Low Cost Microwave Oscillator Using Substrate Integrated Waveguide Cavity

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***Abstract*—A topology is proposed for designing a low-cost microwave oscillator. This new feedback oscillator makes use of a substrate integrated waveguide (SIW) cavity that acts as a frequency selector as well as a feedback-coupling device. The oscillator is stabilized by using an injection-locking scheme. A 12.02-GHz oscillator prototype was designed. Experimental results for phase noise, locking range, and quality factor of the new circuit are presented. An external Q of 178 was measured.**

***Index Terms*—Cavity, feedback oscillator, phase noise, substrate integrated waveguide (SIW).**

I. Introduction

The search for low-cost microwave and millimeter-wave oscillators has stimulated a rapid development of many new concepts [1]–[3]. Recently, a new scheme called substrate integrated waveguide (SIW) [4]–[6] was presented and developed as an attractive technique for low-loss, low-cost and high-density integration of microwave and millimeter-wave components and sub-systems. In particular, it was shown that high-Q resonant cavities could be built with such a technique [7]. This led to the development of a novel SIW oscillator in this work. This oscillator can provide low phase noise because of high Q of the SIW cavity.

The topology of the proposed oscillator is illustrated in Fig. 1. It is a feedback circuit composed of an amplifier and an SIW cavity that is formed on the same dielectric substrate. The SIW cavity acts as a frequency selector and at the same time as a coupling device for the positive feedback loop. This can effectively get rid of a conventional externally mounted resonator (e.g., dielectric block). A 20-dB directional coupler is also added in the circuit for injection locking purpose of the oscillator. Finally, ports P_A and P_B are added for phase and gain tuning of the open loop, as suggested in [8]. Jumpers $JP1$ and $JP2$ are used to open or close the feedback loop.

In this letter, we will first discuss the topology and the design of the SIW cavity. Then, we will explain the design of the oscillator. Finally, we will present its experimental results as well as its electrical performances.

II. SIW Cavity Design

An SIW structure consists of two separate rows of metallized holes made in a dielectric substrate to form a dielectrically filled

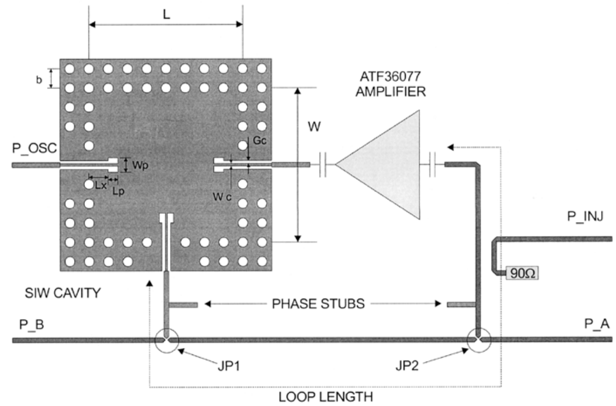

Fig. 1. Topology of the proposed SIW feedback oscillator.

"synthesized" rectangular waveguide [4]. The spacing "W" between the two rows determines the frequency band of the guide. Almost no leakage exists along the guide if the metallized holes spacing "b" is equal or smaller than twice the diameter of the metallized hole (this diameter should be equal or smaller than a tenth of the wavelength of the maximum frequency of operation). In our case, we use a via hole diameter of 0.8 mm, which gives us a maximum operating frequency of 38GHz.

In [6], it was shown that propagation properties of the TE_{10}-like mode in the SIW are very similar to the TE_{10} mode of a rectangular guide. So, an SIW cavity can be designed by using the following relation:

$$F_{R(\mathrm{TE}m0q)} = \frac{c_O}{2\cdot\sqrt{\varepsilon_R}}\sqrt{(m/W_{eff})^2 + (q/L_{eff})^2} \qquad (1)$$

where

$$L_{eff} = L - \frac{D^2}{0.95\cdot b} \qquad W_{eff} = W - \frac{D^2}{0.95\cdot b} \qquad (2)$$

and D is the diameter of the metallized hole. Equation (1) provides a good first approximation for the dimensions W and L of the cavity (see Fig. 1). Current probes are used to connect the cavity to the microstrip lines. Such probes are formed by short-circuited sections of coplanar waveguide. Dimensions Lp and Wp determine the level of coupling to the cavity. As the probes are comparable in size to the cavity, they can change its frequency of resonance. Therefore, a three-dimensional (3-D) electromagnetic simulator, such as [9], is necessary to accurately design the cavity. Of the three probes, one is used as an output port and one to couple power to the positive feedback loop. To adjust the coupling level, which depends on the gain of the amplifier, probe lengths Lx, Lp, and width Wp are changed. Coupling level from 4 dB to 20 dB can easily be achieved.

