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Abstract: The article describes possible ways and techniques for reducing the electromagnetic interference that is produced by electronic devices. Electromagnetic interference is handled by national and international authorities. The authorities define individual limits of mentioned electromagnetic interference within specific frequency bandwidth. Provided information can help engineers to identify root cause of product noncompliance in the field of electromagnetic interference. Experimental measurements supports provided theory about cable assemblies interaction with the unintentional generator output quantities occupying frequency spectrum.

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Abstract *– The article describes possible ways and techniques for reducing the electromagnetic interference that is produced by electronic devices. Electromagnetic interference is handled by national and international authorities. The authorities define individual limits of mentioned electromagnetic interference within specific frequency bandwidth. Provided information can help engineers to identify root cause of product noncompliance in the field of electromagnetic interference. Experimental measurements supports provided theory about cable assemblies interaction with the unintentional generator output quantities occupying frequency spectrum.*

1 Introduction

Many of techniques are available to make electronic device compliant with the limits provided by international standards for radiated emissions. One of the validation techniques is radiated interference verification in semi-anechoic chambers. Equipped semi-anechoic chamber can provide complete overview of electronic product radiated emissions. It is a time consuming process that is looking for highest value of radiated electric field. For this reason the electric field is measured from every device side. Turn table secures automatic device rotation. Electronic device is also wanted to be compliant in each operational state it can operate. Transition behaviors and intermittent operational states can be typically excluded from such a compliance measurement. Measurement of radiated emissions per standards recommendations is not a suitable method in case of flexible electronic product development. Any individual change in product design needs to be verified. Every manufacturer is aware of possibility to see design behavior immediately after the change is made. Slight modification in product hardware or firmware can bring important results that help to find a solution. Any fast indirect comparison method then supports dynamic product development. Key information is hidden in reality of tens of kilohertz oscillator as a source of electric field exceeding significantly standard limits at frequency of hundreds of megahertz. The experimental measurements are conducted just with single wire antenna.

2 Wires as effective unwanted antennas

Every piece of wire that leads outside the electronic device is a potential antenna. Usually cables of various lengths lead into the product terminals from various directions. These unwanted antennas and its tunability during the electromagnetic interference measurement is typically depending on wire diameter, wire length, wire cable assembly and device wiring versus semi-anechoic chamber surrounding.

2.1 Unintentional monopole antennas

Fig. 1 shows possible device unintentional antennas. Those two effective antennas can be found in a common electronic system. Unintentional antennas are also located inside the electronic product especially as layers on printed wiring board. The same rules of electromagnetic waves propagation as for cable assemblies are expected. From the physical point of view the product common mode emissions make the monopole antennas radiating. Setup for typical radiated interference measurement consists of a potential dipole antenna. The first half of dipole antenna is made by product cable, wire or wire harnesses and its second half is presented by ground plane of semi-anechoic chamber. Dipole resonant frequency is based on dipole physical length $l = \lambda/2$. Unintentional product monopole antenna is then created by length of $l = \lambda/4$. Unless otherwise stated the product manufacturer is forced by standard to verify product emissions with 1 m cable length. Product cables are usually lead in horizontal polarization against the semi-anechoic chamber ground floor. Power cable is usually vertically polarized and directly plugged into the socket. The rest of cables length is used for product interconnections. Directivity of a quarter wave monopole above a ground plane is equal to twice that of a half-wave dipole radiating in free space [1]. The maximum directivity occurs along the ground plane and the radiation is vertically polarized. Ideal monopole resonant frequency can be easily calculated by expression (1).

$$f = \frac{c}{\lambda}, \tag{1}$$

where $\lambda = 4l$ and l is monopole length, f is the resonant frequency, c is velocity of the light. ***Example 1:*** Obviously the most critical frequency that collocates with expression (1) is approximately $f = 100$ MHz.

