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PROCESSING, FABRICATION, AND DEMONSTRATION OF HTS INTEGRATED MICROWAVE CIRCUITS

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R&D STATUS REPORT

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Short Title of Work: Processing, Fabrication, and Demonstration of HTS Integrated Microwave Circuits

Reporting Period: 1/25/93 to 4/25/93

DESCRIPTION OF PROGRESS

TASK 1.0: COMPARATIVE TECHNOLOGY ASSESSMENT

This task is essentially complete, but we are continuing to monitor progress in other technologies as they relate to the goals of this program.

TASK 2.1: INTEGRATED SUBSYSTEM SPECIFICATIONS

Measurements of nonlinear distortion in HTS filters at 77K and 20K were completed in this reporting period. These measurements were carried out on an X-band filter. Figures 1 and 2 show the results obtained. The solid and dotted lines in both plots have slopes of unity and three corresponding to the linear response and third order intermodulation distortion, respectively. The filter used for the measurement was 150 MHz wide and centered at 9.65 GHz. Two tones of the same power level at 9.640 GHz and at 9.660 GHz were input into the filter. The experimental arrangement included a TWT amplifier, a precision step attenuator, and a spectrum analyzer. Two separate frequency synthesizers were used as sources. From the plots shown here, it is clear that the third order intermodulation distortion spurs do not follow the typical 3:1 slope, but rather a 1.5:1 slope, approximately. The reasons for this are under investigation.

Measurements of the noise figure in an HTS filter were planned but not performed during this quarter due to financial restraints. Noise figures will be measured in the next quarter in order to confirm the theoretical prediction for thermal noise reported on in the last period. An assessment of the dynamic range expected of HTS filters will be completed from the data taken for noise and nonlinear behavior for the sample X-band filter used. The impact of HTS material quality on nonlinear distortion is expected to be significant and will be assessed.