Manuscript received July 3, 2002; revised August 6, 2002. The review of this letter was arranged by Associate Editor Dr. Shigeo Kawasaki.

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Digital Object Identifier 10.1109/LMWC.2003.808720

Note that this coupling scheme does not provide any isolation between the feedback loop and the output port P_OSC. So impedance mismatch at the P_OSC port will affect the oscillator.

III. Feedback Oscillator Design

The design of a feedback oscillator can be done using only a linear circuit simulator. First, a small signal amplifier is designed. The amplifier is combined with the SIW cavity. Then, the feedback loop is added on. The coupling level of the SIW cavity is adjusted so that the gain of the loop is slightly higher than 1 dB, as indicated in [8], to take into account the gain drop of the amplifier when it is in saturation. The loop length is also adjusted so to obtain 0° phase difference. Small stubs are placed in the loop to make fine tuning adjustment of the loop phase. After the circuit is constructed, the loop gain and phase measurements are done for fine tuning [8].

IV. Experimental Results

A 12-GHz feedback oscillator was designed and constructed. The amplifier used here is the ATF36077 low noise pHEMT transistor from Agilent. Small signal gain of the amplifier is 7 dB, with $P_{1\ \mathrm{dB}}$ of 5 dBm. The cavity is designed with a coupling level of 5.8 dB. Dimensions of the cavity, as sketched in Fig. 1, are: $L = 12.21$ mm, $W = 11.31$ mm, $b = 1.53$ mm, $Wc = 0.4$ mm, $Gc = 0.3$ mm, $Wp = 1.4$ mm, $Lp = 1.15$ mm, $Lx = 0.75$ mm and $D = 0.8$ mm. For the coupling probe, $Lp = 0.5$ mm, and $Wp = 0.4$ mm. The feedback loop length is 42.5 mm and the microstrip line width is 0.55 mm. The dielectric substrate has a dielectric constant of 2.33 and a thickness of 0.508 mm (Duroid 5870). Simulation results of the cavity are presented in Fig. 2, showing an insertion loss level of 3.5 dB. Rejection level of the second harmonic is better than 10 dB. Note that the coupling level is higher than 15 dB outside the bandwidth of interest around 12 GHz. This ensures that the oscillator will not generate unwanted spurious signals. Finally, a 20-dB microstrip coupler is added near the input of the amplifier to allow injection locking of the oscillator.

The circuit was built and the open feedback loop was tuned for appropriate gain and phase using ports P_A and P_B, with jumpers $JP1$ and $JP2$ set for an open loop. The gain was adjusted by modifying Lp of the coupling probe of the cavity, and the phase was corrected by tuning the length of the phase stubs.

A free running oscillating frequency of 12.02 GHz was obtained. Fig. 3 shows the output spectrum of the oscillator. The power output level is 0 dBm if the 10-dB loss of the measurement setup is taken into account. The maximum harmonic level is −20 dBc. The free running phase noise was measured following the comments in [10] where the following relation is used

$$P_{NOISE} = P_{SIDEBAND} - P_{CARRIER} - 10\log(RBW). \quad (3)$$

With $P_{CARRIER} = 0$ dBm, $P_{SIDEBAND} = -43$ dBm at a 100 KHz offset, and a resolution bandwidth of 1 KHz on the spectrum analyzer, a phase noise of −73 dBc/Hz is calculated.

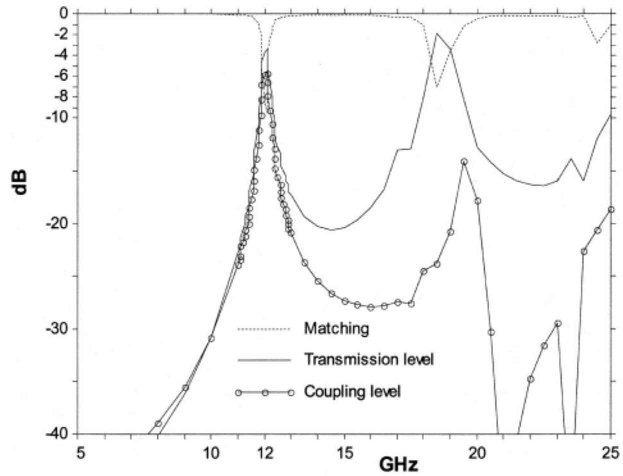

Fig. 2. Simulation results of the SIW cavity (obtained with [9]).

