A High Q Cavity Stabilized Gunn Oscillator at 94 GHz

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Abstract

The set up and the performance of a 94 GHz second harmonic Gunn oscillator that is cavity stabilized at its fundamental frequency is described. The cavity has a quality factor of about 7000 and reduces the phase noise by nearly 40 dB. The oscillator generates an output power of 40 mW, sufficient to drive low noise balanced mixers, to synchronize Impatt oscillators or to operate as a reference source in coherent radar systems.

Introduction

The phase noise of local or reference oscillators degrade the sensitivity of receivers, doppler radars and coherent radars. For this reason phase locking techniques as well as passive stabilisation techniques have been developed to reduce the phase noise of oscillators.
In the mm-Wave region above 70 GHz 2nd harmonic mode GaAs Gunn oscillators are commonly used although in the past few years fundamental mode oscillators using InP Gunn devices up to 100 GHz are available.
Because of their extremely high external Q factor ($Q_{ext} > 1000$), 2nd harmonic oscillators are not well suited to be passively stabilized at their 2nd harmonic frequency 2 f_o /1/.
To overcome this restriction the fundamental frequency f_o has to be stabilized while only the second harmonic wave is coupled out.
In this paper the set up and performance of such an oscillator working at 94 GHz and stabilized by a TE 013 circular waveguide cavity at 47 GHz is given. The cavity has a loaded Q af about 7000 and the external Q of the oscillator at f_o amounts to 80.
From these figures the expected phase noise reduction can be calculated as

$$PNR \approx 20 \lg\left(1 + \frac{Q_o}{Q_{ext}}\right) \approx 39 \text{ dB}$$

Principle of operation and Set Up

Fig. 1 shows the set up of the oscillator in a cross sectional view. In the bottom of Fig. 1 the related simplified equivalent circuit is sketched out. The diode is connected to the bias filter by a combination of a short line section, acting as an inductor, and a disc, acting as a capacitor for the fundamental wave. This disc simultaneously works as a radialline resonance transformer at 2nd harmonic frequency /1/, /4/.

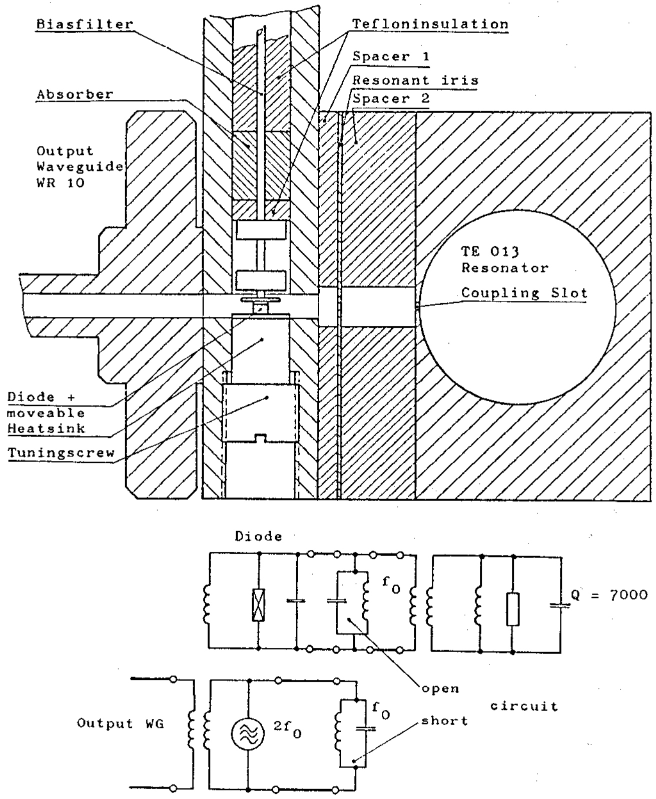

Fig. 1: Set up of the stabilized oscillator

The bias filter is optimized to shorten both frequencies f_o and 2 f_o. Because of this fact, the inductor and the capacitor are shunted to the diode. Together with the diode parasitics the resonator for the fundamental frequency is formed. The frequency increases if the disc diameter or the length of the line section will be decreased or the diameter of this section is increased.
The position of the disc related to the waveguide-buttom slightly influences the output frequency and this is used for finetuning by moving the diode

