25 - 42 GHz GaAs HETEROJUNCTION BIPOLAR TRANSISTOR LOW PHASE NOISE PUSH - PUSH VCOs

D. M. Smith, J. C. Canyon, D. L. Tait

TRW Inc.
Electronic Systems Group
1 Space Park, Redondo Beach, CA 90278

ABSTRACT

Two Push-push thin-film VCOs utilizing GaAs/AlGaAs Heterojunction Bipolar Transistors (HBT) that cover the 25 - 42 GHz frequency range are presented. Key features of the designs are: Greater than 33% continuous tuning bandwidth, SSB phase noise less than -70 dBc/Hz at 100 kHz offset, and better than -90 dBc fundamental spur suppression.

INTRODUCTION

Heterojunction Bipolar Transistors are in the process of revolutionizing EHF system performance. The HBT's inherently high Fmax (>50 GHz), linearity, and efficiency make it superior to FETs for low phase noise, high power applications. Capitalizing on this performance, two Push-Push voltage controlled oscillators were built and tested. The first operates between 25 and 31 GHz and the second operates between 32 and 42 GHz.

These wide tuning low phase noise EHF VCOs will have a significant impact on the size, weight, and performance of future wideband communication systems. The ability to generate low phase noise signals at EHF will eliminate the need for post multiplication, filtering, and amplification of lower frequency VCOs. This article will report on the hardware designed, important aspects of push-push oscillator design, techniques used to measure phase noise, and performance of the oscillators constructed.

CIRCUIT DESIGN

The oscillators designed are series resonant push-push VCOs. A push-push oscillator is a frequency doubling oscillator employing two transistors, each oscillating at one-half the desired output frequency. The transistors oscillate out of phase with each other, causing the fundamental frequency to cancel out and the second harmonic to add in phase. Push-push designs have several major advantages over other oscillator topologies. Designing at one-half the output frequency increases the resonator Q, decreases the parasitics that are encountered, and extends the useful frequency range of the transistors.

The oscillators were fabricated in microstrip on 0.37 mm fused silica. GaAs/AlGaAs HBTs with a 3 µm emitter and self-aligned base metal were used as the active devices. These have been fully described in an article presented by Michael Kim at the 1988 GaAs IC Symposium (1). Each HBT was biased with a single current source on its emitter, both the base and the collector were DC grounded. Bias line isolation was achieved with a single quarter wave structure designed to present a high impedance at both the fundamental and the harmonic. Electrical tuning of the oscillator was implemented using GaAs abrupt varactors $C_j(0) = 0.5pF$.

Our experiments have shown that a poor mismatch at either the fundamental or second harmonic frequency can cause up to a 5 dB variation in phase noise, and discontinuous tuning. This necessitated the design of a diplexer to properly terminate both the fundamental and the second harmonic output. The diplexer is a combination of a low pass filter for the fundamental / tuning port, and a band pass filter for the harmonic port. The band pass filter is an 8 section series/shunt quarter wave resonator filter. The shunt elements were realized with wrap-around ground ribbons, and fine tuning was done by varying the width of the substrate. The low pass filter is a generic distributed series L shunt C type, terminated in an AC coupled 50 ohm load at the varactor tuning port. Tuning port isolation is achieved with a series air core inductor. The entire circuit was assembled in a single housing that included all DC bias and RF circuitry, see figure 1.

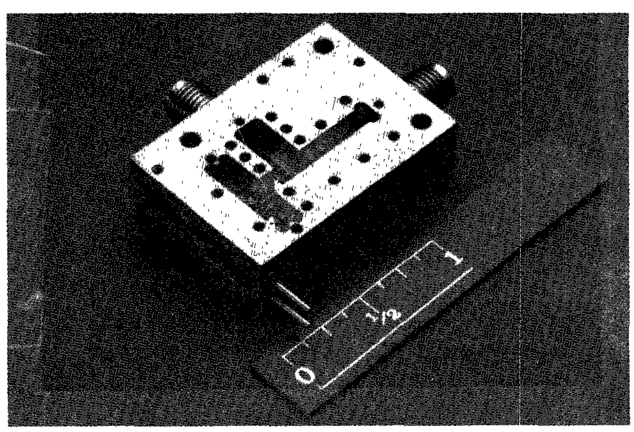

Figure 1. Assembled HBT Push-Push VCO

CONDITIONS FOR STABLE OSCILLATION

Push - push oscillator operation requires that the transistors oscillate in only the odd mode (+ -). This condition can be assured by proper choice of the terminating impedance, and adjustment of the transistor gain at the fundamental. A lumped element schematic of a push - push VCO is shown in figure 2a. In the odd mode of operation the center point 'A' becomes a virtual ground, so the circuit can be redrawn as in figure 2b. In this circuit each transistor is represented as a series combination of negative resistance and its input capacitive reactance. Losses in the microstrip and the varactor are represented as a small resistance Rs. For this circuit to start oscillating the negative resistance of the transistor must be greater than the positive losses in the tuning elements.

