NOVEL PHASE NOISE REDUCTION TECHNIQUE USING HTSC-LIMITERS

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ABSTRACT

This work presents a novel technique for reducing oscillator phase noise. A high-temperature superconducting (HTSC) limiter is implemented in a feedback oscillator in order to operate the amplifier in its linear region. Less 1/f-noise is upconverted by the amplifier which leads to reduced phase noise in the oscillator. A decrease of phase noise up to 10 dB at 1 kHz offset from the carrier could be measured. The new device is well suited for integration in an HTSC microstrip resonator layout.

INTRODUCTION

The development of stable microwave oscillators plays an important role in radar and communication technology. An often used oscillator configuration consists of an amplifier, which is fed back through a resonator determining the operating frequency. Stationary oscillations are obtained if the loop gain is equal to unity and the round trip phase angle is a multiple of 2π radians. To limit the amplitude the amplifier is normally driven into saturation.

The quality of stable sources is determined by phase noise. According to Leeson's model [1], the phase noise spectral density of a feedback oscillator is represented by

$$S_\phi(f) = \left(\frac{\alpha}{f} + \frac{Fk_B T}{2P_{in}}\right)\left[1 + \left(\frac{f_c}{2Q_L f}\right)^2\right], \qquad (1)$$

where α / f is the baseband noise of the amplifier, F the noise figure, f_c and f are the carrier and the offset frequencies, and P_{in} is the input power to the amplifier.

A common way to improve the noise behaviour of such an oscillator is to increase the loaded quality factor Q_L of the oscillator. This can be done by using resonators with high unloaded quality factors Q_0. Sapphire resonators using whispering gallery modes can reach quality factors up to several 10^7 at 10 GHz and 77 K [2]. It is the most common way to use HTSC in oscillators by shielding a low order TE mode resonator using superconducting films [3]. Increasing Q_0 tenfold leads to a phase noise reduction of 20 dB.

Another approach for reducing phase noise is to decrease the internal noise sources of the involved amplifying loop by avoiding the operation of the amplifier at saturation, where transistor noise increases due to nonlinear effects and augmentation of internal sources.

Additional nonlinear passive semiconductor elements outside the amplifier can be used for this purpose. Darwish has employed diodes to minimize the effect of upconversion of baseband noise in the amplifier, although diodes also show 1/f-noise [4]. The oscillator noise improvement, however, was significant in spite of the additional flicker noise of the diodes.

As a novel approach, this paper presents an oscillator, where the implementation of a new HTSC limiter offers the opportunity of minimizing the noise contributions of the amplifier. For a low noise oscillator utilizing superconductors, the application of external amplitude limiting elements becomes superfluous, because the superconductor itself can be utilized for that purpose, having the advantage of not adding further 1/f-noise.

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NOISE ANALYSIS

At the operating point of the oscillator the active device is driven into the nonlinear region. This increases the noise figure of the amplifier and the upconversion of baseband noise, as is shown in Fig. 1. The latter dominates the noise behaviour of the oscillator close to the carrier. Measurements of the upconverted flicker noise were made using a phase bridge setup under large signal conditions. The 1 dB gain compression point of the amplifier under test was at -15 dBm input power. Fig. 1 suggests that there is a potential of reducing oscillator phase noise by 20 dB. This is equivalent to the noise improvement obtained by a resonator with a tenfold higher quality factor.

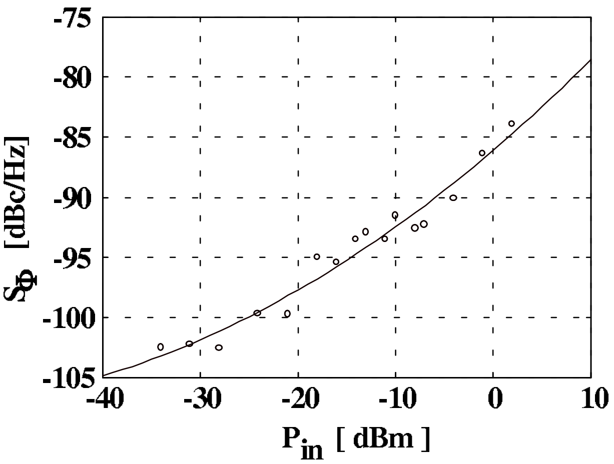

Fig. 1. Phase noise spectral density S_ϕ of upconverted 1/f-noise of the amplifier as a function of input power at an offset frequency of 20 Hz (measured points and fitted curve)

In order to suppress the 1/f-noise upconverting process a device has to be added, which limits the available input power of the amplifier in order to operate in a linear region. In HTSC oscillator applications the integration of the new HTSC limiter can take over the limitation of input power in order to reduce phase noise. No further of fabrication step is needed, because the limiter can be easily included in any HTSC microstrip circuit.

