Adjustment of a Temperature Compensated Ka-Band Ring Resonator VCO Using Fully Automated Laser-Trimming

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***Abstract* — A new Ka-band voltage controlled oscillator (VCO) using a planar ring resonator (RR) and a GaAs-pHEMT microwave monolithic integrated circuit (MMIC) is presented. The resonator operates at harmonic frequencies and is manufactured on a temperature stable calcium magnesium titanate substrate using photo-lithographic thinfilm processes. An innovative fully automated active laser-trimming procedure is used to adjust the frequency of the free-running oscillator as well as the varactor tuning sensitivity. In addition, automated laser-trimming is used to equalize the electrical length between the ring resonator and the MMIC.**

High unloaded quality factors of more than 350 have been obtained for the harmonic ring resonator. With these high quality factors a single side-band phase noise of better than –110dBc/Hz is achieved at an offset frequency of 1MHz. In addition, the frequency tuning range of the laser-trimming procedure is larger than 10% without any significant change of the VCO's characteristics like phase noise and varactor tuning sensitivity. The typical temperature drift of the oscillator frequency is less than 4ppm/K.

We use a RR-VCO with an electrical length of four wavelengths, which is phase-locked to an external reference, as local oscillator in our latest microwave Point-to-Multipoint (PMP) transceivers.

I. Introduction

Demand of wireless communication systems has been growing rapidly during the last years and today new frequency bands have to be opened. Moreover, very wide band frequency ranges are required for high-speed data communication. Ka-band and millimeter-wave frequency ranges are applicable for nowadays and future data communication systems, such as Point-to-Point (PP), Point-to-Multipoint (PMP) and satellite communication systems. These systems strongly require smaller and cheaper RF components, but keeping the same level of excellent RF characteristics than years ago. In addition, for high volume production fully automated tuning and testing is necessary.

Dielectric resonators (DR), e.g. laterally coupled to a microstrip line [1]-[3], are often used for oscillator applications at microwave frequencies. DRs can achieve high quality factors resulting in good phase noise performance of the oscillator. But the adjustment of the oscillator frequency requires mechanical tuning elements, which have to be integrated into the oscillator housing. In an RF module using chip & wire technology those tuning elements additionally have to be hermetically sealed. Thus, the oscillator becomes complex and expensive.

In contrary, oscillators with resonators in microstrip technique can be manufactured at low cost levels. On the other hand their quality factor, compared to the DR-version is low. They have a high temperature drift and they are difficult to trim. However, low temperature drift and accurate trimming (e.g. to compensate for substrate material and production tolerances or to adjust a channel dependent center frequency) is necessary for oscillators. Therefore, commercially applicable Ka-band oscillators using microstrip resonators are very unusual up to now.

This paper describes a new approach for a Ka-band oscillator with a planar ring resonator, that eliminates the above identified disadvantages of oscillators with microstrip resonators.

II. Configuration Of The Oscillator

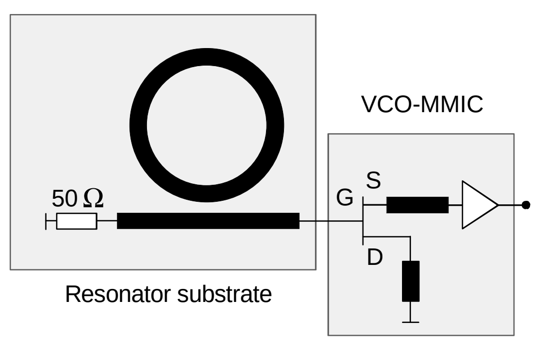

Fig. 1. Equivalent circuit of the RR-VCO.

A reflection type oscillator topology with a pHEMT MMIC in common drain configuration and series feedback has been selected (s. Fig. 1). The ring resonator is coupled to an adjacent transmission line connected to the gate port of the MMIC's oscillator stage. Due to the gate line termination, there is no other possible frequency oscillation than the desired one corresponding to the ring resonator. In addition, this configuration has a low phase noise and excellent frequency stabilization due to its good isolation between the frequency determining resonator and the RF output port [3].

III. The Ring Resonator

A. Design

Fig. 2 shows the basic configuration of the planar resonator arrangement proposed in this paper. A ring resonator (RR) is coupled to two adjacent transmission lines. One end of the right line in Fig. 2 is used to connect the resonator to the oscillator MMIC. This line is terminated at the other end. The second line couples a varactor diode tuning network to the RR.

