HYBRID SEMICONDUCTIVE/HIGH-TEMPERATURE SUPERCONDUCTIVE TUNABLE PRESELECTOR

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ABSTRACT

HTSC lumped element filters with GaAs varactor tuning, P-HEMT LNAs with HTSC lumped element matching and a GaAs MMIC SP4T switch with integrated decoding are described for use in a broadband cryogenic preselector operating from 200MHz to 2GHz. The filters tune over their respective sub-bands and have insertion losses ranging from 2 to 14dB. The sub-band LNAs have from 8.5 to 11.5dB of gain, noise figures under 1.5dB and input return losses greater than 20dB. The SP4T MMIC multiplexing switch has under 0.5dB insertion loss, isolation in excess of 30dB and 10/90% switching speed under 100nsec. These components are designed to be assembled into a 30 cubic centimeter electronically tunable four-channel proof-of-principal preselector operating over portions of the 200MHz to 2GHz band.

INTRODUCTION

With advances in MMIC technology, the array antenna concept using active transmit/receive (T/R) modules is firmly established as an effective antenna system for a wide range of applications. While many active MMIC components have been reduced to practice, passive filters are difficult to implement in MMIC technology due to the low Q-factors of monolithic passive reactive elements [1]. Recent advances in HTSC technology offer promises of compact integration of high-Q front end cryogenic filters compatible with broadband T/R modules. In addition, cryogenic operation also reduces the insertion loss contribution to noise figure [2] and lowers semiconductive active element noise figure.

This paper describes our effort to combine thin-film HTSC technology with GaAs technology to develop a novel low-loss, tunable cryogenic preselector to provide interference suppression in MMIC-based T/R modules for wide-band phased-array radar. Three-section HTSC passive lumped element filters with GaAs varactor tuning, P-HEMT feedback LNAs with HTSC lumped element matching and a custom GaAs MMIC SP4T switch with integrated decoding are described for use in a four-channel proof-of-principal broadband cryogenic (77K) preselector.

SYSTEM ARCHITECTURE

The basic function of the preselector is to reject out of band interference while passing the operating signal spectrum of the radar with the minimum effect on receiver noise figure and power handling. The multi-channel preselector architecture, shown in Figure 1, was selected to satisfy the 3dB noise figure requirement while tuning over the 200MHz to 2GHz decade band. Seven channels, each operating over progressively smaller percentage bandwidths, were found to be the best tradeoff of insertion loss with tuning range. Each channel is selected with a pair of custom low-loss SP4T MMIC switches, and the appropriate filter is voltage tuned to the correct frequency of operation. Each channel has a three-stage varactor-tuned HTSC lumped element filter to provide selectivity and a HTSC lumped element matched P-HEMT LNA with sufficient gain to establish channel noise figure. The low insertion loss of the lower frequency channel filters allows the losses of an additional pair of SP4T switches to be tolerated. The operating temperature of all components within the dashed box is 77K, while low loss coaxial transitions to room temperature mate with the T/R module and antenna. All HTSC circuits were fabricated on double-sided, 2" diameter, TlBaCaCuO/LaAlO wafers, commercially available through Superconductor Technologies Inc.

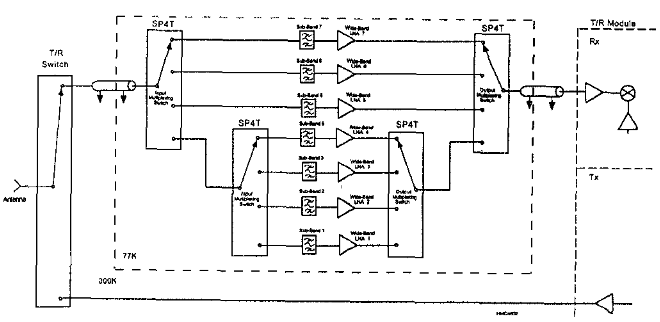

Figure 1. Preselector block diagram.

