Frequency Locking a Microwave Source

The frequency locked loop method provides a spectrally clean source which can be frequency modulated. Unlike the phase locked loop, it does not require a reference signal.

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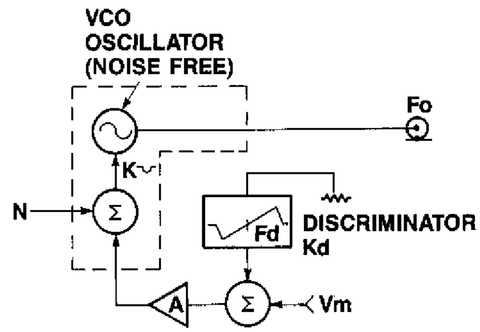
The frequency locked loop has properties which make employment particularly attractive for applications requiring a spectrally clean source, capable of linear frequency modulation. Unlike the phase locked loop, the frequency locked loop does not require the generation of a reference signal.

This paper shows the improvement obtained in the FM noise properties of a low 'Q" voltage controlled Gunn oscillator after it was frequency locked to a dielectric resonator cavity using a discriminator and an operational amplifier to form a a feedback loop. The FM spectrum around the oscillator frequency is improved via the effective 'Q' of the discriminator and can be predicted using the noise model developed by Kurokawa [1].

The work was conducted to demonstrate the frequency locked technique for application within a low cost Doppler module where controlled, linear frequency modulation and a spectrally clean signal were required.

The Frequency Locked Loop Block Diagram

The block diagram in Figure 1 depicts the configuration and components required to implement the



N IS THE EQUIVALENT VOLTAGE WHICH RESULTS IN THE NOISE POWER SPECTRAL DENSITY OF THE OSCILLATOR

Vm IS THE MODULATING VOLTAGE AND MAY ALSO REPRESENT THE EQUIVALENT NOISE OF THE AMPLIFIER AND DISCRIMINATOR

Figure 1. Frequency locked loop block diagram

frequency locked loop. The output of a voltage controlled oscillator is coupled to the input of a frequency discriminator whose output in turn is amplified by the loop amplifier and applied to the oscillator frequency voltage control terminal

The closed loop equation describing the output frequency (derived in the appendix) is:

$$Fo = Fd + Fe/(1+AKvKd) + AKd$$

where:

Fo is the output frequency,
Fv is the free running frequency of the VCO,
Fd is the discriminator center frequency,
Fe is the frequency difference (Fv-Fd),
A is the voltage gain of the amplifier,
Kv is the VCO gain constant (Mhz/volt),
Kd is the discriminator gain constant (volt/Mhz),
N is the FM noise of the VCO, and,
Vm is an externally applied modulation signal or the the equivalent noise of the amplifier and discriminator diodes.

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The equation does not directly account for frequency variations associated with finite video bandwidth of the various components, however this should not pose a problem since the amplifier bandwidth is generally shaped in accordance with specific closed loop requirements for loop stability, noise improvement and modulation capability.

The factor (1+AKvKd), termed the open loop gain Ao, is much larger than unity within the loop bandwidth and if that substitution is made, the output frequency may be approximated by:

$$Fo = Fd + Fe/Ao + Vm/Kd + N/Ao.$$

The significant features of the frequency locked loop are evident from the terms of this equation.

First, the output frequency is equal to the discriminator center frequency plus the error term (Fv-Fd) reduced by the open loop gain factor.

the output signal FM noise . . . is reduced by the open loop gain

Second, the output frequency may be varied with the applied voltage, Vm, and in accordance with the inverse of the discriminator gain constant, thereby allowing frequency modulation with linearity determined exclusively by the discriminator.

Third, the output signal FM noise spectrum is reduced by the open loop gain factor.

These features were explored experimentally using available X-band components, but the method should be applicable at any center frequency for which components are available.

The Brassboard Model

A brassboard model was constructed to test the performance of the frequency locked loop using a coaxial Gunn VCO, a dielectric resonator frequency discriminator, and an integrated circuit loop amplifier. Figure 2. is a schematic diagram for the Gunn oscillator employing a quarter wavelength coaxial resonator with capacitive probe output and varactor diode coupling for frequency variability.

The simple form of the Gunn oscillator together with its small volume requirement and the ease with which varactor and output power coupling can be effected are offset by the circuit's low Q. This causes poor frequency stability and noise spectral performance. However, these poor attributes are exactly those for which the frequency control loop is valuable.

