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C-Band Superconductor/Semiconductor Hybrid Field-Effect Transistor Amplifier on a $LaAlO_3$ Substrate

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C-BAND SUPERCONDUCTOR/SEMICONDUCTOR HYBRID FIELD-EFFECT TRANSISTOR AMPLIFIER ON A $LaAlO_3$ SUBSTRATE

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Abstract--A single-stage C-band superconductor /semiconductor hybrid field-effect transistor (FET) amplifier was designed, fabricated, and tested at 77K. The large-area (1 inch x 0.5 inch) high temperature superconducting (HTS) Tl-Ba-Ca-Cu-O (TBCCO) thin film was rf magnetron sputtered onto a Lanthanum Aluminate ($LaAlO_3$) substrate. The amplifier showed a gain of 5.75 dB and a 3dB bandwidth of 150 MHz centered at 7.915 GHz at 77K. An identical gold amplifier was also tested at 77K for purposes of comparison, it had a gain of 5.46 dB centered at 7.635 GHz with a 3dB bandwidth of 100 MHz.

I. INTRODUCTION

Since the discovery of high temperature superconductors (HTS) in the Thallium-Barium-Calcium-Copper-Oxide (-TBCCO) and Yttrium-Barium-Calcium-Copper-Oxide (YBCO) systems [1,2], the idea of using superconductors in combination with semiconductor devices in hybrid microwave integrated circuits became feasible at liquid nitrogen temperatures [3]. Semiconductor devices such as Metal Semiconductor Field-Effect Transistors (MESFET's) and High Electron Mobility Transistors (HEMT's) have been shown to have improved device characteristics at cryogenic temperatures [4]. With the development of High T_c superconducting thin films, and Gallium Arsenide (GaAs) monolithic microwave integrated circuits high performance superconductor/semiconductor hybrid integrated circuits can now be realized. The use of superconductors and semiconductors together in microwave circuits has been demonstrated recently [5]. By combining superconducting material with semiconductor devices in microwave circuits, improved performance can be achieved in terms of decreased conductor losses, reduced noise figure (NF), and increased gain [6]. Also, by operating the amplifier at cryogenic temperatures, natural increase in gain due to increased conductivity in the transistor at low temperatures can be exploited.

The objective of this work is to determine the advantage of using High T_c superconducting thin films in the input and output impedance matching networks of a GaAs FET microstrip amplifier. In deep space communications and radio astronomy where ultra low-noise amplifiers (LNA's) are very important because very weak signals need to be detected, the use of superconducting matching networks could provide for lower insertion loss, resulting in improved performance. The amplifier design, fabrication, and results are presented in the following sections.

II. AMPLIFIER DESIGN AND FABRICATION

A single-stage microstrip amplifier was designed for a gain of 6 dB at a center frequency of 8 GHz and a 3dB bandwidth of 500 MHz. The amplifier circuit was designed using TOUCHSTONE [7] on a Sun Workstation. For the purpose of obtaining an optimized cryogenic design the Scattering Parameters (S-Parameters) of a Toshiba GaAs transistor were measured at 77K. The S-Parameters are shown in Figure 1.