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SUB-BAND FILTERs

The three-stage tunable HTSC filters consist of three *T*-type capacitively-coupled LC resonators and input/output impedance matching circuits. The inter-resonator series capacitors are implemented as varactor diodes of the same value. Varying these capacitors by a control voltage tunes the filter center frequency and changes the coupling coefficients simultaneously. As a result, the filter pass-band ripple characteristics do not change appreciably with frequency tuning. The transformation ratio of the input/output impedance matching circuits is also controlled by the same control voltage to maintain the 3 dB bandwidth relatively constant over the tuning range.

Lumped element components are used for all inductors and capacitors to miniaturize the filters. The variable capacitors are implemented as discrete GaAs abrupt varactor diodes with *Q*-factors from 900 to 4,000. Three custom 3" diameter varactor diode wafers were fabricated and wafer probed to obtain uniform (1% C_{j0} tolerance) devices for use in each of the sub-band filters. The inductors are 75μm wide HTSC spiral transmission lines. Small value capacitors for demultiplication/Q enhancement and input/output coupling are implemented with HTSC/polyimide/gold structures patterned on the HTSC die. Larger coupling network shunt capacitors are implemented as external MIM capacitors. Figure 2 shows the photograph of sub-band filter #1 mounted on a thermkon carrier. Overall substrate dimensions are 12.5 x 5.0 x 0.25 mm^3. The varactors receive bias through discrete resistors attached to the substrate and a custom MMIC resistor array attached to the carrier.

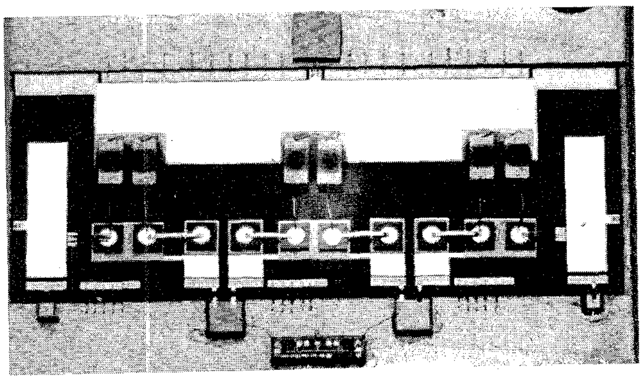


Figure 2. Photograph of sub-band filter #1.

Figure 3 shows the frequency response of sub-band filter #1 for various tuning voltages. As the filter tunes from 200 to 280MHz, bandwidth varies from 19MHz to 12MHz with less than 1dB peak-to-peak in-band ripple while insertion loss varies from 2.0 to 3.6dB. Table 1 summarizes the performance of the three sub-band filters. Insertion loss is much higher in filters #6 and #7 than was expected due to a combination of low Q varactors, inductors and MIM capacitors.

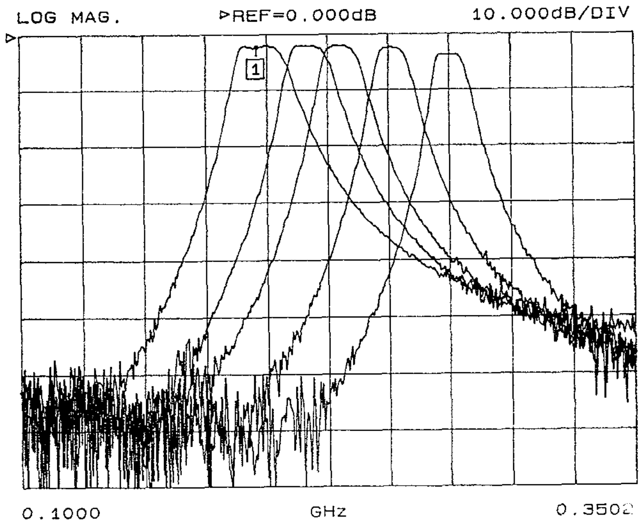


Figure 3. Sub-band filter #1 transmission responses.

Sub-Band	Frequency Range (MHz)	Insertion Loss (dB)	3dB Bandwidth (MHz)
#1	200-280	2.0-3.6	19-12
#6	1130-1530	8-13	84-40
#7	1530-2000	10-14	100-60

Table 1. Sub-band filter performance summary (@77K).

