Application Note

Skin Effect on Wire

This application note discusses material effect on skin depth on an electrical conductor such as wire.

What is Skin Effect?

Skin effect can be defined as the tendency for alternating electric current (AC) to flow mostly near the outer surface of an electrical conductor, and not through the core. The term "skin" refers to the outer surface of the conductor. "Depth" is used to describe the depth of the skin where the current is flowing. Skin depth can also be thought of as a measurement of distance over which the current falls from its original value. The decline in current density (electrical current in a given area) versus depth is known as the **skin effect.**

The skin effect causes the effective resistance of the electrical conductor to increase as the frequency of the current increases. This occurs because most of the conductor is carrying very little of the current, and because of the oscillation of the electrical AC current to the skin of the conductor. Therefore, at high frequencies of current skin depth is small. Analyzing skin depth helps to determine the material properties of a good conductor on a solid conductive wire.

The skin depth formula equation below can be utilized to determine skin depth effect on a solid conductive material:

$$Skin\ Depth = \delta_s = \sqrt{\frac{2\rho}{2\pi f \mu_0 \mu_R}}$$

where :

$\rho = bulk\ resitivity\ (ohm - meters)$

$f = frequency\ (Hertz)$

$\mu_0 = permeability\ constant\ (Henries\ /\ meter) = 4\pi \times 10^{-7}$

$\mu_r = relative\ permeability\ (usually \sim 1)$

Skin effect occurs when frequencies start to increase, and as conduction starts to move from the inner cross section of the conductor toward the outer surface of the cross sectional of the conductor. Skin effect is mainly cause by circulating eddy currents. Eddy currents effectively oppose the original current that was flowing to the center of the conductor, thus pushing it to the outer surface of the conductor.

Take for example a solid wire: When current flows it is mainly concentrated on the outer surface of the wire. In this case, skin depth is shallow and the material of the solid conductor can be replaced with a hollow conductor.

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Importance of Skin Effect

It is critical to determine skin effect for a solid wire that will be implemented close to other wires like cables or coils in a design. This is primarily due to what is know as the proximity effect. This occurs when the current from the first conductor (wire) is constrained to a smaller region (coil), resulting in "current crowding". The proximity effect can significantly increase the AC resistance.

LCR Meters like IET Labs's 1920 or 7600 Plus Precision LCR Meters can help determine the AC resistance on a single conductor, allowing the data that is extracted to help determine the severity of skin effect. Measurements can be made with a single trigger or by performing a sweep on the full frequency spectrum of the unit.

Sample

Figures 1 and 2 below show data measurements from a sample tested with frequencies from 100 kHz to 230.5 kHz, with 500Hz incremental. Figure 2 illustrates data measurements from the 1920 Precision LCR Meter. These calculations are very accurate and can be a reliable way to determine the severity of skin effect on a solid conductor.

Figure 1 displays the theoretical behavior on a solid conductor, where the effect on skin causes the resistance to increase as frequency increases. These calculations are derived from the sample properties outlines in Table 1. The sample data that is shown in Table 2 displays a portion of test frequencies, which are between approximately 500 kHz – 667 kHz. The graphical data also displays full range test frequencies from approximately 200 kHz up to 1 MHz.

Table 1: Properties of 24 AWG and 32 AWG copper wires

Relative Permeability of Copper:	9.99994E-01
Air Permeability:	1.25664E-06
Resistivity of Copper:	1.67800E-08
Wire Length	6.00000E+01
32 AWG Wire Diameter	8.00000E-03
24 AWG Wire Diameter	2.01000E-02

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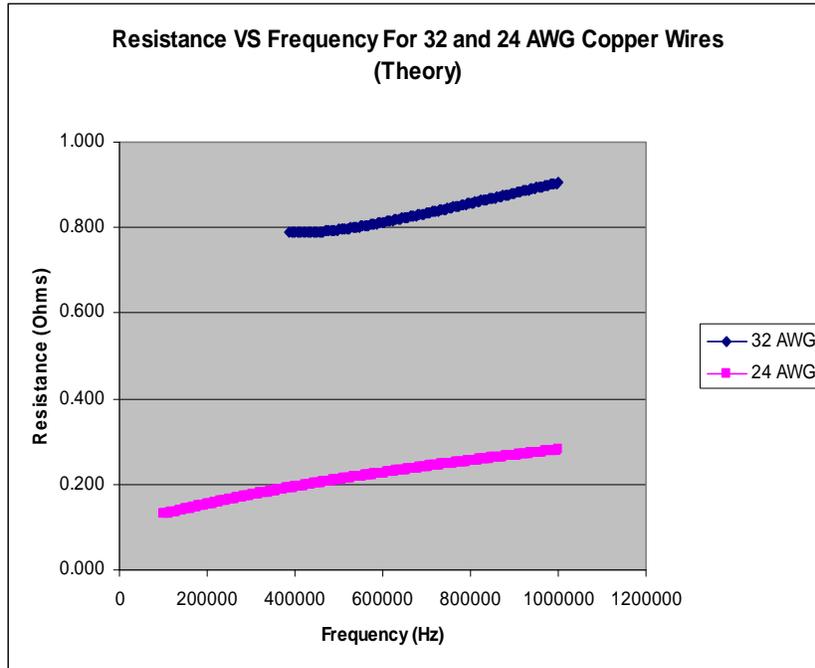## Figure 1: Theoretical Resistance vs. Frequency

