On Magnetic Delay Lines

1. Introduction

Figure 1 shows the magnetic and electric field lines around two types of transmission lines where the propagation direction is into the paper. Figure 1(a) is a cross section of the classical balanced line with parallel copper conductors in air. Electric field lines run from one conductor to the other while the magnetic field lines form closed contours around each conductor. The E and H fields form a transverse electromagnetic (TEM) wave propagating through the paper, and although there are arguments about whether the energy actually propagates through the air as this TEM wave or travels within the conductor as voltage and current, the net power transfer is the same whichever way it is calculated. Figure 1 (b) shows a cross section of a magnetic line (this could be the cross section of a ring core where the primary and secondary windings are above and below the paper). The H field lines would normally be considered as flux leakage, and the closed E fields are what actually drives the conduction electrons within coils. The similarity to the electrical line (a) is obvious, one difference being that the E and H fields are interchanged. These fields still create a TEM wave transporting energy to the load.

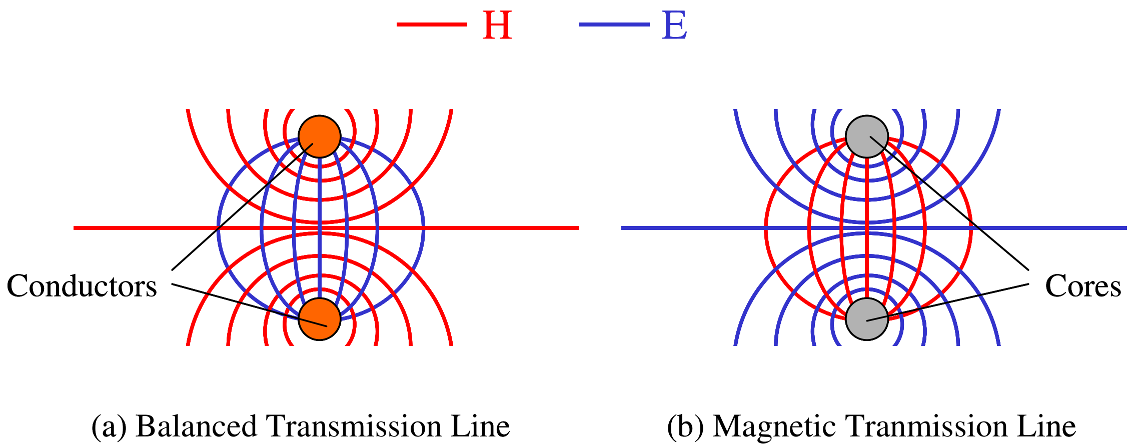

Figure 1. Comparison between Electric and Magnetic Transmission Lines

It is known that the electrical line (a) has a characteristic impedance determined by the geometry (conductor diameter and separation) so it can be expected that the magnetic line would have a similar characteristic. However there is one more significant difference between these two lines; whereas the characteristic impedance of the electrical line is resistive because E and H are in phase, in the magnetic case the impedance is reactive because E and H are at in phase quadrature. Now reactive impedance lines are not generally recognized or used for transporting energy, but classical transmission line theory does cover such lines. In view of the recent discovery that a transformer having magnetic delay between primary and secondary might exhibit anomalous characteristics, examination of the theory applied to reactive impedance lines would seem worthwhile.

2. Transmission Line Theory

The impedance Z_{in} looking into a line of characteristic impedance Z_0, of length x (m) and terminated in an impedance Z_{load} is given by

$$Z_{in} = Z_0 \frac{Z_{load} \cosh \gamma x + Z_0 \sinh \lambda x}{Z_0 \cosh \gamma x + Z_{load} \sinh \gamma x} \qquad (1)$$

where γ is the propagation constant

$$\lambda = \alpha + j\beta \qquad (2)$$

α is the attenuation constant (nepers/m) and β is the phase constant (radians/m). If attenuation is ignored (1) reduces to

$$Z_{in} = Z_0 \frac{Z_{load} + jZ_0 \tan\theta}{Z_0 + jZ_{load} \tan\theta} \qquad (3)$$

where θ is the line length βx expressed electrically in radians. We are interested in the case where Z_0 is purely reactive (say jX_0) and where the line is terminated in a reactive "load" (say jX_{load}). Putting these into (3) yields

$$Z_{in} = \frac{X_0 \tan\theta (X_{load}^2 - X_0^2) + jX_0^2 X_{load}(1 + \tan^2\theta)}{X_0^2 + (X_{load} \tan\theta)^2} \qquad (4)$$

Note that if $X_0 > X_{load}$ then the real part of this impedance is negative.

$$R_{in} = \frac{X_0 \tan\theta (X_{load}^2 - X_0^2)}{X_0^2 + (X_{load} \tan\theta)^2} \qquad (5)$$

Classical theory allows some passive components to create negative resistance. Negative resistance is an energy source, so the question must be asked where does this anomalous energy come from? Perhaps the answer to that is found in Prof. Turtur's assertion that field propagation involves an interchange of energy with the zpe. The magnetic delay line not only involves a reactive TEM field propagating in air, but also a longitudinal magnetic field propagating within the core material.

For small attenuation (1) becomes

$$Z_{in} = Z_0 \frac{Z_{load} + \alpha x Z_0 + j(Z_0 + \alpha x Z_{load}) \tan\theta}{Z_0 + \alpha x Z_{load} + j(Z_{load} + \alpha x Z_0) \tan\theta} \qquad (6)$$

Applying the reactances jX_0 and jX_{load} as before yields

$$R_{in} = \frac{X_0 \tan\theta \left([X_{load} + \alpha x X_0]^2 - [X_0 + \alpha x X_{load}]^2 \right)}{[X_0 + \alpha x X_{load}]^2 + [X_{load} + \alpha x X_0]^2 \tan^2\theta} \qquad (7)$$

which reduces to (5) when α=0. The condition for R_{in} to be negative is the same, $X_0 > X_{load}$.

3. Conclusion

Classical theory does not prohibit the use of passive components to create an energy source in the guise of a negative resistance. It is shown that a delay line with reactive characteristic impedance, when terminated in a reactance, can exhibit such a negative resistance at its input. Normally such reactive delay lines are not found, but magnetic delay lines *are* reactive and it is perhaps surprising that this feature has not been exploited in the past. This work should offer credence to the possibility of a magnetic delay transformer (MDT) producing overunity performance.