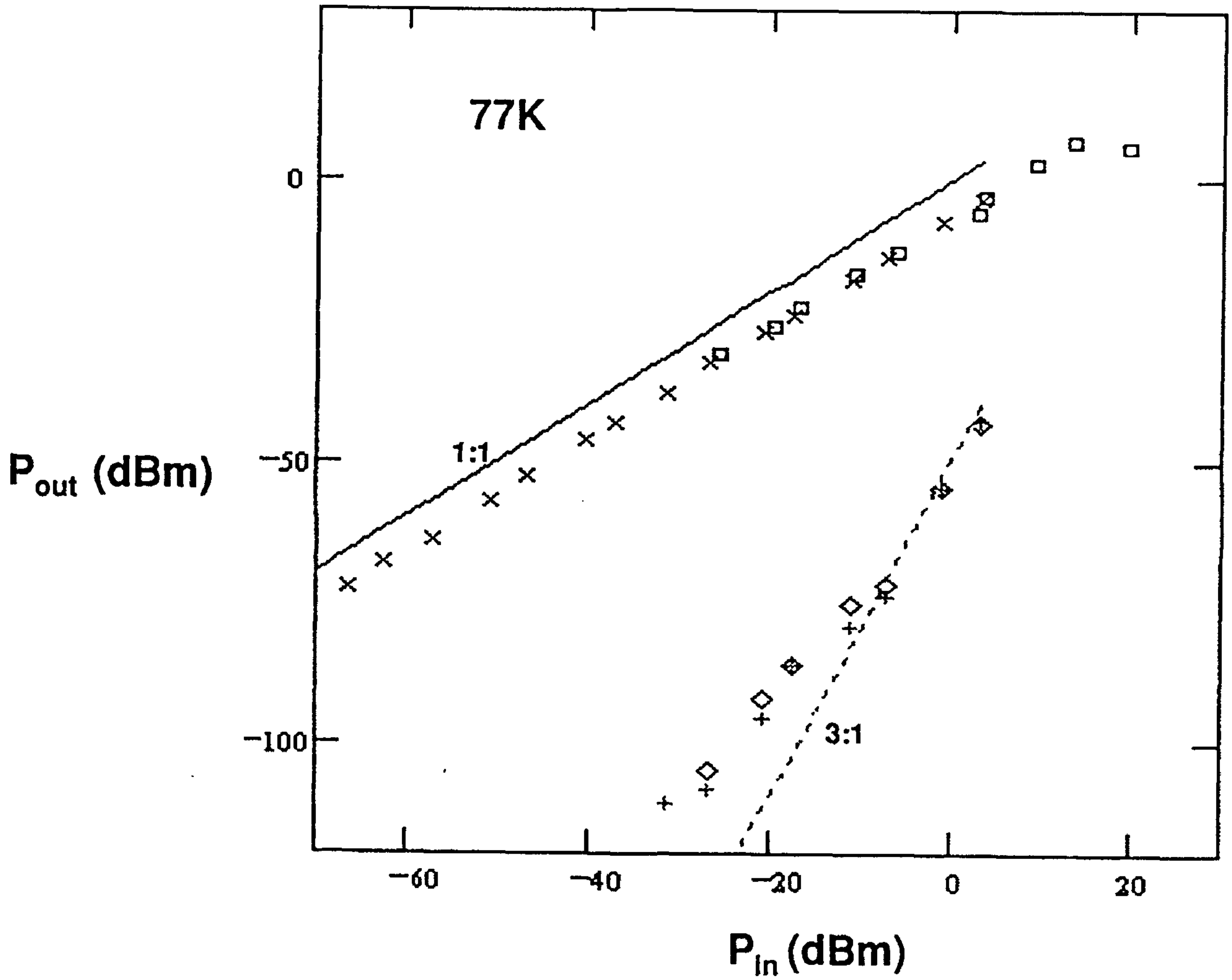


Figure 1. Linear response and third order intermodulation spurs at 77K.

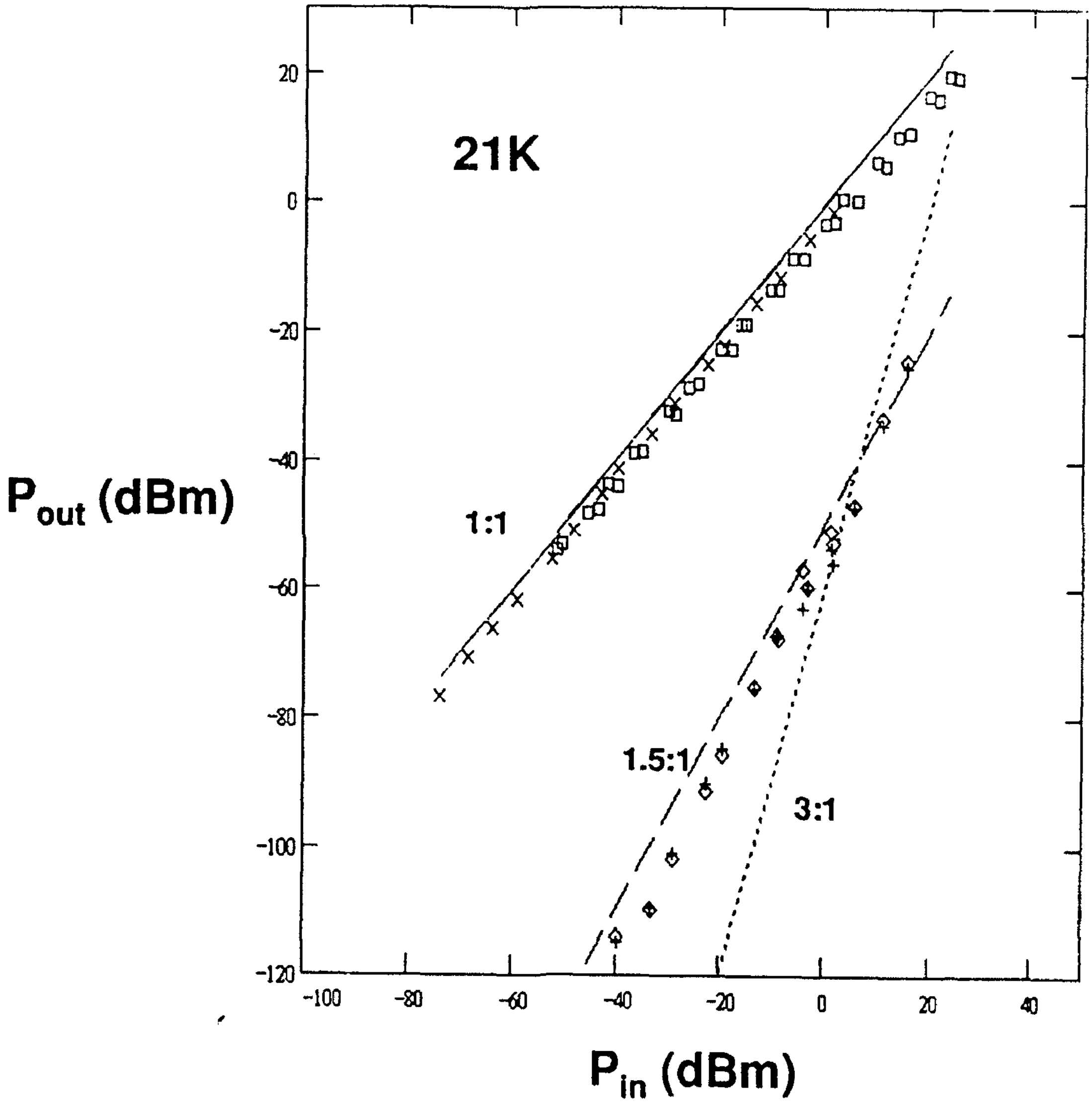


Figure 2. Linear response and third order intermodulation spurs at 22K.

