NEW HIGH-PERFORMANCE VOLTAGE-CONTROLLED LC-OSCILLATOR

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ABSTRACT

VCO with serial LC-contour, loaded with low input/output impedances of a resonance loop-amplifier, provides stable frequency of oscillations, and employs very low-Q inductors on Silicon. The control voltage changes the bias in one of the amplifying sections, and indirectly the voltage over P-N junction, which acts as a Varactor. This way the separation between the control and oscillation circuits is provided effectively. On 0.8μm BiCMOS technology (17 GHz NPN) the new VCO circuit operates with 0.4mW from only 1V, and produces 600mV sinusoid on 6.6GHz with 3.6% non-linearities, and low-phase noise. Suitable for modern communication and microprocessor circuits.

INTRODUCTION

LC- and Relaxation- types Oscillators. In the LC-types of oscillators the active circuit components are kept away from non-linear regions of operations, while in relaxation-types [2], the generation of a sinusoid is a result of the inability of a pulse circuit to switch fast enough for very high frequencies. Due to operation in non-linear regions, many spectral components with high energy are present in the output signal. Thus, very 'clean' spectrum can be obtained by developing LC-types of oscillators. While for relaxation-types a capacitor only is needed, for the LC-types, in addition to the contour capacitance, an inductance with reasonably high Q-factor is required. This causes technological difficulties. The frequency control in the relaxation-type is simple. It changes only the DC-bias of certain components, affecting the relaxation R-C time-constants, and consequently the generated frequency. For LC-types, special component, a Varactor, is required. The control changes the barrier capacitance of a PN-junction by changing the applied reverse bias voltage. Unfortunately, the typical varactor's technologies are in general not compatible with the standard IC technologies, and currently the varactor has to be externally mounted. This causes matching and technology problems, and price increase.

The Inductor on Silicon Technology. The silicon technologies are preferable for the frequency range up to few GHz (NMT, GSM, GPS, DECT). The inductor when implemented on a silicon [3], has low and frequency dependent Q-factor. It is still an externally mounted component in the traditional designs where high-Q-factor inductors are needed. Thus, circuits with less critical Q-factor demands may have more chances for total integration.

The traditional LC-Oscillator Circuits. Due to historical reasons and devices characteristics, a parallel LC resonance contour is mostly used [4]. It requires a current generator to supply the energy the contour, or to implement a weakly connected (high-internal impedance) voltage generator. Also, only high input impedance amplifying stages have to be connected to buffer the output of the contour. Controversially, when high I/O impedances are required, even if the noise has low energy, they will be keeping it well "alive".

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The control method and circuit components involved. Traditionally [4], in order to provide the control voltage across the varactor, the circuits have an direct input point to one of varactor's nodes. Thus a good care has to be taken to prevent RF-energy; to not add more noise; and to keep the frequency stability. Frequently a huge (RFC) inductor is used, which makes the whole design not suitable for one-chip implementation.

THE NEW CIRCUIT

The new method and circuit presented here, are further development of our work [1], toward the usage of very low-voltage power supply. Here the amplifier stages are implemented as relatively not-narrow band LC-amplifiers, providing the general possibility for significant increase of the amplification, decrease of the voltage power supply, and also several other local advantages compared to [1]. The approach is supported by the natural low Q factor of inductors on Silicon. This way the needed frequency band for the VCO tuning is naturally ensured. The simplified circuit of the proposed here voltage-controlled LC-oscillator is shown on Fig.1. Similar idea has been used in the well known Butler's quartz oscillator [4]. Q1 is a voltage amplifier in common-base connection, loaded with the low-Q inductor L2, which can be satisfactory modelled by distributed RLC model.

