Dual 5 MHz PCS Receiver Front End

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Abstract **– The American Personal Communications Service (PCS) uplink spectrum is divided into 6 frequency bands located between 1850 MHz and 1910 MHz. One of the consequences of this frequency division is that a single service provider can have multiple non-adjacent frequency bands in the same region. STI has developed and built a dual 5 MHz front-end system for PCS base stations. Each channel in the system consists of two double-diplexed 5 MHz wide band pass filters and a balanced cryogenic low noise amplifier (LNA). Each psuedo-ellptic band pass filter consists of 8 resonators and two cross-coupling paths.**

I. INTRODUCTION

In the United States, the 1800 MHz PCS uplink market is divided into 6 frequency bands (Figure 1). Originally, one of the purposes of the 6 bands was to encourage competition in the American PCS market. Due to consolidation in the industry, a single service provider may have more then one band in the same geographic region. This provides an excellent opportunity for high temperature superconducting (HTS) filters and cryogenic LNA's due to the need for both high selectivity and sensitivity. This new requirement builds on previous STI technology[1,2,3]. STI has developed and built a multi-channel system consisting of a pair of 5 MHz filters in a double-diplexed configuration and a cryogenic balanced LNA. A block diagram of the system is shown in Figure 2.

II. FILTERS AND DIPLEXER

Filter design began with the selection of an appropriate resonator structure[4] that would maintain a high Q in order to minimize passband losses. Any losses before the cryogenic LNA will lower the noise figure of the front end and degrade its sensitivity. For this application, an 8^{th} order quasi-elliptic filter design with 2 finite frequency transmission zeros was chosen. The bandwidth of both bands of interest, PCS block D and block E, is 5 MHz. A Chebyshev filter[5] is next designed to meet the desired equal-ripple bandwidth specifications. Synthesis techniques to create a planar thin-film HTS microstrip filter from the Chebyshev model are shown in [2]. STI's in house field solver Nodal[6] was used to analyze the microstrip structure. To achieve the necessary rejection, a capacitive inverter was added from resonator 3 to resonator 6. Capacitive coupling was used on the curved sections of the resonators because it is easily controlled and modeled using Nodal. The result of coupling between resonators 3 and 6 is that a pair of finite frequency transmission zeros[4] are created. One zero above the passband and one zero below the passband are created with just one coupled line. Filter optimization time can be reduced significantly if the filter is symmetric. Symmetry is maintained by adding a second cross-coupling to the other end of resonators 3 and 6. This second coupling structure does not yield any additional transmission zeros but adds to the coupling capacitance that the original zeros were created from. This additional coupling is beneficial because it widens the gap for the cross-coupling capacitor making it easily fabricated. The length of transmission line to couple the resonators is somewhat arbitrary and a transformation from a simple capacitive inverter to a physical transmission line structure is shown in [4].

Next, a phasing manifold is needed to diplex the incoming RF signal. Due to the small fractional bandwidth of the filters and the frequency separation between the filters, a simple phasing manifold was used on both input and output of the two filters to produce a double pass band response. The length of transmission line from the T-junction to the input of one filter is chosen such that it appears open or nearly open circuited to the other filter's frequency range. Filters are characterized by having good impedance matching between the source and load at passband frequencies and a strong mismatch at frequencies outside the passband. Creating an open circuit helps to minimize any variation in impedance that the filter passband will see. The output phasing manifold was creating in a similar manner.

These filters were fabricated on 20 mil MgO substrates with STI's thin film TBCCO thallium superconducting material. The substrate size for these filters is 12 mm x 34 mm. This allows for 3 filters on the 2-inch diameter wafers used in STI's production process. The phasing manifolds are also built using HTS material. As stated earlier, any resistive losses before the first LNA will degrade sensitivity, so by using HTS for the phasing manifold, this degradation is minimized. A drawing of the filters and phasing manifold is shown in Figure 3

