

High spectral purity 26 GHz oscillator based on a SiO₂ Whispering Gallery Mode Resonator

P. Salzenstein, R. Barhaila, Y. Gruson, Y. Kersalé and V. Giordano

Laboratoire de Physique et de Métrologie des Oscillateurs (LPMO) du CNRS UPR3203,
associé à l'Université de Franche-Comté,
32 avenue de l'Observatoire, F25044 Besançon Cedex, France
e-mail: patrice.salzenstein@lpmo.edu

Indexing terms :

phase noise, oscillator, quartz

Abstract :

One of the key parameters to achieve high spectral purity microwave oscillators is the resonator Q-factor. Ultra high performances have been already demonstrated in X-band with Sapphire resonator. SiO₂ monocrystal is another dielectric material to be considered. It presents low dielectric losses, is low cost and available in large size and high purity. We present the evaluation of a 26GHz-oscillator using a SiO₂ monocrystal Whispering gallery mode resonator as frequency reference. The SiO₂ resonator features a loaded Q-factor of 23000 leading to a phase noise $S_{\phi}(1\text{kHz}) = -73 \text{ dB}\cdot\text{rad}^2\cdot\text{Hz}^{-1}$. This first prototype though not yet completely optimised demonstrates the potentiality of dielectric quartz resonator for the achievement of low phase noise microwave source .

Introduction :

Achievement of low phase noise microwave oscillators concerns number of scientific and technological applications such as fundamental and applied metrology, radar and telecommunication systems. According to well known Leeson model [1], the power spectral density of phase fluctuations $S_{\phi}(f)$ of an

oscillator is related to its resonator loaded Q-factor by :

$$S_{\phi}(f) = \left(\frac{n_0}{2 \cdot Q_L} \right)^2 \left(\frac{1}{f} \right)^2 \cdot S_{\theta}(f) \quad (1)$$

for $f < \nu_0/2Q_L$ where ν_0 is the carrier frequency and $S_{\theta}(f)$ is the Phase Spectral Density (PSD) of the intrinsic phase fluctuations of the loop amplifier. As $S_{\theta}(f)$ is dominated by flicker phase noise (1/f noise) at low Fourier frequencies, $S_{\phi}(f)$ shows flicker frequency noise dependence. Equation (1) shows one of the key parameter is the resonator Q-factor which has to be increased to reach low phase noise performances. Ultrahigh Q values can be obtained with sapphire (Al₂O₃ monocrystal) resonator [2-4]. So long as extreme performances are not required, quartz appears as efficient and yet low cost dielectric medium presenting low dielectric losses. Despite of the low value of SiO₂ relative permittivity it is possible to build high-Q resonator by using Whispering Gallery Mode Resonator (WGMR) techniques [5]. In that case electromagnetic energy is well confined in the dielectric leading to a Q-factor essentially limited by $\tan\delta$. In this article, after a brief description of our 26GHz SiO₂ WGMR we present the implementation of an oscillator circuit incorporating this frequency reference. Phase noise measurements demonstrates the

potentiality of such a resonator to achieve low noise performances.

Resonator design :

The dielectric resonator consists in a 24.6 mm diameter and 6.5 mm thick quartz disk with a 3mm diameter hole drilled along the axis.

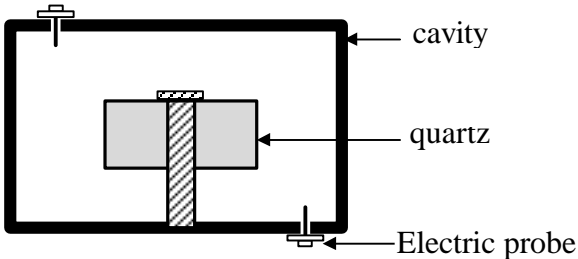


Fig. 1 : WGM Quartz resonator scheme

A brass screw and an alumina rod enable to centred the quartz disk in a gold-plated copper cavity. Two electrical probes (antenna) fixed on each lid of the cavity are used to excite the quasi-TM whispering gallery (WGH) mode family of this resonator. In order to demonstrate the ability of quartz resonator oscillator to achieve low phase noise performances at high frequency, we choose to operate on the $WGH_{10,0,0}$ mode at 26 GHz. This frequency nearly corresponds to the limitation of the technology available in our lab. Coupling coefficients have been adjusted by changing the penetration length of the antenna into the copper cavity. We then set the insertion losses to -15 dB and obtained a loaded Q-factor of 23 000.

The electromagnetic tool used to determine resonant frequencies is based on finite element method [6].