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with the aid of a tuning screw shown in Fig. 1.
The so generated fundamental wave passes the resonant iris -where the 2nd harmonic wave is reflected- and is fed into the cavitiy through a couplingslot. The 2nd harmonic wave passes the output wave-guide WR10 where the fundamental wave is reflected totally.
The length of spacer 1 and hence the position of the iris determines the 2nd harmonic output power and is found by optimizing the oscillator without high Q cavity shown in Fig. 1. To do this, a backshort plate instead of the cavity was positioned by another spacer 2' to achieve the desired frequency and then spacer 1 and 2' were varied until maximum output power occured. The length of spacer 2 then was found by varying a spacer in steps of 1 mil until the high Q cavity locked the oscillator. This was indicated by the reduction of a frequency shift caused by a sinusoidal amplitude modulation of the bias voltage. This procedure was surprisingly simple compared to the tuning effort required to optimize passive stabilized fundamental wave oscillators.
Two oscillators have been set up, one at 93 GHz as a signal source, and one at 94 GHz as a local oscillator for measurement purposes.

Design of the Cavity

In /2/ the design criteria for circular waveguide cavities are described extensively. The TE 013 mode was chosen because it offers

- very high qualityfactor,
- low volume,
- absence of undesired modes over a range of 4 GHz.

The cavities are made of electrically grown copper. The surface was lathed by a diamond cutting tool having a negative cutting angle. This provides a very dense and mirrorlike surface giving in practice approximately the theoretical value for the loaded Q-factor ($Q_{unloaded} \approx 20000$, $Q_{loaded} \approx 10000$). Coupling was done by a very narrow slot /2/ to prevent the excitement of the TM 112 mode. The loaded Q has been measured as $Q_l \approx 7000$.
Fig. 2 shows the frequency response of the 47 GHz cavity used for the 94 GHz oscillator.

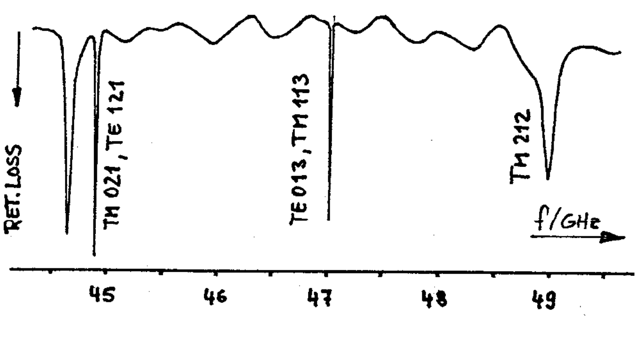

Fig. 2: Separation of the wavemodes

Measurement results

Fig. 3 displays the spectrum of the 94 GHz oscillator measured by harmonic mixing. For example, the noise to carrier ratio N/C at an offset frequency of 10 kHz is found to be

$$N/C\Big|_{10kHz} = -45\ dBc - 10\ lg\frac{res.\ BW}{Hz} = -75\ dBc/Hz$$

(res. BW ← 1 kHz)

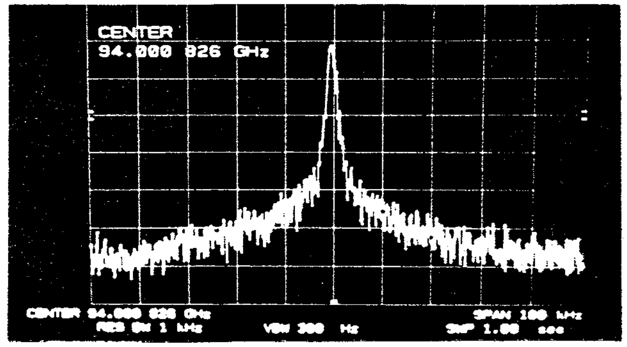

Fig. 3: Spectrum of the stabilized 94 GHz oscillator (harmonic mixing)

Fig. 4a shows the spectrum obtained by downconverting the signals of both stabilized oscillators by means of a balanced mixer. In Fig. 4b the spectrum obtained by mixing the signals of the unstabilized 93 GHz oscillator and the stabilized 94 GHz source is shown.

