

TECHNICAL REPORT: CVEL-13-052

**Maximum Radiated Emission Calculator:
Differential-Mode EMI Algorithm**

Chentian Zhu and Dr. Todd Hubing

Clemson University

October 12, 2013

Abstract

The Maximum Radiated Electromagnetic Emissions Calculator (MREMC) is a software tool that allows the user to calculate the maximum possible radiated emissions that could occur due to specific source geometries on a printed circuit board. This report describes the *Differential-Mode EMI* algorithm, which determines the maximum possible radiated emissions that could occur due to direct radiation from the differential currents flowing on circuit board traces. The method used, calculations made, and implementation details are described.

1. Introduction

Differential-mode (DM) currents are currents that travel from the source to the load on one trace and return on another trace or plane along a path that is parallel and very near to the out-going path. Because the fields from the out-going current are nearly canceled by the fields from the returning current, differential-mode currents are inefficient radiation sources. They are much less likely to radiate significant amounts of electromagnetic energy when compared to common-mode currents that flow in one direction on one or more conductors with no near-by return path. Nevertheless, large differential-mode signal currents on circuit board traces are capable of causing radiated emission problems. The differential-mode EMI calculator was developed to calculate the maximum possible radiated emissions due to the DM currents on PCB traces. The calculator utilizes simple closed-form expressions described by Paul [1]. This report is intended to provide details of the implementation sufficient to allow others to develop their own version of this calculator.

The circuit board trace configuration to be analyzed is illustrated in Fig. 1. The trace with a length, l_t , is located above a plane that carries the return current. The dielectric layer has a thickness of t . The differential-mode signal on the trace is terminated with a capacitive or resistive load. The calculator determines the maximum radiated electric field from this configuration at a distance of 3 meters and plots the results in $dB\mu V/m$ up to 500 MHz, as shown in Fig. 2.

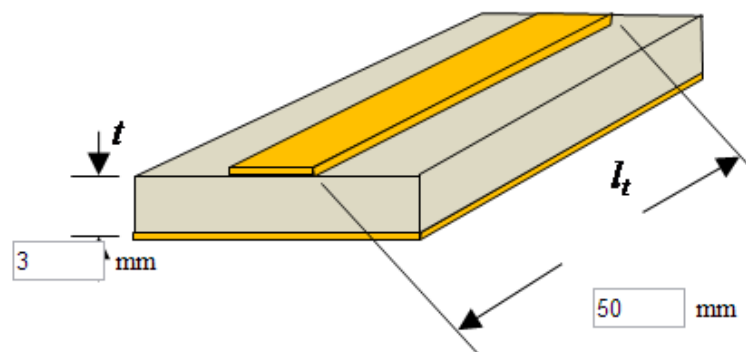


Fig. 1. Printed circuit board trace above a plane.

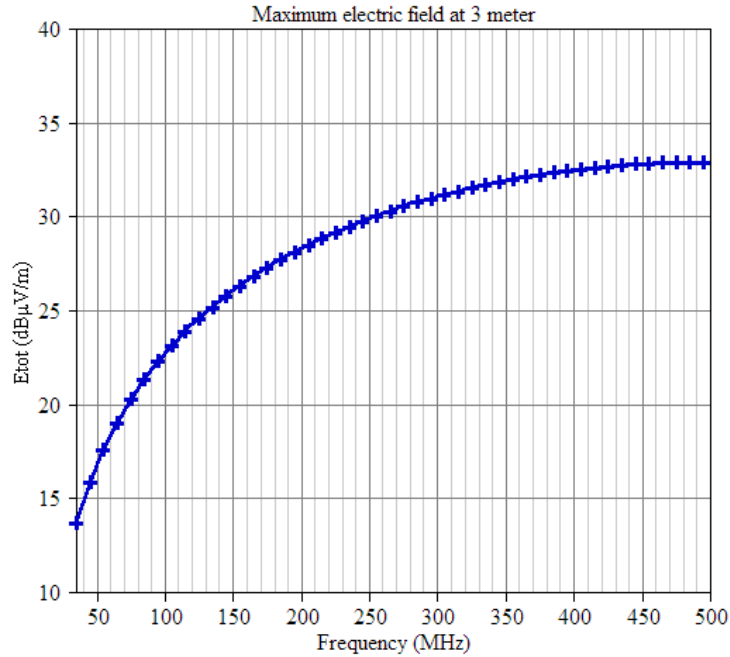


Fig. 2. Example of output from the Differential-Mode EMI calculator.