Fig. 2a : 26GHz-cavity before packaging

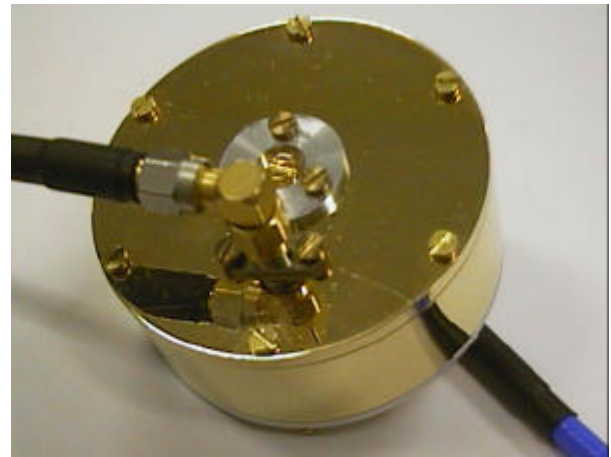


Fig. 2b : 26GHz-cavity after packaging and connecting

Oscillator description

The oscillator circuit follows a classical transmission oscillator scheme. Although, modal selection techniques exist and have been successfully tested on such a type of resonator [7], the prototype presented here does not include any modal selector. Then a band-pass filter has been required to ensure the oscillation on the right mode. This filter realized in a standard wave guide technology presents a bandwidth of 300 MHz which appears sufficient to suppress the main spurious resonances. The loop amplifier is a GaAs commercial unit presenting 35dB gain and an output power of 12dBm at 1dB compression point. Variable attenuators and phase shifter have been inserted in the circuit to adjust power and phase of the signal in the loop. As this resonator is not equipped with a modal selector, in the loop, we include a filter realized in a rectangular waveguide. We choose the dimensions of the two circular iris by establishing a compromise between losses and suppression of parasitic modes. It is also possible to adjust mechanically the frequency. The bandpass of the filter is about 306MHz centered around 26.05GHz with -9 dB of insertion losses. A 10dB directional coupler enable to extract the useful signal. The figure 3 shows the RF spectrum of this signal presenting a power of 2dBm at 26.00 GHz.

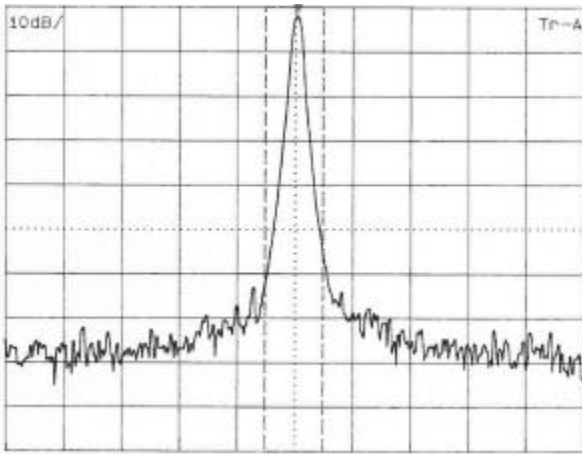


Fig. 3 : RF spectrum (center freq.26.00GHz, span1MHz, RF level 5.00dBm, res.BW.10kHz, video BW.10kHz)

Phase noise measurement :

The set-up used to evaluate the phase noise of our oscillator is described on the figure 4.

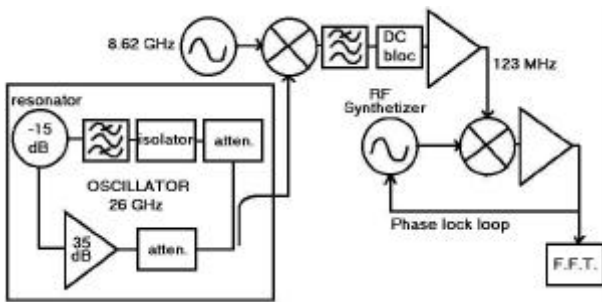


Fig. 4 : Set-up

A first beat note signal at 123 MHz has been obtained by mixing the output of the 26GHz oscillator with the third harmonic of a 8.62GHz signal generated by a low noise microwave frequency synthesizer. The phase noise of the beat note signal is then measured thanks the phase noise measurement test set including an low noise RF synthesizer as reference. As working at low temperature does not lead to any great performance improvement [5], we worked at room temperature. The results of the phase noise measurements are shown on the figure 5. For Fourier frequencies higher than 10kHz, the measurement is limited by the phase noise of the 8.62GHz synthesizer.

Results and discussion :

The phase noise of our oscillator appears equal to $-73\text{dB}\cdot\text{rad}^2\cdot\text{Hz}^{-1}$ at 1kHz of the carrier with a $1/f^3$ dependence as expected. From this results we deduce the phase noise of the amplificator of the oscillator. According to the Leeson model, the amplifier intrinsic phase noise should be equal to $-97\text{dB}\cdot\text{rad}^2\cdot\text{Hz}^{-1}$ to fulfil the preceding measurements. Such a value is quite large compared with the phase noise of state-of-the-art amplifiers [8].