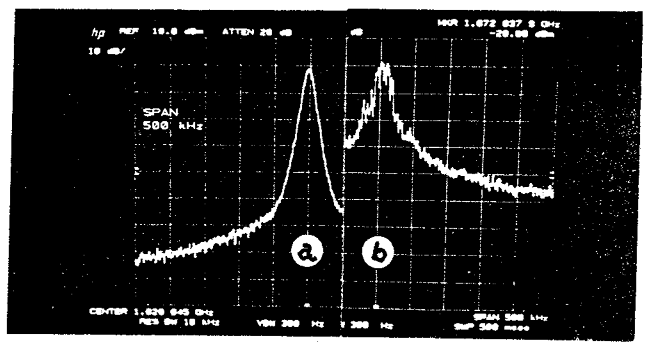

Fig. 4: Spectra of the stabilized/unstabilized 93 GHz oscillator

The results are:

$$N/C\Big|_{50kHz} = -27\ dB - 10\ lg\ 10000 = -67\ dBc/Hz \text{ unstab.}$$

$$N/C\Big|_{50kHz} = -55\ dB - 40\ dB = -95\ dBc/Hz \text{ stab.}$$

A phase noise reduction of 28 dB can be measured with the hp 8566 spectrumanalyzer. As the spectral purity of analyzer and external downconverter is limited, this result fails the theoretical result of 39 dB.

Therefore, to measure the phase noise reduction directly the oscillator was frequency modulated by superposing a weak 1 MHz-Signal to the bias voltage. In the unstabilized state carrier and first sidebands have the same amplitude. This corresponds to a modulation index of

$$\Delta\phi_{peak} = \frac{\Delta f_{peak}}{f_m} = 1{,}43.$$

In the stabilized state, the first sideband was measured as -40 dB below the unmodulated carrier. This corresponds to a mod. index of $_{peak}$ stabilized of 0,02. The phase noise reduction then can be found by

$$PNR = 20 \lg \frac{\Delta\phi_{peak\ unstab.}}{\Delta\phi_{peak\ stab.}} = 37\ dB.$$

This is in good agreement with the theoretical prediction. The corresponding spectra are shown in Fig. 5.

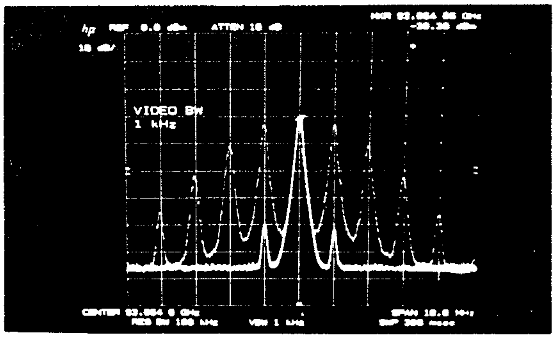

Fig. 5: Spectra of the frequency modulated 93 GHz oscillator,
bright: stabilized, weak: unstabilized

Fig. 6 shows the noise to carrier ratio of various oscillators depending on the offset frequency. A 93 GHz Impatt-oscillator, the unstabilized and the stabilized 93 GHz Gunn-oscillator have been examined. As can be seen the stabilized Gunn-oscillator has a N/C that is more than 25 dB lower than this of the unstabilized oscillator using the same Gunn diode. Compared to the Impatt-oscillator, the stabilized Gunn-oscillator is 50 dB better in phase noise.