TASK 2.2: FUNCTIONAL COMPONENT AND SUBSYSTEM DESIGN, FABRICATION AND TESTING

Filterbanks

The fabrication and packaging work reported here is related to progress made in the parallel program High-Temperature Superconducting Space Experiment-II (HTSSE-II). Filterbanks, delay lines, and their microwave packaging issues which pertain to the HTSSE-II program are being used as test vehicles for the technology developed in this ONR/ARPA program. Although the filter characteristics for HTSSE-II are different than those required in this program, the filterbank recently delivered to NRL for testing is reported on here as a first demonstration of the technology developed in this program. The differences and similarities between the ONR/ARPA and HTSSE-II filters are summarized in Table I. In spite of the differences, the technology developed will be fully applicable and extendable to the more challenging EW filterbank required in this program.

Figure 3 is a photograph of the HTSSE-II channelizer, showing the external loads and connections between channels. Each channel is housed in a separate package. No attempt at minimizing the weight and size were made in this first prototype; the highest level of integration was confined to each individual channel. Internal connections and thin film loads have yet to be included. The package itself will be integrated into a single, lighter unit.

Figure 4 are the responses for all four channels. The out-of-band rejection is greater than 60 dB for all channels and the center frequencies are within 20 MHz of the design ones, as indicated by the arrows in the figure.

Delay Lines

A YBCO delay line was also fabricated and delivered to NRL. Its response was very similar to that reported last quarter for a Nb test delay line. A photograph of this device is shown in Figure 5. The response is shown in Figures 6 and 7. Delay lines for both this and the HTSSE-II program are designed to the same characteristics.

Table I - Comparison between ONR/ARPA and HTSSE-II filterbank characteristics

	ONR/ARPA	HTSSE-II
Characteristics	Center Freq: 4 GHz Channel Bandwidth: 50 MHz 4 Channels	
Filter Type	Quasi-Cos^3 (7 poles)	Chebychev (4-poles)
Application	EW	Space Comm.
LAO Substrate	10 mils	20 mils

