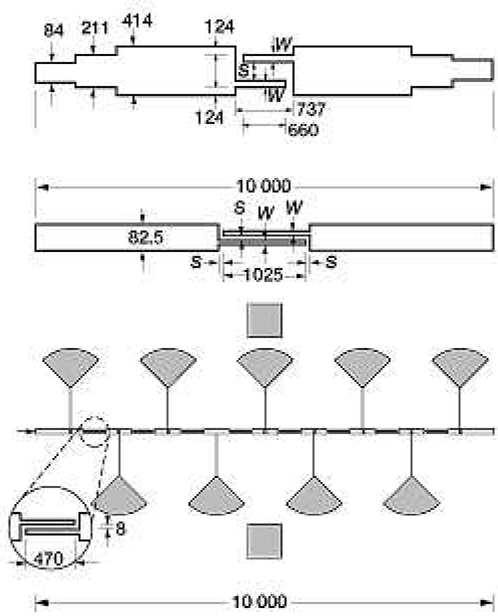
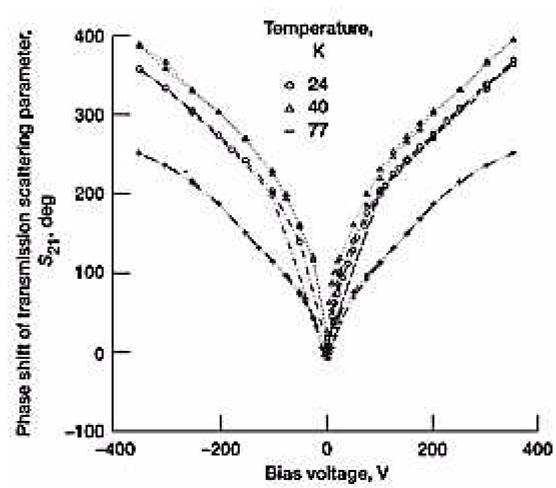
High-Temperature Superconducting/Ferroelectric, Tunable Thin-Film Microwave Components

At the NASA Lewis Research Center, ferroelectric films such as $SrTiO_3$ and $Ba_xSr_{1-x}TiO_3$, are being used in conjunction with $YBa_2Cu_3O_{7-\delta}$ high-temperature superconducting thin films to fabricate tunable microwave components such as filters, phase shifters, and local oscillators. These structures capitalize on the variation of the dielectric constant of the ferroelectric film upon the application of a direct-current electric field, as well as on the low microwave losses of high-temperature superconductors relative to their conventional conductor counterparts. For example, the surface resistance for a $YBa_2Cu_3O_{7-\delta}$ thin film at 10 GHz and 77 K is more than two orders of magnitude lower than that of copper or gold at the same temperature and frequency. $SrTiO_3$ and $Ba_xSr_{1-x}TiO_3$ films are used because their crystal structure and lattice parameters are similar to those of $YBa_2Cu_3O_{7-\delta}$, thus enabling the growth of highly textured $YBa_2Cu_3O_{7-\delta}$ films with high critical current densities (i.e., greater than 1 MA/cm^2) on the underlying ferroelectric film, or alternatively, of highly textured ferroelectric film on the underlying $YBa_2Cu_3O_{7-\delta}$ film.



($YBa_2Cu_3O_{7-d}$, Au) /$SrTiO_3$/$LaAlO_3$ coupled microstripline phase shifters. All dimensions are in micrometers. Top: 25-W phase shifter ; S = 12.7 mm, W = 76.2 mm. Middle: 50-W phase shifter; S = 7.5 mm, W = 25 mm. Bottom: Eight-element, 50-W phase shifter; S = 7.5 mm, W =25 mm. Shaded areas represent bias pads and radial stubs for direct-current bias.

So far, our efforts have been concentrated on supporting industry and academia in determining the deposition parameters required for optimal ferroelectric thin-film growth (i.e., maximum tunability and lowest loss) and in investigating different varactor and microwave component configurations to determine which geometry is most advantageous in terms of tunability, losses, and required bias for a given communication application. For example, we have observed that for optimized $SrTiO_3$ films in a parallel-plate capacitor configuration with $YBa_2Cu_3O_{7-\delta}$ conducting plates, tunabilities of up to 47 percent and dissipation losses (tanδ) of 0.05 are attainable at 1 MHz and 80 K, within a 0- to 5-Vdc range. In contrast, for interdigital configurations made of the same films, tunabilities of up to 70 percent and tand ranging from 0.015 to 0.001 (depending on the bias) have been observed at 1 MHz and 77 K within the 0- to 100-V bias range.



Insertion phase shift versus voltage for an eight-element, 50-W $YBa_2Cu_3O_{7-d}$ (350-nm-thick)/$SrTiO_3$ (2.0-mm-thick)/$LaAlO_3$ (254-mm-thick) coupled microstripline phase shifter. Data were taken at 16 GHz.

Efforts are underway to use these results in developing planar microstrip phase shifters for phased arrays, tunable filters for receiver front ends, and tunable local oscillators for Ku- and K-band communication systems. For example, we recently demonstrated an eight-element, $YBa_2Cu_3O_{7-\delta}$/$SrTiO_3$ on $LaAlO_3$ coupled microstripline phase shifter (CMPS) with a phase shift of 390° and an insertion loss of less than 10 dB at 16 GHz and 350 Vdc (see the figures). The effective coupling length for this device is 0.33 cm, and its total length is less than 1 cm. Similarly, we demonstrated tunable filters and multiconfiguration (e.g., contiguous, interdigital, and concentric) ring resonators at 19 GHz that exhibit frequency tunabilities of up to 1 GHz with respect to the center frequency without insertion loss and quality factor degradation. These components are the proof of concept of a hitherto unavailable technology to meet the stringent performance requirements of foreseeable satellite and wireless communication systems (e.g., contiguous, vibration-free steering antennas; bandpass filters with narrow bandwidth, small insertion losses, and steep out-of-band rejection; and low-noise figure and phase noise receivers) in a more advantageous fashion than with currently available technology (e.g., phase-shifting diodes, dielectric-filled cavities, and dielectric resonator oscillators). Optimization of the aforementioned components is underway at NASA Lewis.

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