ULTRA LOW NOISE MICROWAVE OSCILLATORS WITH LOW RESIDUAL FLICKER NOISE

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ABSTRACT

This paper describes the design of two low noise microwave oscillators operating at 7.6 GHz. These oscillators use room temperature Sapphire resonators operating in the $TE_{01\delta}$ mode which demonstrate unloaded Q's of 44,000. Silicon transposed gain amplifiers are used to produce low Flicker noise corners of 1 to 2KHz and a phase noise of -131dBc at 10 KHz offset. Further improvements of 30 dB are expected using this technique

INTRODUCTION

Microwave Oscillators are usually built using GaAs active components. These GaAs devices demonstrate high Flicker noise corners which greatly degrade oscillator noise performance close to carrier. Silicon transistors have low Flicker noise corners but also have low gain at microwave/mm wave frequencies. It is however fairly easy to fabricate silicon Schottky barrier mixer diodes operating at microwave frequencies.

This paper describes the design of two low noise 7.6 GHz oscillators with Flicker noise corners of 1Khz to 2 KHz and a noise performance better than -131 dBc at 10 KHz offset. This noise is within 8 dB of the theoretical minimum for a Sapphire dielectric resonator oscillator with an unloaded Q_0 of 44,000 and a power of 1 mW. We also believe that these noise measurement are limited by the HP 8662A signal generator used for phase noise measurements in the DC FM mode. The noise changes at a rate of $1/\Delta f^2$ down to around 1KHz. These oscillators use the transposed gain of a low frequency silicon amplifier and demonstrate a suppression greater than 40 dB of the reference LO phase noise.

TRANSPOSED GAIN

Transposed gain is achieved using two mixers, a low frequency amplifier and a local oscillator as shown in Figure 1. This upconverts the LF gain to microwave frequencies on both sides of the reference LO. The frequency of the local oscillator (which can be noisy) is therefore used at a frequency close to that required for the gain. The noise from the local oscillator is significantly suppressed (>40 dB) in an oscillator using transposed gain.

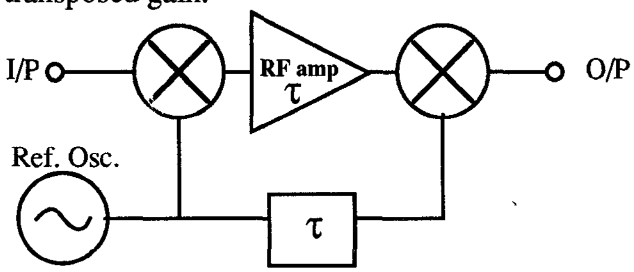

Figure 1. Transposed Gain Amplifier (TGA)

NOISE CONVERSION

It is important to ensure that the noise performance of the LO does not degrade the AM/PM noise of a signal passing through the TGA.

Phase noise on the local oscillator can cause an output phase modulation because of the group delay of the amplifier. This is corrected by introducing a delay line with the same delay (and dispersion) characteristics of the amplifier in between the LO drive of the two mixers.

AM on the reference oscillator has two effects on the output of the TGA. the first is to vary the mixer conversion losses, effectively transferring

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AM to the output. The second effect of LO drive variation is to alter the phase shift of the TGA. This is due to the mixer impedance changing with drive level. This is less serious with a broadband mixer. The LO should therefore have low AM by using an oscillator which incorporates 'hard limiting'.

OSCILLATORS

With the addition of a resonator a TGA can be made into a transposed gain oscillator (TGO) as shown in Figure 2. Because of the cancellation of FM and AM described above, such an oscillator is shown to have much lower phase noise than the original local oscillator.

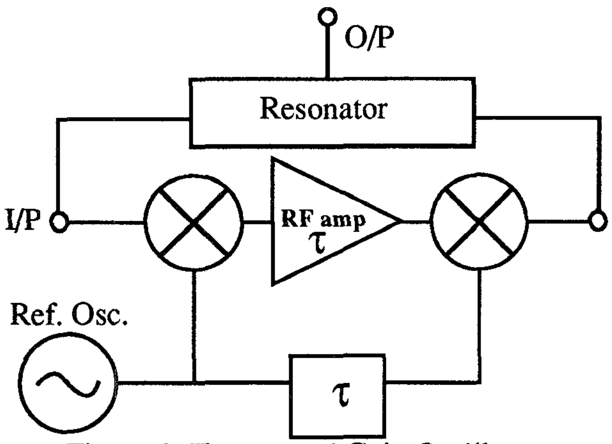

Figure 2, Transposed Gain Oscillator.

Theories have been developed which show how minimum noise can be obtained in oscillators operating in the thermal/additive noise regime[1,2,3,4]. These theories predict that for minimum additive noise the insertion loss of the resonator should be between 6 and 9 dB, in other words the ratio of loaded to unloaded Q should be between 1/2 to 2/3.

