Case Study of Electromagnetic Interference in Surgery Environment

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Abstract – **In this paper, a case of electromagnetic interference (EMI) in medical display systems is reported. It concerns the nearby use of an electrosurgical knife disturbing video-monitors, interconnected by Ready-Made Connecting Devices (RMCD), in a surgery room. Based on full wave simulations, three parameters of these RMCD in a medical display installation, including the total length, location of connecting and the number of GND reference - wires, are identified. The simulation results demonstrate that these parameters can not only lead to EMI but are also influencing the characteristics of such EMI.**

Keywords –**EMC/EMI, ready-made connecting devices, electrosurgery knife; medical environment.**

I. Introduction

Ready-Made Connecting Devices (RMCD) are a set of cables/connectors inside electronic systems for the transmission of data and/or power. Current regulations do not consider RMCD as EMC-relevant since they are passive components. However, it has been shown in an example of HDMI cables that RMCD could contribute to RF disturbances [1]. This indicates that RMCD inside electronic systems should actually be paid extra attention to, otherwise they may lead to electromagnetic interference (EMI) issues. One such case is that the image of a medical display system gets distorted or even blanked due to the radiation caused by a nearby electrosurgery knife. Fig. 1 shows the conceptual layout of the operation room in the above case.

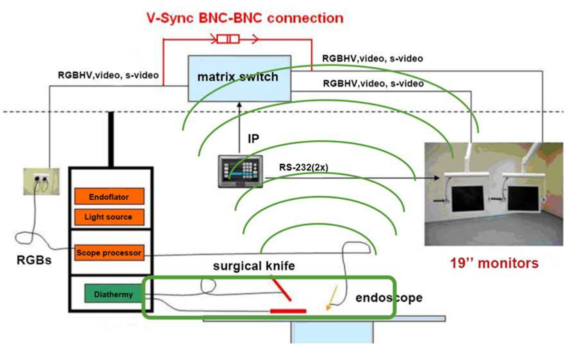


Fig. 1. Conceptual overview of a typical operation room with a surgical knife and medical displays

When the electrosurgical knife is operated (the working frequency is at least 200kHz), its radiated EMI couples into the medical display system. It has been found that this occurs through a RMCD of that installation.

As a result, the images obtained through the endoscope and shown on the medical display get distorted, or even a black screen is appearing (false triggering of the monitor).

The electrosurgical knife cannot be shielded, because the tip of the knife must be free accessible in order to touch the skin of the patient. The effect is that the induced electric and magnetic field will always radiate in space. The operation of the electrosurgical knife on the skin of the patient is demonstrated in Fig. 2.

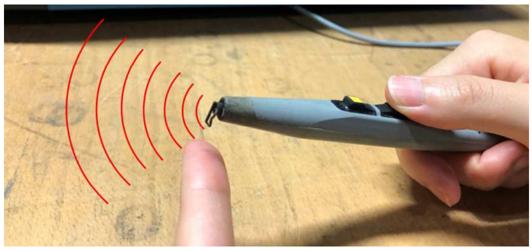


Fig. 2. Demonstration of the operation of electrosurgical knife on the skin of the patient

It must explicitly be noted that in this case, all equipment is properly CE marked, which means they are considered eligible to be used in a surgery environment. The only exception is a wall plug connector which connects different parts of the total installation. In this case, it consists out of 8 shielded cables, where inside the connector, all shields are bound together into only a few ground (GND) connecting wires, generating a "pigtail"- like connection, as shown in Fig. 3. It has been found that the radiated EMI from the electrosurgical knife couples into the display system via this not-well shielded connector in the RMCD.

