Q-11

LOW PHASE NOISE X/Ku-BAND VCO

DAVID A. BOYD

EATON CORP. MICROWAVE PRODUCTS DIVISION

ABSTRACT

A balanced, thin-film VCO utilizing silicon bipolar transistors and hyper-abrupt varactor diodes has yielded 40% tuning bandwidth while demonstrating excellent frequency stability. Key features of this design are: High RF output power, linear tuning characteristics, excellent sub-harmonic rejection, and low single sideband phase noise. At an operating frequency of 11.5 GHz, single sideband phase noise of -104 dBc/Hz at 100 KHz offset has been obtained. An X-band VCO subsystem designed for missile LO applications utilizing the developed oscillator is also presented.

INTRODUCTION

Requirements for VCO subsystems exhibiting good spectral purity and frequency agility are increasing. Advances in device and circuit processsing has significantly improved the performance characteristics of VCOs utilizing MIC technology. A unique design approach utilizing matched devices has resulted in VCO phase noise approaching that of YIG-tuned oscillators. A balanced, thin-film VCO utilizing silicon bipolar transistors and hyper-abrupt varactor diodes has been developed for X and Ku-band operation. The balanced or push-push VCO topology illustrated in Figure 1, utilizes distributed transmission line circuit elements. Biasing networks are incorporated to ensure accurate Q-point adjustment, and to reduce any deleterious effects on the performance due to uneven RF balance of the circuit.

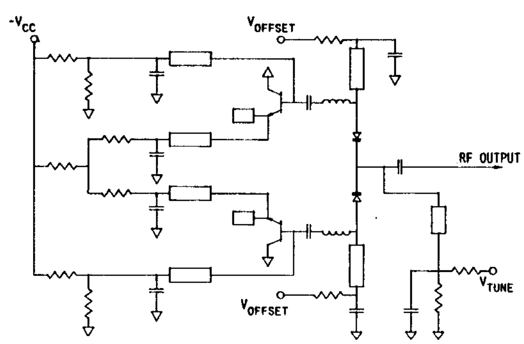
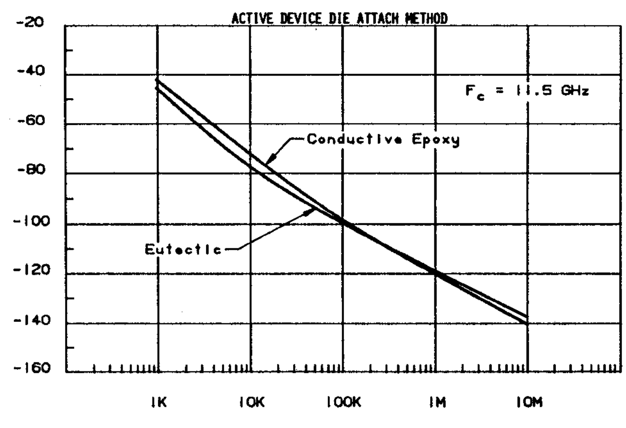


FIGURE 1

Analyzing the small signal S-parameters of the balanced VCO indicate that the magnitude of S22 is higher for the second harmonic than the fundamental. This characteristic, results in second and even harmonic emphasis, and fundamental and odd harmonic suppression. In practice, the 1/2f harmonic is generally suppressed 10-15 dB below the output. Balanced designs can extend the frequency range of bipolar transistor VCOs well into Ku-band. The most significant advantage of this approach (over FET devices) is lower noise performance inherent to silicon bipolar devices.

Utilization of matched devices results in improved RF current balance, and further minimizes the 1/2f harmonic content. In addition, this limits presaturation of the active devices (resulting from high 1/2f harmonic content) and minimizes the total power dissipation of the device. To ensure low thermal resistance, eutectic die attachment is required. Figure 2-a, illustrates the improvement in SSB phase noise due to device attachment. Careful selection of the varactor diode and utilizing a matched diode pair further improves the noise



