Wideband Low Phase Noise Push-Push VCO

Push-push topology reduces noise compared to a conventional design

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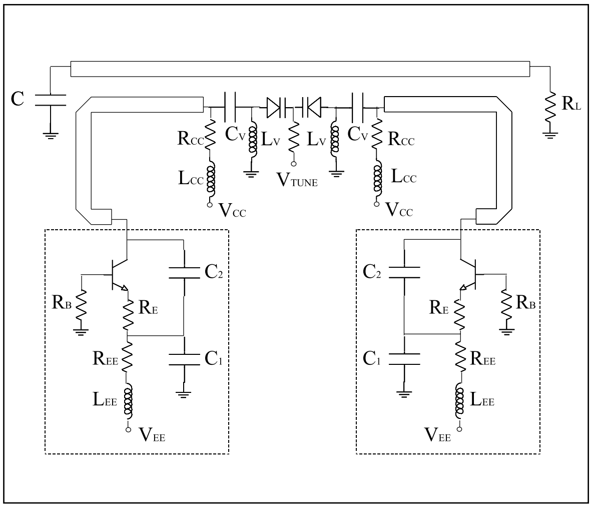
Many papers have shown the effectiveness of the push-push configuration in the reduction of oscillator phase noise and attempted to theoretically explain its behavior. This paper proposes an explanation based on the theory of phase noise in coupled oscillators and phase opposition and expects a 9 dB reduction of noise-to-carrier ratio for the push-push oscillator compared to that for the single oscillator. The simulation and experimental implementation of a wideband, low phase noise push-push VCO is also presented.

The push-push oscillator

A push-push oscillator consists of two identical oscillators that share one common resonator and oscillate 180 degrees out of phase with each other. According to existing literature, the push-push configuration can be used to realize a VCO characterized by a very wide tuning band, maintaining low phase noise levels. If we have a set of N identical oscillators and their output voltages are summed in phase, then the total carrier power is multiplied by N^2. However, the noise power increases by N if we assume that noise sources of different oscillators are independent [1]. Thus the phase noise relative to the carrier decreases by a factor of N. Theory of coupled oscillators shows that phase noise can be improved [2]. According to Chang et al., the output phase noise spectral density $S_{\Phi}(\omega)$ produced by two bilaterally coupled identical oscillators is 3 dB lower than the single oscillator. If the signals generated by two coupled oscillators in phase opposition are subtracted, the amplitude of the sinusoidal waveform generated by the push-push oscillator is doubled compared to the one generated by one single oscillator, and the output power is 6 dB higher. The noise-to-carrier ratio $L(f_m)$ for the push-push is then 9 dB lower than the single oscillator. This theoretical result agrees with the experimental results reported in [3].

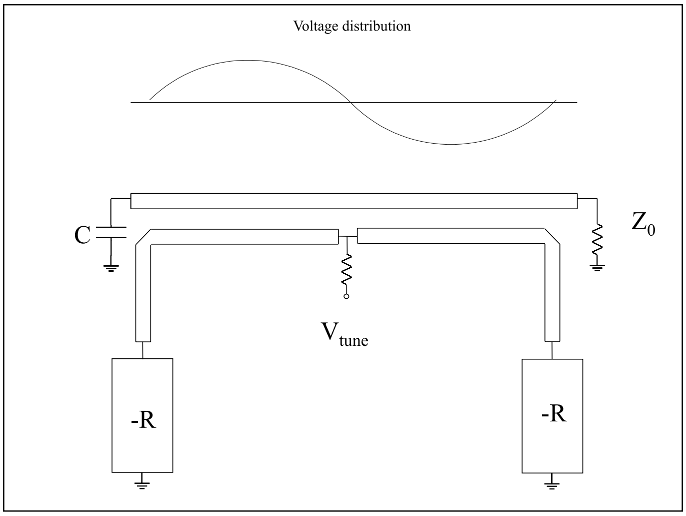


▲ **Figure 1. A bipolar push-push VCO based on a microstrip resonator is used to evaluate the performance of the push-push configuration.**