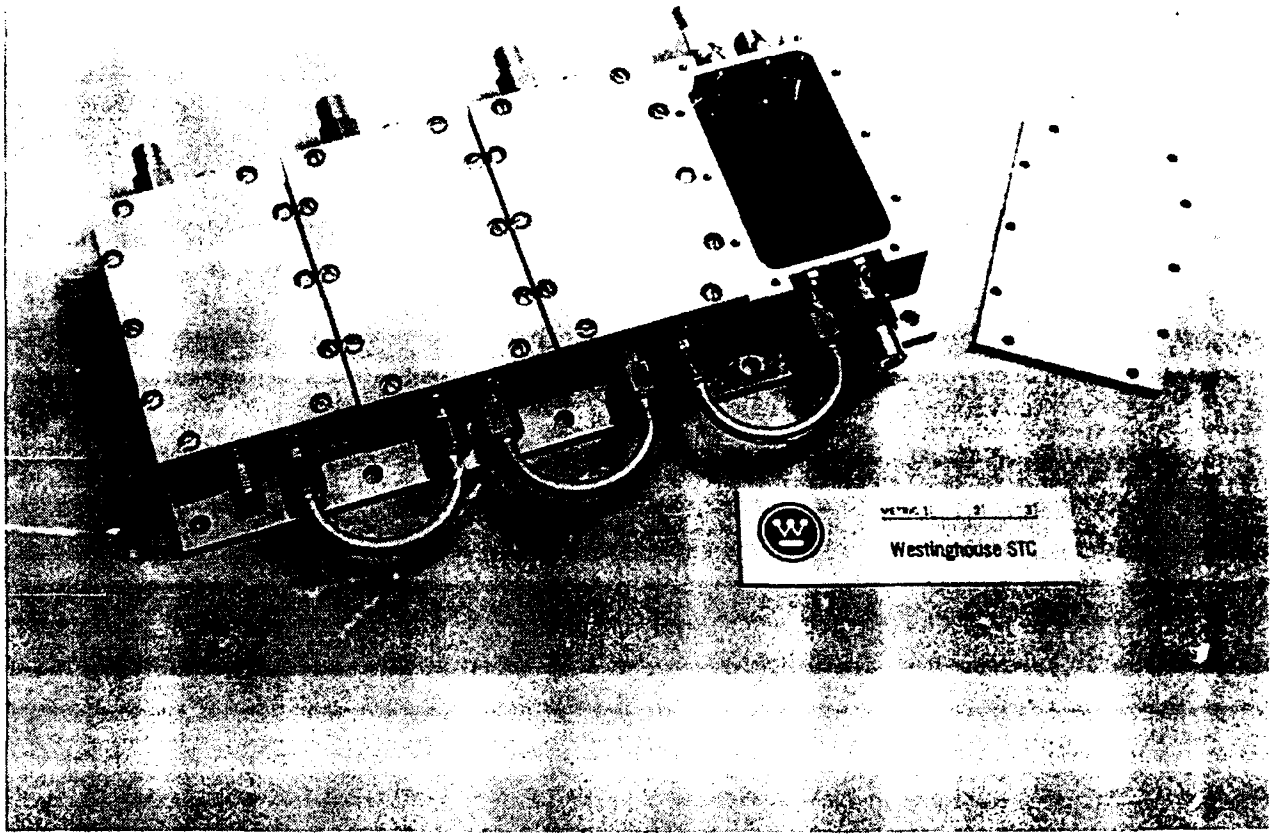


Figure 3. Photograph of prototype channelizer delivered to NRL for testing. External loads and channel interconnections were used.

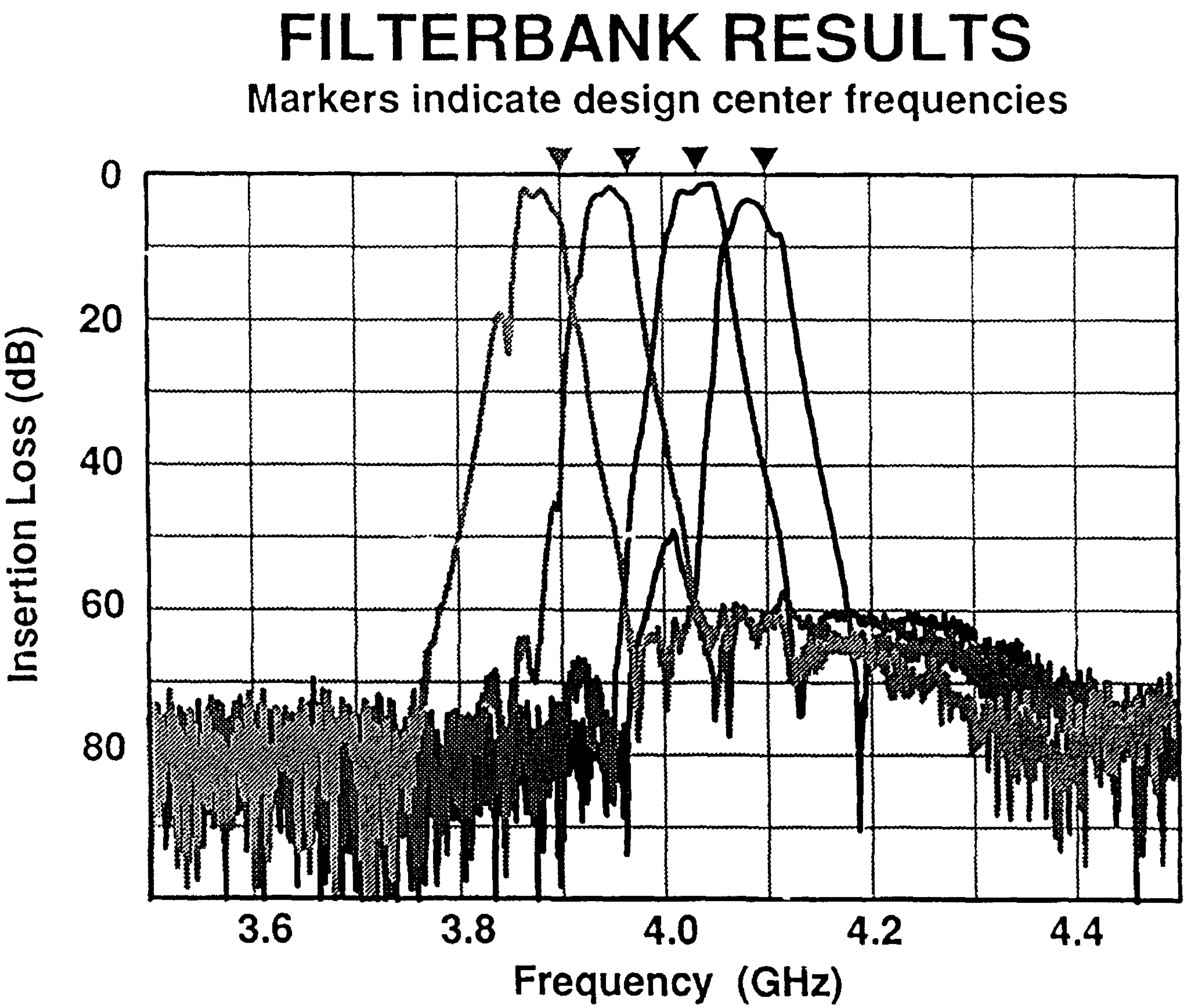


Figure 4. Measured transmission responses for all four channels.

