2013 EOS/ESD Symposium for Factory Issues

Evaluation of Length to Diameter Ratio of Grounding Wires

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Objectives

1. To understand skin effect

2. To determine length-to-diameter ratio

3. To maintain a safe ESD ground & meet “I ohm law”

Outline

1. Problem statement
2. Skin effect
3. Formulas
4. Comparison between different types of wires (Single, Stranded and Braided)
5. Comparison between wires made of different materials (Aluminium, Copper and Silver)
6. Conclusion
7. References

1. Problem Statement

Single Wire

Stranded Wire

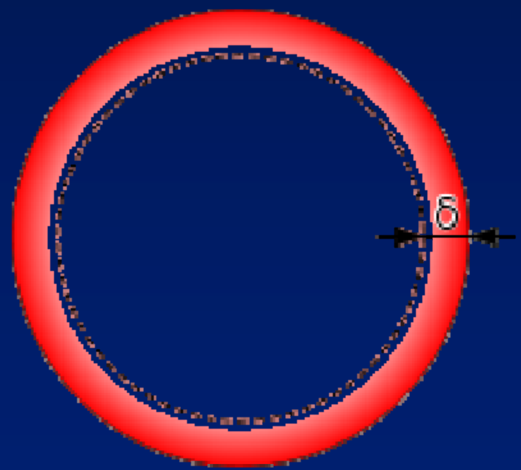
Braided Wire

Which one to select??

2. Skin Effect

Skin effect is the tendency of an AC current to become distributed within a conductor such that the current density is largest near the surface, and decreases with greater depths in the conductor.

Skin depth: 63% electric current flows at the skin of the conductor



Skin effect causes resistance of conductor to increase

3. Formulas

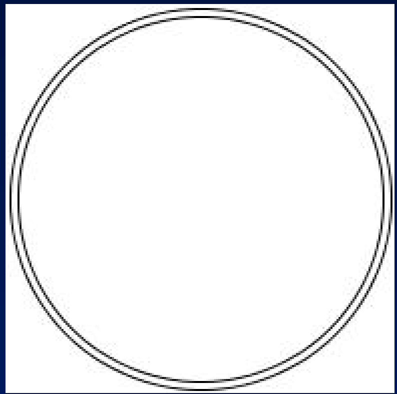
1. Skin Depth $$\delta = \frac{1}{\sqrt{\pi f \mu_0 \mu_r \sigma}}$$

- Vacuum Permeability $\mu_0 = 4\pi \times 10^{-7} H/m$
- Relative Permeability $\mu_r = 1$
- Conductivity σ

2. Current Frequency: $$f = \frac{1}{\pi t_r}$$

- Rise Time t_r

4.1. Single Wire



Cross-section

$$R_{single} = \frac{l}{\sigma \pi d \delta} = \frac{l}{\pi d}\sqrt{\frac{\mu_0}{\sigma t_r}}$$

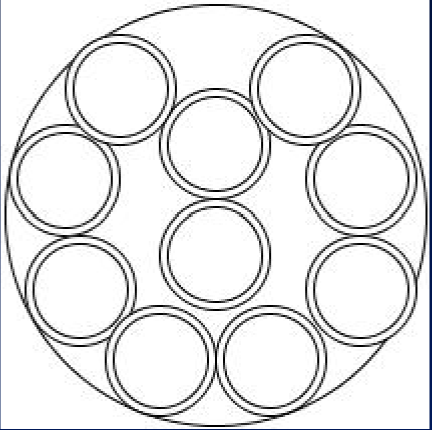
$$\frac{l}{d} = \pi \sqrt{\frac{\sigma t_r}{\mu_0}}$$

Current flowed uniformly through a layer of thickness δ

4.1 Single Wire

Rise time (ns)	Frequency (MHz)	Skin depth (um)	Ratio l/d
318.31	1	65.19	12206
31.83	10	20.62	3860
3.18	100	6.52	1220
0.318	1000	2.06	386

4.2 Stranded wire



Cross-section, with the same copper area with single wire

$$\frac{\pi d^2}{4} = n\frac{\pi {d_s}^2}{4} \longrightarrow d_s = \frac{d}{\sqrt{n}}$$

For example, when n=10, $d_s = 0.3162d$

$$R_{stranded} \approx \frac{l}{n\sigma\pi d_s\delta} \longrightarrow \frac{l}{d} = \pi\sqrt{\frac{n\sigma t_r}{\mu_0}}$$

4.2 Stranded wire

Rise time (ns)	Frequency (MHz)	Skin depth (um)	Ratio l/d
318.31	1	65.19	38597.13
31.83	10	20.62	12205.48
3.18	100	6.52	3859.71
0.32	1000	2.06	1220.55

4.3 Braided Wire

Cross-section, with the same copper area with single wire

$$\frac{\pi d^2}{4} = n\frac{\pi {d_s}^2}{4} \longrightarrow d_s = \frac{d}{\sqrt{n}}$$

