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**Maximum Radiated Emission Calculator:
Power Bus EMI Algorithm**

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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 *Power Bus* EMI algorithm, which determines the maximum possible radiated emissions that could occur from a rectangular power bus structure. The methods used, calculations made, and implementation details are described.

1. Introduction

High frequency noise on the power bus can result in significant radiated emissions. The Power Bus EMI calculator was developed to calculate the maximum possible radiated emissions from printed circuit board power plane structures. The calculator utilizes simple closed-form expressions developed by Leone [1], Shim [2] and Zeng [3].

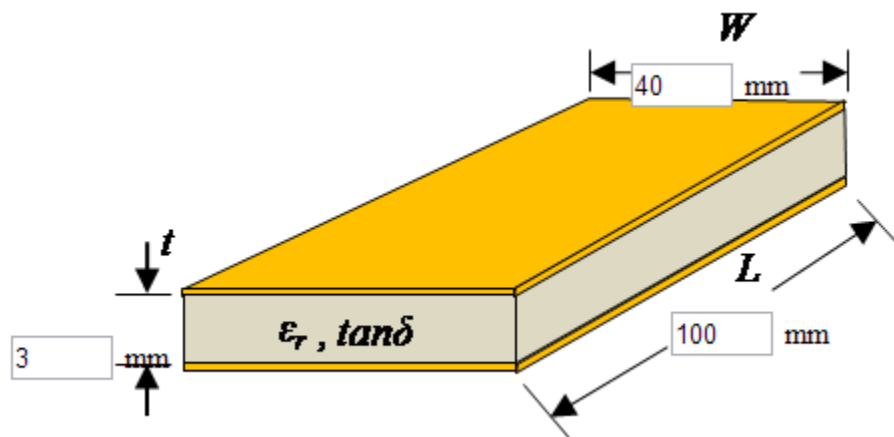


Fig. 1. Power plane structure.

The power bus structure is illustrated in Fig. 1. The power planes have a length, L , a width, W , and a conductivity, σ . The dielectric layer has a thickness, t , a relative dielectric constant, ϵ_r , and a loss tangent, $\tan\delta$. The noise source can be expressed as the maximum current drawn from the planes by the active devices, I_i , or the maximum voltage fluctuation at the board edge, V_{max} . For the current source, parameters of the components on the board are needed to estimate the voltage fluctuations that will appear on the planes. These parameters include the number of active and passive component connections to the power bus, N_c , the equivalent series resistance of these components, R_c , and the connection inductance of these components, L_c [2].

The calculator calculates the maximum radiated electric field at a distance of 3 meters from the board and plots the results in $dB\mu V/m$ from a specified minimum frequency, f_1 , to a specified maximum frequency, f_2 , as shown in Fig. 2.