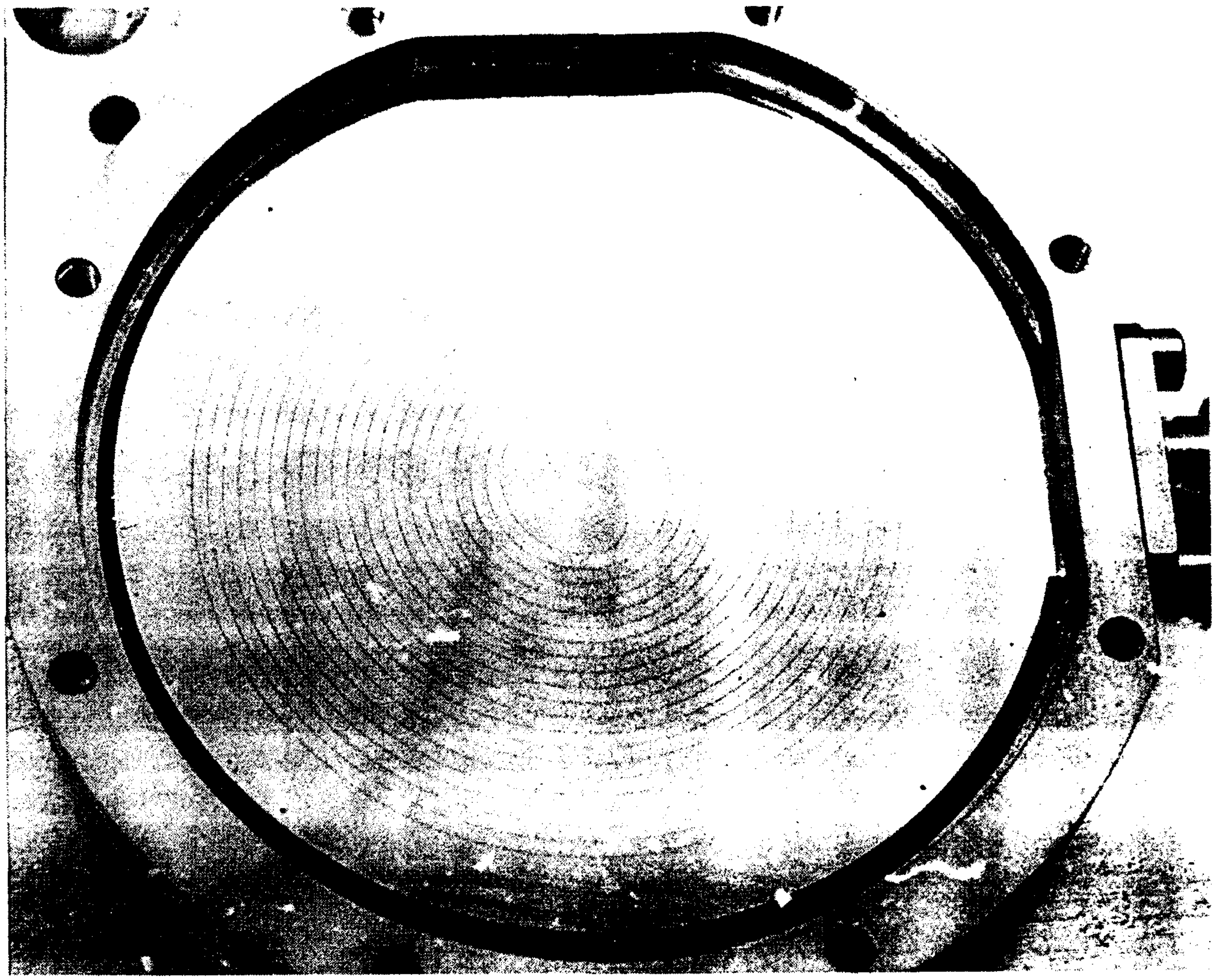
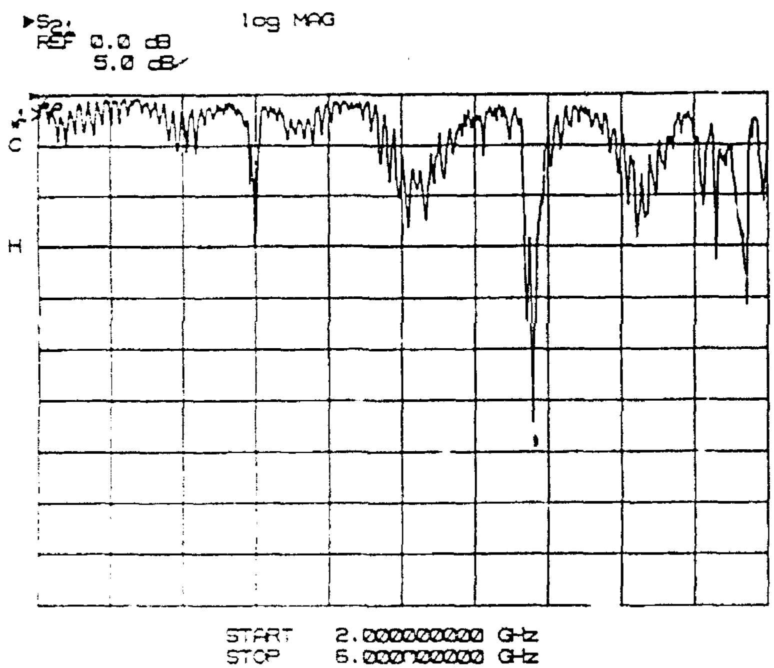


