Microwave Memos

Memo 19

Impedance of Detonator Wires

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The nominal impedance of a detonator has been quoted as nominally 1 Ω. This is a DC value. What happens at high frequency, say 1 GHz?

References:

1. S. R. Hirsch, "RF Current Induced in an Ordnance Circuit", IEEE Trans. EMC, 1965, pp. 15-24.

2. C. M. Petrillose and A. J. Butts, "Design Considerations for an Ordnance Stray Energy Detector", IEEE Trans. EMC, 1965, pp. 184-192.

3. H. B. Einstein and H. B. Warner, "Mathematical Evaluation of Radio Frequency Hazards to Resisitive Devices", IEEE Trans. EMC., 1965, pp. 287-296.

4. D. R. Lide (ed.), *CRC Handbook of Chemistry and Physics*, 80th ed., CRC Press, 1999.

To consider this problem take a hypothetical case of a wire.

Nichrome: $\sigma \simeq 10^6 \; S/m$

$$R_0'(DC) = \frac{1}{\sigma\pi a^2}$$

$$R_0 = R_0'\ell \simeq 1\,\Omega \quad \text{(nominally)}$$

$$\ell = 1\,cm = \text{length} \quad \text{(could be more)}$$

$$R_0' = 100\,\Omega/m$$

$$a^2 = \frac{1}{\pi\sigma R_0'} \simeq \frac{10^{-8}}{\pi} \simeq 0.32 \times 10^{-8}$$

$$a \simeq 56\,\mu m$$

$$2a\,\text{(diameter)} \simeq 0.11\,mm \quad \text{(reasonable?)}$$

High frequency internal impedance – skin effect – equal resistance and reactance

$$Z' = \frac{1}{2\pi a}\left[\frac{j\omega\mu}{\sigma}\right]^{1/2} = R' + j\omega L'$$

assume $\mu = \mu_0$ (if larger gives minimum Z')

$$R' = \frac{1}{2\sqrt{2}\pi a}\left[\frac{\omega\mu}{\sigma}\right]^{1/2} = \frac{1}{2a}\left[\frac{f\mu}{\pi\sigma}\right]^{1/2}$$

$$\frac{R'}{R_0'} = \frac{\sigma\pi^2}{2a}\left[\frac{f\mu}{\pi\sigma}\right]^{1/2} = \frac{a}{2}\left[\pi\mu\sigma f\right]^{1/2}$$

Setting this to 1 gives a break frequency f_0

$$f_0 = \frac{4}{\pi a^2 \mu\sigma} \simeq \frac{4}{\pi\, 0.32\times 10^{-8} 4\pi\times 10^{-7}\times 10^{6}} \simeq 0.32\, GHz$$

So we are starting to see some increase in the resistance by a factor

$$\left[\frac{f}{f_0}\right]^{1/2} \simeq 1.8$$

This still has $R << 100\ \Omega$ or so (the source impedance), changing the current negligibly.

Required power level is reduced by this factor, and range is increased by

$$\left[\frac{f}{f_0}\right]^{1/4} \simeq 1.3 \equiv \text{range increase}$$

This just emphasizes the need to know the resistance at high frequencies. It would also help to have better data on materials, μ, σ, and geometry of the detonator wire(s). One could make measurements of the detonator impedance as a function of frequency at *very low* power levels (far below detonation threshold).