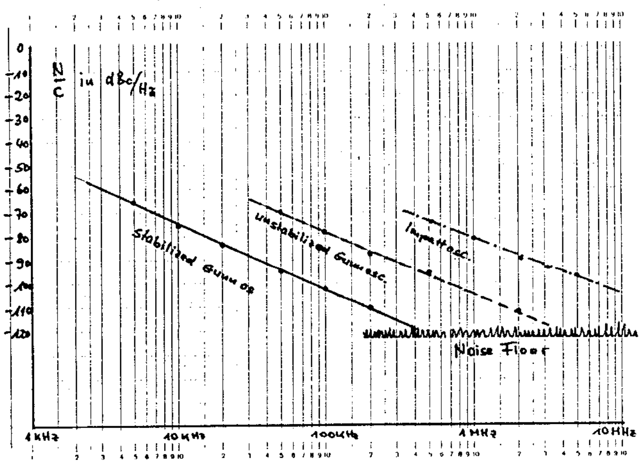

Fig. 6: Noise to carrier ratio of various oscillators versus offset frequency

To prove the capability of the stabilized oscillator as a synchronisation source, the 93 GHz Impatt-oscillator delivering 100 mW output power was injection locked by the stabilized 6 mW signal. The result is shown in the Fig. 7.

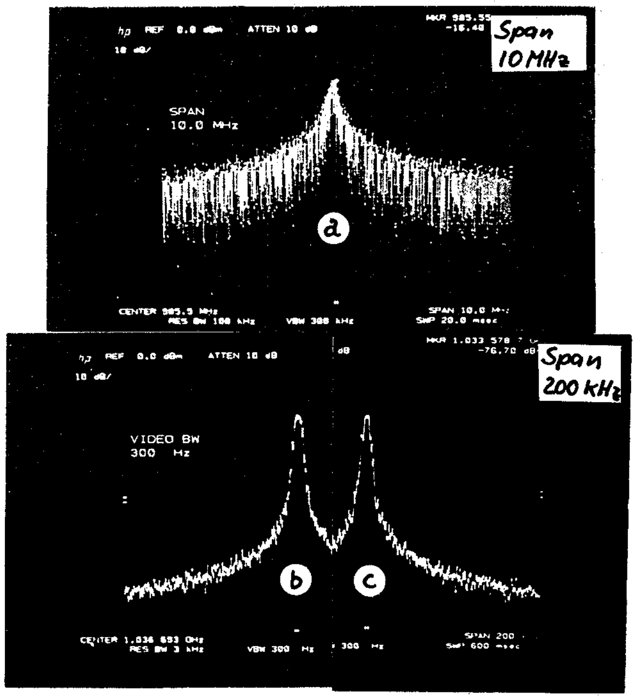

Fig. 7: Spectra of an Impatt-oscillator
a) freerunning, b) synchronized,
c) synchronizing signal

Fig. 7a shows the spectrum of the free running Impatt source. The analyzer setting was: span = 10 MHz and res. bandwidth = 100 kHz. After synchronizing the Impatt oscillator, the spectrum shown in Fig. 7b is obtained. In Fig. 7c the locking signal is displayed. The analyzer setting was changed to: span = 200 kHz and res. bandwidth = 3 kHz. The locking gain was about 12 dB.
Both spectra b and c are practically congruent.
This indicates, that the noise contribution, added by the Impatt source, may be neglected. The so generated signal shows the phase noise behaviour of the stabilized Gunn-oscillator and the 100 mW output power of the Impatt source.
In Fig. 8 is a photograph of the set up. The high Q cavity is opened.