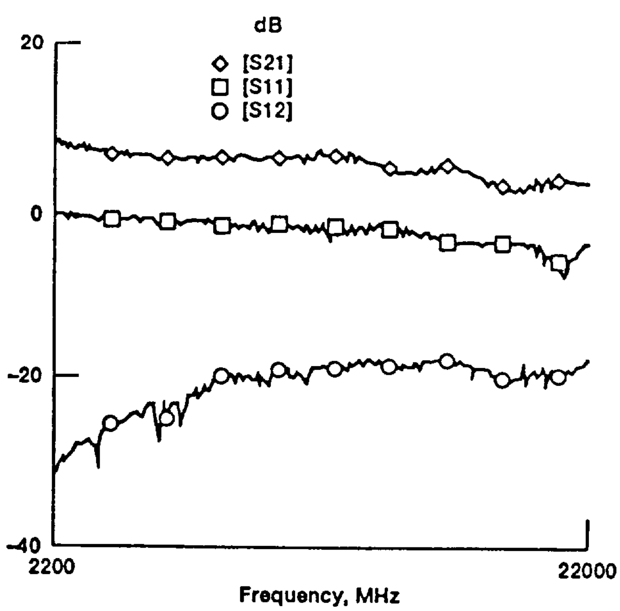

Fig. 1 S-Parameters of Toshiba GaAs FET at T= 77K

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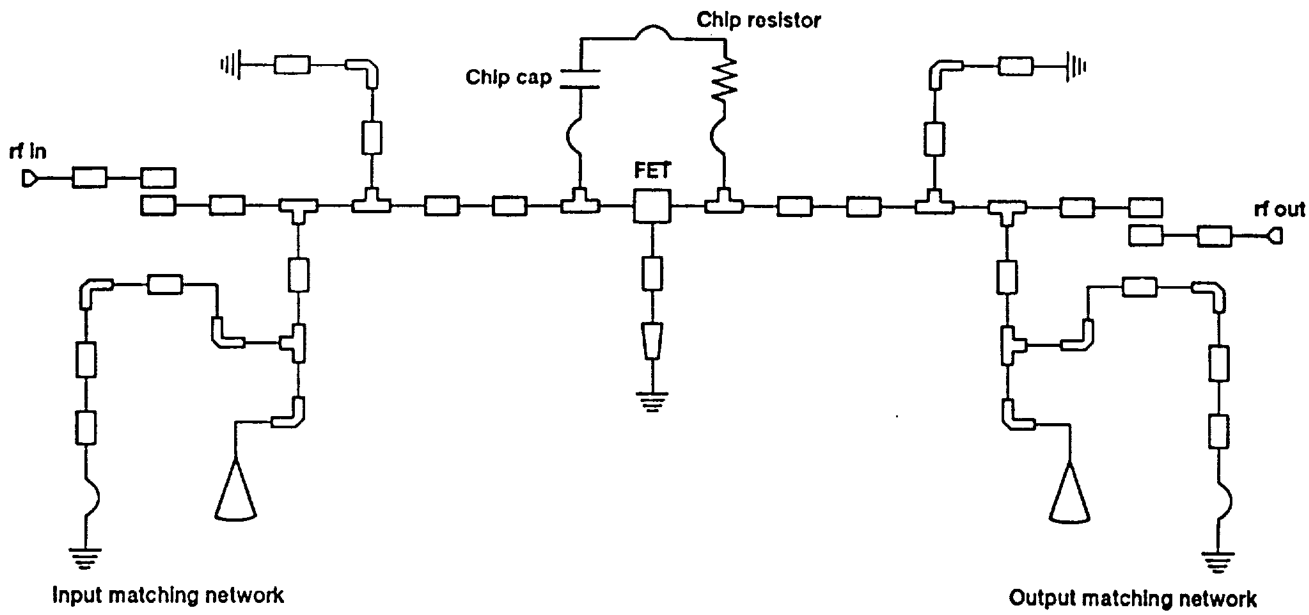

Fig. 2 Schematic of Amplifier Generated in TOUCHSTONE

The measured S-Parameter data was used to design the input and output single-stub impedance matching networks. A schematic of the design is shown in Figure 2. Input and output 50Ω feed lines are followed by coupled lines which function as dc blocks. Impedance matching was done using transmission lines of different length and width, and open-circuited shunt stubs to avoid the problem of fabricating high quality wide band short circuits. The grounding of the source terminal of the transistor was performed by using a low impedance transmission line terminated in a low impedance tapered line. The end of the tapered line came to the edge of the substrate and silver paint was applied to this edge in order to provide an rf ground path to the test fixture.

The amplifier matching and dc bias networks were fabricated by rf magnetron sputtering a TBCCO film from a single composite powder target of $Tl_2Ba_2Ca_2Cu_3O_x$ to a thickness of 3750 Å onto a 20 mil thick $LaAlO_3$ substrate [8]. Gold contact areas for wire bonding purposes were formed through a lift-off process and 2.5μm of silver was thermally evaporated on the opposite side of the substrate which acted as the ground plane. A Toshiba GaAs FET was mounted on the substrate using silver-filled conductive epoxy and cured at 150°C for 1 hour. A feedback network consisting of a chip resistor and chip capacitor was added to the amplifier design in order to ensure stability because the amplifier had a tendency to oscillate. The FET, chip capacitor, and chip resistor were connected to the appropriate microstrip lines with 0.7 mil diameter gold bond wires. The amplifier was mounted in a brass test fixture inside a cryogenic chamber on a cold-head platform. Inside the chamber semi-rigid coaxial lines connected the input and output ports of the amplifier to the outside of the cryogenic chamber. Input and output 3.5mm SMA female connectors provided a coax to microstrip feed line transition. Silver paint was used to ensure electrical contact between the launcher pin and the microstrip line. A photograph of the amplifier in its test fixture is shown in Figure 3. An identical amplifier using gold film for the microstrip lines and ground plane was also fabricated for use as a comparison to the hybrid amplifier.