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III. CRYOGENIC BALANCED LNA

The LNA, based on the NEC NE33200N Hetero-Junction GaAs FET, was specially designed for use in a cryogenic environment. This required characterization of the device at the intended operating temperature, 77K, since both its S-parameters and noise matching change significantly from their room temperature values. It also required the use of special components and bonding epoxies which remain effective at cryogenic temperatures and do not outgas in a vacuum. Due to the large range of temperatures the LNA is exposed to, from 400K for epoxy curing to 77K for operation, the various thermal expansion coefficients of the components must be kept in mind during the design process. In addition to the mechanical constraints, all the components and epoxies used in the amplifier must be vacuum compatible. A balanced amplifier circuit, shown in block diagram form in Figure 2, was chosen for this design. This topology, which consists of two single ended LNAs combined via directional couplers at input and output, provides excellent input and output return loss over a broad bandwidth while enabling the designer to achieve an optimum noise match. The small insertion loss of the couplers causes minimal increase in noise figure, about 0.05 dB at 77K, and is more than offset by optimizing the noise match. Keep in mind that noise figure of a resistive element is a function of the ratio of physical temperature of the resistive element to 290K. As a resistive element is cooled, its noise figure decreases. Equation 1 is the definition of fractional loss where α is the loss in dB. Next, the effective noise temperature, Te, of the resistive element at 77K is calculated in equation 2. Equation 3 is the definition of noise figure in dB for the resistive loss.

$$\text{Loss} = 10\text{^}(\alpha/10) \quad (1)$$

$$Te = 77*(\text{Loss}-1) \quad (2)$$

$$NF(dB) = 10*LOG_{10}(1+Te/To) \quad (3)$$

Where:

Te = effective noise temperature of a resistive load.
To = Reference noise temperature (290K)
Loss = Factional resistive loss of device
α = Loss in dB
NF(dB) = noise figure in dB

Microstrip Lange couplers for this circuit were designed using STI's NODAL electromagnetic modeling software. The small substrate size (1/2 inch square, 20 mil thick alumina) required folding of the couplers as shown in Figure 4. These folded Lange couplers produced equivalent performance to the more traditional linear design. Typical amplifier performance parameters between 1850 MHz and 1910 MHz are as follows:

Gain: 14 dB
OIP3: +28 dBm
|S11|: < -20 dB
|S22|: < -20 dB
Noise Figure: 0.30 dB

These amplifiers are typically biased at 3.4 V and have a current draw of approximately 25 mA.

IV. SYSTEM

All the components are integrated into a sealed vacuum dewar that can contain 3 complete double-diplexed RF paths. Given that cooling is necessary for the HTS, there is a need to package everything in a vacuum insulated environment in order to maintain the operating temperature of the HTS and cryogenic circuitry. The cryopackaging technology employed by STI is adapted primarily from the infrared detector industry, which has been in existence for 35+ years and is now itself heading into the commercial arena. Vacuum packaging provides the thermal/vacuum insulation required in order to eliminate two of the principal modes of heat transfer: gaseous conduction and convection. The other modes of heat transfer, radiation and solid structural conduction, are minimized by the careful design and material choices of all of the components going into the dewar. The longevity of the vacuum package is also of great importance and is integral with thermal design aspects of the dewar. The dewar is designed to have a greater then 7 year lifetime. This dewar is then mated to a cooler. The cryocooler is a Stirling cycle cooler with a design MTTF in excess of 50,000 hours. The availability of low cost, highly reliable compact cooling technology is critical to the successful commercialization of STI's HTS products. Because such a cryogenic cooler was not available commercially, STI developed a low cost, low power cooler designed to cool to 77K with sufficient heat lift for its HTS applications and with a target life of over 50,000 hours. STI has developed a cooler that is both compact and reliable enough to meet industry requirements and which will also exhibit significantly less unit cost, in volume production. The dewar/cooler assembly is installed in the system enclosure, which measures 8.5" x 20" x 7" and can contain up to 3 complete RF paths. A picture of the completed system is shown in Figure 5. This complete system requires a +27 VDC power supply and uses less then 40 watts of power in steady state operation. The system also includes a single PCB with a digital signalprocessing chip. This DSP board drives the cooler, provides feedback control to maintain the interior of the dewar at 77K and provides power to the LNAs inside the dewar. By having much of the system functionality in software, this platform is low cost, while still achieving a high degree of flexibility. The measured S-parameter performance of one channel of this system is shown in Figure 6. The filters provide more then 50 dB of rejection less then 2 MHz away from the edge of the band of interest. The base station transmit band rejection (1930 MHz to 1990 MHz) is greater then 80 dB. The system noise figure, including all cables and connectors, measured at the center frequency of the filters, is typically 0.75dB.

V. CONCLUSION

STI has demonstrated a design solution for the evolving multi-band PCS market. This consists of a technically challenging HTS filtering function and cryogenic balanced LNA. These RF components are packaged in the smallest fully integrated platform available for commercial cryogenic high-temperature superconducting hardware. The measured performance of this hardware shows outstanding results.

REFERENCES

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[4] Kurt F. Raihn, Robby L. Alvarez, Jim R. Costa, Greg L. Hey-Shipton,, “ Highly Selective HTS Band Pass Filter with Multiple Resonator Cross-Couplings”, 2001 IEEE MTT-S International Microwave Symposium Digest.

