display (LCD) module to a main PCB can couple with an antenna and significantly reduce the RF sensitivity. For a low-frequency range, such as the range used by the global system for mobile communications (GSM), the PCB ground mode is widely utilized for efficient antenna operation [1]. In considering an antenna operation, any signal that excites the PCB ground mode can be strongly coupled to the antenna [2], [3], which may seriously degrade its sensitivity. Therefore, we have previously studied the coupling mechanisms and the techniques of suppression that operate between the digital signal harmonics flowing on an FPCB and a mobile handset antenna [4]. This letter presents a coupling mechanism and a simple but efficient method of decoupling a digital signal harmonic on an FPCB with an antenna.

II. Coupling Mechanism and Decoupling Method

The FPCB functions as the signal and the return current path connecting the integrated circuits (ICs) of the main part and flip part in a mobile handset, as shown in Fig. 1. If currents flow along the signal line of the FPCB, the return currents flow on the ground line. When fast digital signals flow on an FPCB line to transfer information, the coupling between the digital signal and the antenna happens seriously because the PCB ground is resonated by the harmonic of the digital signal and it excites the ground mode current of the PCB [5]. Figure 2 shows a clamshell type of mobile handset with an FPCB and its ground mode current distribution at the dominant resonance frequency. In practice, many signal and ground lines exist in an FPCB; however, for simplicity, we consider only one signal line and one ground line in our FPCB model. When digital harmonics flow on the FPCB, the ground mode current of the PCB is excited. Using an equation slightly modified from [5], [6], this

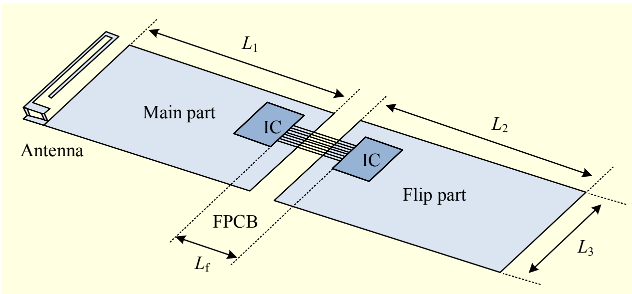

Fig. 1. Clamshell type model of mobile handset with FPCB.

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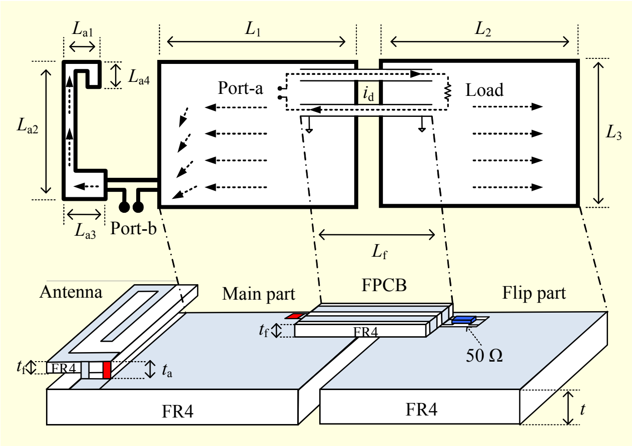
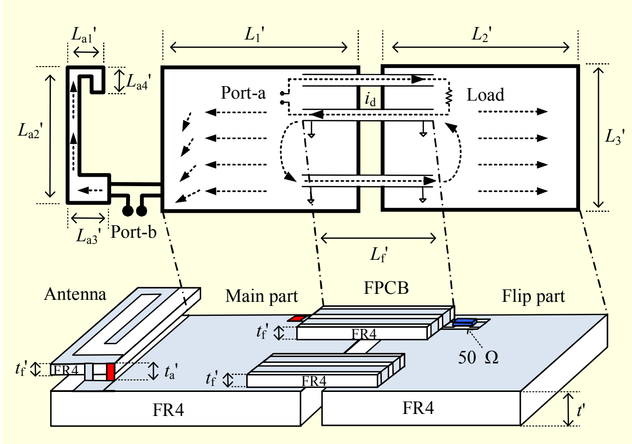


L_1=90 mm, L_2=100 mm, L_3=40 mm, L_f=30 mm, L_{a1}=5 mm, L_{a2}=38 mm, L_{a3}=8 mm, L_{a4}=31 mm, t=1.6 mm, t_f=0.8 mm, t_a=4 mm, FPCB line width=0.5 mm, distance between FPCB signal and ground line=0.5 mm, source and load impedance=50 Ω, permittivity of PCB=4.5.