SUB-BAND LNAs

The LNAs consist of single-stage common-source P-HEMT amplifiers using source inductance, resistive feedback and reactive input/output matching. Resistive feedback lowers the input return loss over the wide percentage bandwidths to prevent out-of-band oscillations and in-band ripple when connecting to the filters and switches. This feedback approach is enabled by the lower feedback resistor noise contribution at cryogenic temperatures. A discrete Fujitsu FHX45X P-HEMT was selected for all sub-band LNAs. Noise modelling was based on [3] and fully de-embedded S-parameters were obtained with in-situ TRL calibrations [4].

A photograph of sub-band LNA #7 mounted on a thermkon carrier is shown in Figure 4. Compact low loss input matching is realized with a high impedance synthetic transmission line implemented with 75μm wide spiral HTSC inductors and parasitic shunt substrate capacitors. Output matching consists of a shunt HTSC choke and discrete MIM series capacitor. Feedback and bias stabilization are provided through custom MMIC R-C networks which minimize capacitive parasitics. Each of the two HTSC substrates shown measure 3.0 x 3.0 x 0.25 mm^3.

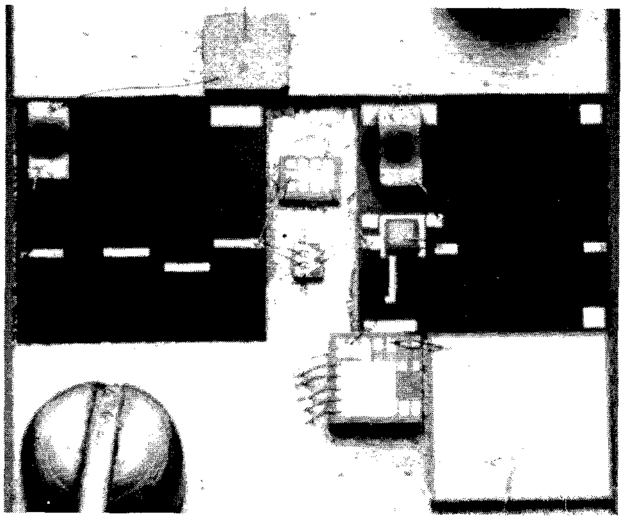
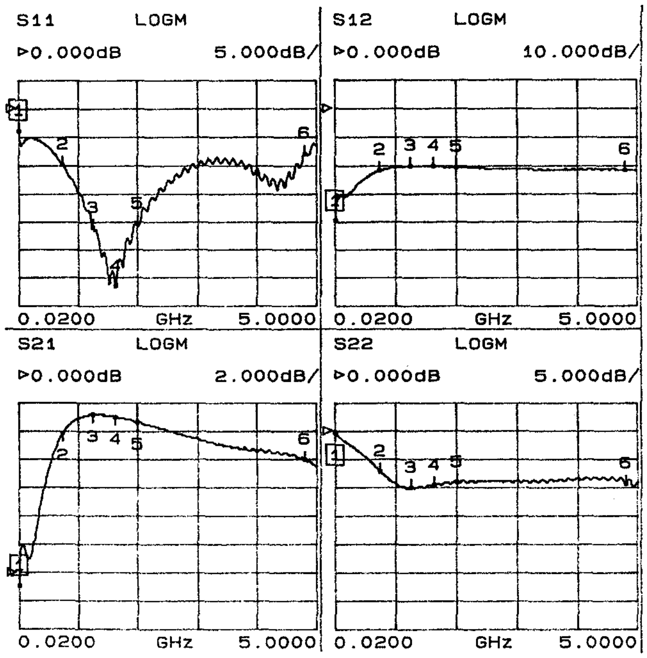


Figure 4. Photograph of sub-band LNA #7.

Figure 5 shows sub-band LNA #7 s-parameters at 77K for the nominal 2V-10mA drain bias. Gain varies from 11.0 to 10.8dB over the 1,530MHz to 2,000MHz band of operation. Input return loss exceeds 20dB, output return loss exceeds 9dB and noise figure (not shown) is under 1.5dB. Table 2 summarizes the performance of the three sub-band LNAs. The lower gain of LNA #1 was required to compensate for the lower insertion loss of filter #1, to provide a constant gain of 6dB through the preselector.

