The Distributed Oscillator at 4 GHz

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Abstract **- This paper describes design and experimental verification of a tuneable oscillator based on a distributed amplifier in microwave band. The oscillator met design expectations, being capable of continuous tuning over the range 1 to 3.5 GHz with good spectral purity.**

I. Motivation.

Commercial available wideband VCO's provide us with tunability about one octave. VCO's possessing higher tunability exhibit worse spectral purity. Other kind of broadband tuneable oscillator using YIG resonator possesses very wideband tuning and good spectral purity. Unfortunately, frequency change of YIG oscillator depends on externally supplied magnetic field. An instant change of magnetic field is far from easy, as well as providing magnetic field is not easily compatible with MMIC fabrication.
That is why we decided to investigate a new oscillator arrangement. This type of oscillator is based on a distributed amplifier. A distributed amplifier is suited well for planar technology, and could result in a MMIC with affordable price.
Distributed amplifier is very broadband in nature. A way of converting a distributed amplifier into a distributed oscillator has been proposed by professor Aitchitson [1]. A distributed oscillator was predicted to be instantly tuneable by differentially biasing one pair of active devices at a time. The tuning range depends on the number of stages, and tuning ranges over one decade are attainable. We verified this idea by an experimental sample of the distributed oscillator at 100 MHz [2]. The experimental sample met expectations, working well and verifying the original idea. Measurements of the distributed oscillator have proved some advantages over other oscillators, like good spectral purity and wideband tuning. Considerable depression of (spurious) harmonic frequencies has been achieved as well as continuous tuning over a range of 1:3.

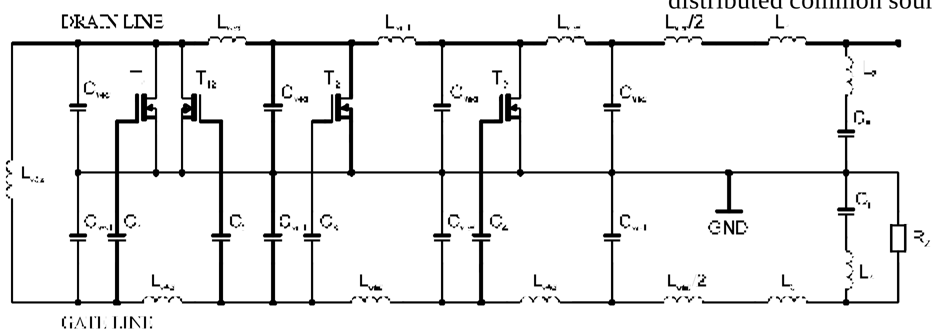

Fig. 1. An idealised schematic chart of a distributed oscillator. Transistor T_{12} overcomes tuning problems at 0.7 f_c.

Still, we have found one problem remaining: the tuning function. The tuning function is the dependence of oscillation frequency on gate bias voltages (e.g. on tranconductivity of active devices). Tuning function predicted as a result of linear circuit analysis corresponds to oscillation build-up. When oscillating, the circuit operation is far from linear and one can not define differential tranconductivity depending on gate bias voltage. Moreover, drain voltages of the active devices are affected by the oscillations, either.
Commercially available distributed amplifier is very wideband in nature. A three-stage oscillator in our arrangement has provided for a tuning band 1:3.5.
Artificial transmission lines possessing critical frequencies of up to 50 GHz are achieved in modern MMICs. That is why we decided to investigate this new kind of oscillator, both theoretically and experimentally, at a "real microwave" frequency.

II. Theoretical background of the Distributed Oscillator.

Distributed amplifier:
The microwave distributed amplifier consists of a pair of artificial transmission lines which are coupled trough distributed common source active devices (FETs). Input signal is fed into the gate line, it drives all transistors and finally vanishes in the gate load. The signals, amplified by each transistor, are of the same phase at the output of the drain line, which is the output of the device. The signals in the drain line are divided and propagate in forward and reverse modes. The forward mode signals reach the load with same phase. The reverse mode signal is distorted by anti-phase interferences and loaded by a resistor in idle drain line load.