Fig. 2. Current distribution at first resonance of PCB ground of clamshell type mobile handset.



L_1'=90 mm, L_2'=100 mm, L_3'=40 mm, L_f'=30 mm, L_{a1}'=5 mm, L_{a2}'=38 mm, L_{a3}'=8 mm, L_{a4}'=31 mm, t'=1.6 mm, t_f'=0.8 mm, t_a'=4 mm, FPCB line width=0.5 mm, distance between FPCB signal and ground line=0.5 mm, source and load impedance=50 Ω, permittivity of PCB=4.5.

Fig. 3. Current distribution at first resonance of PCB ground of clamshell type mobile handset with dummy FPCB.

can be shown as

$$\mathbf{J}=\sum_i \frac{-j\omega\int_v \mathbf{M}\cdot\mathbf{H}_i^* dv}{\left(\omega_i^2-\omega^2\right)}\mathbf{J}_i \approx \frac{-j\omega\int_v \mathbf{M}\cdot\mathbf{H}_0^* dv}{\left(\omega_0^2-\omega^2\right)}\mathbf{J}_0, \qquad (1)$$

where $\mathbf{J}_0$ is the ground mode current of the dominant mode excited by a PCB resonance operation, $\mathbf{H}_0$ is the magnetic field of the dominant mode, $\mathbf{M}$ is the equivalent magnetic current source generated by the digital signals on the FPCB, ω_0 is the complex resonance frequency of the dominant mode, ω is the frequency of the digital harmonic, $\mathbf{J}$ is the total excitation ground mode current in the handset, and the subindex i represents the i-th mode. The magnetic field near the PCB is linearly related to the ground mode currents [5].

To investigate the coupling between two ports, we apply the concept of reaction. The reaction of the magnetic field caused by the equivalent magnetic current source of port-a acting on the equivalent magnetic current source of port-b is defined by the following [6]:

$$\langle \text{port-a},\ \text{port-b}\rangle = -\int_v \mathbf{H}_{\text{ba}}\cdot\mathbf{M}_{\text{b}} dv = V_{\text{b}} I_{\text{ba}}, \qquad (2)$$

where $\mathbf{H}_{ba}$ and I_{ba} are the magnetic field and the current at port-b due to the source of port-a, respectively, $\mathbf{M}_b$ is the equivalent magnetic current source at port-b, and V_b is the voltage source at port-b. Y_{ba} of the admittance parameter can be expressed as

$$Y_{\text{ba}} = \frac{\langle \text{port-a},\ \text{port-b}\rangle}{V_{\text{a}} V_{\text{b}}}, \qquad (3)$$

where V_a is the voltage source at port-a. When the digital harmonics excite the PCB ground mode, the ground mode current of the dominant mode $\mathbf{J}_0$ is excited, and a corresponding magnetic field $\mathbf{H}_0$ is generated. In particular, the magnetic field at the antenna port $\mathbf{H}_{ba}$ is strongly generated because $\mathbf{J}_0$ is concentrated near the antenna port (port-b) at the resonance frequency of the PCB. Therefore, the reaction of the magnetic current source at the digital signal port (port-a) acting on the magnetic field of the antenna port (port-b) is large, and transfer admittance Y_{ba} is also large. The coupling between the two ports is represented by the S_{ba} of the scattering parameter, which is directly obtained from the admittance matrix by the following [7]:

$$S_{\text{ba}} = \frac{-2Y_{\text{ba}}Y_0}{(Y_{\text{aa}}+Y_0)(Y_{\text{bb}}+Y_0)-Y_{\text{ab}}Y_{\text{ba}}}, \qquad (4)$$