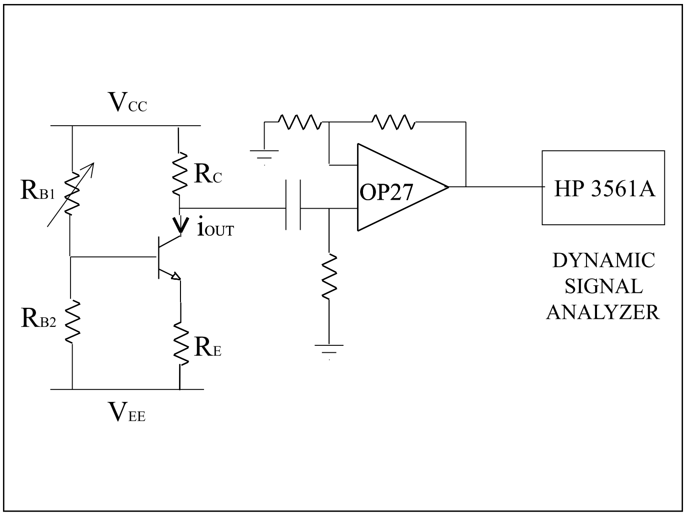
Topology

The implementation of a push-push configuration by a microstrip resonator allows us to vary the oscillation frequency over a very wide band, using a couple of varactors for tuning. To evaluate the performance of the push-push configuration, a bipolar push-push VCO based on a microstrip resonator has been designed, as shown in Figure 1.

Two identical negative resistances share the same resonator coupled to the output microstrip



▲ **Figure 1b. A low value resistor placed on the common cathode node of the varactors, where there is the symmetry plane of the VCO.**



▲ **Figure 2. The test bench for the measurement of the corner frequency of the BJT, operated at rest.**

line. The voltages in phase opposition are summed at the output by the properly loaded and dimensioned coupler.

The coupler is very important for this topology of VCO. It has been designed by placing two sources in phase opposition where the negative resistances will operate. The termination load for the best summation of voltages is not a 50 ohm resistor but a capacitor with a value that varies with the gap and the length of the coupler. The impedance of the sources is an estimate of the average value presented by the active devices. Although this procedure is not rigorous, it is useful at least for a coarse design of the coupler. Tuning of capacitance, gap and length of the coupler will allow optimization during non-linear simulation of phase noise.

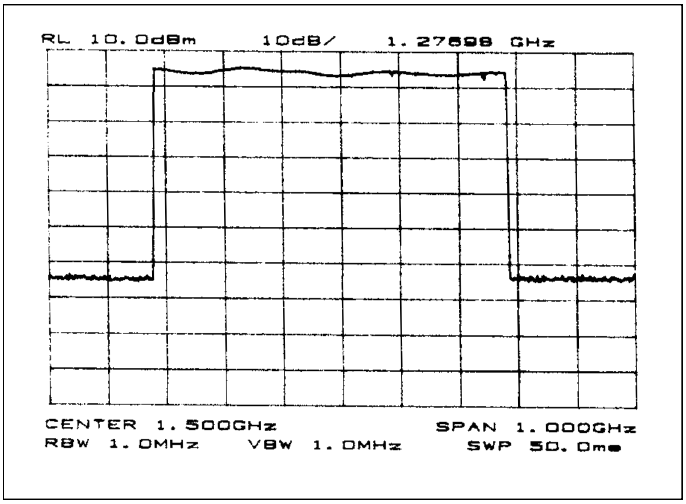
Two coupled oscillators can oscillate in the phase or antiphase mode and, in order to ensure the latter, the former can be suppressed by placing a low value resistor on the common cathode node of the varactors, where we have the symmetry plane of the VCO (Figure 1b).

Because of symmetry and phase opposition, the middle of the resonator behaves as a voltage node, and here the varactors experience the lowest RF voltage swing.

Models

The behavior of the circuit has been simulated with the software tool HP MDS. The BJT is the Avantek AT 42035. For the BJT, the nonlinear model based on the data reported in the datasheets has been used. This nonlinear model has been completed (for the noise analysis) with the A_f and k_f parameters for the BJT's flicker noise:

