From January 2010 *High Frequency Electronics*

DESIGN NOTES

Magnetic Materials in Transmission Line Transformers

This discussion is in regard to the required charactersitics of magnetic materials used in transmission line transformers. Figure 1 shows the comparison of K5 and Q1 ferrite cores operating at a 50:12.5 ohm using Ruthroff's 1:4 design. These are in turn compared to an autotransformer using the Q1 core. As can be seen, the autotransformer is vastly inferior and the TLTs have similar efficiencies at this impedance level. Also the K5 transformer has a better low frequency response because of the higher permeability of this material.

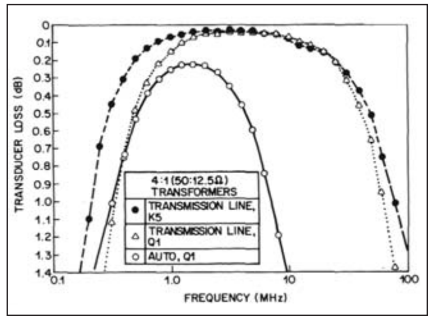

Figure 1 · Loss and bandwidth performance of 4:1 transformers operating at the 50:12.5 ohm level.

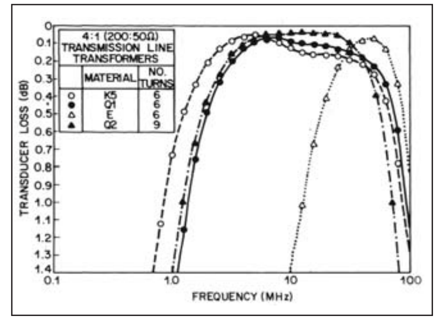

Figure 2 · Loss vs frequency of four 4:1 transformers at the 200:50 ohm level.

Figure 2 includes a comparison of the two cores used in Figure 1, but at the higher impedance level of a 200:50 ohm ratio. A similar transformer using a Q2 core is also shown in the figure. The Q2 core shows that at a higher impedance level a higher bulk resistivity is required for optimum efficiency. Results for a fourth transformer using a powdered iron core (E material) are also included. Since this material has much lower permeability than the ferrite materials, its low frequency response suffers accordingly.

After consideration of the available information in these figures and other experiments, we can conclude:

1) Since very little flux occurs in the cores in the passband, the losses are basically due to the potential difference along the lengths of the transmission lines. The losses are due to the voltages and are therefore dielectric in nature. As was seen, the highest bulk resistivity yields the highest efficiency.

2) The other parameter that is important with transmission line transformers is the permeability. High permeability of core materials results in shorter transmission lines. This directly benefits Ruthroff's bootstrap approach, which adds a delayed voltage to a direct voltage. Further, with shorter transmission lines, their characteristic impedance is somewhat less critical. If a toroid is used for the core, the magnetizing inductance L_M (in henrys) is:

$$L_M = 0.4\pi N^2 \mu_0 \left(\frac{A_e\,(\mathrm{cm}^2)}{L_e\,(\mathrm{cm})} \right) \times 10^{-8}$$

where N is the number of turns, μ_0 is the permeability of the core, A_e is the effective cross-sectional area of the core, and L_e is the average magnetic path length.

We can see from the above equation that by increasing the permeability ten-fold, the number of turns is reduced by about one-third. Thus, for a Ruthroff transformer, which adds a delayed voltage to a direct voltage, the high frequency response is about three times greater.

3) When looking at the table [1] and the above figures, two properties of the core material stand out: permeability and bulk resistivity. In fact, a figure of merit can be defined in this case, which is permeability times bulk resistivity.

Also, powdered iron and manganese zinc (MnZn) ferrite are not recommended for the broadest bandwidth. Again, from the experimental results it is seen that the nickel zinc (NiZn) ferrite delivers best results.

Reference

1. Jerry Sevick, "Magnetic Materials for Broadband Transmission Line Transformers," *High Frequency Electronics*, January 2005, Table 1. Available in the Archives section at: www. highfrequencyelectronics.com

---

This note is dedicated to, and adapted from the most recent publication of friend and colleague Jerry Sevick, who died this past November 29. A brief obituary is included here:

Sevick, Jerry, Ph.D., of Basking Ridge, NJ died peacefully on November 29, 2009, at the age of 90. Born in Detroit, he was a graduate of Wayne State University and a member of their Athletic Hall of Fame. He was drafted by both the Chicago Bears and Detroit Lions, but did not play professional football. He served as a pilot in the US Army Air Corps in WWII.

Jerry taught at Wayne State University and worked as the local weather forecaster at WXYZ TV in Detroit. After completing a doctorate in Applied Physics from Harvard University, he worked for Bell Laboratories, serving as the Director of Technical Relations prior to his retirement. An avid Ham radio operator (W2FMI), Jerry was renowned for his research and publications related to short vertical antennas and transmission line transformers.