Reverse gain loopback:
[1] brought the idea of omitting the drain line resistor while connecting the former idle drain output directly to the distributed amplifier input. This approach makes use of the so-called reverse gain to form an oscillation loop. The remaining amplifier port becomes an oscillator output now (see Fig. 1.). Each oscillator section consists of two artificial line sections, one of those connected to the drain, the other to the gate of the transistor. Provided only one of the transistor is biased in active region, the oscillation frequency depends on the

position of active transistor, respective r-th active section. The oscillation frequency can be obtained from equation

$$2 \cdot k \cdot p = (2 \cdot r - 1) \cdot \Phi(f_{osc}) + p \qquad (1)$$

where Φ is the phase shift over one artificial transmission line section, r stands for active section position and p stands for a phase shift caused by an active FET in common source arrangement.

The oscillator is capable of oscillating between two discrete frequencies belonging to single transistors if two FETs are biased in active region at the same time. The oscillation frequency is given by total phase path of oscillation loopback. The phase path is calculated as a vector sum of two phase paths per two active FETs with different position and tranconductivity. In such a manner the oscillator can be tuned for all frequencies within its tuning range, with one exception. The exception comes into effect if the phase difference between two active paths approaches π. A result of a sum of two anti-phase vectors is nearly zero resulting in oscillation loopback gain less that unity. This effect is encountered between first and second FETs at 0.7 f_C (critical frequency of artificial transmission line). The problem can be solved by an additional FET connected between the first and the second section, as depicted at Fig. 1.

The oscillation frequency can be predicted using CAD techniques as a function of active FETs positions and differential transconductivities. This tuning function depends on the type of artificial transmission line section used. The tuning function prediction provides for g_m (differential transconductivity) required from each pair of FETs. The tuning function is called here "linear" function because is derived from linear (small-signal) parameters of FET (differential tranconductivity).

III. Experimental realisation of the Distributed Oscillator at 4 GHz.

As we learned from [2] and subsequent analyses, there are several important goals that should be achieved in order to design a good distributed oscillator.

- Good match, both in drain and gate lines. The match should be better than -20 dB over the tuning range. (Otherwise parasitic oscillations occur.)
- The artificial lines should form a lowpass filter. (Otherwise the spectral purity of the output signal suffers.)
- The crucial point is in introducing the transistor between the first and second stage.
- The artificial transmission line should be composed of M-derived sections.
- Periodically loaded transmission line concept [3] was found suitable to achieve these goals.
- The design should take into account non-linearities in the circuit in order to develop a suitable tuning function.

In order to test the idea of a distributed oscillator at microwave frequencies, we have chosen a frequency of 4 GHz approx. The choice has been predetermined by the fact that this frequency is high enough for all circuit parameters to be in effect, yet low enough to allow for use of packaged devices. The design has been enabled by experience obtained in our last distributed oscillator design at 100 MHz [2] and facilitated by a number of computer simulations, both linear and non-linear.

At the design frequency lumped elements (inductors and FETs) exhibit considerable parasitic elements values, some of those bias dependent. These parasitic elements must be accounted for during design. Periodically loaded transmission lines and M-derived sections were used. As to circuit layout, the cornerstone is found in connecting the FET between the first and second stage. Proper line lengths should be maintained, while the demands imposed by first and second stages are somewhat contradictory.

IV. Realisation of the Distributed Oscillator.

The oscillator consists of 3 sections with 4 FETs. The FET is P HEMT ATF35376 that has good gain and minimal values of parasitic elements. The oscillation frequency is controlled by change of gate bias voltages. The critical frequency of the oscillator is 3.8 GHz realised as M-derived sections of periodical loaded transmission line with added capacitors. The oscillator is matched by half M-derived section realised with distributed elements. The gate bias filters are realised with high impedance on the output of the filter and composed of a resistor and shunt capacitor. The drain bias filter is realised with the same goals as LC T-network and each FET drain is biased through the artificial transmission line. This experimental sample of the oscillator has made use of planar technology with MIS capacitors where needed. The oscillator is realised on CU-CLAD substrate with ε_r = 2.33. Low dielectric constant allows for a relatively large circuit. The topology and layout could be seen at Fig. 3.