Single Sideband Phase Noise [dBc/Hz] vs Offset Frequency [Hz]
FIGURE 2-A

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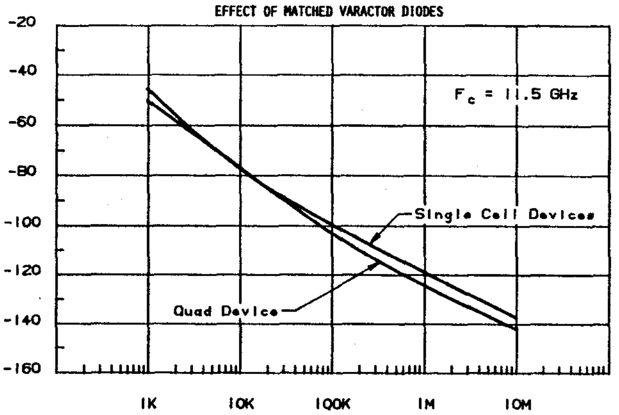
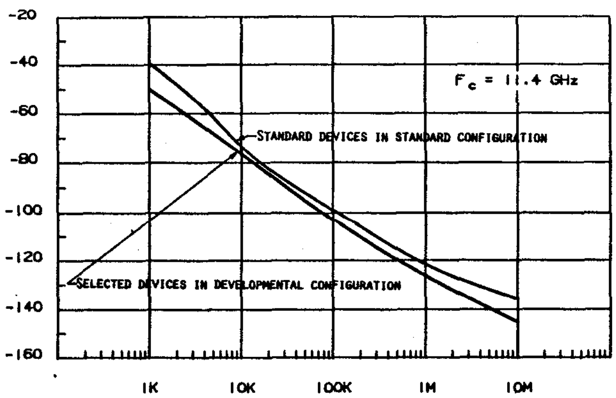
performance over standard devices. These diodes should be screened for minimum leakage current to provide optimum noise performance. Figure 2-b, depicts the improvement in SSB phase noise comparing standard Si-hyper-abrupt diodes and matched diodes (ultra-low leakage current) in a quad configuration.



Single Sideband Phase Noise [dBc/Hz] vs Offset Frequency [Hz]

FIGURE 2-B

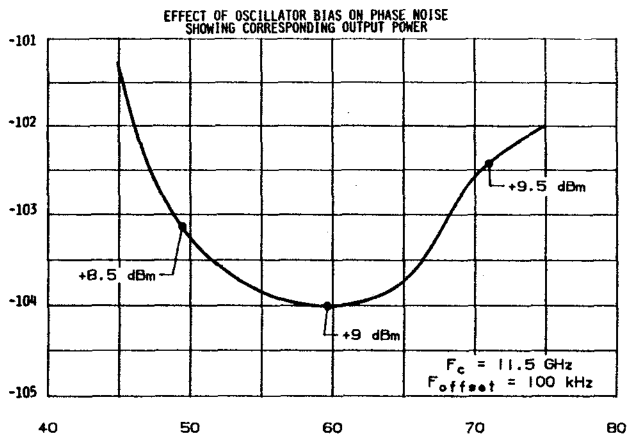
Incorporation of carefully selected active devices and varactor diodes in a matched configuration significantly improves the SSB phase noise over standard devices. Comparison between balanced VCO circuits employing standard and matched active devices indicate approximately 3 dB improvement in phase noise at 1 MHz offset, and better than 10 dB improvement for offsets of 1 KHz. Figure 3 illustrates the measured improvement at 11.4 GHz.



Single Sideband Phase Noise [dBc/Hz] vs Offset Frequency [Hz]

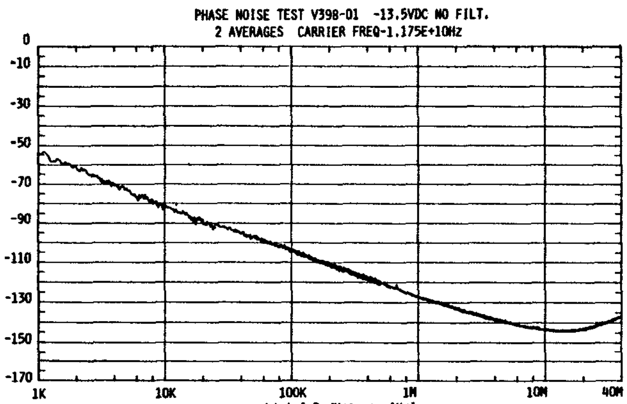
FIGURE 3

DC bias condition also determines the optimum noise performance of the VCO. Comparison of the DC power, RF output power (fundamental output) and the resulting SSB phase noise indicates a reduction in phase noise as RF output power is increased (up to a point where device saturation occurs). The balance VCO has optimum SSB phase noise between 50 and 70 percent of Ic(max), or 30 to 50 percent of Pd(max). Figure 4-a, illustrates the effect of oscillator bias on SSB phase noise. The resulting SSB phase noise for an X-band VCO operating at 11.75 GHz incorporating matched devices, eutectic die attachment and optimum DC bias, is presented in Figure 4-b.