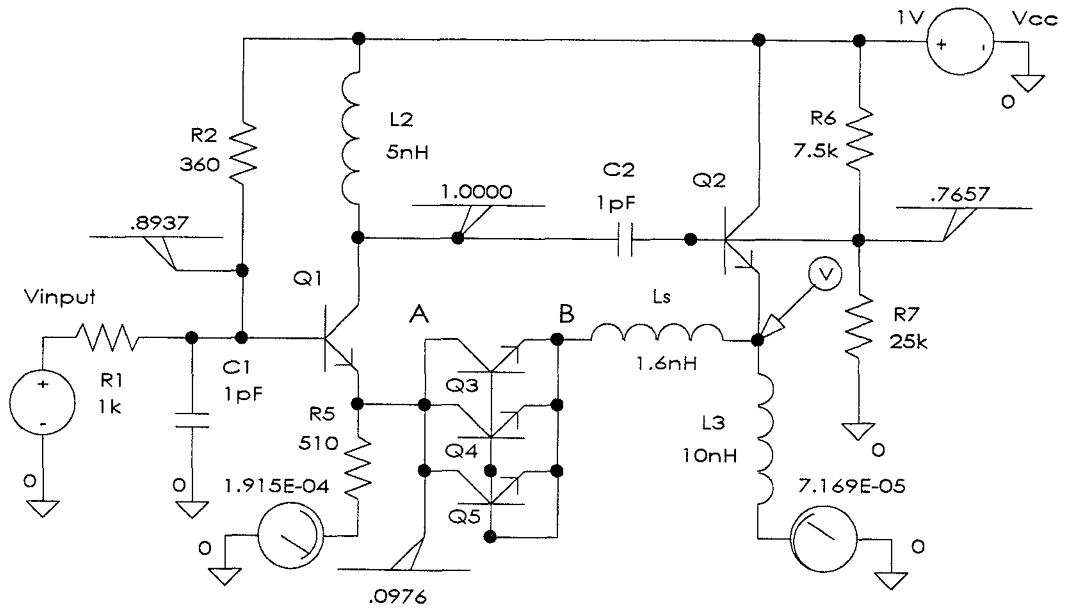

Fig. 1. The new VCO on 0.8μm BiCMOS operates with 0.4mW from only 1V, and produces 600mV sinusoid on 6.6GHz with 3.6% non-linearities.

The common-base RF-capacitor C1 here also prevents the VCO input from interfering with the RF as well. Q2 is a current amplifier in common-collector connection based again on LC-load. Both amplifying stages are practically resonance amplifiers, loaded with the parallel resonance contours, formed by the inductors L1 and L2 and the belonging parasitic capacitances, including those of the transistors as well. Q3-Q4-Q5 act as a 'varactor', using the P-N base-collector junction. Practically, several transistors can be connected in parallel, and also RF-type of capacitor added, in order to provide linearisation of the control characteristics, and also needed frequency deviation & precision. The base-emitter junction can be utilised for smaller deviation ranges and higher frequencies, providing also with the advantage of the lower serial resistance of the heavily doped emitter area. The non-symmetric output buffer stages are not shown for simplicity. All inductors are round spiral on-chip inductors with Q-factor above 3. Of main importance for the low-phase-noise is to have as high as possible Q-factor of the resonance contour inductor **Ls**. For higher frequencies, instead of Bipolar Transistors, Hybrid Bipolar Transistors (HBT), or High-Electron-Mobility Transistors (HEMT) can be used. In general, the circuit can be implemented on any type of transistors or even micro-electronic vacuum tubes.

Oscillations. The transistors Q1 and Q2 form an amplifier with positive feedback trough the serial LC-contour build by the barrier capacitance of Q3-Q4-Q5 and the inductance **Ls**. Since the serial LC contour is powered by the small output impedance [5] of the common-collector stage (Q2), and loaded with the small input impedance of the common-base stage (Q1), almost all interference from the other parts of the circuit are directed to ground throughout those small impedances. More, it is well known that those impedances have inductive character [4,5], which contributes positively to the increase of the total serial inductance.

Voltage Control. Across the base-collector junction of Q3-Q4-Q5, by the proper design of the DC-bias of Q1, is applied an inverse voltage, which is the difference of the voltages at point-**A** and point-**B**. When the input voltage changes, the current through Q1 changes, and leads to voltage changes over R5. This consequently changes the voltage difference between points A and B, which is the DC-barrier voltage across the capacitance of Q3-Q4-Q5. Finally it leads to changes of the barrier capacitance and the oscillation frequency. The circuit has been implemented on 0.8 μm BiCMOS, with transient frequency of 17 GHz for the NPN bipolar transistors.

RESULTS AND CONCLUSIONS

The spectrum of the oscillations is shown on Fig.2. The non-linear distortions in the sinusoid of 600mV amplitude are only about 3.6%, which is several times better than any relaxation-type oscillator. Here a voltage supply of 1.0V was used, but the circuit can work with voltage supply above 0.87V. The frequency control ability is about 250MHz/Volt, and it is shown on Fig.3. The power consumption is only 0.42mW, which is several times less than the results previously reported. The main conclusions below are based on comparison between the circuit proposed here, and our former circuit described in [1]. Both are implemented on the same 0.8 μm BiCMOS technology:

1. Although the minimum voltage power supply here has been cut to less than half, the output amplitude obtained is more two times higher: the amplitude obtained at the output of the new circuit is about 600 mV, while it was not exceeding 220mV for the previous one. In addition, this is achieved here by only power consumption of 0.42mW, against 2mW.

2. The transistors Q3-Q4-Q5, which serve as varactor, now work with one node practically on DC = 0V, through the inductor **Ls**. This leads to as much as nearly twice higher temperature stability of the setting of the frequency of the VCO.