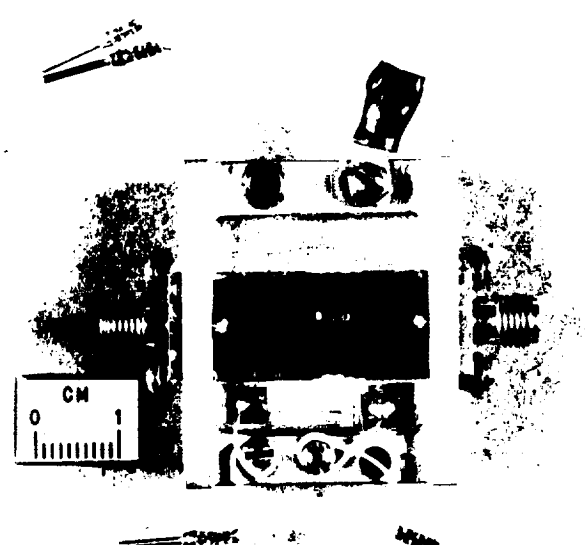

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Fig. 3 Photograph of Hybrid Amplifier in Test Fixture

III. MEASUREMENTS AND RESULTS

An HP8510B Vector Network Analyzer and a model 22C Cryodyne closed-cycle refrigeration system made by CTI-

Cryogenics were used to measure the S-Parameters of the amplifiers at 77K. The amplifier was mounted in the cryogenic chamber and the semi-rigid coaxial lines were connected to the input and output ports respectively. The chamber was evacuated to 50 milli torr and the transistor dc bias was applied. The corresponding S-Parameters were measure and recorded. The forward gain of the hybrid and gold amplifiers are shown in Figures 4 and 5 respectively.

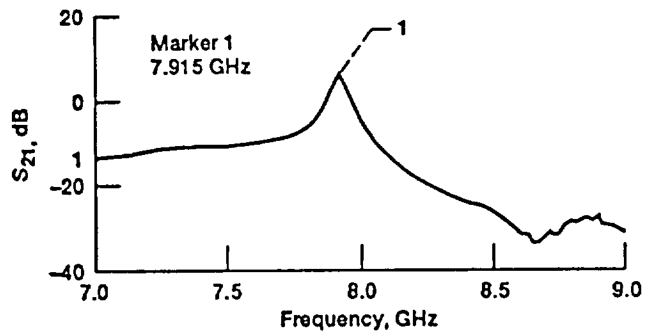

Fig. 4 Measured Gain of Hybrid Amplifier at T= 77K

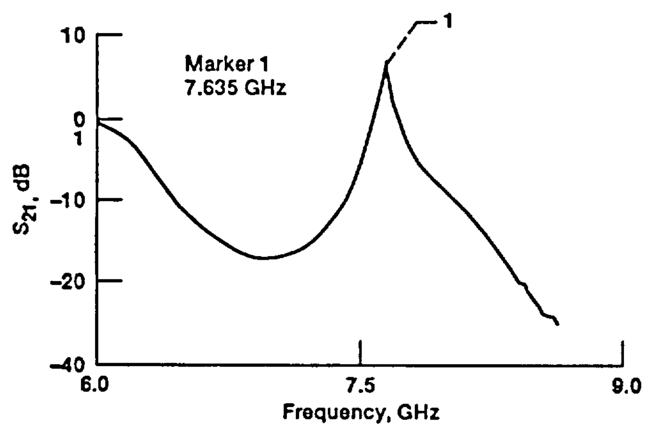

Fig. 5 Measured Gain of Gold Amplifier at T= 77K

The primary advantage of using TBCCO matching networks instead of gold is that the conductor losses are decreased and the NF can also be reduced. Since the superconducting material reacts differently than gold in terms of impedance one must design the matching networks taking into account in the simulation the properties of the superconducting material (i.e. surface resistance, thickness, and film uniformity) as compared to the properties of the gold film.

A comparison of the results obtained for the hybrid amplifier and the gold amplifier are shown in Table 1. Even though the results of the two circuits are not exactly comparable because of the differences in the impedance of the two materials it can be seen from Table 1 that the hybrid amplifier results were closer to the original design goals. This is because the properties of the superconducting material, such as thickness and resistivity, were taken into account in the design.

IV. CONCLUSIONS

A single-stage TBCCO/GaAs FET amplifier was fabricated and its S-Parameters were measured at 77K. An identical gold film amplifier was also fabricated and characterized at 77K. The hybrid amplifier showed a gain of 5.75 dB at a center frequency of 7.915 GHz while the gold amplifier showed a gain of 5.46 dB at a center frequency of 7.635 GHz. The hybrid amplifier was 1.0 inches long and 0.5 inches wide.

ACKNOWLEDGMENTS

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Table 1. Comparisons of Results of Hybrid and Gold Amplifiers at 77K

Amplifier Type	Gain (dB)	Center Frequency (GHz)	3dB Bandwidth (MHz)
Hybrid, T=77K	5.75	7.915	150
Gold, T=77K	5.46	7.635	100

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A single-stage C-band superconductor/semiconductor hybrid field-effect transistor amplifier was designed, fabricated, and tested at 77 K. The large area (1 inch × 0.5 inches) high temperature superconducting Tl-Ba-Ca-Cu-O (TBCCO) thin film was rf magnetron sputtered onto a $LaAlO_3$ substrate. The film had a transition temperature of about 92 K after it was patterned and etched. The amplifier showed a gain of 6 dB and a 3 dB bandwidth of 100 MHz centered at 7.9 GHz. An identical gold amplifier circuit was tested at 77 K, and these results will be compared with those from the hybrid amplifier.

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