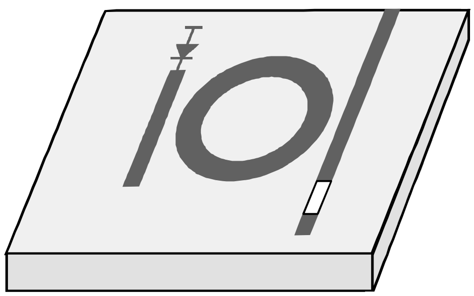

Fig. 2. Basic configuration of the planar resonator with coupling lines, printed onto a substrate.

Due to the symmetrical structure of the RR, there are always two orthogonal modes propagating in the resonator [4]. However, an ambiguous resonance frequency is not tolerable for oscillator applications. The necessary clarity of the finally desired oscillator frequency is reached by implementing transversal slits into the resonator structure at every place, where one of the two modes has its current maximum (s. Fig. 3).

To increase the quality factor of the resonator a low characteristic impedance of the RR and an operation at harmonic frequencies instead of fundamental frequency was chosen. A relative dielectric constant of the substrate of $\varepsilon_r \approx 21$ additionally reduces undesired radiation losses. Due to these operation conditions, ohmic losses as well as radiation losses of the RR are considerably reduced. The result is an increased quality factor of the resonator. Another significant advantage of our new approach is that fringing fields, especially like those of DRs, and related undesired coupling effects within the transceiver module are completely eliminated.

We have used extensive electromagnetic simulations to calculate and optimize the resonance frequency and the quality factor of the RR. In addition, the coupling between the RR and the microstrip lines as well as the varactor network have been investigated, especially to achieve a voltage independent varactor tuning sensitivity. High unloaded quality factors of more than 350 have been obtained at Ka-band frequencies. Agreement between calculation and measurement results is very good.

B. Layout and fabrication

Fig. 3 shows the layout of a realized resonator substrate. The darker areas at the inner radius of the RR, at the end of the varactor line and at the transmission line between the RR and the oscillator MMIC are potential laser-trimming areas.

A temperature compensated ceramic substrate, based on calcium magnesium titanate with a relative dielectric constant of $\varepsilon_r \approx 21$, is used. The thickness of the substrate is 15mil. The resonator is manufactured using thin film gold as conductor layer. The applied processes are similar to those used for standard alumina substrates.

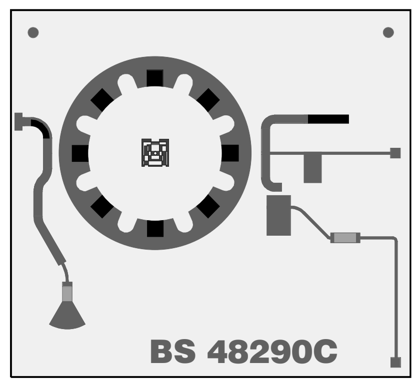

Fig. 3. Layout of the resonator with an electrical length of four wavelength, including marked trimming areas for adjusting the frequency, the varactor tuning sensitivity and the electrical length between the resonator and the MMIC.

IV. The Oscillator-MMIC

The oscillator MMIC [5] is a three stage circuit, that consists of an oscillator stage and two buffer stages. The oscillator stage, providing the negative resistance to the ring resonator, is designed using a common drain configuration (s. Fig. 1). The two buffer amplifier stages are reducing the load-pulling on the oscillator stage due to their isolation. The small signal gain of the two buffer stages is typically 16dB.

The magnitude of the oscillator MMIC's input reflection coefficient $|S_{11}|$ is approximately +10dB from 20GHz to 27GHz. Due to the two buffer stages the MMIC has the capability to deliver a saturated output power of 26.5dBm with a 1dB gain compression point at 24.5dBm typically.

V. Fully Automated Laser-Trimming Of The RR-VCO

A. Laser-trimming principles

We use a RR-VCO with an electrical length of four wavelength, which is phase-locked to an external reference, as local oscillator in our latest microwave Point-to-Multipoint (PMP) transceivers. The frequency of the local oscillator signal is channel dependent in our application. Therefore, we have to trim the frequency of the oscillator for each channel as well. This is done by active microwave laser-trimming.

During the trimming procedure of the frequency conducting material of the ring resonator structure is removed by the laser in that way, that the electrical length of the RR increases. Consequently, the resonance frequency decreases. The maximum tuning effect to the resonance frequency of the desired mode can be achieved in areas, where this mode has its current maximum. The darker square areas at the inner radius of the RR, as shown in Fig. 3, are examples for trimming areas of a RR with an electrical length of four wavelength.