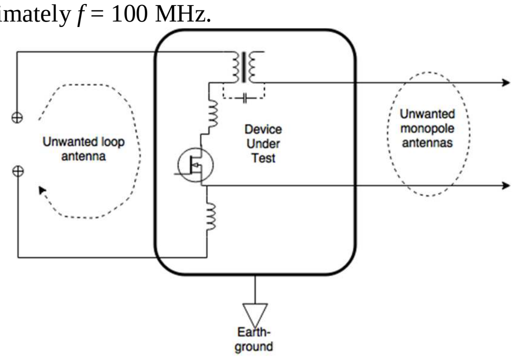

Figure 1: Example of unwanted monopole & loop antennas.

elektrorevue
ISSN 1213 - 1539

Parasitic inductances created by printed wiring board layers are visible in Fig. 1. Inductance voltage can be calculated by (2).

$$v = -L\frac{\Delta i}{\Delta t}, \qquad (2)$$

where v is voltage, i is current, L is inductance and t is time. ***Example 2:*** In case we will use for (2) real values, L = 10 nH, Δt = 10 ns, Δi = 1 A, we obtain v = 1 V of source voltage for monopole antenna.

3 Frequency response of unwanted generators

Most of the electronic products are using digital signals for driving its auxiliary circuitries. These digital signals are being deformed along the path from microprocessor to the product output gates. The digital signal deformations depend on circuitry components non-linearity. Transistors, bus drivers and other active components are amplifying devices of microprocessor signal rising/falling edges. Different $\Delta u/\Delta t$ and $\Delta i/\Delta t$ responses are possible source of disturbance in frequency domain. Fast current and voltage responses on digital signal falling/rising edge are also factors that increase harmonics magnitude of circuitry fundamental frequency. Those harmonics are propagated in to the free space by product wiring, supply lines and communication interfaces as described in 2.1.

3.1 Magnitude spectrum of rising, falling edge and effect of ringing.

The magnitude of specific digital signal harmonics in frequency spectrum is related to signal rising/falling edges, fundamental frequency duty cycle and waveform amplitude. Relation between time domain and frequency domain of trapezoidal pulse is illustrated in Fig. 2. This is based only on simplifying presumption that rising/falling edges duration is equal. Oscillating behavior can occur when rising edge achieves its maximum or falling edge its minimum. This oscillating behavior also known as "ringing" amplifies harmonics magnitude of circuitry fundamental clock frequency. Such ringing is then visible as harmonics magnitude increase at frequencies corresponding to ringing waveform.

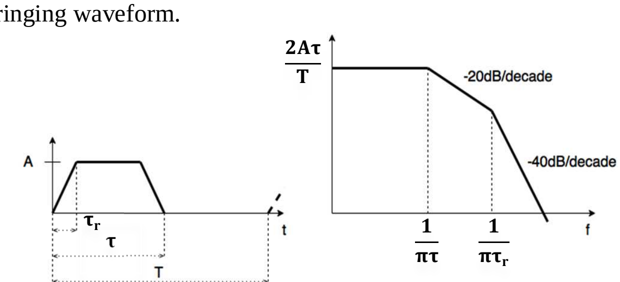

Figure 2: One-sided magnitude spectrum of a trapezoidal pulse train [2]

4 Experimental measurements

Based on example 1 and example 2 the simple transmitter was made. The transmitter was prepared for change of its fundamental frequency. Chosen oscillator frequencies in our case are 32 kHz and 4 MHz. These oscillators were separately connected to 5 V TTL logic. Two kind of TTL logic were exposed to electromagnetic field interference measurement. The LS type with 9 ns rising/falling edge and HCT logic with 3 ns rising/falling edge. The HCT logic also showed ringing effect. Single wire antenna of 0.75 m length and 0.7 mm diameter was connected directly to TTL logic output. ***Example 3:*** Frequency count per Fig. 2 for HCT logic with t_r = 3 ns, $1/\pi\tau_r$ = 106 MHz.