The oscillator phase noise should therefore roll off at $1/df^2$ rate if thermal noise predominates (20dB/decade). Close to carrier this becomes $1/df^3$ (30dB/decade of offset), as flicker noise is transposed into the oscillator. If the flicker noise corner occurs a few MHz from carrier (typical GaAs) this is much more serious than a few hundred Hz (typical LF silicon). At frequencies where this advantage exceeds the effects of a noise floor increase due to the mixer, then such a system could be advantageous.

Systems for measuring the cross correlation between baseband gate and drain noise and the transposed AM/PM components this produces on a carrier have also been produced by this group[5]. This system has a residual noise floor of -180 dBc for offsets greater than 1 KHz.

EXPERIMENTAL MEASUREMENTS

To evaluate the transposed gain method two Transposed Gain Oscillators have been built at 7.6 GHz. Two oscillators, operating 13 Mhz apart, were built to enable the phase noise to be measured as shown in Figure 3. The phase detector method was then used in conjunction with the low noise (HP8662A) signal source.

The oscillators use room temperature Sapphire resonators operating in the fundamental $TE_{01}\delta$ mode. These resonators are operated substantially as a two port with a lightly coupled third port to provide a filtered output. The unloaded Q (including the O/P port) is measured to be 44,000. To obtain minimum noise performance using Thermal/additive noise the insertion loss of the resonator is set to 6 dB[1,2,3,4], producing a loaded Q of 22,000. The insertion loss of the mixers is around 7 dB therefore the open loop gain of the silicon amplifier should exceed 20 dB. The total noise figure of the two mixers and amplifier was around 9.5 dB. The single sideband output power obtained from the O/P mixer was around 0.0dBm. The Local oscillator used for each oscillator was an HP 8672A synthesised signal generator. A GaAs based oscillator using similar dielectric resonators could also have been used.