$$|-Rq| > Rs \qquad (1)$$

The frequency of oscillation is determined from finding the frequency at which the negative reactance of the transistor summed with the positive reactance of the resonator equal zero.

$$-Xq + (Xl - Xv) = 0 \qquad (2)$$

In order to eliminate the possibility of oscillating in the even mode (+ +) a further restriction must be placed on the negative resistance of the transistor. Again consider the circuit in figure 2a. The load resistance can be redrawn as the parallel combination of two resistors,

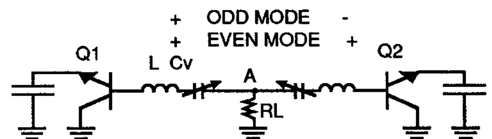

Figure 2a: Lumped Element Push - Push VCO Schematic

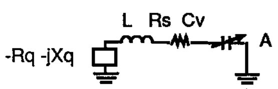

Figure 2b: Odd Mode Simplified Circuit

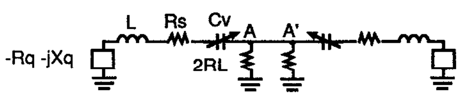

Figure 2c: Push - push equivalent circuit

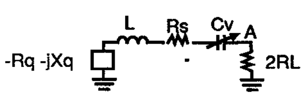

Figure 2d: Even Mode Simplified Circuit

figure 2c. Because the transistors are in phase at the fundamental the current between the center points ' A ' and ' A' ' is zero, and the circuit may be split into two independent halves, figure 2d. The condition for this circuit not to oscillate is that the negative resistance of the transistor must be less than the positive losses in the circuit.

$$|-Rq| < Rs + 2Rl \qquad (3)$$

Summarizing equations 1 and 3 yield the total conditions on the transistors negative resistance to maintain proper series resonant push-push operation.

$$Rs < |-Rq| < Rs + 2Rl \qquad (4)$$

In practice these limits are usually easily met. The losses, Rs, are usually on the order of 2 ohms, and twice the load resistance is 100 ohms. If the transistor has greater than 100 ohms of negative resistance matching can be used to increase the load resistance at the fundamental, or the emitter capacitance can be increased to reduce the transistors gain.

PHASE NOISE MEASUREMENT

Two phase noise measurement techniques exist for measuring free running VCOs that are impossible to phase lock with narrow loop bandwidths; a direct spectrum, and a delay line discriminator. We use the delay line discriminator measurement system (2 - 3) because it has several advantages over a direct spectrum measurement. Namely it has a very low broadband noise floor, and its sensitivity matches the noise characteristics of a free running VCO. A common difficulty with EHF phase noise measurements is that a

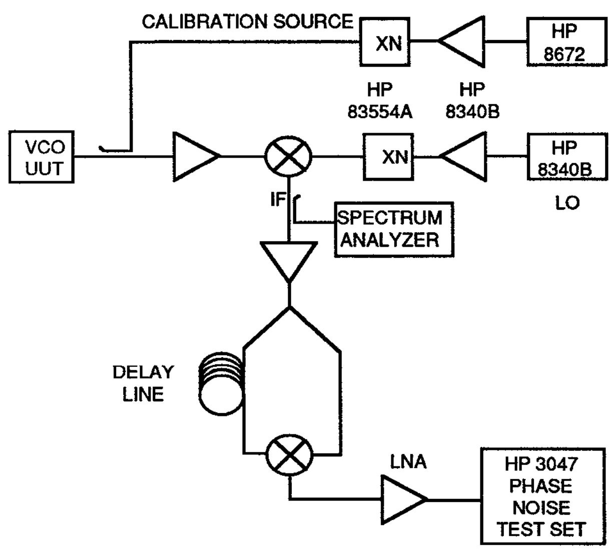

FIGURE 3: Phase Noise Test Set

delay line is difficult to realize in waveguide. To avoid using a waveguide delay line the output of the VCO was down converted to a low frequency IF and then measured. A diagram of our phase noise test set is shown in figure 3.

The LO source is an HP multiplied synthesizer with a single side band phase noise of less than -100 dBc/Hz at 100 KHz offset. This is 20 dB better than the oscillators measured, therefore the downconversion has negligible effect on the phase noise of the IF. To calibrate the delay line system we injection lock the VCO to a second HP synthesizer that was FM modulated (4). Precaution must be exercised in choosing the proper delay line length for use in the delay line discriminator test set. The length of the delay line sets the measurement system sensitivity. Too long a delay line causes the baseband noise to saturate the LNA, and too short a line will cause the system noise floor to interfere with the measurement. Results from the delay line measurement were confirmed with a direct spectrum measurement of the IF signal.