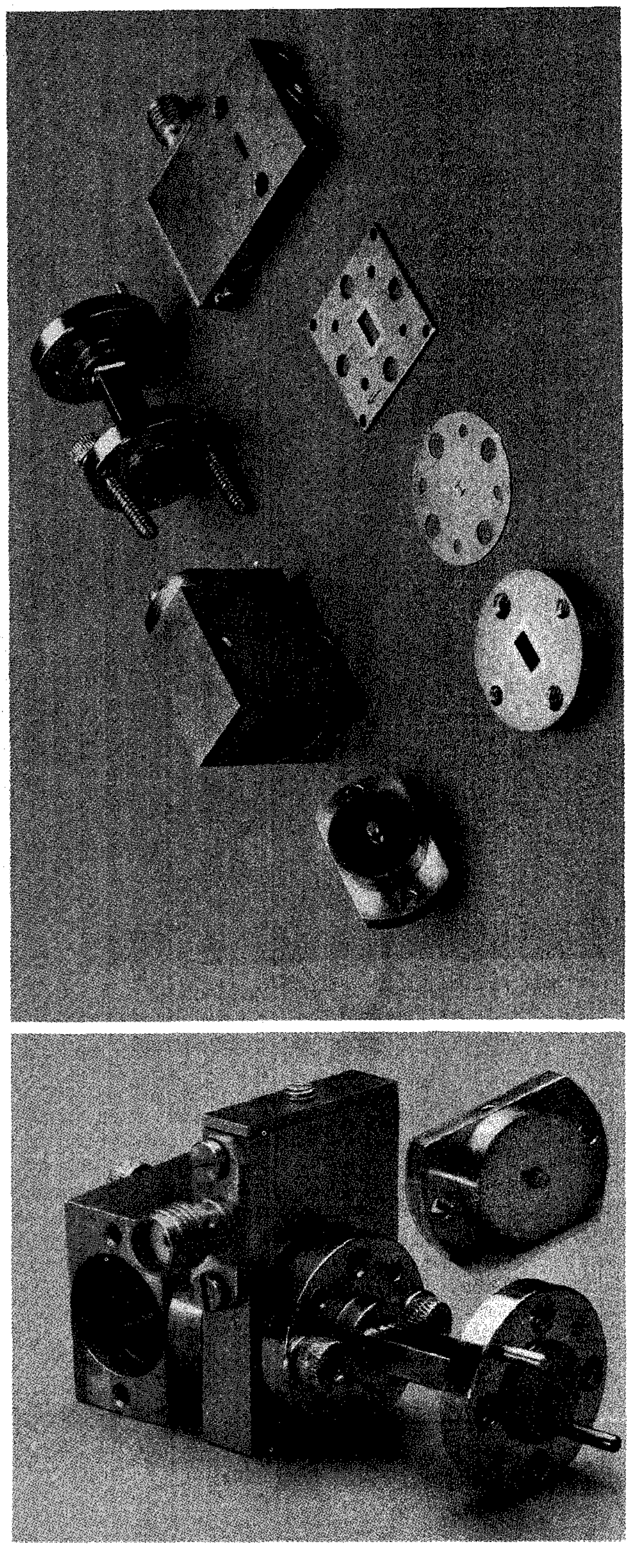

Fig. 8: Set up of the high stable oscillator, the cavity is opened

Conclusion

It has been shown, that applying the techniques of passive stabilizing by high Q cavities to the fundamental wave of 2nd harmonic Gunn-oscillators is a convenient way to achieve signals in the mm-wave range around 94 GHz with very low phase noise and up to 40 mW output power. This is sufficient to drive balanced mixers or to synchronize Impatt sources with powers up to 500 mW. It may be pointed out, that this technique will be succesful even when it is applied to 3rd harmonic gunn-oscillators /3/ and that the frequency range can be extended up to the 200 GHz range by utilizing InP Gunn diodes. Set up and tunig is very simple and repeatable without any problems.

References

/1/ Barth, H.: A wideband, backshort tunable second harmonic w-band Gunn oscillator, Proc. IEEE MTT-S 1981.

/2/ Otto, W.: Berechnung von Hohlraumresonatoren höchster Güte, Nachrichtentechnik 10 (1960) Heft 5 und 6.

/3/ Barth, H.: GaAs Gunn oscillators reach the 140 GHz range, Proc. IEEE MTT-S 1985.

/4/ Ondria, J.: Private communication.