Resistance VS Frequency For 32 and 24 AWG Copper Wires (Theory)

Figure 2: Measured Resistance vs. Frequency (IET Labs 1920 LCR Meter)

Resistance VS Frequency For 32 and 24 AWG Copper Wires (QUADTECH Measured)

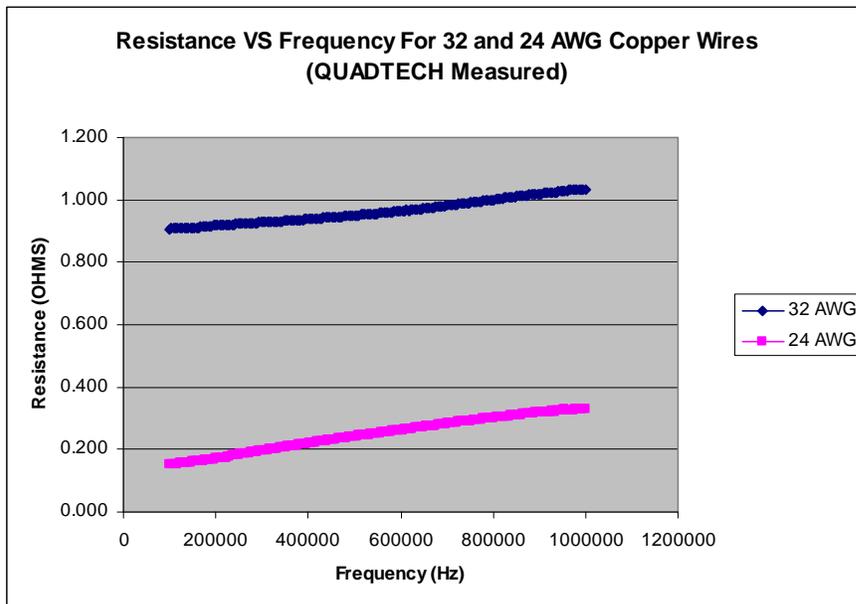## Table 2: Theoretical vs. Measured Sample Data

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Frequency (KHz)	Skin Depth (δ)	Theory		Measured (IET Labs)	
		32 AWG Rs (Ω)	24 AWG Rs (Ω)	32 AWG Rs (Ω)	24 AWG Rs (Ω)
500500	0.00363	0.795	0.211	0.951	0.241
505000	0.00361	0.796	0.212	0.951	0.243
509500	0.0036	0.797	0.213	0.951	0.244
514000	0.00358	0.797	0.213	0.952	0.244
518500	0.00356	0.798	0.214	0.952	0.245
523000	0.00355	0.799	0.215	0.953	0.246
527500	0.00353	0.799	0.216	0.954	0.247
532000	0.00352	0.8	0.216	0.954	0.248
536500	0.0035	0.801	0.217	0.955	0.249
541000	0.00349	0.802	0.218	0.955	0.25
545500	0.00348	0.802	0.218	0.956	0.251
550000	0.00346	0.803	0.219	0.956	0.252
554500	0.00345	0.804	0.22	0.957	0.253
559000	0.00343	0.805	0.221	0.958	0.254
563500	0.00342	0.806	0.221	0.958	0.255
568000	0.00341	0.806	0.222	0.959	0.255
572500	0.00339	0.807	0.223	0.96	0.256
577000	0.00338	0.808	0.223	0.96	0.258
581500	0.00337	0.809	0.224	0.961	0.258
586000	0.00335	0.81	0.225	0.962	0.259
590500	0.00334	0.811	0.225	0.963	0.26
595000	0.00333	0.812	0.226	0.963	0.262
599500	0.00332	0.812	0.227	0.964	0.262
604000	0.0033	0.813	0.227	0.965	0.263
608500	0.00329	0.814	0.228	0.965	0.264
613000	0.00328	0.815	0.229	0.967	0.265
617500	0.00327	0.816	0.229	0.966	0.265
622000	0.00325	0.817	0.23	0.968	0.267
626500	0.00324	0.818	0.231	0.969	0.268
631000	0.00323	0.819	0.231	0.969	0.268
635500	0.00322	0.82	0.232	0.97	0.27
640000	0.00321	0.821	0.233	0.971	0.27
644500	0.0032	0.822	0.233	0.971	0.272
649000	0.00319	0.823	0.234	0.972	0.272
653500	0.00318	0.824	0.235	0.973	0.273
658000	0.00316	0.825	0.235	0.974	0.274
662500	0.00315	0.826	0.236	0.975	0.275
667000	0.00314	0.827	0.237	0.976	0.276

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Conclusion

Both in theory and in practice, this data proves that resistance increases with frequency, due to the skin effect on a copper wire.

For more information on the 1920 LCR Meter, please contact IET Labs www.ietlabs.com

Credits and Reference:

- http://whatis.techtarget.com/definition/0,,sid9_gci541369,00.html

- http://www.microwaves101.com/encyclopedia/skindepth.cfm

- http://en.wikipedia.org/wiki/Skin_effect

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