Figure 5. Photograph of the packaged bottom substrate of the delay line, showing the 22-μm-wide, 155-m-long doubly-wound spiral.

DELAY LINE RESULTS AT 15K

Transmission



Reflection

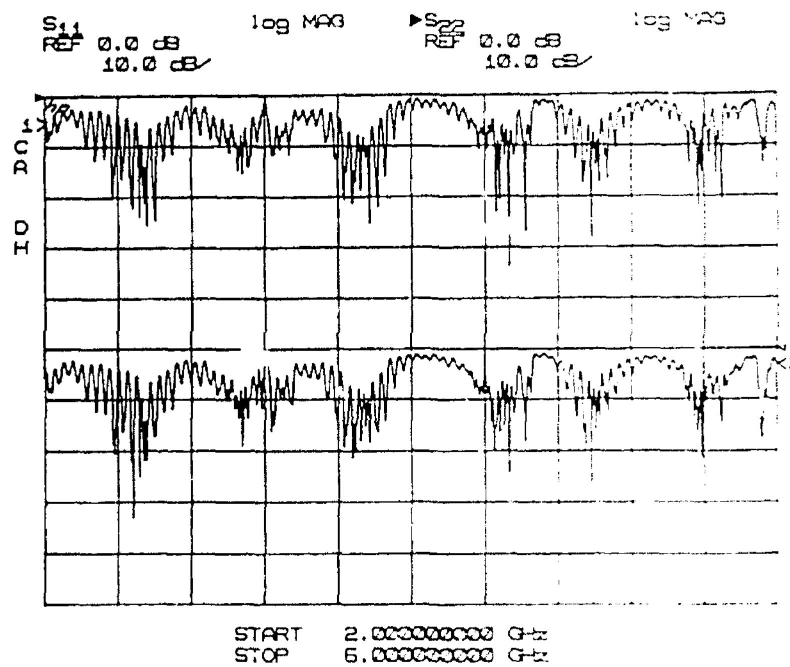


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Figure 6. Transmission and reflection response of the prototype delay line.