LIMITER

Fig. 2 presents the microstrip layout of an HTSC limiter. It consists mainly of a micro bridge with 3 µm width and some ten microns length. This high impedance line is matched to 50 Ohms by two λ/4-transformers.

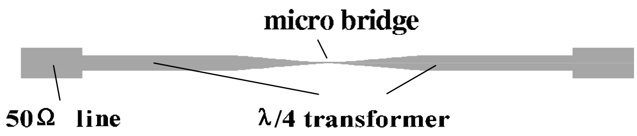

Fig. 2. Layout of the realized limiters

The nonlinear behaviour of the transmission coefficient $|S_{21}|$ with respect to the input power results from the limited current carrying capacity of superconductors. Below a given input power, at which the superconductor transits to its normal state, surface impedance increases with increasing applied power. The attenuation of the superconducting strip increases until the critical current j_c is reached.

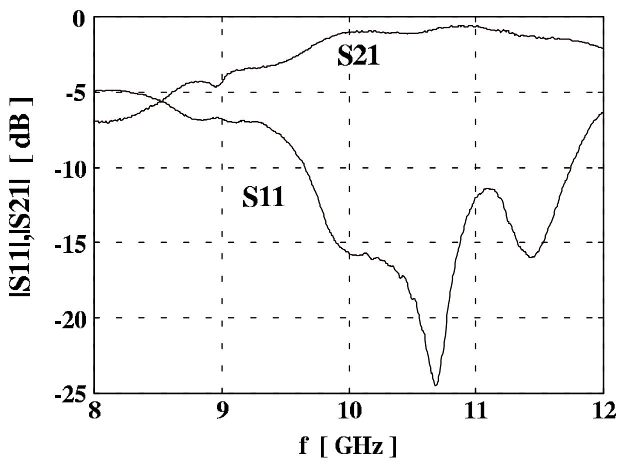

Fig. 3. S-parameters at 77 K, $P_{in} = -20$ dBm

Several limiters operating at 4 GHz and 10 GHz were realized on 10×10 mm^2 MgO substrates with $YBa_2Cu_3O_{7-x}$ as the superconducting material. Measurements show good matching in the required frequnecy band (Fig. 3) and confirm the demanded power dependence (Fig. 4). The attenuation is power dependent at frequencies where microstrip techniques can be used.

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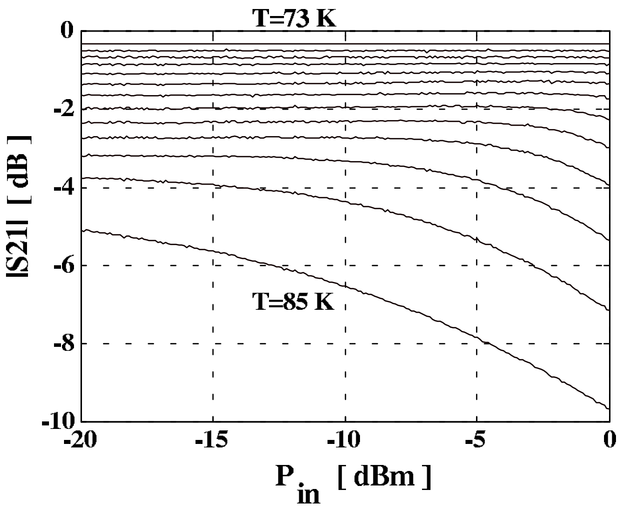

Fig. 4. Power dependence of the limiter at 10 GHz

Therefore the limiter is capable of stabilizing the amplitude of the oscillator, while the amplifier works in a region with less noise.

Fig. 5 shows the transmission coefficient of limiter and amplifier in series as a function of the applied power at the input of the amplifier. Comparing this dependence with the gain of the amplifier alone, it can be seen that the same loop gain can be obtained at lower input power values at the amplifier. The arrow in Fig. 5 indicates, how the limiter reduces the input power of the amplifier by 15 dB if a loop gain G=5 dB is desired.

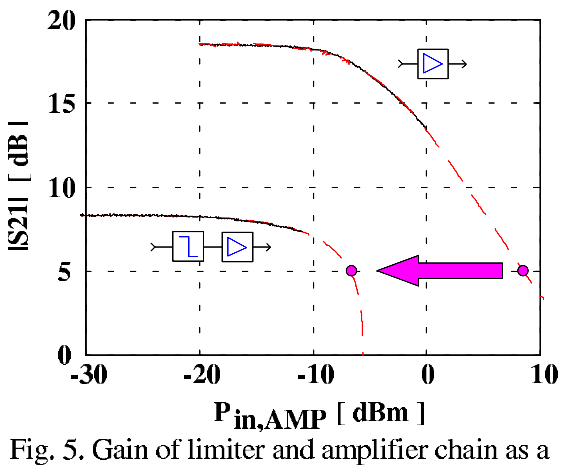

Fig. 5. Gain of limiter and amplifier chain as a function of the input power at the amplifier (dashed lines: theoretical results)

Operating in an oscillator the amplifier maintains the linear region. This reduces the upconversion of its flicker noise which results in less oscillator phase noise. Since the limiter does not add further 1/f-noise into the system [5], it has a noise reducing effect on the oscillator.