OSCILLATOR PERFORMANCE

Two push - push oscillators were produced that cover the 25 to 42 GHz range. The first was a low band version that tuned from 25 to 31.3 GHz with a tuning voltage less than 16 volts. This oscillator used 3X60 μm HBTs and produced as much as -10 dBm output power using only 9 mW of DC power. The single side band phase noise of the oscillator was -75 dBC/Hz at 100 kHz offset. The phase noise performance, tuning curve, and output power are shown in figure 4. Fundamental suppression was measured to be greater than -20 dB across the band. It is important to carefully match the active and passive components on each side of the oscillator because it has been suggested that a better match will improve phase noise (5). Our experiments have shown that HBTs balance better than Si bipolar devices in similar oscillator circuits.

A second oscillator tunable form 33 to 42.3 GHz was constructed with 3x10 μm HBT devices. Output power, phase noise, and tuning voltage were measured v.s. frequency and is presented in figure 5. The smaller device predictably produced a lower output power. The phase noise also suffered with respect to the first, because it was designed for a broader tuning range and a higher operating frequency. When the oscillator was integrated with a diplexer the fundamental present at the output port was lower than -90 dBc across the band. The tuning port was measured to have a 3 dB modulation bandwidth of 450 MHz driven from a 50 ohm source.

CONCLUSION

This work demonstrates the feasibility of low phase noise EHF HBT VCOs with wide tuning range. Using a push - push oscillator design over 10 GHz of tunability has been achieved. This wide tuning range in a single oscillator will make significant size, weight, and power improvements in wideband communication systems. These VCOs represent the first EHF VCO designs attempted, and we feel further improvement in the circuit designs yield better performance.

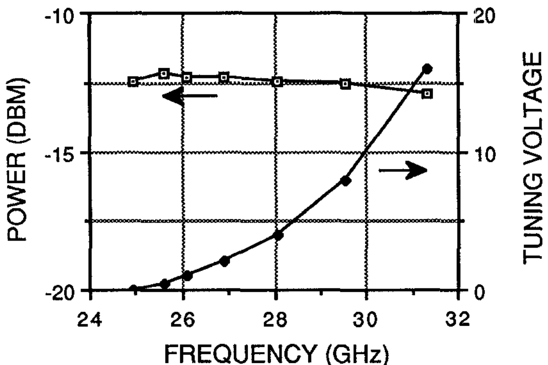

Figure 4a: Tuning and Output Power of Low Band VCO

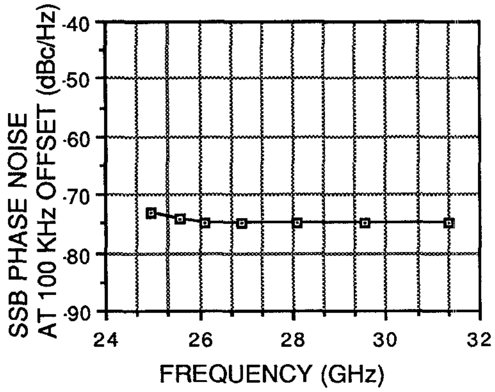

Figure 4b: Phase Noise of Low Band VCO at 100kHz Offset

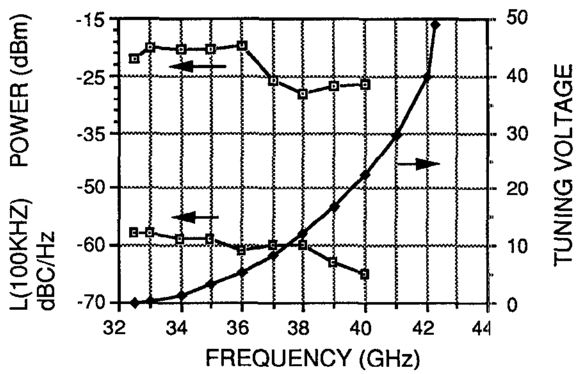

Figure 5: EHF HBT Push - Push VCO Power, Phase Noise, and Tuning Voltage vs. Frequency

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of M. E. Kim, A. K. Oki and all the members of MMTC for the design and manufacture of the HBTs used in these designs.

REFERENCES

(1) M. E. Kim, A. K. Oki, J. B. Camou, P. D. Chow, B. L. Nelson, D. M. Smith, J. C. Canyon, C. C. Yang, R. Dixit, and B. R. Allen, "12-40 GHz Low Harmonic Distortion And Phase Noise Performance Of GaAs Heterojunction Bipolar Transistors," IEEE GaAs IC Symp. Tech. Dig., pp. 117-120, 1988.

(2) Hewlett Packard, "Phase Noise Characterization of Microwave Oscillators," Product Note 11729C-2, September 1985.

(3) T. Decker, B. Temple, "Choosing A Phase Noise Measurement Technique," HP RF & Microwave Measurement Symposium.

(4) A. L. Lance, W. D. Seal, F. G. Mendosa, and N. W. Hudson, "Automating Phase Noise Measurements In The Frequency Domain," Proceedings of the 31st Annual Symposium on Frequency Control, June 1977.

(5) D. A. Boyd, "Low Phase Noise X/Ku-Band VCO," IEEE MTT-S Digest, pp. 587-590, 1987.