LOW PHASE NOISE SUPERCONDUCTING OSCILLATORS

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ABSTRACT

Microstrip resonators fabricated from thallium high temperature superconducting thin films have loaded Q values in the 8,000 to 20,000 range at frequencies up to X band. The resonators are used as the stabilizing elements in low phase noise microwave oscillators. These superconducting oscillators (SCO's) demonstrate improved performance over conventional dielectric resonator oscillators (DRO's) operating at the same frequencies.

INTRODUCTION

Improvements in the quality of high temperature superconductor thin films have made possible the fabrication of microwave resonators with very large loaded Q values. At 2.3 GHz, microstrip resonators with Q_L values in the 15,000 to 20,000 range are possible at temperatures up to 80K (Figure 1). These resonators can be used as the stabilizing element in a low phase noise superconducting oscillator (SCO) operating at frequencies well into X-band. In this paper, we present results on oscillators using TlBaCaCuO superconducting thin film resonators and low noise GaAs FET amplifiers operating at frequencies of 2.3 GHz and 10.2 GHz. The performance of the SCO is compared to typical values obtained using fixed frequency dielectric resonator oscillators (DRO's).

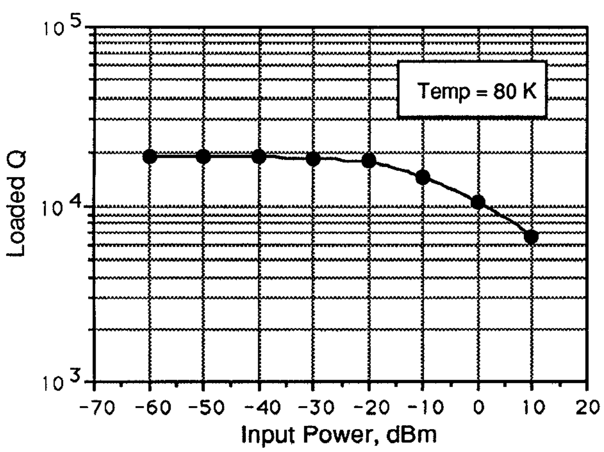

Figure 1. Typical Q_L for 2.3 GHz HTSC Resonator

DESIGN APPROACH

Resonators

The resonators are fabricated from high quality thallium superconducting thin films deposited on 1.0 cm square lanthanum aluminate substrates. The films are nominally 1.0 microns thick, and have transition temperatures greater than 100 K. Typical critical current (J_c) values for these films are on the order of 10^6 A/cm^2 at 77 K. The resonator structures used are gap coupled $\lambda/2$ microstrip transmission lines, as shown in Figure 2. The substrate thickness was .020"; with line and gap widths as indicated on the layouts.

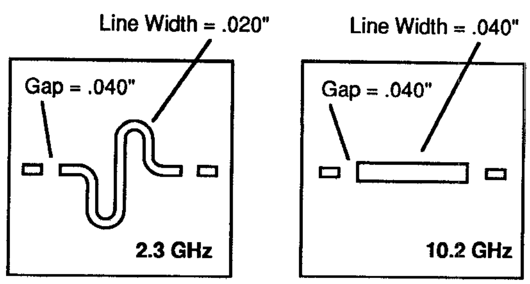

Figure 2. Resonator Mask Detail

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At the time of this experiment, only substrates with film deposited on one side were available. To form the superconducting ground plane, the patterned film was stacked on top of another film with gold wrap-arounds to achieve a microstrip geometry (Figure 3). The transmission lines were patterned using a proprietary wet etch process, and gold bonding pads were deposited on the resonator launches. The films were mounted in sealed and connectorized housings for immersion directly in a liquid nitrogen bath.

