Digital Circuit Radiation

Choose yourself and new technologies

HUMAN CAPITAL
Wroclaw University of Technology
EUROPEAN SOCIAL FUND
Project co-financed from the EU European Social Fund

References

Basic:

Ott H. W., *Electromagnetic Compatibility Engineering*, Wiley, Hoboken, NJ, 2009

Additional:

Williams T., *EMC for Product Designers*, Elsevier-Newnes, 4-th ed., Oxford, 2007

HUMAN CAPITAL Wroclaw University of Technology EUROPEAN SOCIAL FUND Project co-financed from the EU European Social Fund

Wroclaw University of Technology Master programmes in English at Wroclaw University of Technology

Source of illustrative materials

All the illustrative materials have been taken from:

Ott H. W., *Electromagnetic Compatibility Engineering*, Wiley, Hoboken, NJ, 2009

HUMAN CAPITAL Wroclaw University of Technology EUROPEAN SOCIAL FUND Project co-financed from the EU European Social Fund

Digital Circuit Radiation

Radiation from digital electronics can occur as either **differential mode or common mode.**

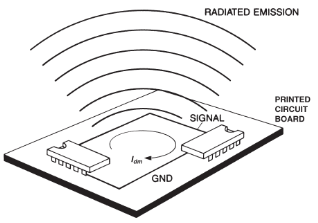
Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

Digital Circuit Radiation

Differential-mode radiation is the result of the normal operation of the circuit and results from current flowing around loops formed by the conductors of the circuit, as shown in the following slide.

Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

Differential-mode radiation

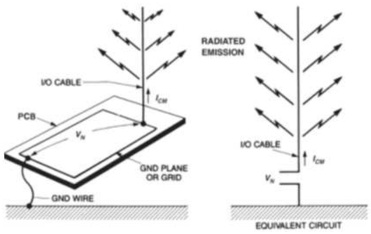


Digital Circuit Radiation

Common-mode radiation is the result of parasitics in the circuit and results from undesired voltage drops in the conductors.

Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

Common-mode radiation



HUMAN CAPITAL
Wroclaw University of Technology
Project co-financed from the EU European Social Fund

Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

DIFFERENTIAL-MODE RADIATION

Differential-mode radiation can be modeled as a small loop antenna. For a small loop of area A, carrying a current I_{dm}, the magnitude of the electric field E measured in free space at a distance r, in the far field, is equal to

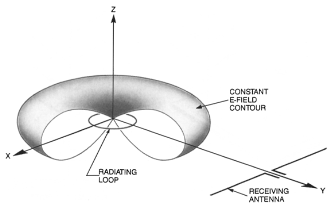
$$E = 131.6 \times 10^{-16} (f^2 A I_{dm}) \left(\frac{1}{r}\right) \sin\theta$$

All small loops having equal area radiate the same regardless of their shape.

HUMAN CAPITAL
Wroclaw University of Technology
Project co-financed from the EU European Social Fund

DIFFERENTIAL-MODE RADIATION

The free-space antenna pattern for a small loop is a torus (doughnut shape).



DIFFERENTIAL-MODE RADIATION

The equation for the magnitude of the electric field E is for a small loop located in free space. The reflective ground plane can increase the measured emission as much as 6 dB (or a factor of two). Thus,

$$E = 263 \times 10^{-16} (f^2 A I_{dm}) \left(\frac{1}{r}\right)$$

DIFFERENTIAL-MODE RADIATION

Differential-mode (loop) radiation can be controlled by

1. Reducing the magnitude of the current
2. Reducing the frequency or harmonic content of the current
3. Reducing the loop area

For a current waveform other than a sine wave, the Fourier series of the current waveshape must be determined before substitution into the discussed equation.

DIFFERENTIAL-MODE RADIATION
Loop Area

$$A = \frac{380\,Er}{f^2 I_{dm}}$$

where E is the radiation limit in microvolts per meter, r is the distance between the loop and measuring antenna in meters, f is the frequency in MHz, I is the current in milliamps, and A is the loop area in square centimeters.

DIFFERENTIAL-MODE RADIATION
Loop Current

If the current in the loop is known, it is easy to use the equation for the magnitude of the electric field E to predict the radiation.

DIFFERENTIAL-MODE RADIATION
Fourier Series

Because digital circuits use square waves, the harmonic content of the current must be known before calculating the emission.