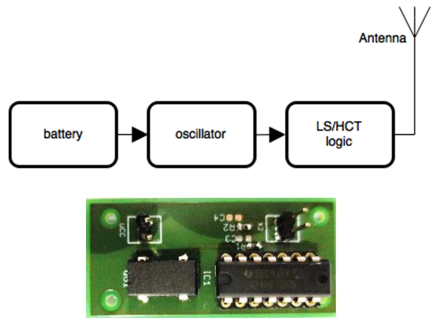

Figure 3: Experimental Transmitter

Spectrum of transmitter output signal was measured by oscilloscope with spectrum analyzer option. Oscilloscope active probe loaded the transmitter output by 1 MΩ impedance and 0.8 pF parasitic capacitance. Oscilloscope analyzer resolution bandwidth was set to 120 kHz which is compatible with resolution bandwidth of semi-anechoic chamber receiver. Shapes of magnitudes at particular frequencies can be comparable in this case. Final measurements were conducted in fully anechoic chamber from 3 m measurement distance. In fully anechoic chamber the wire antenna polarization is not influenced by electromagnetic waves reflection from the chamber ground plane. Receiver filter was set on 120 kHz [4] resolution bandwidth in accordance with radiated emissions standard. Single wired antenna was connected to our experimental transmitter output and polarized horizontally versus test system receiving antenna. The transmitter was supplied by 3 pieces of 1.5 V AA type batteries. Spectral data was measured by EMI receiver with FFT option therefore every measurement took few seconds and transmitter power consumption did not influence measured data at all. For that reason battery discharge did not need to be considered.

4.1 Transmitter output spectra

Figure 4, Figure 5 and Figure 6 show various output spectra of generator output. Table 1 voltage compares magnitudes at frequency 110 MHz. It is a frequency where the antenna resonance was expected and measured.

Table 1: Approximate voltage magnitudes at frequency of interest of 110MHz.

32 kHz HCT logic	32 kHz LS logic	4 MHz HCT logic
~55 dBuV @110 MHz	~40 dBuV @110 MHz	~95 dBuV @110 MHz

elektrorevue
ISSN 1213 - 1539

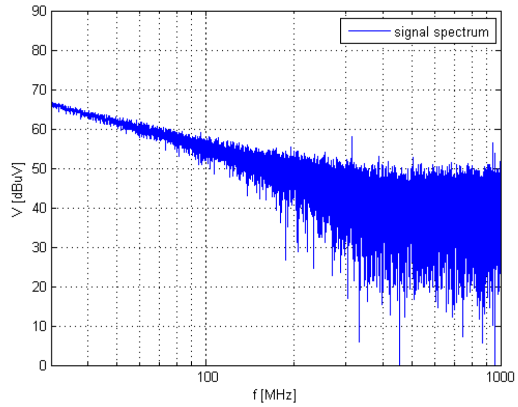

Figure 4: Output spectrum of HCT logic connected to 32 kHz oscillator.

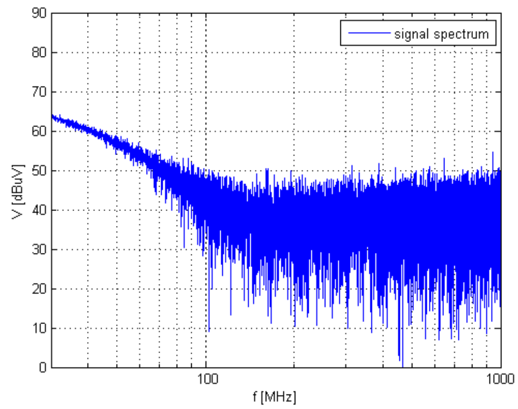

Figure 5: Output spectrum of LS logic connected to 32 kHz oscillator.

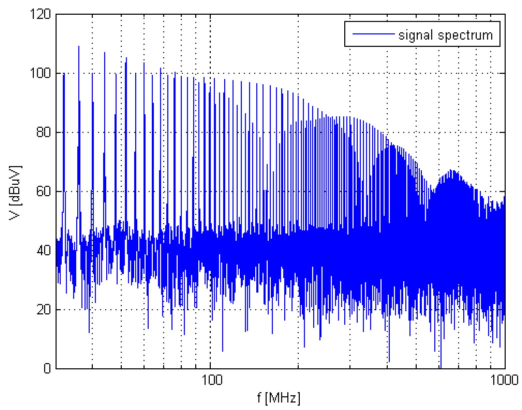

Figure 6: Output spectrum of HCT logic connected to 4 MHz oscillator.

4.2 Radiated emissions measurement comparison

A limit of 40 dBuV/m [3] is specified by standard in frequency range from 30 MHz to 230 MHz for general purpose household appliances at 3 m measurement distance. It is important to note that 5 V source operating at 32 kHz fundamental frequency can make a device noncompliant. In Fig. 7 and Fig. 8 single wire antenna resonance occurred. Electric field magnitudes at single wired antenna resonance frequencies visible in those two figures are dependent on generator rising/falling edges duration. However antenna specific resonant frequency determined from Fig. 7, 8, 10, 11 stays unchanged.