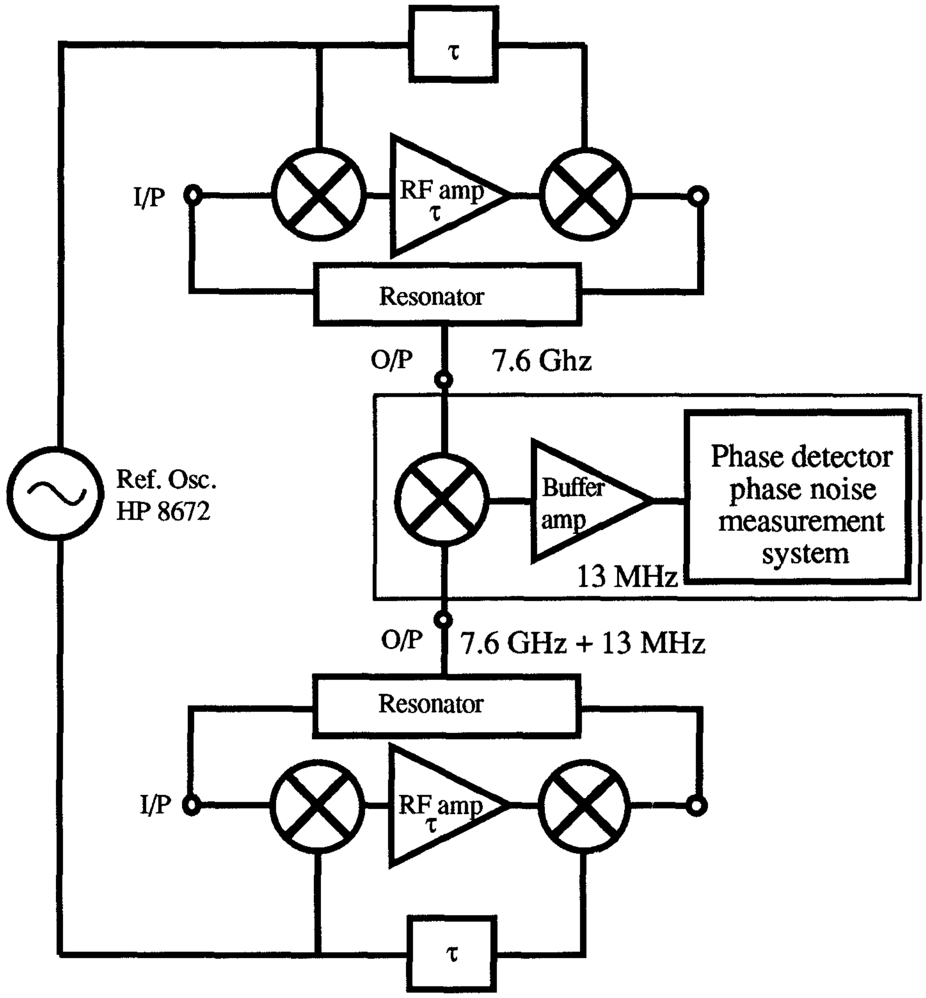

Figure 3. Experimental Oscillators and Phase Noise Measurement System

The noise performance is shown and tabulated in Figure 4. These measurements demonstrate a noise performance better than -131 dBc at 10 KHz offset (assuming that both oscillators are similar and uncorrelated, 128dBc -3dB) and a Flicker Noise corner of 1 KHz to 2 KHz. This noise is within 8 dB of the theoretical minimum for a Sapphire DR oscillator with an unloaded Q_0 of 44,000 and a circulating power of 1 milliwatt. We believe that these noise measurement are degraded by the HP 8662A signal generator used for phase noise measurements in the DC FM mode. The equation used to describe the noise performance L_{fm} under optimum operating conditions for thermal noise is [2,3,4].

$$L_{fm} = (FkT/Q_0{}^2P)(f_0/\Delta F)^2$$

where F is the noise figure under the correct operating conditions, k is Boltzmanns constant, Q_0 is the unloaded Q, P is the power available at the output of the TGA, f_0 is the centre frequency and Δf is the offset frequency.

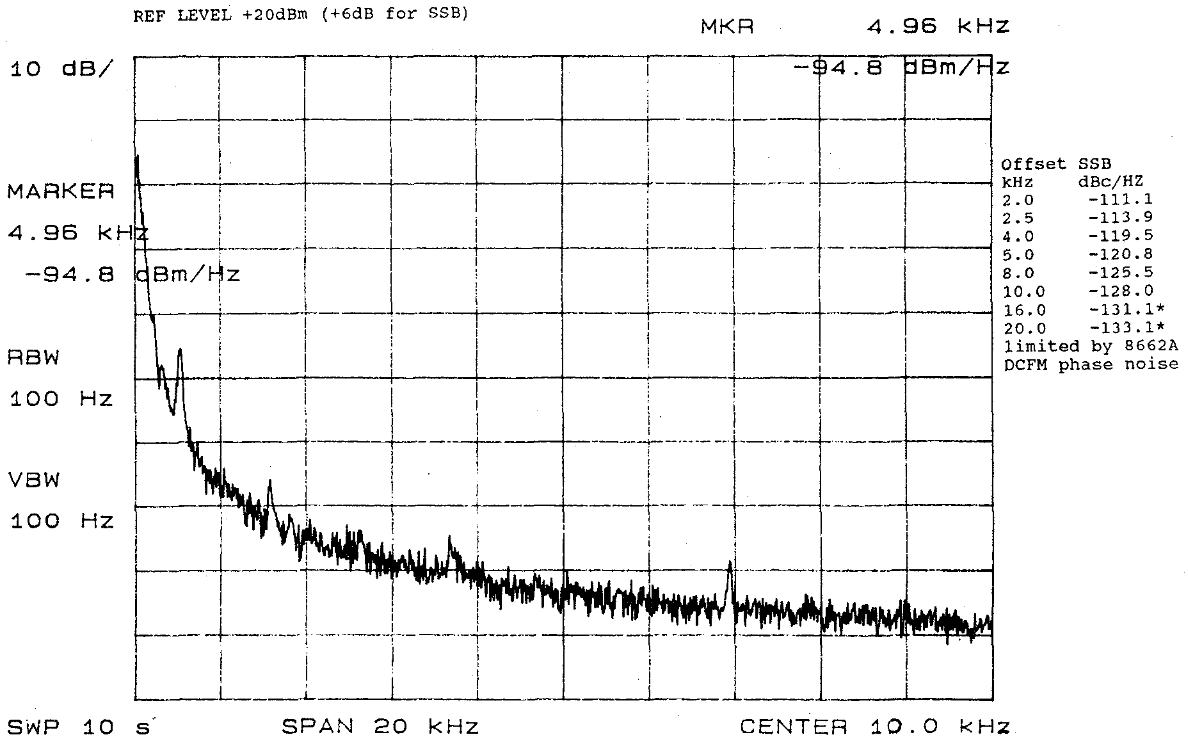

Figure 4. Phase Noise of the beat signal of two Transposed Gain Oscillators operating around 7.6 GHz

The typical noise performance of the HP8672A signal generator at 10 KHz offset is -90 dBc. The transposed gain oscillator is therefore suppressing this noise by more than 40 dB.

FUTURE WORK

Higher unloaded Q, Higher power operation and Zero IF operation are currently under investigation. It is expected that a further noise improvement of >30 dB can be achieved using these methods.

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