DELAY LINE RESULTS AT 15K

Time Domain: Return Loss at Port 1, Short at Port 2

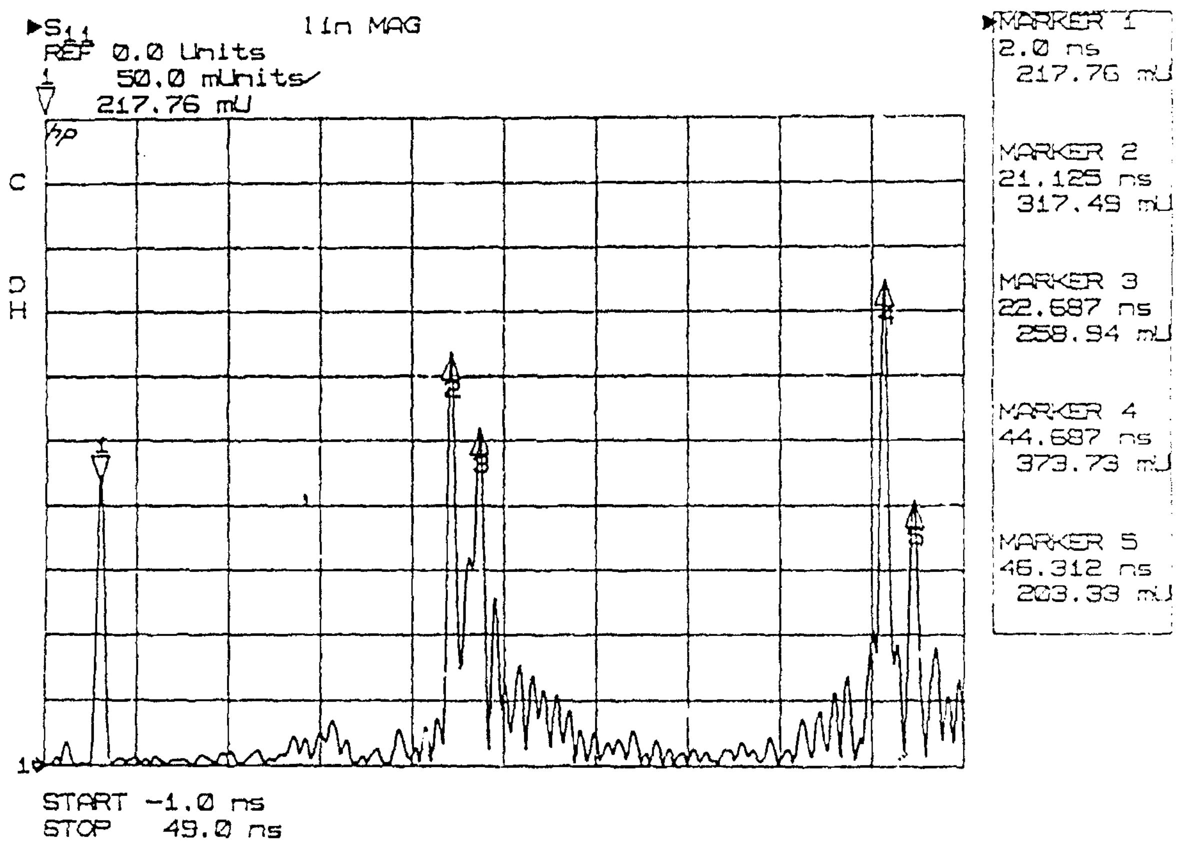

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Figure 7. Reflection time-domain response of the delay line when terminated in a short circuit. The two discontinuities in the middle of the line are believed to be due to air gaps between the stripline substrates.

Unfortunately, due to a fault in our fabrication process, the YBCO film was degraded and the delay line delivered was operational only below 50K. Steps are being taken to optimize our processing and increase fabrication yield.

The two discontinuities shown clearly on the time domain trace appear to be, as discussed in the last report, due to an air gap between the two $LaAlO_3$ substrates which make up the stripline configuration. A study was conducted to investigate the effect of an air gap on the microwave response of the delay line. It was found that an air gap, by altering the symmetry of the dielectric, can generate significant forward coupling between adjacent turns of the spiral. The forward coupled energy appears in the measurements as would a discontinuity in the middle of the delay line. Estimations of the tolerable size of the air gap are now being completed, and will determine whether our present approach is practically feasible. Alternative approaches which minimize or eliminate the effect of air gaps are being explored.

TASK 3.1: PVD MULTILAYER FILM FABRICATION

The two tasks scheduled for this reporting period required delivery of YBCO films on both sides of two-inch diameter substrates to Task 2.2, and development of a multilayer deposition capability on four-inch wafers.

In contrast to the previous quarter, during which a low level of expenditure limited production of YBCO films for filter channels (0.020-inch thick wafers) and delay lines (0.010-inch thick wafers), full production began in which approximately five 2"-diameter wafers per week were coated on one or both sides. To ensure that films were substantially thicker than the magnetic penetration length at 77K, the standard film thickness was increased to 400 nm. A production schedule was charted for this program and HTSSE II which calls for approximately 80 such wafers to be coated between May 1 and October 1, 1993.

The standard growth process results in films that are smooth and completely free of CuO particles. Spot checks performed on the rf surface resistance of films for filter channels indicated that all films were in the required range $R_S \sim 0.5$ mΩ at 77K and 10 GHz. The critical process variable in determining R_S, a substrate temperature during growth of $\gtrsim 750^\circ$ C, has not affected reproducibility since it was identified earlier in the program. At present, the weakest link affecting film reproducibility is a problem that can be easily monitored - the homogeneity of commercially-available stoichiometric YBCO sputtering targets. The consequence of an inhomogeneous target is that one or several hot spots develop causing a non-stoichiometric evaporation of the target material in that region. As wafer production increased, better statistics were obtained on the extent of the problem. Approximately one of every five targets exhibited this problem the first time it was used and had to be replaced. The other targets remained well-behaved during a lifetime of producing approximately 16 films.

The schedule for production of 2-inch YBCO films requires nearly a 100% duty cycle for the sputtering chamber in which they are currently being produced. A second chamber, nearly identical to the first, has produced films of identical high quality. It is committed to other programs but serves as a backup if production in the primary chamber should be interrupted for any reason. Another potential backup was explored by purchasing commercially available 2-inch diameter wafers coated with YBCO on one side from Conductus. Measurements of R_S with a 2" end-wall replacement cavity showed that the Conductus films meet the program requirements. Although Conductus deposits a film on only one side of a wafer, our processing time could be cut in half by having to grow YBCO on just the second side. The Conductus films received so far, however, have a high density of "boulders" on the surface and packaging experiments are being performed to determine if their rough surfaces can be adequately protected from indium solder by a diffusion barrier that works well for smooth films.