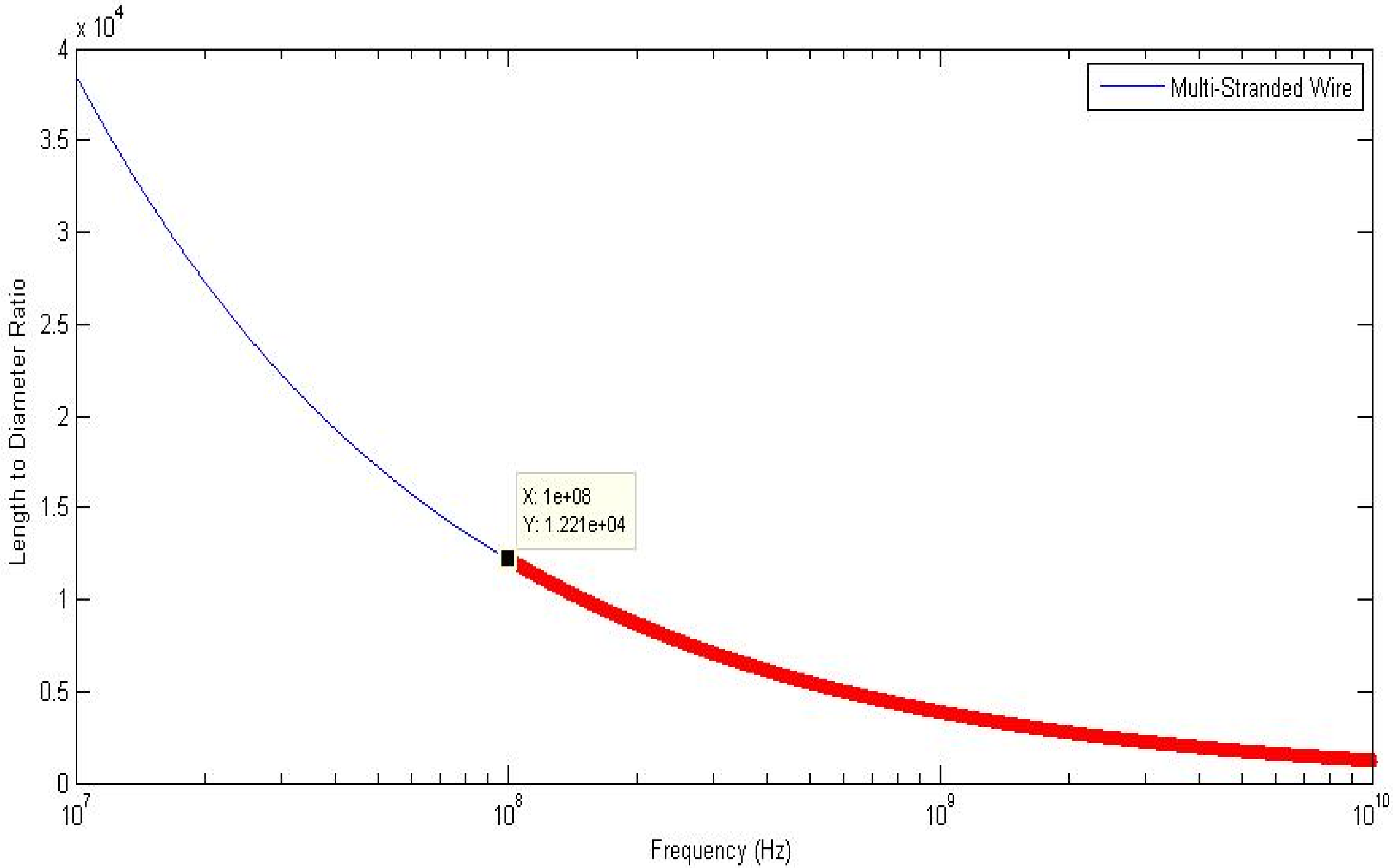
For example, when n=25, $d_s = 0.2d$

$$R_{stranded} \approx \frac{l}{n\sigma\pi d_s \delta} \longrightarrow \frac{l}{d} = \pi\sqrt{\frac{n\sigma t_r}{\mu_0}}$$