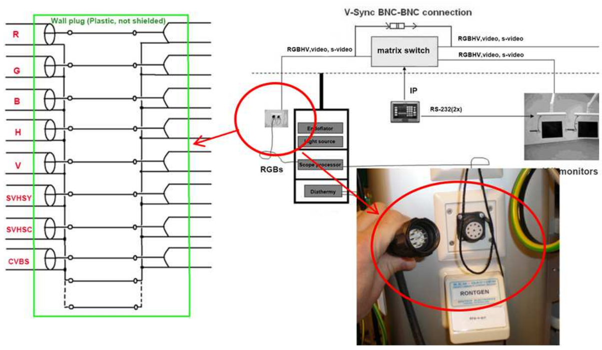


Fig. 3. Principle schematic of the ready-made connector

To verify this, the input of the display system was disconnected from the cabling, which was terminated with a matched impedance (75 Ohm). Once the electrosurgical knife was operated, an up to 2V peak-to-peak interference signal was observed, by connecting an oscilloscope at the cable output, as shown in Fig. 4.

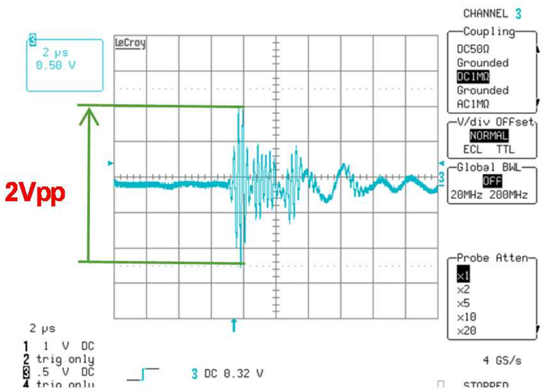


Fig. 4. Received interference signal by the medical display due to the radiation of a surgical knife

Since such RMCD may cause EMI issues and can be used everywhere in real electronic systems, it is important to understand how the radiated EMI couples into a system through such RMCD. To investigate this, a simplified model of that RMCD, consisting of only two coaxial cables, interconnected by a pigtail-like connector (hereinafter referred to as "connector") was created for use in a full wave simulation. Since it was clearly seen from the measurements that this connector caused the disturbance, only the parameters of the connector will be investigated. Considering that in practice, the length, location and the number or quality of the GND connection (called connection strength) of the connector will vary due to different user environments, these three parameters are selected for investigation.

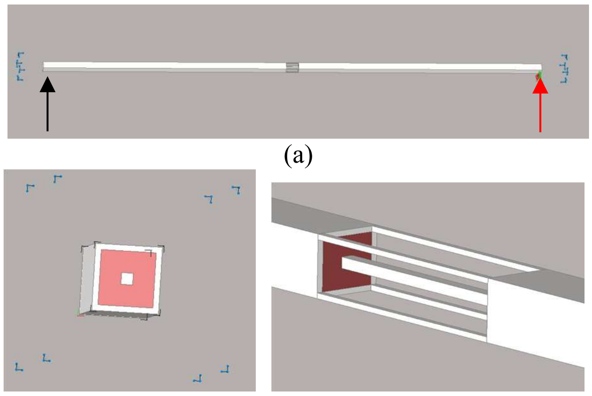
The remainder of this paper is organized as follows. In Section II, the RMCD simulation model together with detailed simulation setups are described. Section III compares and analyzes the simulation results of each parameter investigation. Finally, Section IV draws the conclusions and discusses future work.

II. Simulation Model and Setup

In the case of an electrosurgical knife, the RMCD functions as a receiving antenna regarding the EMI from the external surgery environment. However, in simulations it is difficult to model a source like a complicated electrosurgical knife. Based on the principle of reciprocity, the RMCD model will be used as transmitter. By observing the radiated power in the environment, similar conclusions as when it acts as a receiving antenna, can be drawn.

As mentioned before, the RMCD model consists of a connector and two coaxial cables as is shown in Fig. 5. The coaxial cable is based on a square cross section, with an inner conductor, outer conductor and the intermediate dielectric materials, as is for a common real coaxial cable. This square shape will optimize both the size of the mesh and the calculation time. Nevertheless, this simplification will not influence the conclusions, as long as the characteristic impedance of the coaxial cable and the "pigtail" is correctly designed.