$$S_B(\omega) = \frac{d < i_B{}^2 >}{df} = 2qI_B + k_f \frac{I_B{}^{A_f}}{f},$$



▲ **Figure 3. The tuning band results of the measurements.**

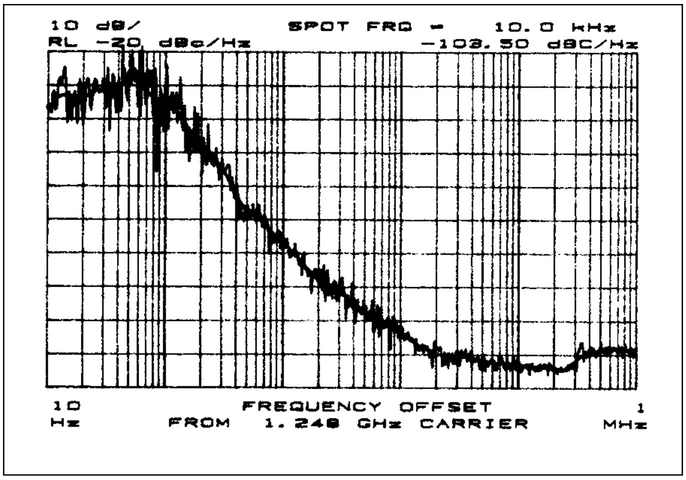
where I_B is the base current. The values for these parameters have been obtained by a measurement of the corner frequency of the BJT operated at rest. The test bench for this measurement is shown in Figure 2.

For the low noise measurement test bench, the OP27 opamp has been used with metal film resistors, ceramic capacitors and battery supply voltages [4]. Two measurements at two different collector currents allowed the solution of a nonlinear algebraic system for A_f and k_f.

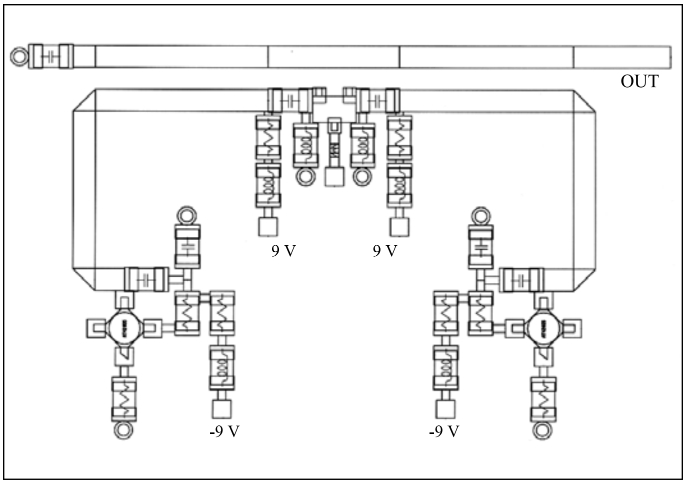
The values $A_f = 1.304$ and $k_f = 1.574.10^{-14}$ have been introduced in the model in MDS.

The varactor used is an Alpha SMV 1206-004 with junction capacitance, $C_j(V_A)$, modeled as indicated in [5], by fitting the curve reported in the datasheets; two devices are housed in SOT23 package.

Resistors (Philips), capacitors (ATC) and inductors



▲ **Figure 4. The noise-to-noise carrier ratio for VTUNE=3 V.**



▲ **Figure 5. The layout of the VCO.**

(AVX) have been described by the equivalent models suggested in the datasheets.

The simulations show that the oscillation frequency of the VCO ranges from 1.267 to 1.815 GHz, with tuning voltage from 0 to 22 V.

Careful dimensioning of negative resistance and resonator is necessary to intersect their reflection coefficients Γ_D^{-1} and Γ_R orthogonally, minimizing phase variations due to active devices for the whole voltage tuning range of varactors [6].

The results of the measurements agree with the results of the simulation. The tuning band ranges from 1.187 to 1.780 GHz (Figure 3): it is a 40 percent band around a 1.48 GHz center frequency. The output power of the VCO is between 4.4 and 5.6 dBm over the entire tuning band.

The measurement of the phase noise $L(f_m)$ has been realized by locking the oscillation frequency of the VCO with a narrow band PLL. Thus the phase noise levels measured represent the intrinsic phase noise limits of the VCO, and are not corrupted by contributions associated with the long term frequency fluctuations of the free-running VCO. The resulting phase noise level $L(f_m)$ @ f_m = 10 kHz is lower than –103 dBc/Hz over the entire tuning band. The noise-to-carrier ratio $L(f_m)$ for V_{TUNE} = 3 V is shown in Figure 4. The layout of this VCO is shown in Figure 5.

Conclusion

A theoretical explanation for the behavior of a push-push oscillator has been proposed. The good phase noise performance of this configuration has been experimentally proved by realizing a wideband push-push VCO (600 MHz tuning band around a 1.5 GHz center frequency) with less than –103 dBc/Hz over the entire tuning band.

More detailed simulations may be performed with low noise dynamic measurements of the devices becuase there are big differences in flicker noise distribution compared to static conditions. ■

References

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