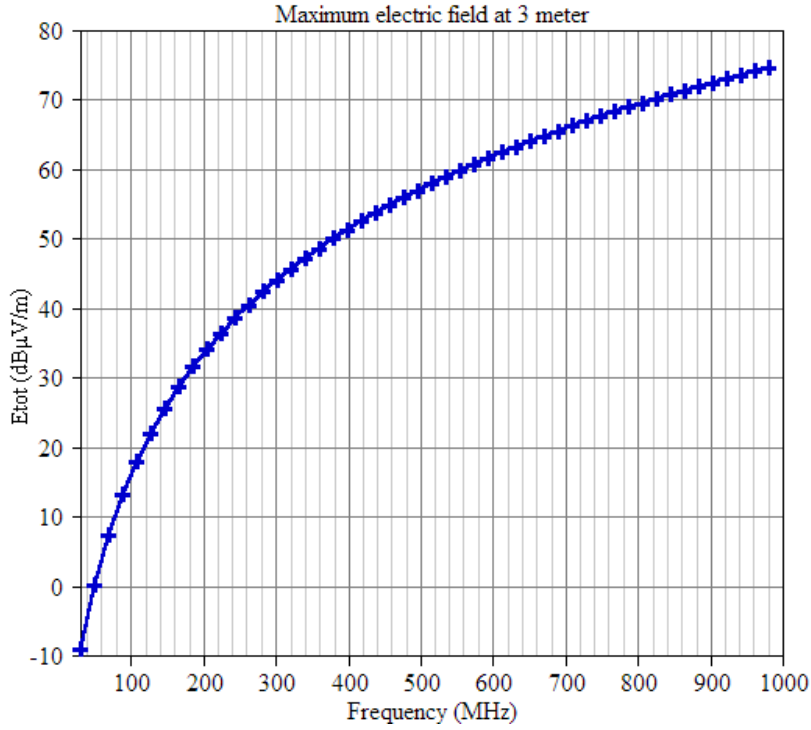


Fig. 2. Example of output from Power Bus EMI calculator.

2. Description of Algorithm

The calculator uses one of two separate algorithms depending on the type of noise source specified. The *Components on Board* algorithm determines the maximum radiated emissions based on the maximum noise current drawn from the power planes and information about the components on the board. The *Maximum Voltage at Board Edge* algorithm determines the maximum radiated emissions based the maximum voltage fluctuation at the board edge.

2.1 Components on Board Algorithm

The derivation of the closed-form expression used by the algorithm is well documented in [2]. For relatively high-Q resonances, the maximum radiated field from a populated rectangular board can be expressed as,

$$|E| \leq \frac{120I_i}{\epsilon_r \cdot \min(W, L)} \cdot \frac{t}{r} \cdot \left(\tan \sigma + \frac{\delta_s}{t} + \frac{N_c R_c}{\omega C_0 (R_c^2 + \omega^2 L_c^2)} \right)^{-1} \quad (1)$$

where r is the distance from the board, δ_s is the skin depth of the plane conductors, and C_0 is the capacitance between the power planes. r is set to three meters in the calculator, δ_s and C_0 can be found by,

$$\delta_s = \sqrt{\frac{2}{\omega \mu_0 \sigma}} \quad (2)$$

$$C_0 = \epsilon_r \epsilon_0 \frac{W \cdot L}{t} \quad (3)$$

The calculator returns an error if the input value of the board width, W , is greater than the input value for the board length, L . As a result, the term, $\min(W, L)$, in (1) is equivalent to W .

2.2 Maximum Voltage at Board Edge Algorithm

The noise current drawn from the power planes causes voltage fluctuations. For boards that have already been built, it is usually easier and more accurate to measure the power bus voltage instead of estimating it based on the current drawn by the active components. The *Maximum Voltage at Board Edge* algorithm is based on the closed-form equation in [3], which calculates the maximum radiated emissions from a rectangular power bus with a given maximum voltage along the board edge. The maximum radiated electric field strength is expressed as,

$$|E_{\max}| = \begin{cases} \frac{f \sqrt{\mu \epsilon_0} V_{\max} W}{r} & f < f_{t1} \\ \frac{f \sqrt{\mu \epsilon_0} V_{\max} L}{r} & f_{t1} \leq f < f_{c2} \\ \frac{f \sqrt{\mu \epsilon_0} V_{\max} \sqrt{L^2 + W^2}}{r} & f \geq f_{c2} \end{cases} \quad (4)$$

where f_{t1} is a transition frequency that occurs midway between adjacent resonances just below the cutoff frequency of the TM_{01} mode and f_{c2} is the cutoff frequency of the TM_{11} mode. They can be found by [3],

$$f_{t1} = \frac{1}{2} \left(\frac{1}{2\sqrt{\mu \epsilon_r \epsilon_0} W} + \frac{1}{2\sqrt{\mu \epsilon_r \epsilon_0} L} \right) \quad (5)$$

$$f_{c2} = \frac{1}{2\sqrt{\mu \epsilon_r \epsilon_0}} \sqrt{\left(\frac{1}{L}\right)^2 + \left(\frac{1}{W}\right)^2}. \quad (6)$$

The term $\frac{1}{2\sqrt{\mu \epsilon_r \epsilon_0}} \frac{m}{L}$ in (5) is the cutoff frequency of the TM_{m0} mode that occurs at the mode frequency closest to, but lower than, the TM_{01} mode.