For this report, the full wave simulation has been done in PathWave EM Design (EMPro) [2]. In order to consider a more generic situation, the characteristic impedance of the coaxial cable is designed to 50 Ohm and is verified in frequency domain (S_{11}), as shown in Fig. 6. The "connector" consists of GND connecting wires which connect the shields (outer conductor) of the two coaxial cables.



(a) (b) (c)

Fig. 5. Modeled RMCD (a) Overview of RMCD (b) cross section of coaxial cable (c) pigtail-like connector

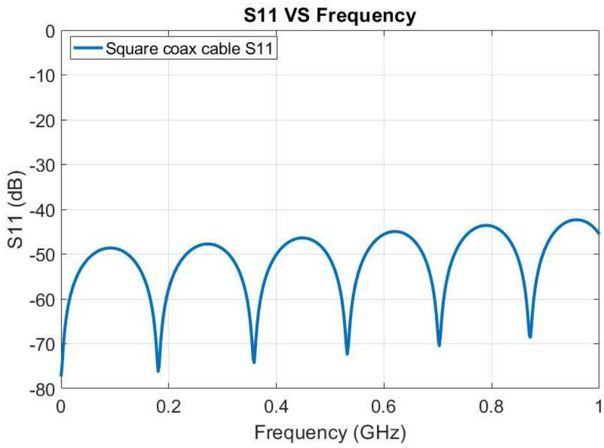


Fig. 6. Verification of the coaxial cable characteristic impedance: frequency domain results (S_{11})

Since the RMCD is used as an emitter, an input signal is applied to the coaxial cable structure. In this paper, a Gaussian pulse was adopted as the input signal, as shown in Fig. 7. As can be seen from the frequency domain, the spectrum may be considered as flat up to the frequency of interest of 1 GHz (black arrow).

The input signal with a net available power (i.e., total injected power) 0.0025W is applied at one end of the RMCD coaxial structure (black arrow in Fig. 5a). The other end was terminated with a matched impedance (red arrow in Fig. 5a). How each parameter of the connector influences the radiated EMI can be investigated by comparing the corresponding radiated power spectrum, from 10MHz to 1GHz, with the power spectrum of the reference case (without the connector).

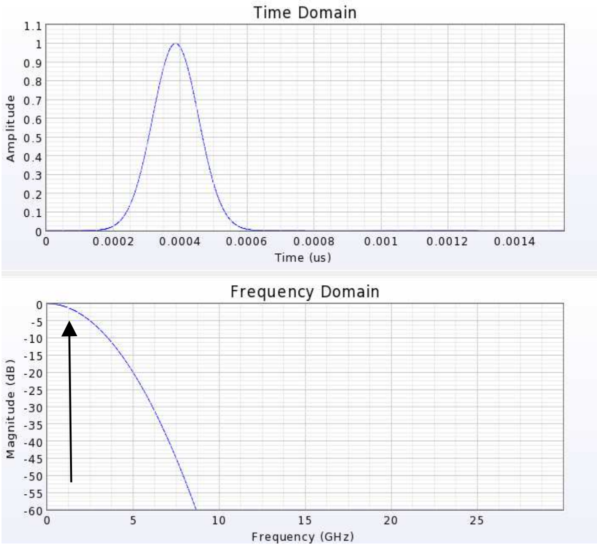


Fig. 7. Time domain and frequency domain of the input signal (Gaussian pulse)

III. Simulation Results and Analysis

In this section, the influence of each parameter of the connector will be investigated separately. For each parameter investigation, the target parameter will be assigned different values, while the other two parameters will be kept constant. By comparing the radiated power spectrum of each value and the reference case, the influences of each parameter can be identified.

A. Reference case (pure coaxial cables without pigtail-like connector)

Ideally, the whole RMCD in reality should be fully shielded to prevent EMI. Thus, the coaxial cables should be connected with a fully shielded connector (if a connector is needed), which will cause almost no radiation. In the simulation of the reference case, the connector was removed to mimic a fully shielded RMCD.

