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Space Applications of Superconducting Microwave Electronics at NASA Lewis Research Center

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ABSTRACT

Since the discovery of high temperature superconductivity in 1987, NASA Lewis Research Center has been involved in efforts to demonstrate its advantages for applications involving microwave electronics in space, especially space communications. The program has included thin film fabrication by means of laser ablation. Specific circuitry which has been investigated includes microstrip ring resonators at 32 GHz, phase shifters which utilize a superconducting, optically activated switch, an 8x8 32 GHz superconducting microstrip antenna array, and an HTS-ring-resonator stabilized oscillator at 8 GHz. The latter two components are candidates for use in space experiments which will be described in other papers. Experimental data on most of the circuits will be presented as well as, in some cases, a comparison of their performance with an identical circuit utilizing gold or copper metallization.

THIN FILM FABRICATION

High quality thin films of YBCO have been deposited by means of ablation of stoichiometrically correct targets by a pulsed excimer laser [1,2]. The facility is shown schematically in Figure 1

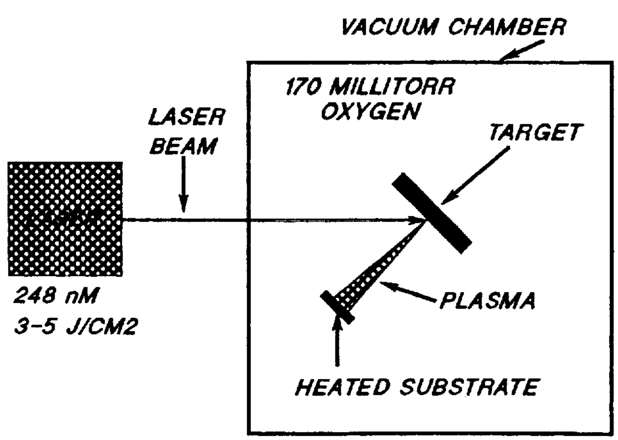

Figure 1. Laser Ablation Facility

A typical deposition is carried out by evacuating the sample chamber to $3x10^{-7}$ torr or less, warming the substrate to near 500C, introducing a continuous flow of oxygen (120 sccm) into the chamber, and heating the sample to 775°C. During deposition, chamber pressure is approximately 170 mtorr. The laser wavelength is 248 nm; the energy density is typically 1.5 J/cm^2/pulse, with a pulse repetition rate of 4 pps. Following deposition, the oxygen pressure is raised to 1 atmosphere and the sample allowed to cool prior to removal from the chamber.

Using this technique, strongly c-axis oriented YBCO films have been deposited on strontium titanate, lanthanum aluminate, and MgO. The most useful of these, in terms of the film characteristics and the microwave properties of the substrate, are those on lanthanum aluminate, where a Tc of 90.6K was achieved, with a critical current density of $2x10^6$ amps/cm^2 at 77K. A typical measurement of DC resistance vs. temperature is shown in Figure 2.

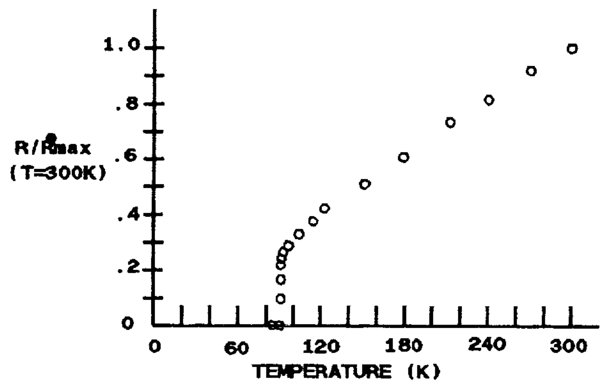

Figure 2. Measured DC Resistance of YBCO Film

MICROWAVE CIRCUITS

Microstrip Ring Resonators

Among the first microwave circuits to be fabricated and tested was the microstrip ring resonator at 35 GHz [3,4]. A schematic diagram of this device is shown in Figure 3.