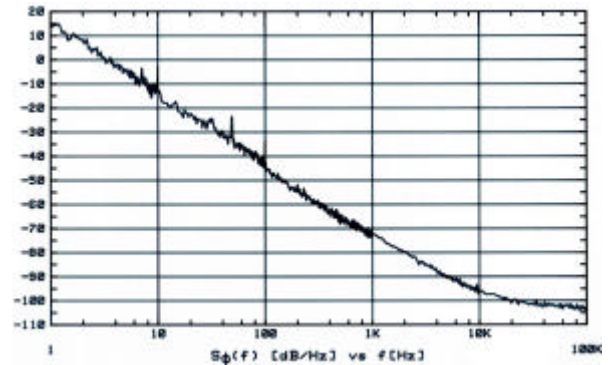


Fig. 5 : Phase noise measurements at 26GHz

Intrinsic noise of the amplifier is relatively high. It should be possible to increase the performances of our oscillator by the use of low noise transistors.

From $S_{\phi}(1\text{Hz})=15\text{dB}\cdot\text{rad}^2\cdot\text{Hz}^{-1}$, we can also deduce $h^{-1}=-193.3\text{dB}/\text{Hz}$. As the equivalent term of the Allan variance is $\sigma_y(\tau)=\sqrt{2\ln 2}\cdot h^{-1}$, a flicker level of $\sigma_y(\tau)=2.6\cdot 10^{-10}$ is expected for our oscillator in time domain.

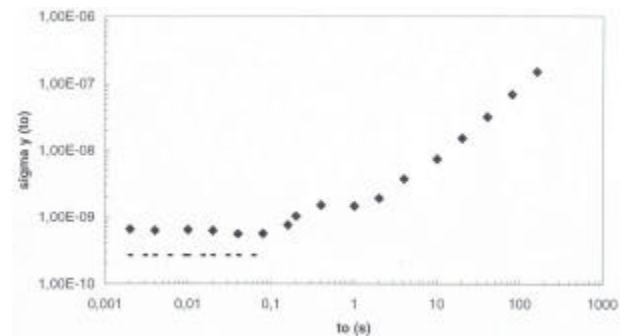


Fig. 6 : 26 GHz oscillator in the time domain

The flicker level $\sigma_y(\tau)=5.10^{-10}$ measured using a counter for $0.001\text{s}<\tau<0.01\text{s}$ shown on figure

6 is found a little bit higher than that deduced from the spectral measurements.

Despite our none optimized amplifier, we obtain state-of-the-art results at 26GHz with our oscillator. However, our 26 GHz oscillator presents interesting phase noise performances which compares favourably with already published results [9].

References :

- [1] D. B. Leeson, 'A simple model of feedback oscillator noise spectrum', Proceedings of the IEEE, feb.1966, pp. 329-330
- [2] S. Vitusevich, K. Schieber, N. Klein, I. S. Ghosh and M. Spinnler, 'An all-cryogenic low phase-noise hybrid K-band oscillator for satellite communications', IEEE Microwaves Trans. on Techn. conference 2001
- [3] A. N. Luiten, A. G. Mann and D. G. Blair, 'Ultrahigh Q-factor cryogenic sapphire resonator', Electronics Letters, 1993, **29**, (10), pp. 879-881
- [4] V. Giordano, Y. Kersalé, O. di Monaco and M. Chaubet, , 'Progress report on the development of microwaves spectral references at the LPMO', Eur. Phys. J. App. Phys. **8**, 1999, pp. 269-274
- [5] I. Lajoie, R. Barhaila, Y. Kersalé, D. Cros, D. Durichon and V. Giordano, 'High Q microwave resonators using quartz monocrystal', Electronics Letters, 20th january 2000, **36**, (2), pp. 150-152
- [6] M. Aubourg and P. Guillon, 'A mixed finite element formulation for microwave devices problems. Application to MIS structure', J. Electromagn. Waves Appl., **415**, (5), 1991, pp 371-386
- [7] O. Di Monaco, W. Daniau, I. Lajoie, Y. Gruson, M. Chaubet and V. Giordano, 'Mode selection for a whispering gallery mode resonator', Electronics Letters, 28th march 1996, **32**, (7), pp. 669-670
- [8] O. Llopis, J.B. Juraver, M. Regis, M. Chaubet and J. Graffeuil, 'Evaluation of two non-standard techniques for the phase noise characterization at microwave frequencies', Proc. of the 2000 IEEE Int. Freq. Contrl. Symp., Kansas City (USA), june 2000, pp. 511-515

- [9] U. Güttich, H. Shin, U. Erben, C. Gaessler and H. Leier, '24-27GHz dielectrically stabilized oscillators with excellent phase noise properties utilizing InP/InGaAs HBTs', IEEE Microwaves Trans. on Techn. Conference, TUF2-2, 1999