A Superconducting Resonator Stabilized Low Phase Noise Oscillator

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A low phase noise oscillator has been developed using a superconducting high-Q thin-film microstrip resonator as the stabilizing element. At 23 GHz, the superconducting resonator has a loaded-Q of greater than 7000 at 77°K, which is 30 times higher than the equivalent circuit in gold microstrip. The oscillator consisted of a GaAs FET amplifier, power splitter, phase shifter and the resonator stabilizing element. The phase noise of the superconducting resonator stabilized oscillator at 77°K and 2.3 GHz was 20 dB lower than that obtained using the gold resonator.

Introduction

Low phase noise microwave sources are essential elements in many military and commercial systems. Currently, dielectric resonator oscillators (DROs) are the most common choice when a low phase noise, temperature stable microwave oscillator is required. These oscillators use a ceramic dielectric resonator as the stabilizing element, coupling it to a microwave transmission line in a series or parallel configuration. Typical quality factors (Qs) obtainable with today's dielectric materials range from 10,000 to 25,000 in the 2 to 10 GHz frequency range.

Recent developments in high temperature superconductor (HTSC) material have made possible the construction of microwave resonators with very high Q values. These resonators are fabricated in microstrip and have demonstrated Q values at 77°K in the 5000 to 20,000 range. Quality factors of 50,000 are possible in the near future as materials continue to improve. To demonstrate the potential application of HTSC to microwave devices, a low phase noise oscillator using an HTSC resonator as the stabilizing element was built and tested.

High Temperature Superconductors

High temperature superconductors for microwave applications are fabricated in the form of thin films on a low loss dielectric substrate. These HTSC films have a microwave surface resistance that is orders of magnitude lower than gold microstrip. Most HTSC materials are relatively lossy at room temperature, and only become superconducting at temperatures below 100°K. The most common operating temperature for these films is 77°K, the boiling point of liquid nitrogen.

Figure 1 shows the surface resistance of a typical HTSC film as a function of temperature and RF drive level, measured at 10 GHz. The films are deposited on lanthanum aluminate, which has a dielectric loss tangent (tan δ) of 1×10^{-5} and a dielectric constant of 24. The sizes of the substrate currently in use are one cm^2, with a thickness of 0.01" or 0.02".

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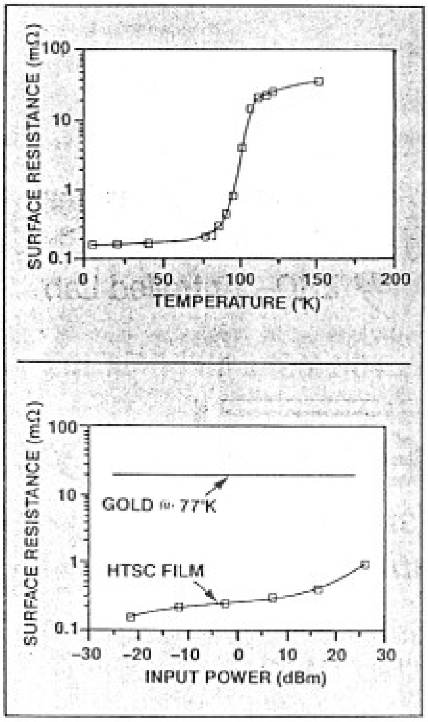

Fig. 1 Microwave characteristics of HTSC film.

Oscillator Design

Figure 2 shows a schematic diagram of the parallel feedback oscillator using a 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 transmission 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, resulting in a higher loaded-Q with associated reduction in phase noise.

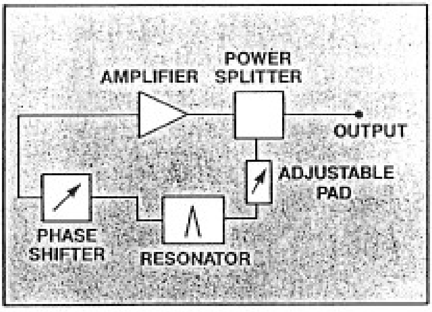

Fig. 2 A schematic diagram of an oscillator.

The layout of the HTSC resonator is shown in Figure 3. The design is a $\lambda/2$ gap coupled transmission line, with a line width of 0.02" and a length of 0.71". The fundamental resonant frequency is 2.3 GHz and insertion loss was set at 20 dB nominal. Two resonators were built; the first was constructed using gold microstrip and the second using HTSC film. Figure 4 shows the performance of both devices as a function of input power.