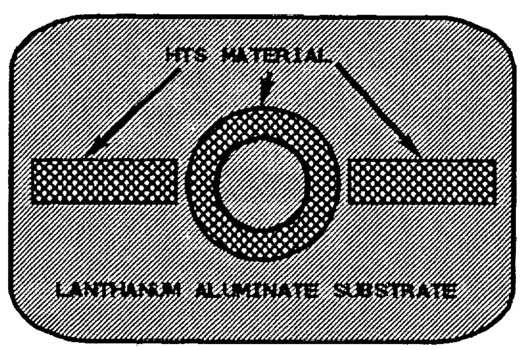

Figure 3. Microstrip Ring Resonator

Q-values of such devices yield realistic estimates of the microwave performance of superconducting circuits since they reflect both conductor and dielectric losses, as would a functional application. Results for two such resonators, one fabricated from YBCO and the other from $Tl_2Ca_2Ba_2Cu_3O_x$ (TCBCO), deposited at the University of Cincinnati, are shown in Figure 4.

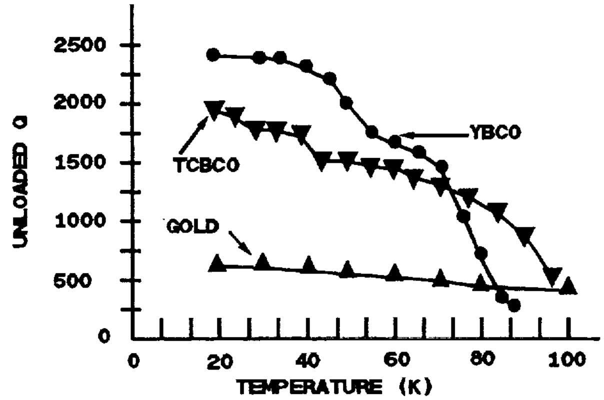

Figure 4. Unloaded Q Values for Ring Resonators at 35 GHz

Both circuits use a normal metal ground plane. It is clear that at 35 GHz, neither superconducting resonator is much superior to an identical gold circuit. At lower temperatures, however, the Q of the YBCO resonator is four to five times that of gold, while the TCBCO one is approximately three times that of gold.

Superconducting Phase Shifters

One device which, in principle, could benefit greatly from the use of superconductivity is the true-time-delay phase shifter. Such a circuit, which is required for electronically steered phased array antennas, switches an RF signal between two alternate paths, one of which is physically longer than the other so as to provide a true time delay phase shift. Such devices, using a field effect transistor as the active switching element, will typically exhibit insertion losses of one or two dB, so that a five bit phase shifter, as would be required in order to obtain phase resolution of 11.5 degrees would suffer a loss of 5 to 10 dB. The use of a superconducting patch as the switching element should provide considerable improvement. The layout for such a phase shifter is shown in Figure 5.

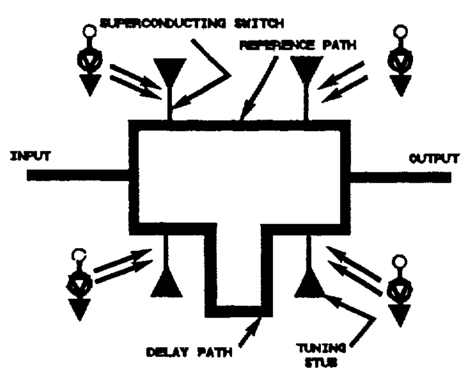

Figure 5. Optically Activated HTS Phase Shifter

Such a device, utilizing bolometric switching from normal to superconducting state, with the heat being delivered optically via optical fiber, has been fabricated at NASA Lewis. Preliminary results indicate that switching times on the order of 100 milliseconds are achievable in this manner. Unfortunately, this is only marginal for most antenna beam steering applications. Thermal analysis indicates that faster switching times are unlikely unless a low thermal conductivity substrate with acceptable microwave properties can be identified. A possible candidate for such a material is yttrium-stabilized zirconia (YSZ), which has been used in the fabrication of another device. Data for this circuit are not yet available.