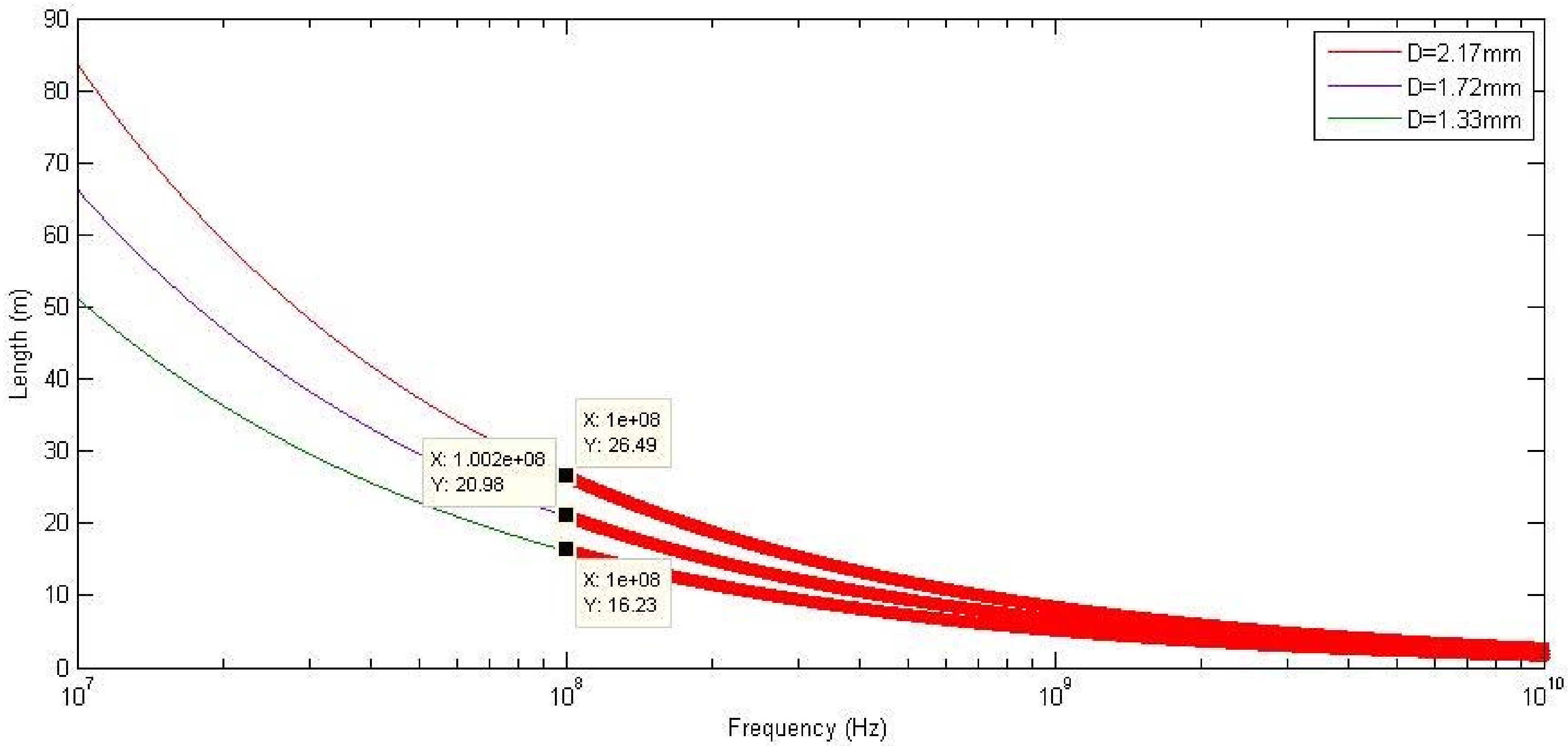
4.3 Braided Wire

Rise time (ns)	Frequency (MHz)	Skin depth (um)	Ratio l/d
318.31	1	65.19	86300.35
31.83	10	20.62	27290.57
3.18	100	6.52	8630.03
0.32	1000	2.06	2729.06

4.4 Ratio Against Frequency



4.5 Length Against Frequency



5. Comparison of Al, Cu and Ag Wires

	Aluminum	Copper	Silver
Conductivity	3.50E+07	5.96E+07	6.30E+07
Relative Permeability	1.000022	0.999994	0.99998

5. Comparison of Al, Cu and Ag Wires

Frequency (MHz)	Ratio l/d		
	Al	Cu	Ag
1	9354	12206	12549
10	2958	3860	3968
100	935	1220	1254
1000	295	386	396

6. Conclusion

Single Stranded Braided

→ Length to Diameter Ratio

1. Skin effect is severe at high frequency.
   – Diameter of every single wire >> skin depth,

2. Increasing frequency -> reducing skin depth.

3. Choose the most cost-effective ones & meets “1 ohm rule”.

7. References

[1] E. S. D. Association, "ANSI/ESD S6.1-2005, Revision of ANSI/ESD S6.1-1999, For the Protection of Electrostatic Discharge Susceptible Items Grounding," ESD Association, 2005, p. 14.

[2] W. H. Hayt, *Engineering electromagnetics*: McGraw-Hill Book Co., 1981.

[3] H. A. Wheeler, “Formulas for the Skin Effect,” *Proceedings of the IRE,* vol. 30, no. 9, pp. 412-424, 1942.

[4] M. I. Montrose, and I. E. C. Society, *Printed circuit board design techniques for EMC compliance*: IEEE Press, 1996.

[5] D. Fink, and H. W. Beaty, *Standard Handbook for Electrical Engineers*: McGraw-Hill Companies, Incorporated, 2006.

[6] F. Murray, Jr. Hawkins, Louisiana State U, A Note on the Skin Effect, Journal of Petroleum Technology, 1956.

Thank You