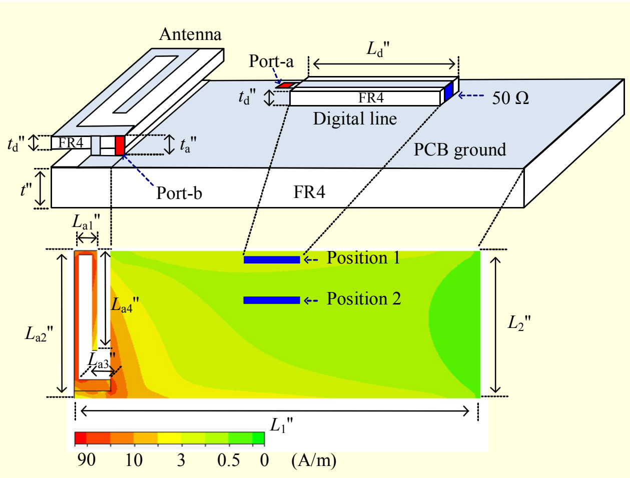
where Y_{aa} and Y_{bb} are the input admittance of port-a and port-b respectively, and Y_0 is the reference characteristic admittance used in scattering parameters. In (4), it is clearly shown that stronger coupling is obtained as the transfer admittance Y_{ba} increases.

According to (1), the ground mode current may be strongly excited if the equivalent magnetic current source (the digital signal loop) is placed where the values of the magnetic field $\mathbf{H}_0$ are large. In a clamshell type mobile handset, the ground mode current is strongly excited, and the digital signal on the FPCB is well coupled to the antenna because large values of $\mathbf{H}_0$ are formed at the narrow signal lines of the FPCB. Therefore, one way to reduce the coupling between the digital signal on the FPCB and the antenna may be to reduce $\mathbf{H}_0$ where the large digital signal loop is placed.

Figure 3 shows the current distribution at the first resonance of the main and flip parts of the PCB ground connected by an FPCB and an additional dummy FPCB, which consists of several conductor lines. In this case, $\mathbf{H}_0$ may be reduced because the dummy FPCB provides another ground mode current path between the main part and the flip part of the handset. Therefore, the harmonics of the digital signal excite the ground mode relatively weakly when the digital signal flows on the FPCB and the reaction <port-a, port-b> is reduced. As a result, the coupling between the digital signal and antenna may become weak. A simple but efficient technique can be used to reduce coupling between the FPCB and antenna.

III. Simulation and Measurement

All simulation results were obtained using a solver CST MWS, with measurements carried out using a network analyzer (Agilent E8358A). Port-a of the network analyzer is connected to the FPCB port, and port-b is connected to the antenna port of the handset model. Figure 4 shows the absolute value of the magnetic field at the first resonance frequency $|\mathbf{H}_0|$ of the PCB ground of the bar type mobile handset model when port-b is excited. If the digital signal line is placed at position 1, the current at port-b due to the unit voltage source of port-a is 0.24 mA, as shown in Fig. 5. The induced current at port-b is 0.13 mA when the digital signal line is placed at position 2. These results show that the coupling between the digital signal and antenna is not affected by the distance between them, but the coupling is affected by the position of the digital line. When the digital signal loop is placed where $\mathbf{H}_0$ is large and the equivalent magnetic current source $\mathbf{M}_0$ induced by the digital signal line is parallel with $\mathbf{H}_0$, the ground mode current is strongly excited and coupling is very large, as shown in (1).



L_1"=90 mm, L_2"=40 mm, L_d"=5 mm, L_{a1}"=5 mm, L_{a2}"=38 mm, L_{a3}"=8 mm, L_{a4}"=27 mm, t"=1.6 mm, t_f"=0.8 mm, t_a"=4, digital line width=0.5 mm, source and load impedance=50 Ω, permittivity of PCB=4.5.