The microwave amplifier is a three-stage GaAS FET design with a small signal gain of 30 dB nominal. The noise figure at 300°K is 1.2 dB, and power output at 1 dB compression is +13 dBm. The amplifier, power splitter and phase shifter were operated at room temperature for this demonstration. The HTSC resonator was placed in a test fixture and immersed in liquid nitrogen at 77°K, while the gold microstrip resonator was tested at both room temperature and 77°K.

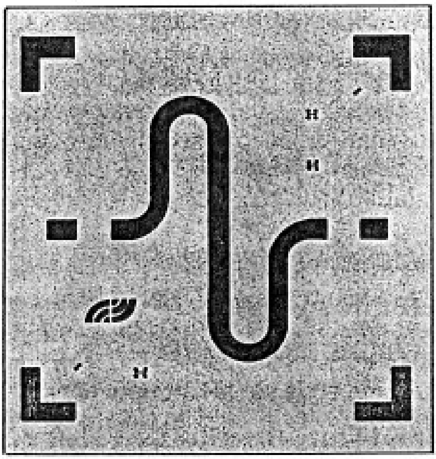

Fig. 3 Resonator layout.

Measured Performance

The setup was assembled and tested for three different configurations, the gold microstrip resonator at 300°K and 77°K, and the HTSC resonator at 77°K. Measurements of output power, harmonic perform-

[Continued on page 130]

TABLE I
PERFORMANCE OF GOLD AND HTSC OSCILLATORS

Parameter	Gold Microstrip 300°K	Gold Microstrip 77°K	Superconductor 77°K
Frequency (GHz)	2.28	2.28	2.27
Power Output (dBm)	+9	+10	+8.8
2nd Harmonic (dBc)	–18	–19	–21
Frequency Pulling into 1.67 SWR (MHz)	4	2	0.1
Frequency Pushing (MHz/V)	0.5	0.2	0.01
Phase Noise (dBc/Hz) at 10 kHz	–80	–84	–99

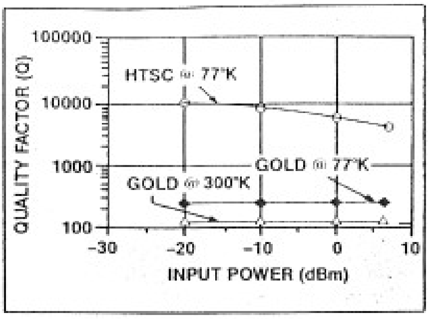

Fig. 4 Effect of input power on resonator Q.

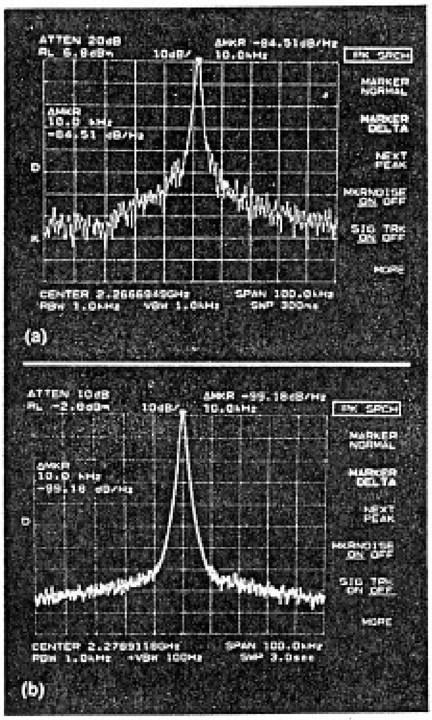

Fig. 5 Phase noise at 70°K for (a) a gold oscillator and (b) an HTSC oscillator.

ance, frequency pushing and pulling, and phase noise were made for each configuration. Table I lists these measurements. The power input at the resonator was +6 dBm, which resulted in a resonator Q of 4000 for the HTSC at 77°K, 375 for the gold resonator at 77°K, and 200 for the gold resonator at 300°K.

Significant improvements in frequency pushing and pulling, and phase noise were achieved through the use of the HTSC resonator. Figure 5 shows the phase noise performance as measured on the spectrum analyzer, comparing gold microstrip at 77°K to the HTSC film. The improvement due to the HTSC resonator is nearly 20 dB better than the gold microstrip at 300°K.

Conclusion

A first attempt to demonstrate HTSC stabilized microwave oscillators has resulted in performance that approaches that of current DROs. A 20 dB improvement in phase noise over a gold microstrip design has been achieved. As the superconducting materials continue to improve, quality factors of 50,000 may be obtainable. Coupled with advances in HTSC circuit design, this could result in phase noise performance rivaling or exceeding that possible with state-of-the-art DROs.

Acknowledgment

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At press time, bio information and photos for the other authors were unavailable.