MEASUREMENTS

Measurements were carried out using the set up shown in Fig. 6. The limiter was cooled in a cryostat to operate in a temperature range between 20 K and 90 K. A double staged FET amplifier was chosen with a 1 dB compression point at 10 dB higher input power than that of the limiter at 85 K. Phase noise measurements were made using the spectrum directly, and by applying the frequency discriminator method.

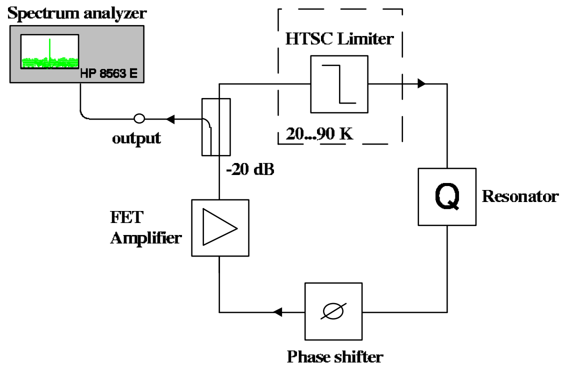

Fig. 6. Block diagram of measurement set up

In order to simplify noise measurements and to prove the effect of the limiter on phase noise we used low Q-factor resonators at $Q_L \approx 1000$. Of course, in a fully engineered oscillator, a high-Q resonator, as described above, will be used. The measured results are presented in Figs. 7 and 8. Phase noise was measured at frequencies f from the carrier where the spectral density S_ϕ decreases with f at 30 dB per decade. This is the region, where 1/f-noise predominates oscillator phase noise. To determine the effect of the limiter on noise performance, measurements were performed at various operating temperatures of the limiter. At 79 K the limiter still shows a nearly constant attenuation in the desired power range, whereas at 85 K $(= 0.98T_c)$ nonlinear behaviour starts. A phase noise improvement of about 10 dB between these two cases was obtained.

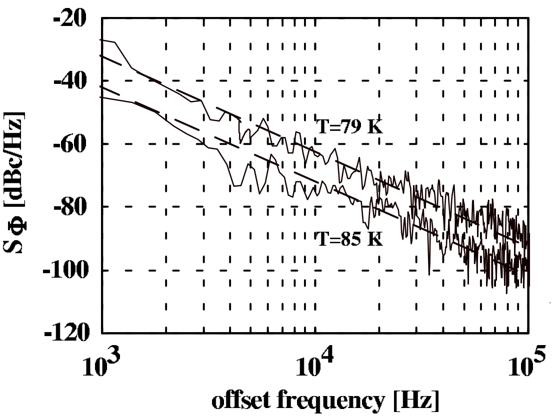

Fig. 7. Phase noise spectral density as a function of offset frequency for two temperatures

Fig. 8 indicates that, in the latter case, the gain of the amplifier is 10 dB higher, according to lower input power and less upconversion of baseband noise.

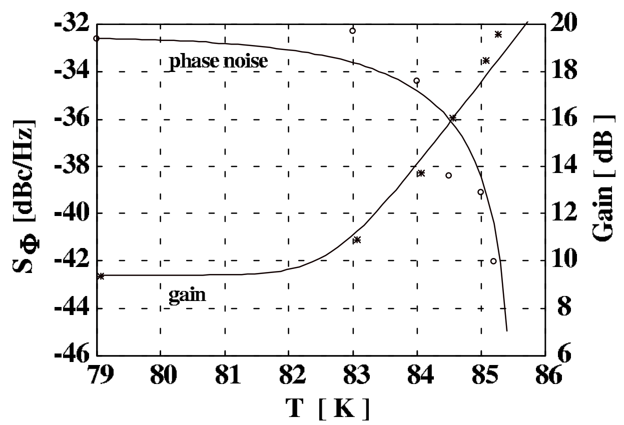

Fig. 8. Phase noise spectral density at 1 kHz, and the gain of the amplifier as a function of temperature of the HTSC limiter (*: measured gain, o: measured noise

Since the output power of the oscillator can be amplified without severely impairing noise performance, the lower circulating loop power does not present a disadvantage.

CONCLUSIONS

An HTSC limiter is introduced as a novel device for reducing phase noise in a feedback oscillator. Experimental results prove a useful power dependence of the attenuation near the critical temperature T_c. It should be possible to lower the working temperature by loading the micro bridge with an additional DC current. The oscillator with integrated limiter showed 10 dB less phase noise when driving the limiter into its nonlinear region. The new technique is well suited, if cooling is needed in order to use a superconducting resonator, anyhow. The limiter offers the possibility to be easily integrated in a superconducting microwave circuit and should also work in a reflection-mode oscillator.

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