Sub-Band	Frequency Range (MHz)	Gain (dB)	Noise Figure (dB)	Input Return Loss (dB)
#1	200-280	8.5-8.7	<1.2	>30
#6	1130-1530	10.0-9.8	<1.4	>20
#7	1530-2000	11.0-10.8	<1.5	>20

Table 2. Sub-band LNA performance summary (@77K).



SWITCH MMIC

A custom low loss SP4T MMIC switch was designed with an integrated low power consumption 2:4 decoder, allowing the preselector channels to be selected with only two control lines. This allows the preselector to be further miniaturized and reduces the heat load on the cryogenic cooler. The 1.2 x 1.7 x 0.25mm^3 MMIC, shown in Figure 6, was fabricated using a standard 1μm gate-length, enhancement/depletion GaAs MESFET foundry process. Figure 7 shows the measured s-parameters at 77K. At frequencies below 2GHz, insertion loss is under 0.5dB, return loss is greater than 13dB, isolation is in excess of 30dB and 10/90% switching speed is under 100nsec. Current consumption at -5V bias averages 2.5mA for all switch states.

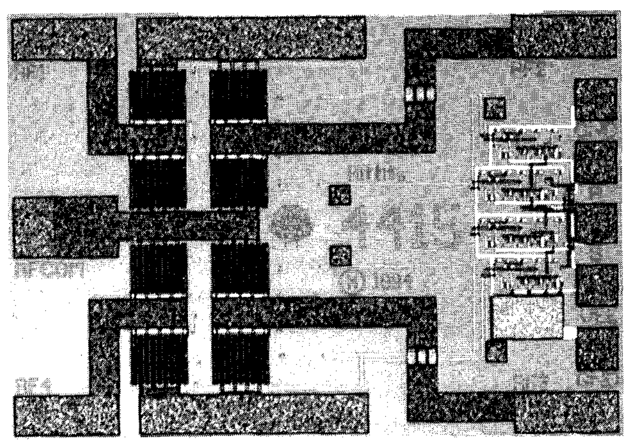


Figure 6. Photograph of SP4T MMIC switch.

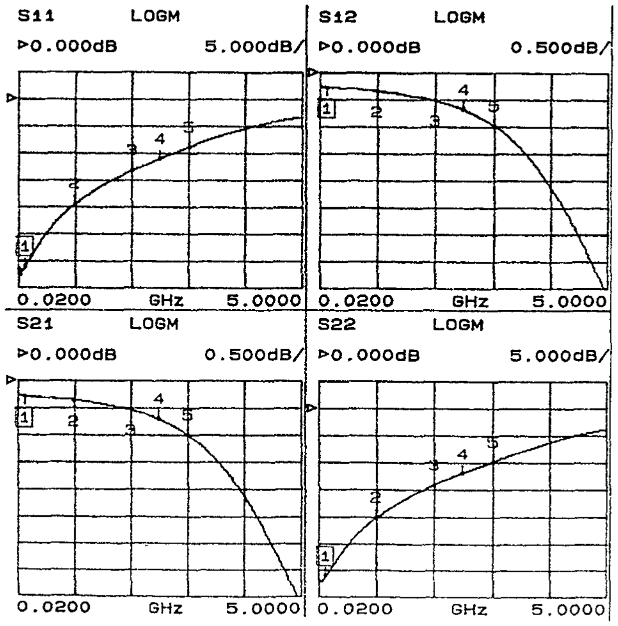


Figure 7. SP4T MMIC switch s-parameters at 77K.

DISCUSSION AND CONCLUSION

Thin-film HTSC technology is combined with GaAs technology to develop novel tunable preselector components operating at 77Kover a 200MHz to 2GHz band. Three-section electronically tunable HTSC filters tune over their respective sub-bands and have insertion losses ranging from 2 to 14dB. P-HEMT feedback LNAs with HTSC matching have from 8.5 to 11.5dB of gain, noise figures under 1.5dB and input return losses greater than 20dB. SP4T MMIC multiplexing switches with integrated decoder circuitry have under 0.5dB insertion loss and isolation in excess of 30dB. These components will be integrated into a 30 cubic centimeter four-channel proof-of-principal preselector which will demonstrate a high level of hybrid semiconductive/high-temperature superconductive circuit integration.

\CKNOWLEDGEMENTS

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