During the trimming of the frequency, the varactor tuning sensitivity and the phase condition between the MMIC and the RR changes. Therefore, for a proper operation of the RR-VCO, it is necessary to trim these two parameters as well. The varactor tuning sensitivity can be adjusted by cutting the length of the varactor coupling line. The electrical length of the transmission line between the RR and the oscillator MMIC can be adjusted by implementing transversal slits at the connecting transmission line. These trimming areas are marked in Fig. 3 as well.

The three parameters frequency, varactor tuning sensitivity and phase length of the VCO are trimmed by a fully automated laser-trimming procedure during the adjustment of the complete transceiver module. Unfortunately, the three parameters to trim are not independent from each other, so that the trimming procedure of the RR-VCO has to be iterative as follows:

1) Frequency, coarse tuning
2) Phase length between RR and MMIC
3) Varactor tuning sensitivity
4) Frequency, fine tuning

The oscillator is trimmed to a frequency, that is approximately 300MHz higher than the desired frequency in the first step. This course trimming step is necessary to be sure, that the frequency doesn't become lower than the desired frequency during the phase-trimming step. The goal of the phase-trimming is to maximize the oscillation margin. The maximum oscillation margin occurs in conjunction with a minimum supply current of the VCO transistor, so that the supply current is used as indirect parameter.

Afterwards the varactor tuning sensitivity is trimmed to a defined value (e.g. 6MHz/V) by shortening the varactor microstrip line. Finally, the frequency is trimmed to the desired frequency.

The trimming process is irreversible. Therefore, especially during fine trimming we have to be careful, that not too much material is removed from the trimming areas by the laser.

B. Implementation and examples

During the trimming procedure the frequency of the oscillator, the varactor tuning sensitivity and the oscillator margin have to be determined and evaluated several times. The whole trimming procedure is software controlled by a HP-VEE program.

Fig. 4 shows measured results of the oscillator frequency subject to the number of fully laser-trimmed areas according to the layout shown in Fig. 3. The trimming range is more than 2.7GHz.

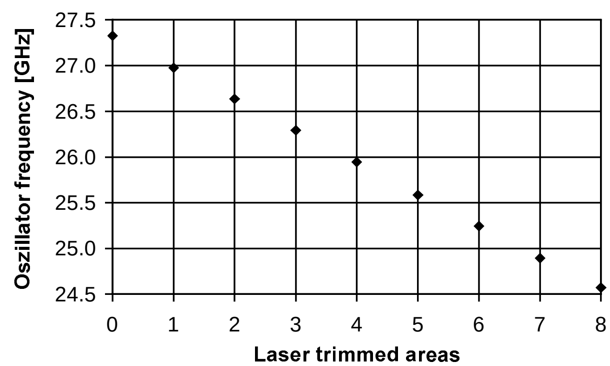

Fig. 4. Oscillator frequency subject to the number of fully laser-trimmed areas for a layout according to Fig. 3.

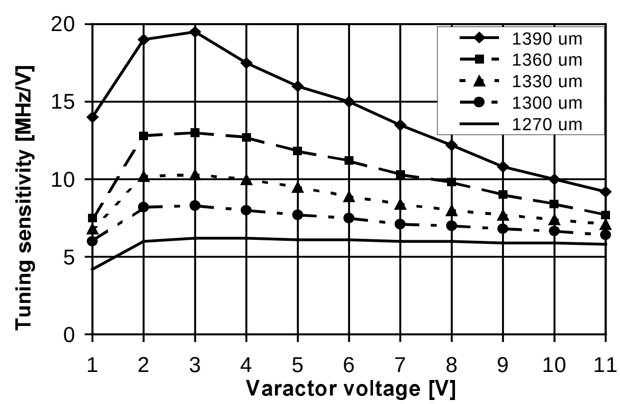

Fig. 5. Varactor tuning sensitivity for several lengths of the varactor line at 26.59GHz.

Fig. 5 shows the varactor tuning sensitivity for several lengths of the varactor line. With a length of 1270µm a varactor tuning sensitivity of (6±0.2)MHz/V has been achieved for voltages between 2V and 11V.

The finally achieved trimming accuracy of the oscillator frequency is better than +/- 10ppm. It is impossible to reach this class of accuracy by use of alternative tuning methods like bond wire trimming or attach of ceramic tuning chips.

VI. Measurement Results

The calculated resonance frequency of an oscillator using a resonator with an electrical length of four wavelengths and a layout according to Fig. 3 without laser-trimming is 27.3GHz. The measured resonance frequency is 27.324GHz (s. Fig. 4).