Wroclaw University of Technology — Master programmes in English at Wroclaw University of Technology

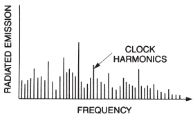
CONTROLLING DIFFERENTIAL-MODE RADIATION
Board Layout

The place to start controlling differential-mode radiated emission is with the layout of the printed circuit board.

Wroclaw University of Technology — Master programmes in English at Wroclaw University of Technology

CONTROLLING DIFFERENTIAL-MODE RADIATION
Board Layout

Figure shows the radiated emission spectrum from a typical digital circuit. In almost all cases, the emission from the clock harmonics exceeds the emission from all the other circuits.



HUMAN CAPITAL — Wroclaw University of Technology — European Social Fund
Project co-financed from the EU European Social Fund

Wroclaw University of Technology — Master programmes in English at Wroclaw University of Technology

CONTROLLING DIFFERENTIAL-MODE RADIATION
Board Layout

Clock signals should be routed first on a PCB, and every effort should be made to route them in a manner that produces the absolute smallest loop area possible.

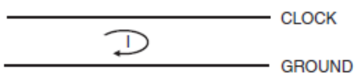
HUMAN CAPITAL — Wroclaw University of Technology — European Social Fund
Project co-financed from the EU European Social Fund

CONTROLLING DIFFERENTIAL-MODE RADIATION
Board Layout

To prevent the clock from coupling to cables that leave the PCB, the clock circuitry should be located away from the input/output (I/O) cables or circuitry.

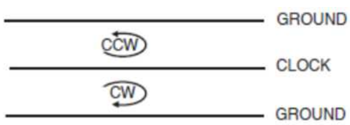
CONTROLLING DIFFERENTIAL-MODE RADIATION
Canceling Loops

Consider the case of a clock trace and its ground return path as shown in the figure. The emission from this loop will be a function of the area of the loop and the current in the loop.



CONTROLLING DIFFERENTIAL-MODE RADIATION
Canceling Loops

Consider the layout shown in the figure below. We have a clock trace with two ground return traces, one on each side. Hence we have two loops, each of which has the same area as the loop shown in the previous slide.



COMMON-MODE RADIATION

Differential-mode radiation can be controlled in the design and layout of the PCB.
Common-mode radiation is harder to control and often determines the overall emission performance of a product.

COMMON-MODE RADIATION

Common-mode emission can be modeled as a dipole, or monopole, antenna (the cable) driven by a noise voltage (the ground voltage). For a short dipole antenna (ideal uniform current antenna) of length l, the magnitude of the electric field strength measured, in the far field, at a distance r from the source is

$$E = \frac{4\pi \times 10^{-7}(flI_{cm}) \sin\theta}{r}$$

where E is in volts/meter, f is in hertz, I is the common-mode current on the cable (antenna) in amperes, l and r are in meters, and Θ is the angle from the axis of the antenna that the observation is made. The maximum field strength will occur perpendicular to the axis of the antenna where Θ = 90º.

COMMON-MODE RADIATION

Common-mode (dipole) radiation can be controlled by:

1. Reducing the magnitude of the common-mode current
2. Reducing the frequency or harmonic content of the current
3. Reducing the antenna (cable) length

For a current waveform other than a sine wave, the Fourier series of the current must be determined before substitution into the equation.

COMMON-MODE RADIATION

Common-mode emission is more likely to be a problem at low frequencies, and differential-mode emission is more likely to be a problem at high frequencies.

For a long cable (**$l > \lambda/4$**) we use the **$\lambda/4$** prediction at all frequencies above where the cable is a quarter-wavelength long.

Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

CONTROLLING COMMON-MODE RADIATION

As is the case for differential-mode radiation, it is desirable to limit both the rise time and frequency of the signal to decrease the common-mode emission.

No common-mode current is required for normal system operation.

HUMAN CAPITAL
Wroclaw University of Technology
Project co-financed from the EU European Social Fund

Wroclaw University of Technology
Master programmes in English at Wroclaw University of Technology

CONTROLLING COMMON-MODE RADIATION

The net common-mode current on a cable can be controlled by:

1. Minimizing the common-mode source voltage, normally the ground potential
2. Providing a large common-mode impedance (choke) in series with the cable
3. Shunting the current off the cable
4. Shielding the cable
5. Isolating the cable from the PCB ground, for example, with a transformer or optical coupler

HUMAN CAPITAL
Wroclaw University of Technology
Project co-financed from the EU European Social Fund