B. Length of connector

To investigate the influences of the connector length, the connector was set to the length of 1cm, 2cm and 3cm, respectively, as shown in Fig. 8. For all the three lengths, the connector consists of only 1 GND connecting wire and is always located at the center of the 1m length RMCD (i.e., coaxial cables at each side of the connector are of the same length). Fig. 9. shows the total radiated power for each length. From the power spectrum, it can be seen that for RMCD with the same number of GND connecting wires, longer connectors will lead to higher radiated EMI power. This is because a longer connector has longer GND connecting wires, causing a higher impedance connection between the two coaxial cables. With the same amount of return current flowing through the GND wiring, a higher impedance connection results in a higher coupling voltage and thus more EMI can be radiated or picked up.

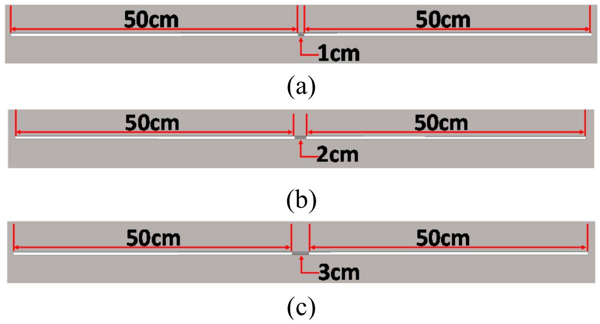


Fig. 8. Examples of the investigation of the length of the connector (a) 1cm connector (b) 2cm connector (c) 3cm connector

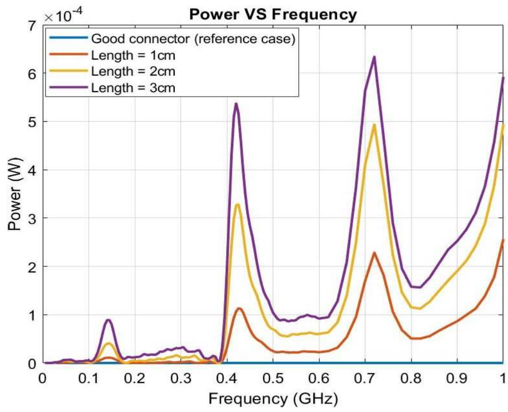
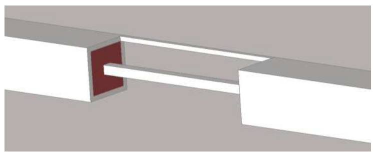


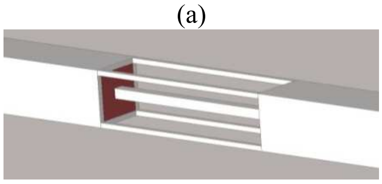
Fig. 9. Radiated power from connectors with different lengths

C. Connection strength of connector

Next, the influence of the number of GND connecting wires inside the connector was investigated. The number of GND connecting wires is set to 1, 2 and 4, respectively. Again, examples are shown in Fig. 10. In each case, the connector was set to 1cm length and placed at the center of the 1m RMCD. As the results shown in Fig. 11., when the not well shielded connectors are at the same location inside a RMCD and have the same length, more GND connecting wires will reduce the radiated EMI power. This is due to the fact that increasing the number of GND connecting wires will reduce the impedance of the connection between the two coaxial cables. Similarly, as above, this decreased impedance can reduce the voltage over the GND wiring, resulting in a lower coupling level and thus a weaker radiation behavior.



