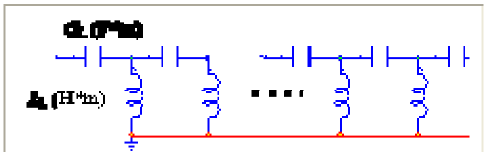
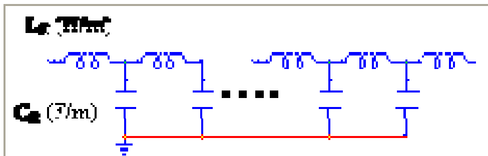
[Emerging Device Technology](#) **> HTS Coplanar Left-Handed Transmission Lines and Resonators**

There have been many so called meta-materials considered in the past; these materials are usually made of conventional materials with some kind of inclusions. The inclusions then produce new propagation characteristics which affect a wave as it propagates through the material. If the material is designed correctly then it can produce a beneficial effect. It is possible to produce materials with negative refractive index. These left-handed (LH) meta-materials, although first proposed theoretically back in 1968, only attracted renewed interests in the past few years. These artificial composites exhibit the unusual left-handedness, i.e. simultaneously negative permittivity and negative permeability. In other words, the LH meta-materials uniquely have anti-parallel phase velocity and group velocity, which gives unusual wave propagation. Here we consider a one-dimensional LH material, made of a simple coplanar transmission line. The transmission line is made of superconductor to reduce the effects of losses. Left-handed transmission lines could have applications in microwave lenses, phase shifters, couplers and antennas.

Table 1. Comparison between a left-handed and right-handed transmission line

	An ideal Left-handed TL	An ideal Right-handed TL
Transmission line circuit model		
Phase constant	$\beta_L = -\frac{1}{\omega\sqrt{L_L C_L}} < 0$	$\beta_R = \omega\sqrt{L_R C_R} > 0$
Phase velocity	Negative (phase advance)	positive (phase lag)
Group velocity	positive	positive

A LH transmission line (LH-TL) is normally composed of a series of unit cells of series capacitors and parallel inductors, like a high-pass filter as shown in Table 1. Several microwave devices using LH-TL have been demonstrated, such as phase shifter, directional coupler, branch-line coupler, hybrid ring, and backward-wave antenna. It is interesting and promising to combine this technique with ferroelectric or high-temperature superconductor (HTS) thin films. LH-TLs can utilise the low loss of superconductors to find new applications in HTS devices.

Previous LH-TL devices were mostly implemented with microstrip line. Vias have to be used in order to realise the parallel inductors shunted to the lower ground plane. To avoid these, coplanar waveguide (CPW) is adopted here. Such a LH-TL is composed of coplanar interdigital capacitors (IDC) and meander line inductors (MLI). In this work,

- Coplanar LH-TLs are realised on a lanthimium aluminate substrate with YBCO superconductor and are measured using a cryogenic probe station; The design mainly relies on accurate extraction of the lumped-element values of the IDC and MLI from simulated S-parameters;
- LH-TL resonators are characterised in terms of the Q-values. Temperature-dependence measurements of the lumped-elements, the LH-TLs and the resonators reveal the effect of the kinetic inductance.

Figure 1 shows the layout of a coplanar LH-TL. Figure 2 gives the simulation results and measurement results at 30K. The measured bandwidth of left-handedness is 4.9-10.9 GHz. Over this band, the minimum insertion loss is 0.03 dB, the maximum insertion loss is 0.93 dB. Figure 3 shows the current and electric field distributions in a 7-unit LH resonator. Of particular interest is the zero-th order resonance (n=0). No E-field minima and maxima is presented along the line, which is in contrast to any other plotted harmonics

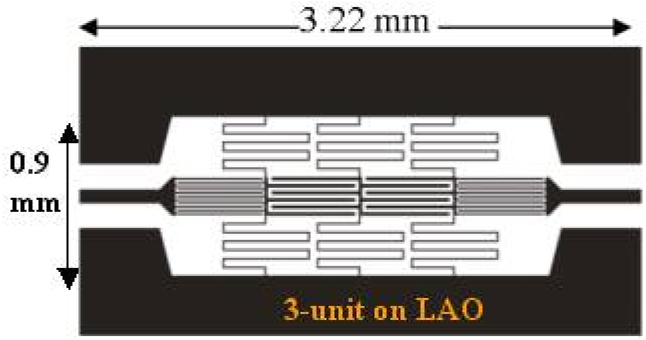


Figure 1. Coplanar waveguide implementation of a 3-unit LH-TL with symmetric shunt MLIs.

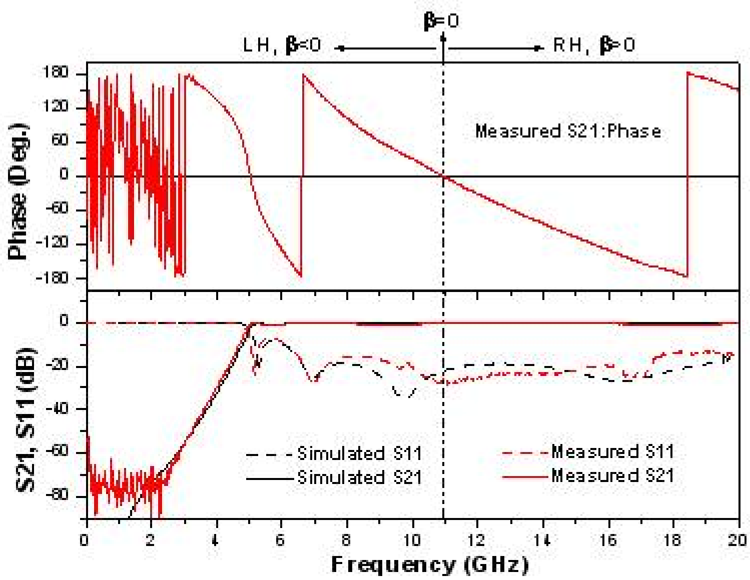


Figure 2. Simulated and measured (30K) results of the structure shown in Figure 1.