Fig. 4. Absolute value of magnetic field at first resonance frequency of PCB with antenna in bar type mobile handset model.

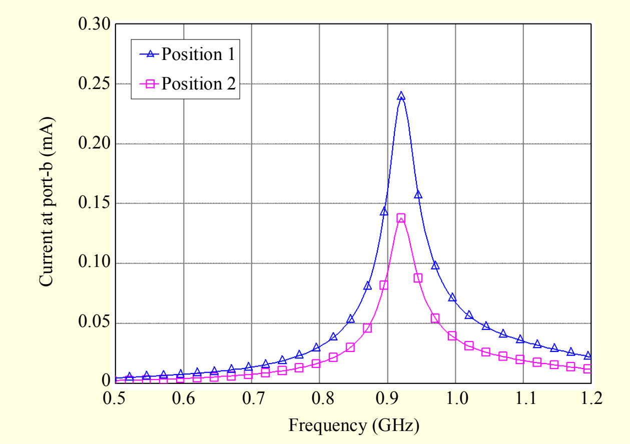


Fig. 5. Current at port-b due to unit voltage source of port-a.

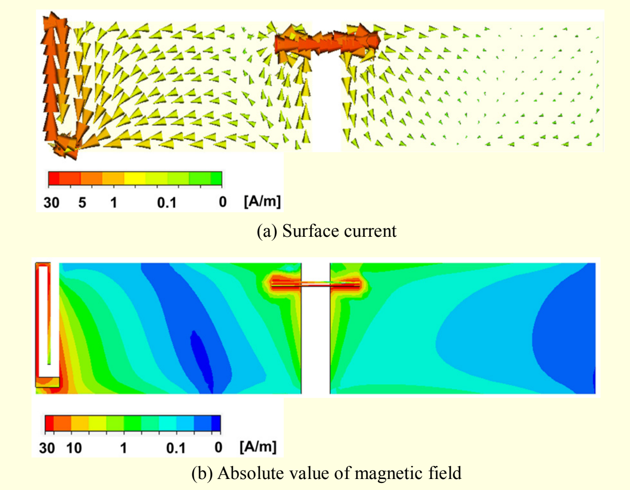


Fig. 6. Top view of surface current and magnetic field at first resonance frequency of PCB of mobile handset in Fig. 3.

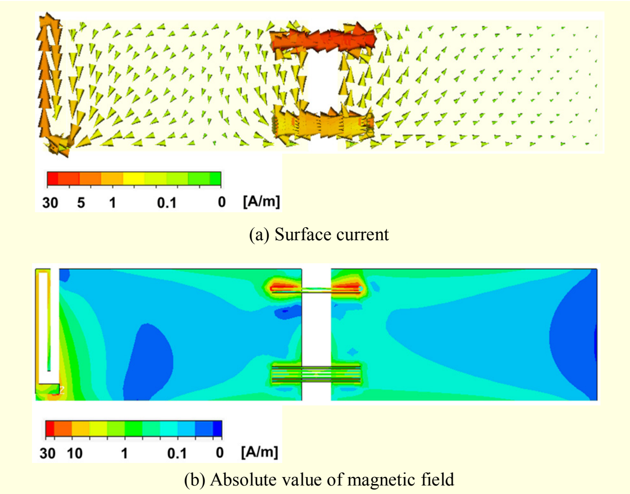


Fig. 7. Top view of surface current and magnetic field at first resonance frequency of PCB of mobile handset with dummy FPCB of mobile handset in Fig. 4.