Microstrip Array Antennas

Dinger [5] has shown that the gain of a multielement microstrip array at millimeter wave frequencies is limited by the ohmic losses in the power divider network, which becomes increasingly complex as the number of radiating elements increases. Work at NASA Lewis, carried out in collaboration with Ball Aerospace, has produced a 64 element (8x8) array antenna operating at 35 GHz. The superconducting film is TCBCO, which is deposited on a two-inch diameter lanthanum aluminate substrate. The TCBCO film was fabricated by Superconductor Technologies Inc., while the array was designed and fabricated by Ball and tested at NASA Lewis. A photograph of the array in its test fixture is shown in Figure 6.

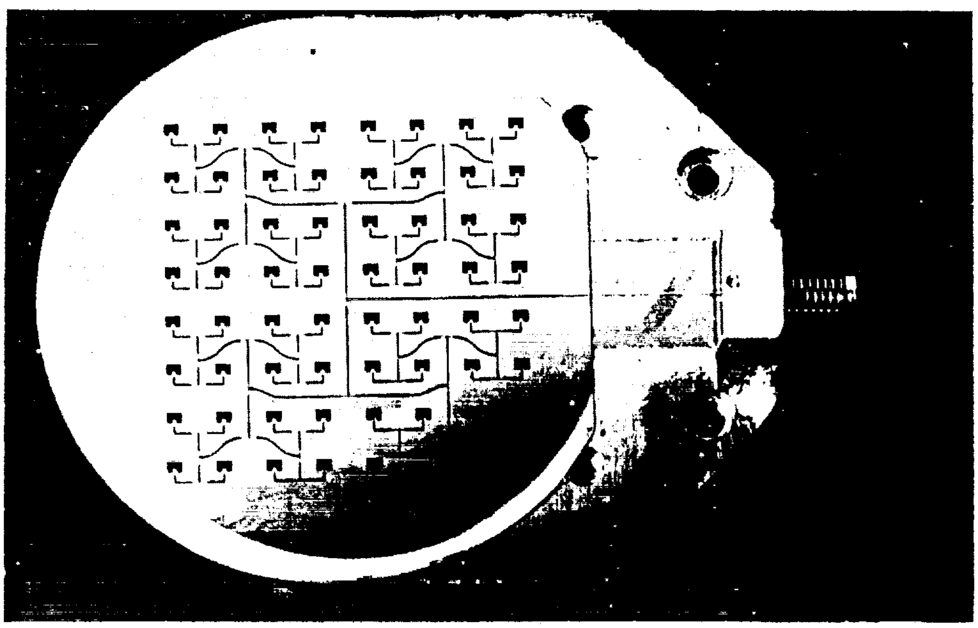

Figure 6. 64-Element Microstrip Antenna Array

Results of gain tests, using the antenna as a receiver are shown in Figure 7.

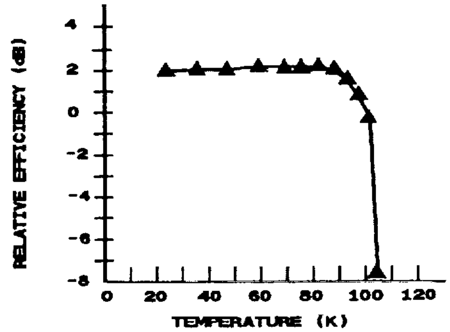

Figure 7. Efficiency of 8x8 Superconducting Array Relative to an Identical Gold Array at the Same Temperature.

As is clearly demonstrated, at 35 GHz, the superconducting 8x8 array and power divider network have approximately 2 dB higher gain than an equivalent cooled gold antenna. Relative to a gold array at room temperature, the HTS antenna exhibited an improvement of approximately 5 dB at temperatures below 90K.