2. Description of Algorithm

To calculate the maximum possible radiated electric field above the PCB, image theory is applied. The ground plane is replaced by an image trace on the other side of the ground plane carrying the same current as the original trace flowing in the opposite direction. For electrically short sections, the trace and its image can be treated as two Hertzian dipoles and their radiated electric field strength can be calculated using the closed-form expression in [1].

$$|E_{\max}| = 1.316 \times 10^{-14} \frac{I_{DM} f^2 l_t \cdot 2t}{r} . \quad (1)$$

In this implementation the distance from the board, r , is set to three meters; so (1) can be further simplified to,

$$|E_{\max}| = 8.8 \times 10^{-15} I_{DM} f^2 l_t t . \quad (2)$$

The magnitude of the differential-mode current flowing on the trace is,

$$I_{DM} = \left| \frac{V_{Signal}}{Z_{load}} \right| . \quad (3)$$

The algorithm caps the trace length, l_t , at one sixth of a wavelength because above that, the assumption of a uniform current along the trace will be inaccurate. As long as the trace is less than about one wavelength, (2) provides a reasonable upper-bound when l_t is capped at $\lambda/6$. For trace lengths greater than one wavelength, the traveling wave antenna model described in [2] is recommended. The expression for the maximum possible radiated emissions from a traveling wave antenna is similar to (2) with no limitation on the trace length, l_t ; however this has not been implemented in the algorithm. Electrically long microstrip traces are capable of producing significant radiated emissions due to differential-mode currents, but they usually don't. Losses in the structure and details of the routing generally prevent DM radiation from these traces from being an issue. For this

reason, electrically long microstrip traces should generally be modeled using full-wave analysis techniques when one suspects that radiation from these traces may be a problem.

This algorithm provides a reasonably accurate estimate of the maximum possible emissions due to radiation directly from the trace/return structure provided that:

1. The length of the trace and the thickness of the dielectric layer are electrically small.
2. The ground plane width is much greater than the trace width and the dielectric thickness.
3. The trace length is limited to one wavelength. At the maximum frequency, 500 MHz, that this calculator supports, the wavelength is 60 cm.

3. Conclusion

This calculator determines the maximum possible radiated emissions due to differential-mode currents flowing on PCB traces. It is limited to traces with lengths that are smaller than a wavelength. For longer traces, the travelling wave antenna model in [2] could be used.

It is important to note that for most realistic circuit board trace structures and currents, the differential-mode radiation should be well below the FCC or CISPR radiated emission limits. Any circuit that has loop areas sufficient to cause excessive differential-mode radiation is likely to have other EMC problems as well.

Differential-mode radiation is rarely, if ever, the dominant source of a radiated emissions problem. For that reason, the relatively simple closed-form equation provided in [1] is accurate enough to flag a significant problem. Precise calculations of the radiation from differential signal currents on a printed circuit board are not helpful when common-mode currents are the dominant EMI source.

References

- [1] C. R. Paul, *Introduction to Electromagnetic Compatibility, 2nd ed.*, Section 8.1.2, John Wiley & Sons, 2006.
- [2] Constantine A. Balanis, "Traveling Wave and Broadband Antennas," in *Antenna Theory Analysis and Design, 3rd ed.*, John Wiley & Sons, 2005.

Appendix (Java code)

Subroutine calcEM()

```
function calcEM(){
    var ymin,ymax;
    pos=new Array(0,0);
    for (i=0;i<vdm.length;i++){
        var lambda=c0/(x[i]*1e6);
        if (lt<=(lambda/6))
            y[i]=sigNumber(20*Math.log(8.8*1e-15*idm[i]*x[i]*1e6*x[i]*1e6*lt*1e6)*Math.LOG10E);
        else
            y[i]=sigNumber(20*Math.log(8.8*1e-15*idm[i]*x[i]*1e6*x[i]*1e6*(lambda/6)*1e6)*Math.LOG10E);
    }
}
```