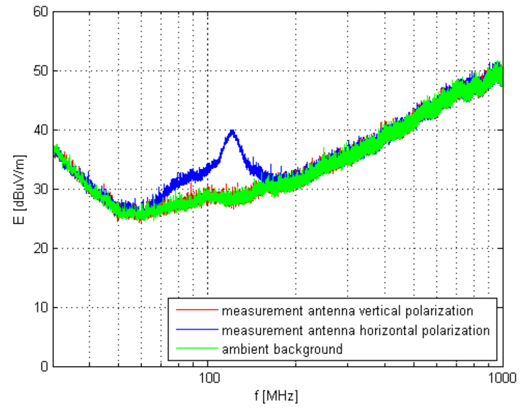

Figure 7: Radiated interference of 32 kHz transmitter with LS logic. Single wire antenna of 0.75 m length was connected to transmitter output.

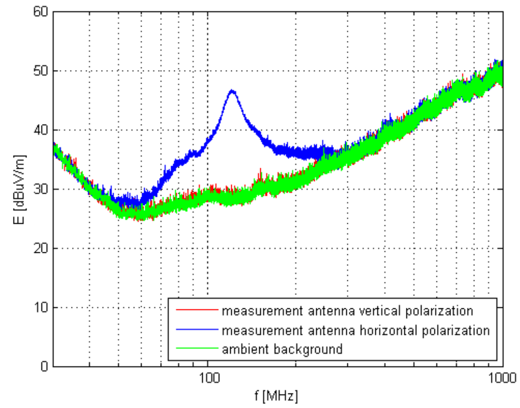

Figure 8: Radiated interference of 32 kHz transmitter with HCT logic. Single wire antenna of 0.75 m length was connected to transmitter output.

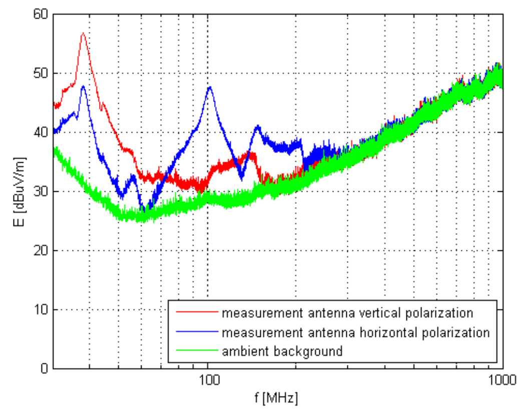

Figure 9: Radiated interference of 32 kHz transmitter with HCT logic. Single wire antenna of 0.75 m length was connected to transmitter output. Transmitter was grounded to chamber chassis.

elektrorevue
ISSN 1213 - 1539

Fig. 9, 12 show changes of resonant frequency while the transmitter is grounded on chamber chassis. Grounding wire of 1 m length made the previous monopole antenna longer and it now resonates with lower frequency. Antenna radiates also in vertical polarization at lower frequency. It is because the transmitter grounding wire is first half of a vertically polarized dipole whereas horizontally polarized wire connected on transmitter output is the second part of dipole antenna.

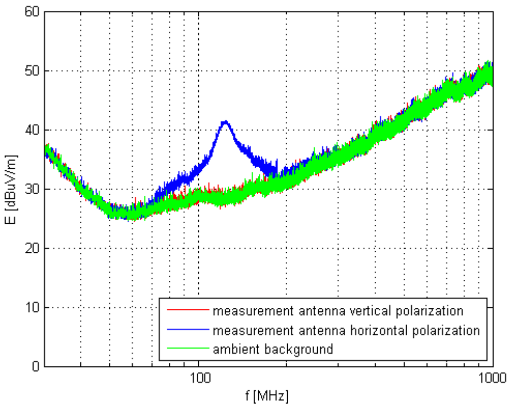

Figure 10: Radiated interference of 32 kHz transmitter with HCT logic. Antenna of a 0.75 m length connected to transmitter output. Instead of single wire ribbon cable was used. Ribbon second wire was connected to transmitter ground.