2.3 Assumptions Made in this Derivation

The closed-form equations in both algorithms are developed based on a resonant cavity model that assumes the spacing between the two planes is electrically small and much smaller than the length and width of the board. Also, the shape of the planes must be rectangular (or nearly rectangular).

The Components on Board algorithm makes additional assumptions in order to estimate the voltage fluctuations caused by the active components on the board. This algorithm assumes that the active and passive components are distributed fairly uniformly over the board. It also assumes that a worst-case equivalent series resistance and connection inductance can be defined that adequately represents the majority of the board components. For boards with large numbers of decoupling capacitors, the ESR and connection inductance of these capacitors should be used. The decoupling capacitor capacitances are not relevant, since the inductance will typically dominate at board resonance frequencies.

3. Conclusion

This calculator determines the maximum possible radiated emissions from a rectangular power bus structure based on equations derived and validated in [1], [2] and [3]. It can be applied to power buses consisting of two nearly rectangular planes with a small spacing relative to the length and width of the planes. It calculates the maximum radiated fields for a board in free space and does not model near-field interactions with cables or enclosures that might also contribute to a radiated emissions problem.

References

- [1] M. Leone, "The radiation of a rectangular power-bus structure at multiple cavity-mode resonances," *IEEE Trans. Electromagn. Compat.*, vol. 45, no. 3, pp. 486–492, Aug. 2003.
- [2] H. Shim, Y. Fu, and T. Hubing, "Radiated emissions from populated printed circuit boards due to power bus noise," *2004 International Symposium on Electromagnetic Compatibility (IEEE Cat. No.04CH37559)*, 2004, vol. 2, pp. 396–400.
- [3] H. Zeng, H. Ke, G. Lorenzo Giuliattini Burbui, and T. Hubing, "Determining the maximum allowable power bus voltage to ensure compliance with a given radiated emissions specification," *IEEE Trans. Electromagn. Compat.*, vol. 51, no. 3, pp. 868–872, Aug. 2009.

Appendix (Java code)

Components on Board Algorithm in Subroutine calcEM()

```
var c0=eps0*epsr*l*w/t;
    var qd=losstan;
    var ymin,ymax;
    for (i=0;i<maxpoints;i++){
        var tans=1/Math.sqrt(pi*mu0*x[i]*1e6*cond);
        var qc=tans/t;
        var
qcomp=nc*rc/(2*pi*x[i]*1e6*c0*(parseFloat(rc*rc)+parseFloat(2*pi*x[i]*1e6*2*pi*x[i]*1e6*lc*lc)));
        var q=parseFloat(qd)+parseFloat(qc)+parseFloat(qcomp);
        y[i]=sigNumber(20*Math.log(120*ic/epsr/Math.min(1,w)*t/r/q*1e6)*Math.LOG10E);
        if (i==0){
            ymin=y[0];
            ymax=y[0];
        }
        else{
            if (y[i]<ymin){
                ymin=y[i];
                pos[0]=i;
            }
            if (y[i]>ymax){
                ymax=y[i];
                pos[1]=i;
            }
        }
    }
}
```

Maximum Voltage at Board Edge Algorithm

```
var m=Math.floor(l/w);
    var ft1=Math.round(1/4/Math.sqrt(mu0*epsr*eps0)*(1/w+m/l));
    var fc2=Math.round(1/2/Math.sqrt(mu0*epsr*eps0)*Math.sqrt((1/l)*(1/l)+(1/w)*(1/w)));

    for (i=0;i<maxpoints;i++){
        if (x[i]*1e6<ft1)
            y[i]=x[i]*1e6*Math.sqrt(mu0*eps0)*vmax*w/r;
        else{
            if (x[i]*1e6<fc2)
                y[i]=x[i]*1e6*Math.sqrt(mu0*eps0)*vmax*l/r;
            else
                y[i]=fc2*Math.sqrt(mu0*eps0)*vmax*Math.sqrt(1*1+w*w)/r;
        }
        y[i]=sigNumber(20*Math.log(y[i]*1e6)*Math.LOG10E);
    }
    ymin=y[0];
    ymax=y[maxpoints-1];
    pos[0]=0;
    pos[1]=maxpoints-1;
}
```