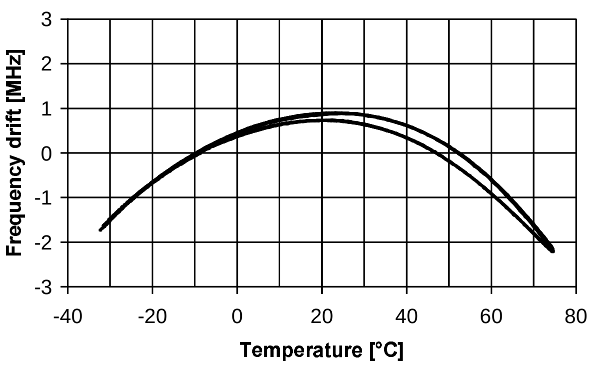

Fig. 6. Measured frequency drift over temperature of a laser-trimmed oscillator with a frequency of 24.68GHz at room temperature.

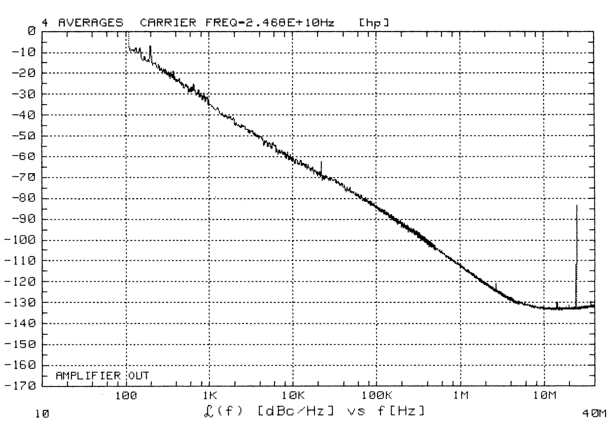

Fig. 7. Measured free-running single side-band phase noise of a laser-trimmed oscillator at a frequency of 24.68GHz.

The measured frequency drift over temperature of a laser-trimmed oscillator with a frequency of 24.68GHz at 25°C is less than 3MHz for temperatures between –32°C and +75°C, as shown in Fig. 6. Generally, the drift is dependent on the oscillator frequency and is less than 4ppm/K. Fig. 7 shows the measured free-running single side-band phase noise. A value of –113dBc/Hz is achieved at an offset frequency of 1MHz. The free-running phase noise for all possible laser trimmed frequencies is lower than –110dBc/Hz.

The influence of housing and lid on the oscillator frequency is less than 1MHz. The influence on the other oscillator parameters is negligible.

VII. Conclusions

In this paper a new approach for a Ka-band VCO using a planar ring resonator is presented. Due to the high quality factor of the resonator low phase noise is achieved. Therefore, this RR-VCO can be used now for applications, which have been exclusively reserved up to now for much more expensive oscillators using dielectric resonators only.

The RR-VCO has a very low temperature drift and the resonator can be manufactured easily using thin film technology. The fully automated active microwave laser-trimming procedure is used to compensate the substrate's material- and production-tolerances as well as MMIC tolerances and allows finally a flexible adjustment of the oscillator frequency. Consequently, this RR-VCO is suitable for nowadays and future commercial high volume production of microwave transceivers at reasonable cost levels.

Acknowledgement

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References

[1] [1] J. Wenger and U. Güttich, "Ka- and W-Band PM-HFET DRO's", *IEEE Microwave and Guided Wave Letters*, vol. 3, no. 6, pp.191-193, June 1993.

[2] A. Gruhle, C. Mähner and K. Weidmann, "Low Phase Noise 10GHz DRO with low 1/f noise SiGe HBTs", *28th European Microwave Conference*, p. 391-394, Amsterdam 1998.

[3] C. Tsironis and V. Pauker, "Temperature stabilization of GaAs MESFET oscillators using dielectric resonators", *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-31, no. 3, p. 312-314, March 1983 .

[4] S. Lu and A. Ferendeci, "Coupling modes of a ring resonator side coupled to a microstrip line", *Electronics Letters*, vol. 30, no. 16, p. 1314-1315, 4. Aug. 1994.

[5] S. Koch, W. Bischof, H. Gill and U. Müller, "K-Band Chipset for Fully Integrated Point to Multipoint Microwave Modules Using 0.25 Micron pHEMT MMIC Technology", *GAAS 98*, pp. 719-724, Amsterdam 1998.