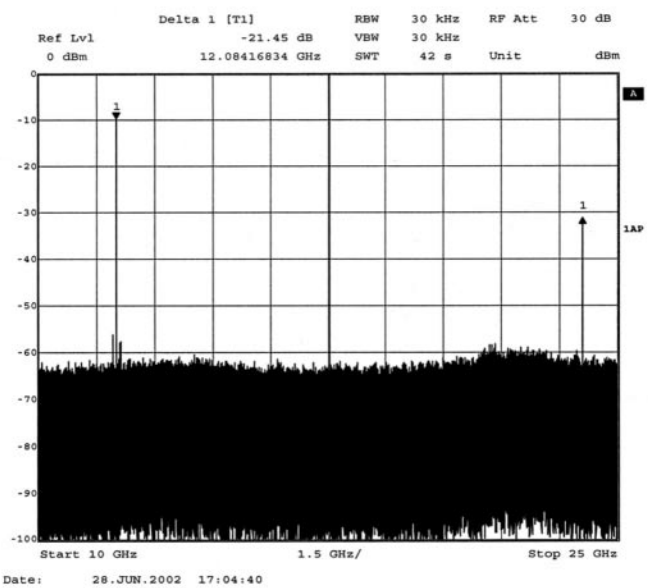

Fig. 3. Measured output spectrum of the SIW oscillator.

On the basis of the injection-locking scheme, it is possible to estimate the external Q factor of the oscillator loop, because of the following relation [11]:

$$Q_{EXT} = \frac{W_O}{W_M} \cdot \sqrt{\frac{P_{INJ}}{P_{OUT}}} \quad (4)$$

where W_O is the free running frequency, W_M is the locking range, P_{OUT} is the output power of the oscillator, and P_{INJ} is the power level of the injected signal in the loop, which is the power at port P_INJ less 20 dB, the 20 dB being the coupling level of the directional coupler used at the P_INJ port. Table I shows the measurement results. The average measured external quality factor is 178. Fig. 4 illustrates the phase noise of the designed SIW oscillator for different injected reference power level, compared to the phase noise of the reference oscillator itself. It shows that an injected signal of −30 dBm is sufficient to get a phase noise close to the reference source.

TABLE I
EXTERNAL Q FACTOR OF THE OSCILLATOR CIRCUIT

W_M (KHz)	W_O (GHz)	P_{INJ} (dBm)	P_{OUT} (dBm)	Q_{EXT}
794	12.0213	-40	-1.0	170
2304	12.0213	-30	-1.0	185
7105	12.0213	-20	-0.5	179
			Average =	178

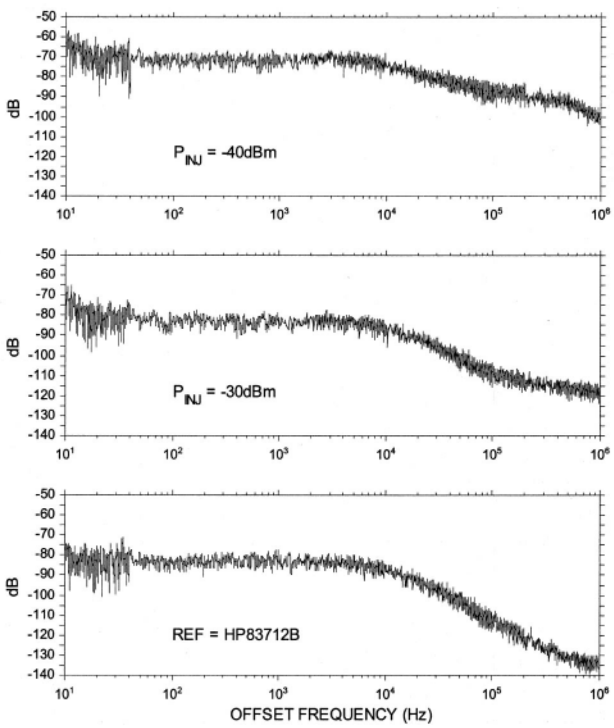

Fig. 4. Measured phase noise of the SIW oscillator for different power level of the injected locking reference compared to the phase noise of the reference.

V. CONCLUSION

In this work, we have proposed and presented a new low-cost topology for designing a high-Q feedback oscillator using an SIW cavity scheme. A 12.02-GHz prototype was constructed. Good phase noise and harmonic level have been obtained. The external quality factor of the oscillator was measured by using injection-locking technique. We believe that this oscillator will be useful in the realization of a low cost microwave and millimeter-wave systems.

ACKNOWLEDGMENT

The authors would like to thank S. Dubé of the Poly-Grames Research Center for his help in the realization of the oscillator prototype.

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