HTS-Resonator-Stabilized Oscillator

By using planar resonators fabricated from superconducting films, it should be possible to implement stable microwave oscillators, such as are now designed using crystal oscillators or dielectric-resonator-stabilized oscillators (DRO). Such a structure would be highly amenable to integration with semiconductor components and would have the advantages of reduced circuit complexity and increased reliability, with only a small sacrifice in performance. Typically, one would anticipate unloaded Q's near 10,000 (at 8 GHz) from a planar superconducting resonator, as compared with the 10,000 to 20,000 possible from a DRO, and the 1000 possible for a planar structure using normal metals. Such a Q should make possible a superconductor-stabilized oscillator with a phase noise better than -100dBc/Hz. Although data is not yet available, the design for such a resonator is complete, and is shown in Figure 8.

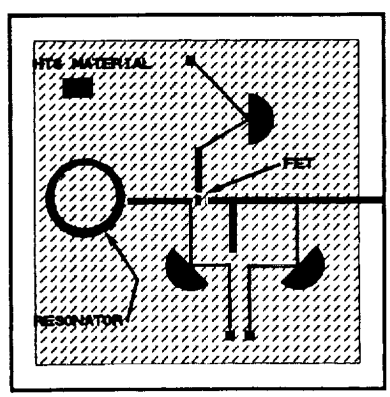

Figure 8. Layout of an HTS-Resonator-Stabilized Oscillator

CANDIDATE FLIGHT EXPERIMENTS

Shuttle/ACTS Communications Experiment

The antenna described above, combined with an appropriate phase shifter is intended to be the forerunner of a steerable array which can be installed on the space shuttle to form the receive terminal of an earth-to-geo-leo 30/20 GHz communications link. A schematic representation of the experiment is shown in Figure 9.

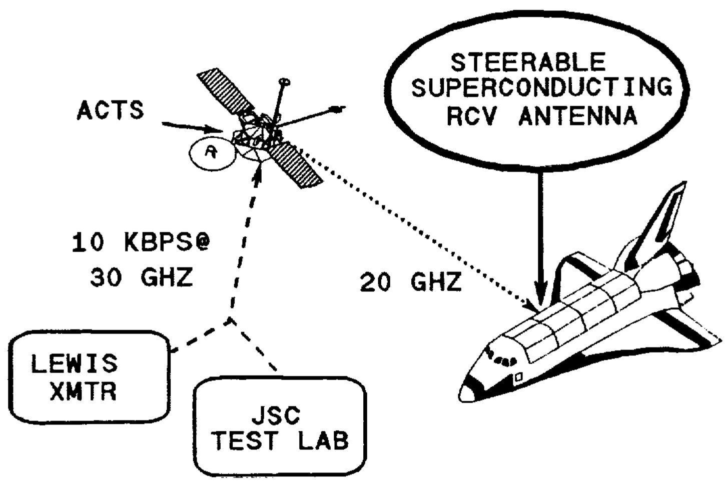

Figure 9. Schematic Representation of ACTS/Shuttle Communications Experiment Using an HTS Antenna

Details of the experiment are described in another paper [6] at this conference.

HTSSE-II

Together with JPL, NASA Lewis is developing a low noise receiver as a candidate to be flown on NRL's HTSSE-II flight experiment [7]. An overall block diagram of the receiver is shown in Figure 10.

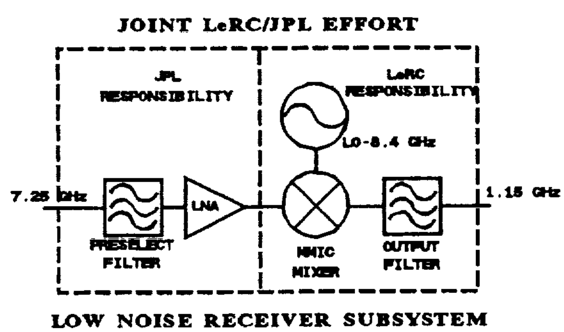

Figure 10. Block Diagram of Lewis/JPL HTSSE-II Receiver

The receiver will employ the superconducting oscillator described earlier in this paper, a superconducting input filter, together with cryogenically-cooled, normal metal low noise amplifier and mixer, both of which will utilize conventional semiconductor components. More details of the experiment are given in another paper at this meeting [8].

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