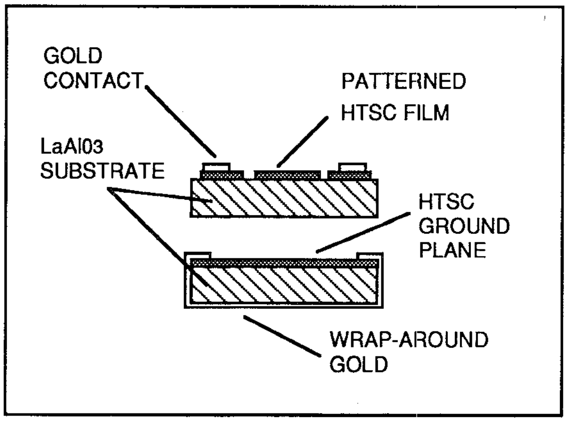

Figure 3. Microstrip Resonator Construction

Amplifier

Both amplifiers used are GaAs FET low noise designs. The 2.3 GHz amplifier is a three stage 0.5 micron gate device with small signal gain of 30 dB, nominal. The noise figure of the amplifier at 300 K is 1.2 dB, and output power at 1 dB compression is +13 dBm. The 10.2 GHz amplifier is a 5 stage design with 2.5 dB noise figure at 300K, small signal gain of 40 dB, nominal, and output power at 1 dB compression of +14 dBm.

Oscillator Design

Figure 4 shows the block diagram of the parallel feedback oscillator, using the transmission type high Q resonator and a GaAs FET low noise amplifier. In a parallel feedback design, the resonator is used as a bandpass filter and is connected across the terminals of an active device with forward gain greater than the insertion loss of the resonator. To oscillate, the electrical line length between the device input and output ports must provide a phase shift around the feedback loop equal to an integer multiple of 2π radians at the oscillation frequency. With the parallel feedback circuit, the use of a high gain amplifier can allow significant decoupling of the resonator. This results in a higher loaded Q with an associated reduction in phase noise.

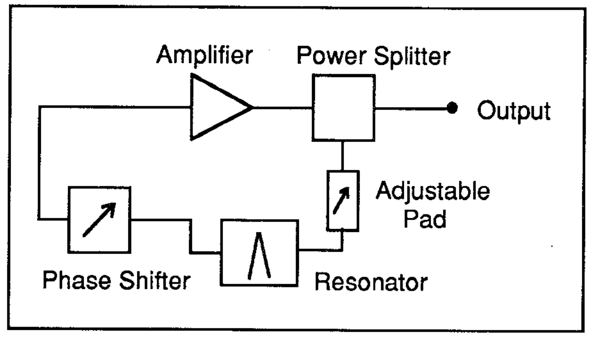

Figure 4. Oscillator Block Diagram

MEASURED PERFORMANCE

For this experiment, the only cooled oscillator components are the superconducting resonators. The low noise amplifier, power splitter, phase shifter, and pads were maintained at room temperature for ease of operation. The resonators were immersed in a bath of liquid nitrogen at 77K, and their performance measured over a narrow range of RF input drive. The loaded Q for all superconducting resonators varies with applied RF power due to defects in the film structure (1). For high quality films, this power dependence is relatively minor, and high loaded Q's are still obtainable at 0 dBm and above. Figure 5 shows the measured Q_L vs Pin performance for both resonators. In the oscillator circuit, the 2.3 GHz resonator was operated at a power level of 0 dBm and loaded Q of 13,800. The 10.2 GHz resonator was operated at a power level of +6 dBm and loaded Q of 6000.

The oscillator circuits were assembled, with the packaged resonators mounted on a cold stage in the liquid nitrogen bath. After adjusting the phase shift for oscillation, data was taken on each circuit; this data is