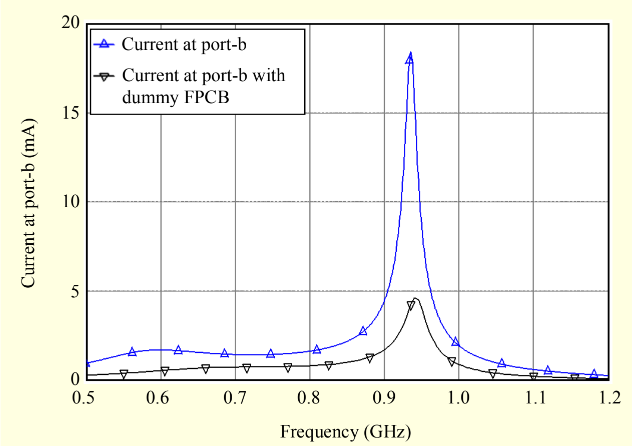


Fig. 8. Simulation results of current at port-b due to unit voltage source of port-a.

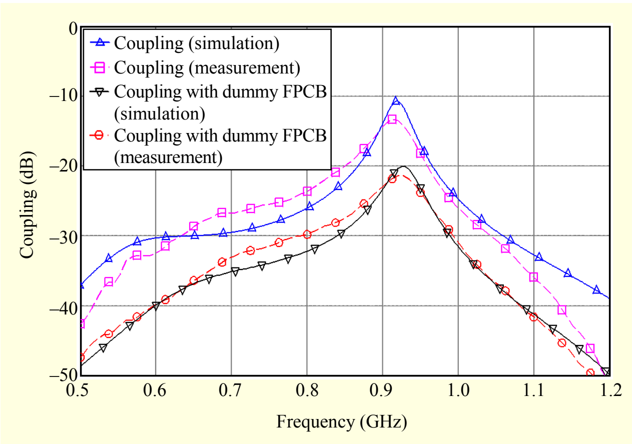


Fig. 9. Simulation and measurement results of coupling S_{ba} between FPCB port and antenna port.

Figure 6 shows a top view of the surface current and the absolute value of the magnetic field at the first resonance frequency of the model in Fig. 2. Because $\mathbf{H}_0$ is structurally very large at the FPCB part, the digital signal harmonics that flow on the FPCB strongly excite the PCB ground mode and form a corresponding large magnetic field distribution. Figure 7 shows the surface current and the absolute value of the magnetic field at the first resonance of the model in Fig. 3. Because the additional dummy FPCB (which consists of five conductor lines) provides another current path, we expect that $\mathbf{H}_0$ will be reduced, and thus the reaction <port-a, port-b> will also be reduced.

Figure 8 shows the simulation results of I_{ba} for a unit voltage source at port-a. In a comparison between I_{ba} of the model in Fig. 2 and I_{ba} of the model in Fig. 3, the flowing current is reduced approximately fourfold when using the dummy FPCB model in Fig. 3. If we use a unit voltage source at port-b (V_b=1), <port-a, port-b> is equal to I_{ba} and Y_{ba}, as shown in (3).

The coupling S_{ba} between the FPCB port and the antenna port can be calculated by Y_{aa}, Y_{ab}, and Y_{bb} of the Y-matrix as explained in section II, and the results of coupling are shown in Fig. 9. When the frequency of the digital harmonics is close to the antenna operating frequency, the ground mode current may be strongly excited by (1), and the coupling becomes large due to the strong ground mode current. In both simulated and measured results, when the FPCB model has another current path, such as the dummy FPCB, the coupling is decreased by 10 dB. This occurs because the generated magnetic field $\mathbf{H}_{ab}$ is decreased for the additional ground lines of the dummy FPCB, and $\mathbf{H}_{ba}$ is also decreased by the reciprocity theorem [6].

IV. Conclusion

In this letter, we investigated a method of decoupling a digital signal on an FPCB with an antenna, pointing out the context of the ground mode current and the reaction concept. We modeled the signal and ground lines in an FPCB as a loop circuit that excites the PCB ground modes. Because digital harmonic noises are primarily coupled to the antenna via the PCB ground, the coupling between the FPCB port and antenna port can be suppressed by the addition of a ground mode current path, such as a dummy FPCB. This is a simple but efficient method to reduce coupling between the FPCB and the antenna. Based on this method, RF sensitivity reduction caused by the digital harmonic noise can be significantly improved.

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