(a)



(b)

Fig. 10. Examples of the investigation of the connection strength of the connector (a) 1 GND wire (b) 4 GND wires

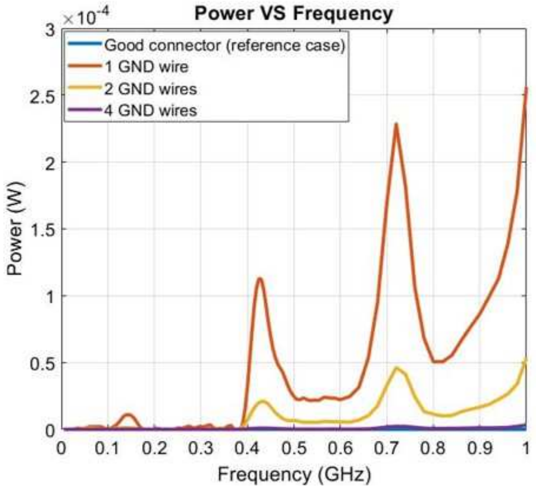


Fig. 11. Radiated power from connectors with different connection strength

D. Location of connector

Finally, the influences of the connector locations inside a RMCD were explored. In this part, the connector inside the RMCD was placed at 20cm (from the signal injection end of the RMCD, same below), 25cm and 50cm, respectively. Once again, examples are shown in Fig. 12. At each location, the connector always has 1 GND connecting wire with a length of 1cm. The simulated radiation power spectrum is shown in Fig. 13.

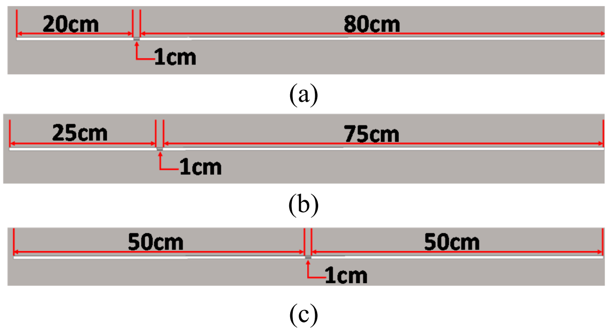


Fig. 12. Examples of the location of the connector (from the signal injection end) (a) 20cm (b) 25cm (c) 50cm

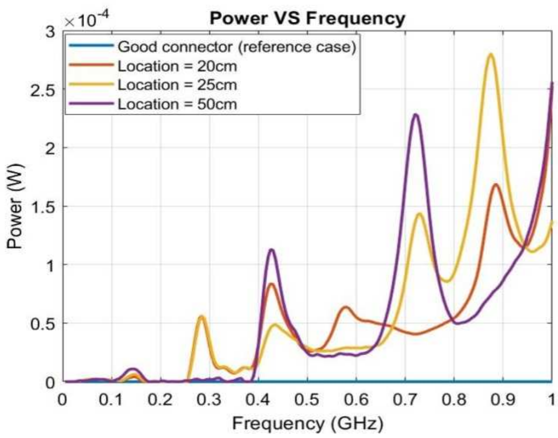


Fig. 13. Radiated power from connectors at different locations

From the spectra, two phenomena are observed. First, different connector locations lead to almost the same first radiation peaks. Second, the peaks in the symmetrical location case (in this simulation is the 50cm case) and the asymmetrical cases (the other two cases) are different, regarding the frequency and the amplitude. This phenomenon is similar as the behavior of a dipole antenna [3][4].

IV. Conclusion and Future Work

In this paper, a case study of an image distortion on a medical display system has been reported. This image distortion is due to the nearby use of an electrosurgical knife. It has been found that the radiated EMI from the electrosurgical knife couples into the medical display system through a RMCD. To understand which parameters of a RMCD could influence the coupling effect, according to reality, a RMCD simulation model was created. Based on full wave simulations, three physical parameters of the RMCD have been identified: the location of the RMCD in the connecting cabling, the length of the RMCD connector and the number of GND connecting wires.

Based on this case study, it can also be concluded that although standalone active devices have been EMC compliant, EMI issues could still occur when these active devices are inter-connected with passive devices [1][5].

Future work will focus on a generic in-depth analysis of these three parameters of a RMCD, both by simulations and measurements, as well as the modeling of the RMCD, as a component coupling to the environment.

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