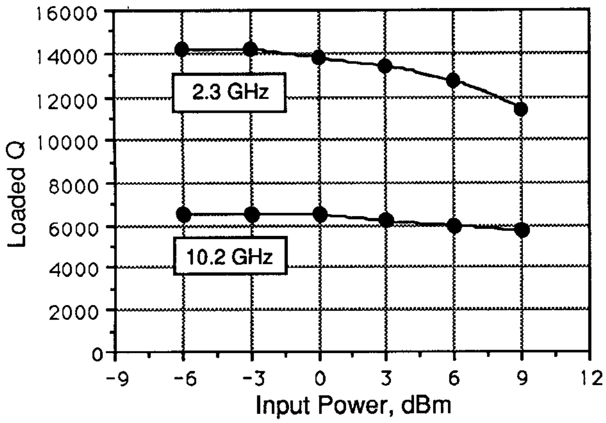

Figure 5. Resonator Q vs Input Power at 77K

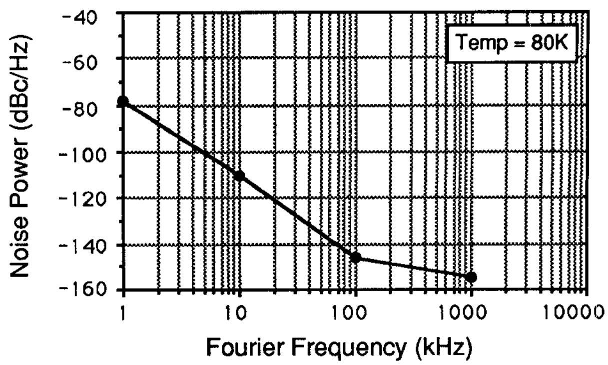

Figure 6. 2.3 GHz Oscillator SSB Phase Noise

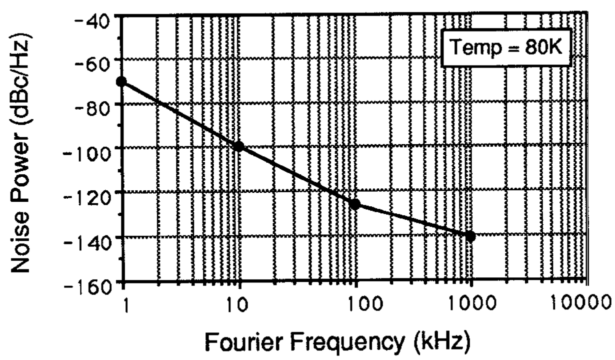

Figure 7. 10.2 GHz Oscillator SSB Phase Noise

summarized in Table 1. Also included in the table are specifications for a dielectric resonator oscillator (DRO) operating in the same frequency ranges. Plots of phase noise performance were taken, and are presented in Figure 6 for the 2.3 GHz SCO; Figure 7 for the 10.2 GHz SCO.

Improvements in performance over a conventional DRO are achieved at both 2.3 GHz and 10.2 GHz. Harmonic output, frequency pushing, and frequency pulling data for the SCO outperforms the DRO specifications in both oscillators. Phase noise performance at 2.3 GHz meets or exceeds the DRO specification. At 10.2 GHz, the SCO demonstrates a 5 dB improvement in phase noise at 10 kHz from the carrier, and a 6 dB improvement at 100 kHz. In

	2.3 GHz		10.2 GHz	
Test Parameter	**SCO**	**DRO**	**SCO**	**DRO**
Power Output (dBm)	+8.8	+13.0	+12.0	+13.0
2nd Harmonic (dBc)	-21	-20	-29	-20
Frequency Pulling (kHz) into 1.67: 1 VSWR Load	100	460	50	2040
Frequency Pushing (kHz/V)	10	23	2.0	102
Phase Noise @ 10 kHz (dBc/Hz)	-110	-110	-100	-95
Phase Noise @ 100 kHz (dBc/Hz)	-148	-135	-126	-120
Phase Noise @ 1 MHz (dBc/Hz)	-155	---	-143	---

Table 1. Superconducting Oscillators (SCO's) vs. Dielectric Resonator Oscillators (DRO's)

addition, a SCO maintained at 77K has a significant advantage in frequency stability over temperature.

CONCLUSIONS

We have demonstrated superconducting resonator stabilized oscillators at 2.3 GHz and 10.2 GHz. The performance of these devices is equal to or better than currently available dielectric resonator oscillators.

Further improvements in SCO performance will result from optimization of the oscillator circuitry. Resonators with higher loaded Q's are now available; Q_L approaching 50,000 at 5.0 GHz have been demonstrated at 77K. We are currently evaluating experimentally the effect of resonator loaded Q on phase noise performance. The low noise GaAs FET amplifiers will be replaced with very low noise GaAs or Si bipolar designs, optimized for the specific oscillation frequencies.

As phase noise performance improves, we are approaching the noise floor of our measurement equipment. More sophisticated and sensitive measurement techniques will be required to properly characterize the extremely low noise levels of these devices.

ACKNOWLEDGEMENTS

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