3. This fact also presents the possibility to employ in much more safety way the varactor at much lower bias voltages, where, according to the non-linear nature of the C-V curve, its effectiveness is much higher. Consequently, the controlled frequency range is much broader, without any risk of reaching positive biasing of the P-N junction, and turning it into simple resistor, which would suspend the oscillations. Shortly, the new circuit is also well protected against Temperature and Technology hazards.

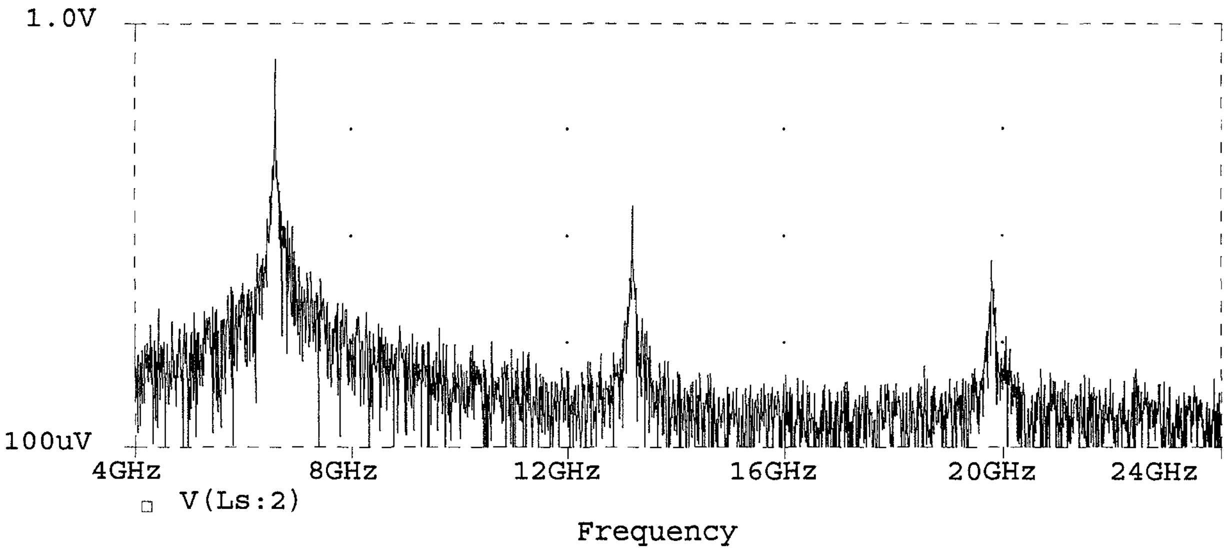

Fig. 2. The spectrum of the oscillations.

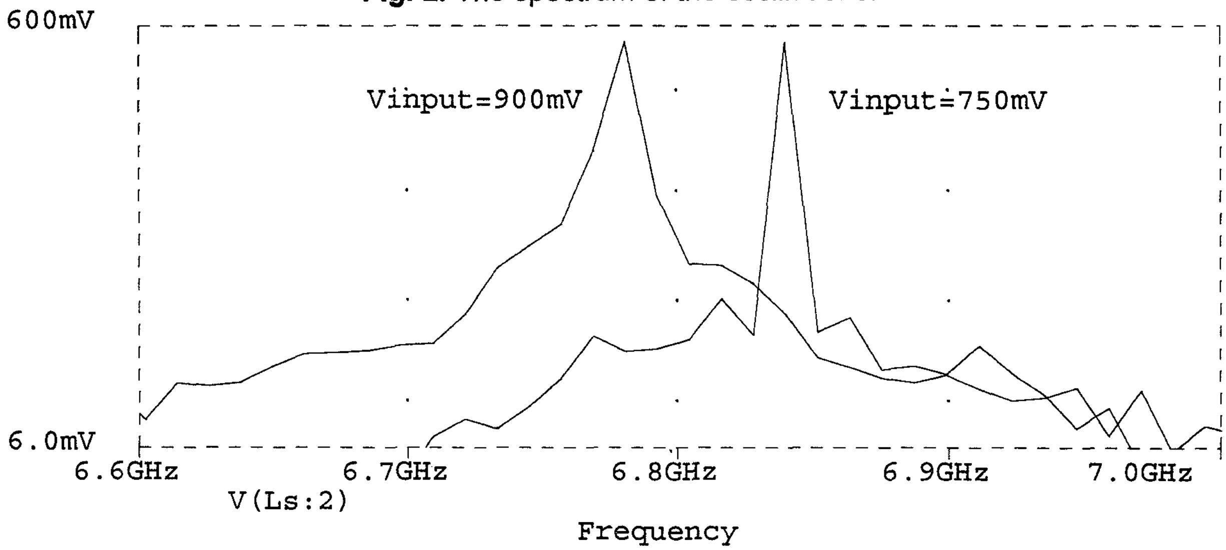

Fig. 3. VCO's frequency control.

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