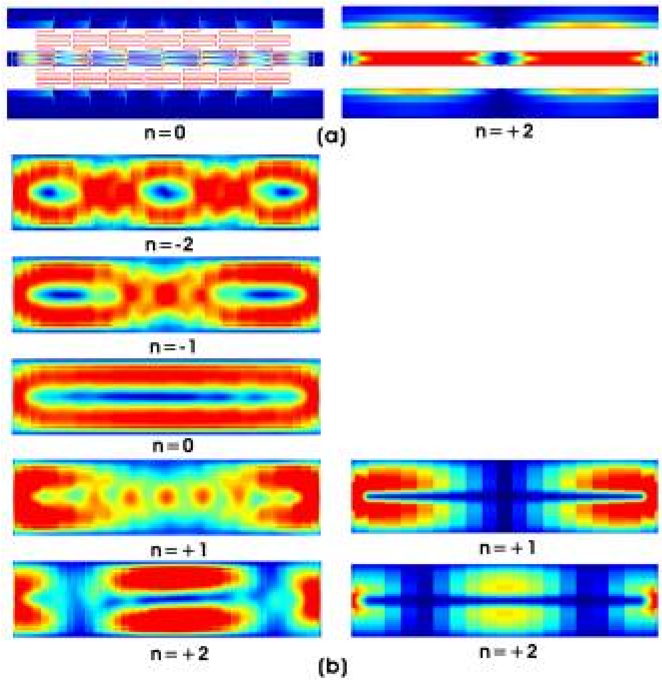
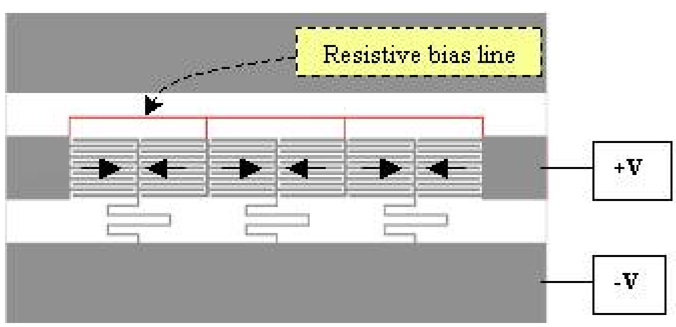


Figure 3. (a) Simulated current distribution on the circuit layer; (b) Simulated tangential electric-field distributions at a plane 0.2mm above the circuit layers. (Left column: a 7-unit LH resonator; Right column: an ordinary CPW line resonator.) The magnitude of the current density or E-field is represented by the color palette from blue (low) to red (high). The number n indicates the index of each harmonic plotted.

Figure 4 shows an electrically tunable LH-TL implemented using ferroelectric/superconductor thin-film structures. Here the structure consists of a basic substrate such as MgO with thin film ferroelectric deposited on the surface followed by the patterned thin film superconducting left-handed transmission line. Bias to the ferroelectric interdigital capacitors is applied through a resistive line. When a voltage is applied phase response of the LH line changes. The measured figure-of-merit for this new phase shifter are shown in figure 5.



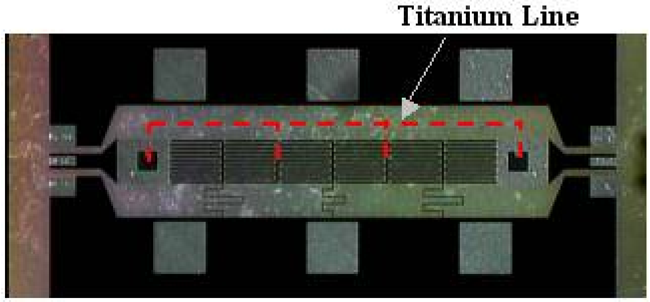
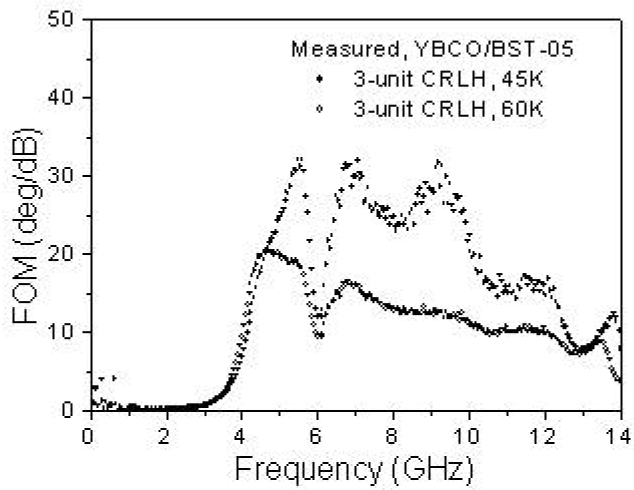


Figure 4. Diagram and picture of a tunable LH-TL based on ferroelectric/superconductor thin films with a resistive bias line (titanium line).



(b)