Single Sideband Phase Noise [dBc/Hz] vs Bias [% $I_{c\ max}$]

FIGURE 4-A



L(F) [DBC/HZ] VS F[HZ]

FIGURE 4-B

DESIGN CONSIDERATIONS

To provide low phase noise and broad tuning bandwidth, several design factors must be considered. These include the additive noise effects of voltage regulators and buffer amplifiers, as well as the intrinsic noise characteristics of the oscillator circuit. In summary, the design should incorporate:

- Low 1/f devices
- Low noise figure buffer amplifiers
- Highly stable voltage regulators
- Minimization of AM to PM conversion and additive noise of the buffer amplifiers

ACTIVE DEVICE SELECTION

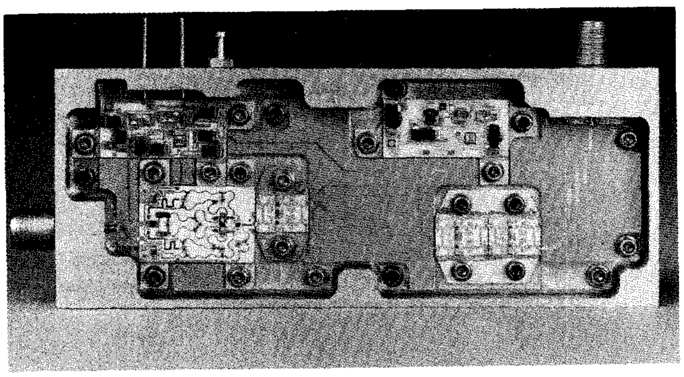
The selection of active devices for low phase noise generally requires the device to exhibit high f(max) characteristics to ensure good RF efficiency. In addition, the device must have reasonable junction areas to provide high RF output power, and have low thermal resistance to minimize thermal instability. These constraints are generally not mutually conducive for device manufacturing. Higher f(max) devices generally have small junction geometries, and large junction geometries usually have low f(max). A silicon BJT was selected to provide a good trade-off between the following:

- Low noise figure
- Low 1/f characteristics
- Low thermal resistance
- High RF signal level
- Use matched pair devices

The selection of varactor diodes is based on similar criteria with the following additional requirements:

- Highest possible Q
- Low leakage current
- Metalization to support eutectic attachment

APPLICATION: VCO SUBSYSTEM FOR MISSILE LO APPLICATION



A VCO Subsystem was designed specifically to provide low phase noise and spectral stability while operating in the adverse environment required for missile applications. The basic block diagram for this VCO subsystem is presented in Figure 5.

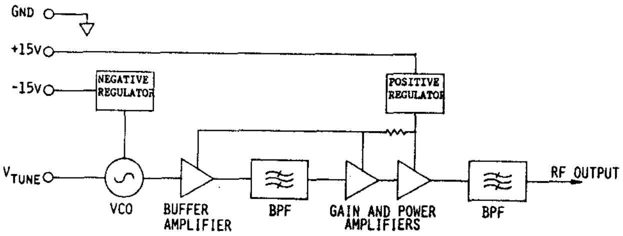


FIGURE 5

This design approach minimizes the intrinsic oscillator phase noise overall, and reduces the additive noise contribution of the buffer amplifiers.

PERFORMANCE RESULTS

The VCO Subsystem was designed to provide approximately 10% tuning bandwidth at upper X-band from 11.0 to 12.0 GHz. In addition to the frequency stability, the VCO must be modulated at frequencies greater than 20 MHz. The VCO must operate under high vibration levels (greater than 20 GRMS) with no apparent degradation due to mechanically induced instabilities. Phase noise performance and spectral purity are illustrated in Figure 6. The following summarizes the performance:

Frequency Tuning:	10.85 to 13.5 GHz (limited to 11 to 12 GHz by filter and input control)
RF Output:	19.8 to 20.8 dBm
Linearity:	1.42:1 Full Band Mod Sense Ratio
Mod. Bandwidth:	Greater than 20 MHz
Spurious:	Less than -30 dBc (harmonics) Less than -60 dBc (non-harmonic)
Temperature:	Frequency Stablility less than 50 ppm/'C (-54'C to +85'C)