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[6] “Nodal” is a proprietary linear circuit simulation software package developed at Superconductor Technologies, Inc., Santa Barbara, CA, 93111.

Figures:

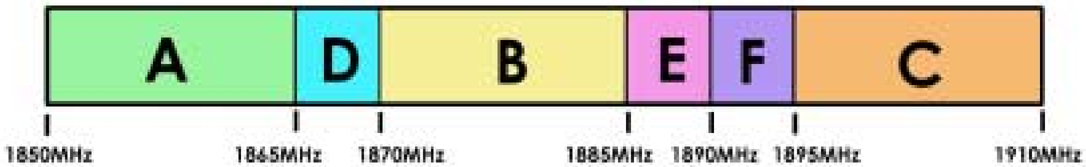

Fig 1. American PCS Uplink Frequency Band Allocation Chart

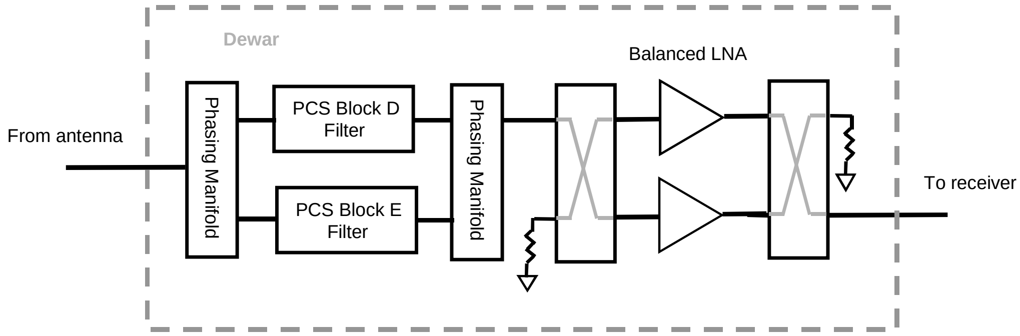

Fig. 2. RF Chain Block Diagram

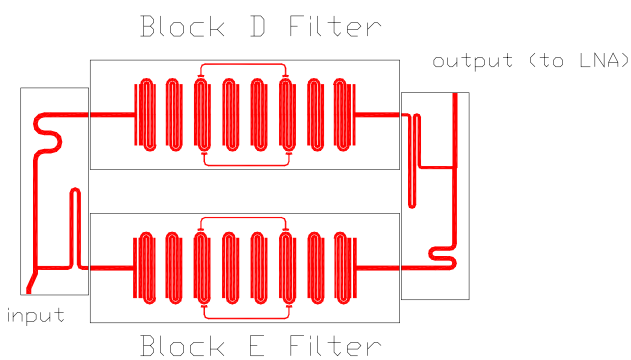

Fig. 3. PCS Double-Diplexed 5 MHz Filters

Fig. 5. PCS System Platform

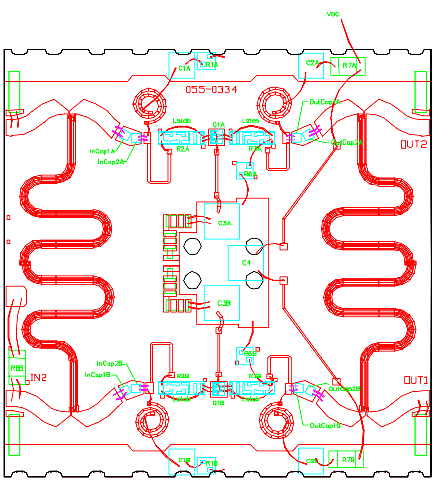

Fig. 4. Balanced LNA substrate.

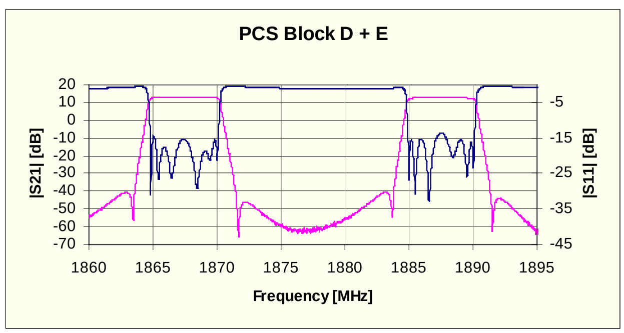

Fig. 6. Plot of Measured System Performance