Antenna resonant frequency stays unchanged while using a two wires ribbon cable. One of the ribbon cable wire is connected directly to transmitter output whereas the other from ribbon cable wire is connected to generator ground. See Fig. 10 for waveform.

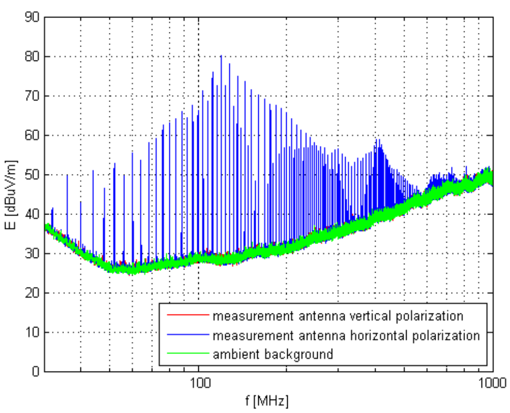

Figure 11: Radiated emissions of 4 MHz transmitter with HCT logic. Single wire antenna of 0.75 m length connected to generator output.

Fig. 11 in comparison to Fig. 7, 8, 10, 11 shows similar shape of antenna resonant frequency waveform. Visibility of 4 MHz harmonics is caused by usage of 120 kHz EMI receiver resolution bandwidth. Same receiver resolution bandwidth was applied for interference measurement of transmitter with 32 kHz oscillator. 32 kHz harmonics are not visible in this case because EMI filter resolution bandwidth is four time wider and measured harmonics are overlapped and creating the envelope.

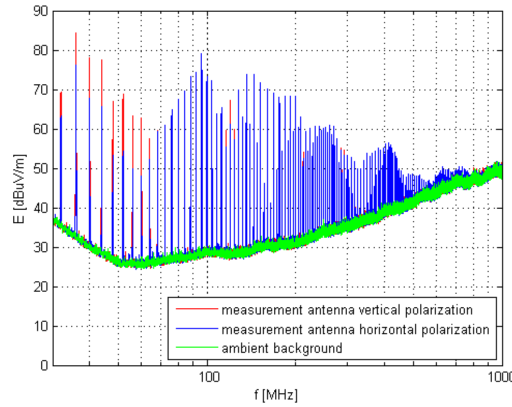

Figure 12: Radiated emissions of 4 MHz transmitter with HCT logic. Single wire antenna of 0.75 m length connected to transmitter output. Transmitter was grounded to chamber chassis.

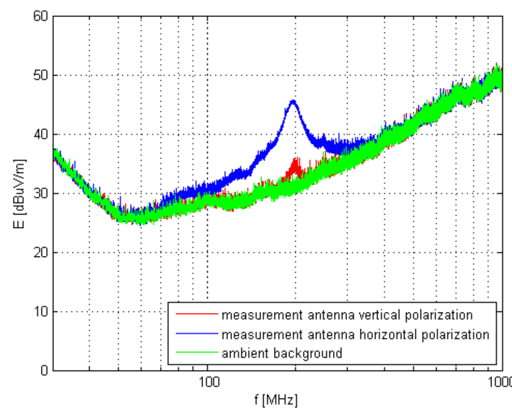

Figure 13: Radiated emissions of 32 kHz transmitter with HCT logic. Single wire antenna of 0.4 m length connected to transmitter output.

Fig. 13 illustrates wire antenna resonant frequency while the wire antenna length was reduced to 0.4m. Antenna resonant frequency change corresponds with wire length again.

Table 2: Approximate magnitudes of electric field at frequency of interest during emissions measurement of non-grounded transmitter.

32 kHz HCT logic	**32 kHz LS logic**	**4 MHz HCT logic**
~47 dBuV/m @110 MHz	~40 dBuV/m @110 MHz	~80 dBuV/m @110 MHz

5 Conclusions

In the article it is described general product development technique for electromagnetic interference source identifica-

elektrorevue ISSN 1213 - 1539

tion. From the experimental measurements it is obvious that device cables and their specific length plays significant role in electromagnetic unintentional interference propagation into the surrounding. Its tunability is especially depending on its length. Change of EMI receiver resolution bandwidth to product lowest internal frequency can help to investigate source of interference at unintentional antennas resonance frequencies. Specific product output that works as emissions generator can be then investigated by removing each input/output cable individually.

Acknowledgements

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