Progress in the development of YBCO-coated four-inch wafers continued with installation of a new sputtering chamber built to a Westinghouse design by Nordiko Ltd., which can accommodate 2, 3, or 4-inch wafers. Installation was completed by a Nordiko service engineer at the end of February. The critical component of the chamber is the substrate heater which must hold the substrate at 750°C during deposition without direct contact. Eight 2"-diameter films have now been deposited but each experiment led to additional iterations in the configuration of thermal shielding. The films had high T_cs but also had high R_s due to excessive heating of elastomer seals and rotary feedthroughs in the vicinity of the substrate heater and subsequent contamination of the sputter gas. The latest design has reduced the heater power needed to maintain the desired substrate temperature from an initial value of 70% to less than 30% of the heater's 2.6 kW maximum.

TASK 3.2: MOCVD MULTILAYER FILM FABRICATION

Work under this task was performed at EMCORE on YBCO film growth, at Northwestern University on the development of new Ba precursors for YBCO and growth of epitaxial insulating films, and at Westinghouse STC where measurements were made of the rf surface resistance of YBCO films.

Two batches of Ba precursors were delivered to EMCORE in January, 1993, by the group at Northwestern University. The first was a purified $Ba(thd)_2$, the standard precursor which can only be obtained commercially in a low-purity form. The bubbler temperature had to be raised by 10-15°C to obtain the same vapor pressure with the purified material that had been obtained with the commercial source. Despite the apparent difference in the precursor, there was no observable change in film properties in switching to the high-purity source. Since each 25 gram re-load of the bubbler is usually sufficient for film growth over a six month period, the high-purity precursor was in use throughout this reporting period.

The second precursor batch delivered to EMCORE was a $Ba(hfa)_2$-tetraglyme. No films were grown with it. It has the necessary vapor pressure at low temperatures (comparable to the Y and Cu sources now in use), but contains fluorine. Reports of YBCO films grown with fluorinated MOCVD sources, as well as evaporation and sputtering sources, indicate that fluorine was not incorporated into the film during growth at high temperature. However, its disadvantage is that the exhaust gas contains highly corrosive HF. Since Northwestern has recently developed non-fluorinated Ba precursors with similarly high vapor pressures, the Ba-tetraglyme will not be tested. Film growth and Ba transport with the new precursors, bis(tri-butylcyclopentadienyl)barium and bis(di-butylcyclopentadienyl)barium, are being tested at Northwestern in deposition of BaO and $BaPbO_3$ before preparing a batch for shipment to EMCORE.

A planning meeting was held at EMCORE at the end of April. EMCORE is behind schedule in starting work on two-sided deposition of YBCO films. The reactor in which earlier 2-inch diameter YBCO films were deposited was dedicated to $SrTiO_3$ deposition and a second reactor was dedicated to low-ϵ insulator deposition as parts of their HTS MCM program. A third reactor, now dedicated to YBCO growth, was modified during this quarter to coat the same large-area (5-inch diameter) sample holder used in the first system. Composition uniformity and high T_cs were confirmed for YBCO films produced in the newest chamber. Although no films were sent yet to Westinghouse for R_s measurements, deposition of YBCO on the second side is scheduled to begin.

TASK 3.3: RF CHARACTERIZATION OF FILM PROPERTIES

A copper cavity measurement set up for two-inch diameter wafers (end-wall replacement technique) was used for spot checks of the films to be patterned for filters. Values of $R_s \approx 0.5$ mΩ at 77K and 10 GHz were found indicating that the films were qualified for device fabrication. A parallel-plate measurement technique for 1 cm^2 and 1/4×1/2-inch samples was used for evaluation of MOCVD-grown films and as a check on the calibration of the copper-cavity measurement. As part of an AFOSR-sponsored program, further improvements in the parallel plate measurement were instituted to improve sensitivity for measurements at low temperature (< 20K). The device is now capable of measuring $R_s = 0.05$ mΩ at 10 GHz, a factor of ten lower than required for high-quality YBCO films at 77K.

PROBLEMS ENCOUNTERED AND/OR ANTICIPATED

Although the start date of this program was July 24, 1991 with the approval of anticipatory spending, the contract was not signed until September 30, 1991 when the first increment of funding was received. Our current allocation is sufficient for the first year of effort, but is designated to cover the work through October 31, 1992. The work effort was slowed at DARPA's request to stretch the FY92 funding through 12/31/92. However, FY93 funds were not received until March 30, 1993. These funding limitations will place the program at least six months behind schedule.

FISCAL STATUS

Amount currently provided	$3,100,000
Expenditures and commitments through 4/25/93:	2,110,794 *
Funds required to complete:	2,169,203
FY93 funds required:	300,000

*Includes $353,303 committed to subcontractors and purchase orders.