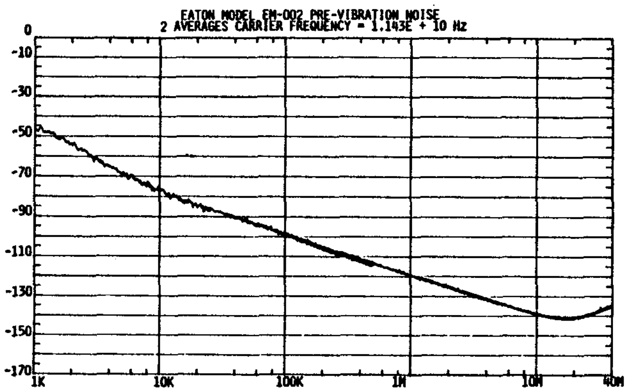


FIGURE 6-A

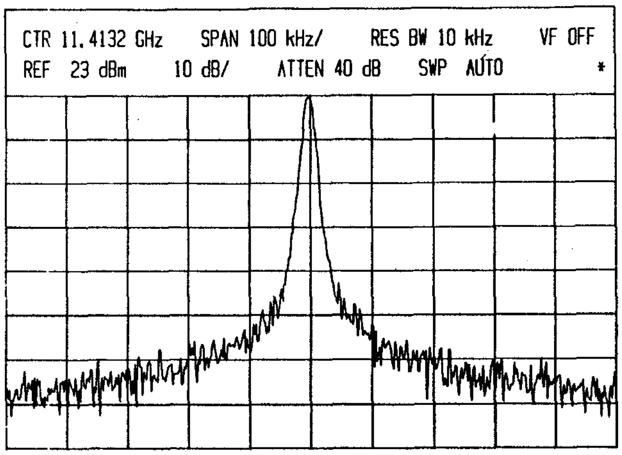


FIGURE 6-B

There is no apparent degradation in performance during the operational vibration profile depicted in Figure 7. The design approach ensures that sensitivities to microphonics, and other mechanical instabilities are greatly reduced.

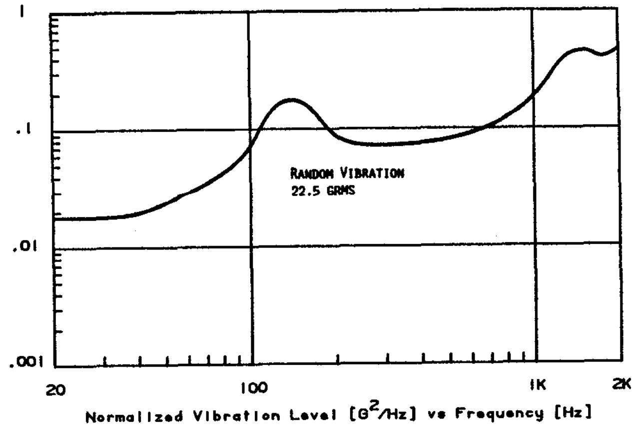


FIGURE 7

Figure 8, compares the SSB phase noise of the VCO Subsystem at rest and during vibration.

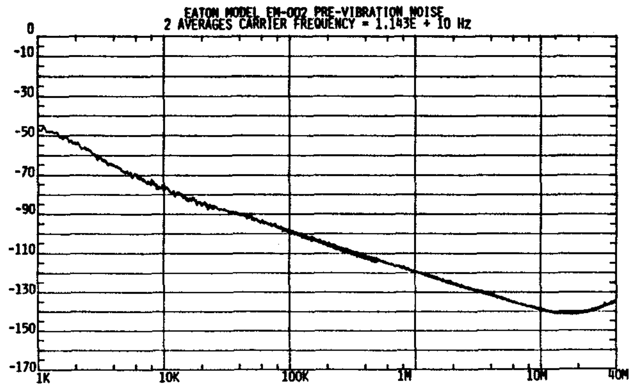


FIGURE 8-A

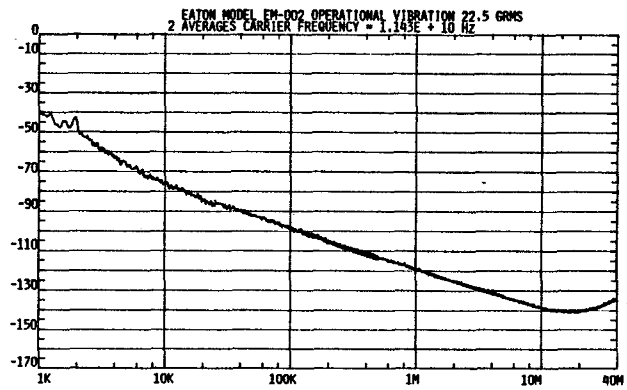


FIGURE 8-B

CONCLUSION

The presented X-band low phase noise VCO provides stable open loop performance which is comparable with YIG oscillators demonstrating broad tuning characteristics. The VCO provides wide tuning bandwidth with fast tuning characteristics and low noise performance. Further improvement in the frequency stability can be obtained by incorporating PLL techniques. Other stabilization methods such as dielectric resonators, and feedback networks can be used to maximize the loaded Q (this of course will reduce the frequency tuning range significantly).

ACKNOWLEGEMENTS

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