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ASK THE EXPERTS

What are Left-Handed Materials?

Via e-mail:

I've been reading about a number of new technologies that sound very counter-intuitive. Without going back to graduate school, it's hard to understand what such things as *left-handed materials* and *frequency-selective structures* really represent.

Can you provide a simpler introduction to these foreign concepts? (And let me know if they are real or fictional!)

It's Not Easy, but We'll Try

We searched widely for some explanations of "left-handed" behavior, and hope that the following summary is helpful:

The concept of left-handed materials (LHM) has been around for a while, since it is a valid mathematical solution to Maxwell's equations. The earliest known reference that suggests that LHM can actually be created is a Russian paper from 1968.

Basically, LHM involves a "negative" counterpart to a naturally-occurring "positive" behavior. The simplest explanation is in optics, where light passing through left-handed glass would have a refraction opposite that of ordinary glass. Yes, this means that the speed of light would "increase" in the LHM instead of slowing down as it does in normal materials. In optics, the most-often mentioned advantages are in the creation of nearly lossless lenses and more highly-focused laser beams.

According to current thinking, "universal" left-handed materials like glass or electronic circuit dielectrics cannot be made. However, there are structures that provide left-handed behavior over a certain bandwidth. These are some of the frequency selective structures (FSS) you have been reading about.

Left-Handed Transmission Line

Look at Figure 1 (top). This is the equivalent circuit of an ordinary transmission line, with the familiar distributed series inductance and parallel capacitance. Left-handed line (bottom) inverts these distributed reactances, having series capacitance and parallel inductance. We know that ordinary transmission lines have a lowpass characteristic (greater loss with increasing frequency). Left-handed line will have a highpass characteristic.

Also—this where it gets counter-intuitive—a left-handed line will have a negative delay, a phase advance instead of a phase delay. There is not enough room to explore the ramifications, but it is easy to imagine that having both normal and inverse behavior would result in completely new designs.

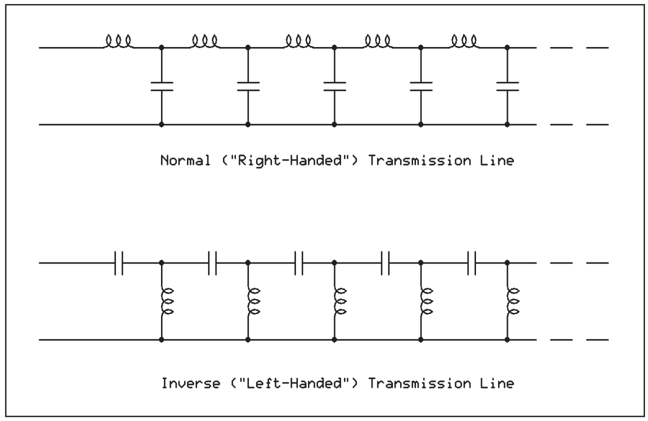

Figure 1 · Equivalent circuits for an ordinary transmission line (top) and for a left-handed transmission line (bottom).

As noted above, we don't have left-handed dielectrics to build this new transmission line, so we must assemble a facsimile from actual capacitors and inductors. As shown in Figure 2, there are parasitic series inductances and parallel capacitances that limit performance. As a result, the line has the desired performance over a limited bandwidth. This is not a problem for many coupling structures and filters, which are narrowband anyway. Significant university research is focused on structures that implement these lines with greatest bandwidth and smallest size.

Microwave antennas may see the first widespread use of narrowband LHM implementation. Metallic objects, such as wires or rings, have been embedded in a dielectric material, imparting left-handed qualities at the frequency of interest. The resulting antennas should be able to achieve the same beamwidth and sidelobe performance in smaller structures than conventional reflectors, lenses or phased arrays.

Hopefully, this short review helps start the learning process for this interesting concept.

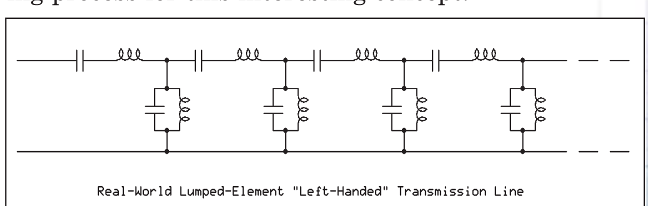

Figure 2 · A more accurate real-world implementation of left-handed transmission line will have a limited bandwidth due to parasitics.