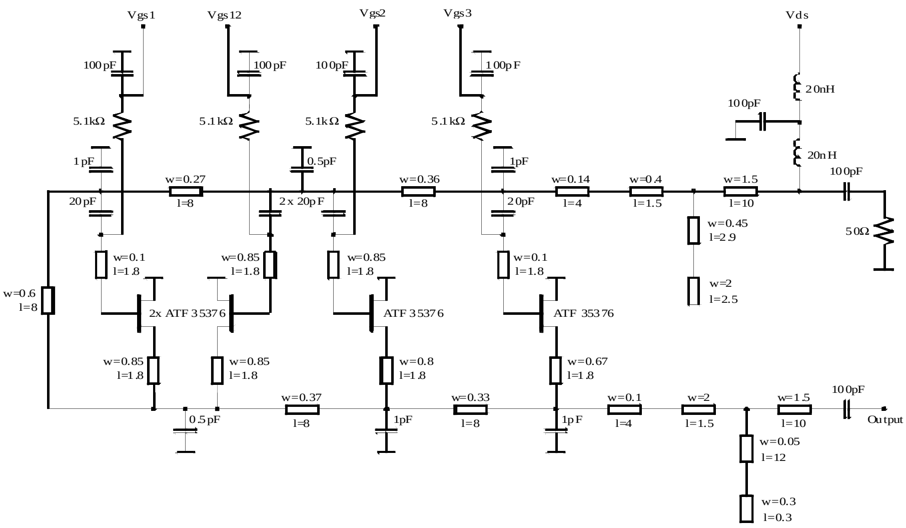

Fig. 2. Simplified schematic diagram of the oscillator.

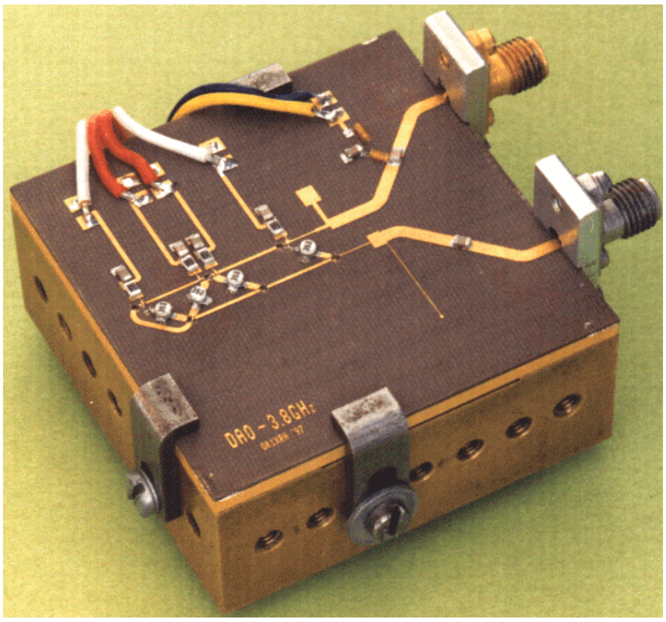

Fig. 3. Photo of real sample of the oscillator at 4 GHz. Dimensions of the board 50x50 millimeters.

V. RESULTS.

The oscillator is working well, meeting design goals. The tuning range is 1 to 3.5 GHz with output power 3 to 11 dBm. The oscillator has very good spectral purity as a narrow spectral line and very good depression of second and third harmonic frequency have been achieved (see Fig. 3). The depression of second harmonic frequency ranges from -44 dB to -18 dB. The depression of about -35 dB is achieved at frequencies over $f_c/2$ (second harmonic) or $f_c/3$ (third harmonic), where second (third) harmonic frequency is not propagated. f_c stands for the critical frequency of artificial transmission line. The third harmonic frequency is depressed from -55 dB to -17 dB. A sample of output spectrum can be seen on Fig. 4.

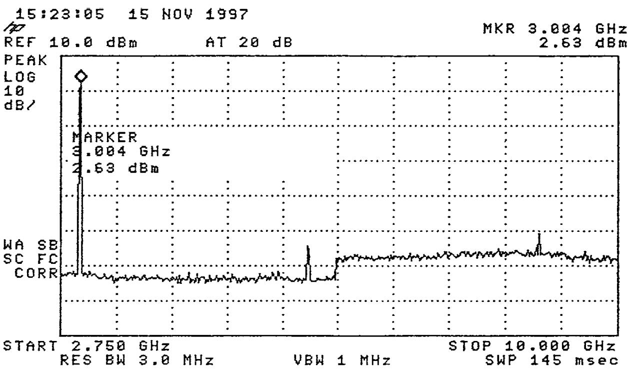

Fig. 4. An example of measured output spectrum of the oscillator depicted at Fig. 3. Gate bias voltages set for oscillation at 3 GHz.

VI. CONCLUSION

The idea of a distributed oscillator has been found viable in microwave region. The oscillator is instantly tuneable. The output signal harmonic purity is at least well comparable to other tuneable oscillator arrangements in use. The oscillator is suitable for MMIC technology.

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