A suitable frequency discriminator is illustrated in the diagram of Figure 3. A balanced mixer is used in conjunction with a dielectric resonator. The phase versus frequency characteristic produced by

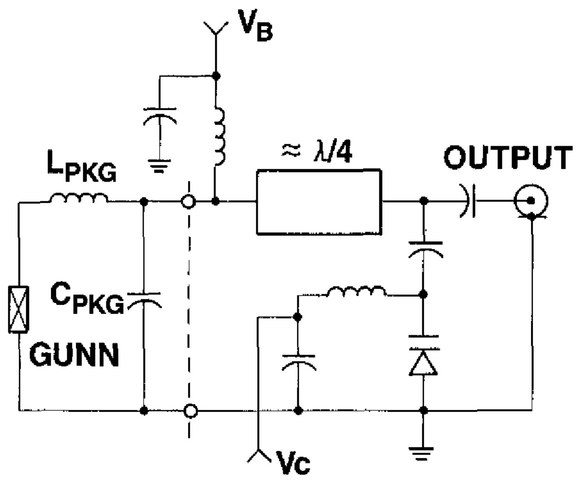

Figure 2. Schematic of the low Q Gunn oscillator with varactor tuning.

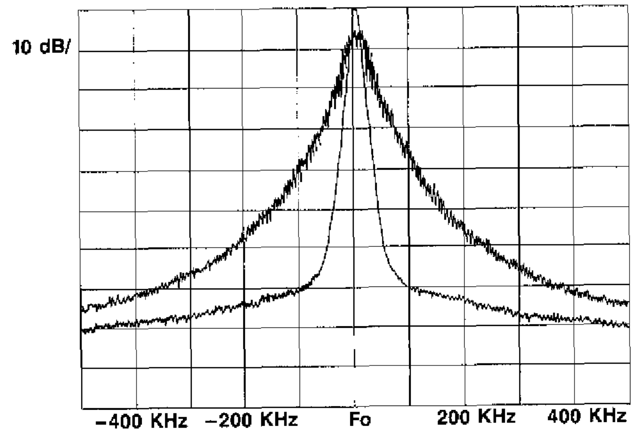

Figure 4. Oscillator noise spectral density under open and closed loop conditions. The center frequency was 9.6 GHz, residual bandwidth 10 KHz and the viewing bandwidth 100 Hz.

the dielectric resonator transmission cavity is applied to one arm of the mixer to create a voltage at the mixer output that is proportional to the input frequency. This results in a discriminator characteristic with a gain of 100 mV/Mhz around the discriminator center frequency.

At 100 Khz off carrier, . . . the improvement in noise spectral density is 32 dB

The loop amplifier was realized using an integrated circuit low noise operational amplifier (OP37). Special consideration should be given to the selection of the loop amplifier, since the limits of the spectral noise improvement are determined by the amplifier, the detector diodes within the discriminator, and the available output signal level from the discriminator.

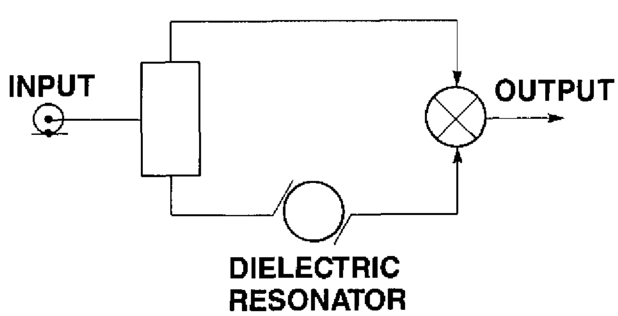

Figure 3. Block diagram of the balanced mixer frequency discriminator.

The measured open and closed loop spectra for the oscillator are shown in Figure 4. Note in particular, the significant improvement in the noise spectral density under closed loop conditions. At 100 Khz off carrier, for example, the improvement in noise spectral density is 32 dB; and at 500 Khz, 6 dB. The improvement at 500 Khz offset is believed to be somewhat better than 6 dB, however, the spectrum analyzer noise limited the sensitivity of the measurement.

In order to determine the FM capability of the frequency locked loop, a sinusoidal voltage at 50 Khz was introduced at the summing junction of the operational amplifier and the spectrum observed for various indices of modulation; the residual AM modulation was also measured using the test equipment configuration of Figure 5. The residual AM was surprisingly low and remained at a fixed level below the FM sidebands, as the data below demonstrates:

FM to AM CONVERSION

FM Sideband Level (DBC)	AM Sideband Level (DBC)
-10	-82
-20	-93
-30	-102

The symmetry of the FM sidebands (Figure 6.) attests to both the modulation linearity and the low residual AM performance of the loop locked oscillator.

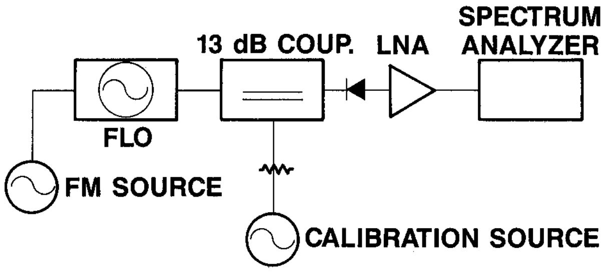

Figure 5. The test setup used for measuring residual AM.

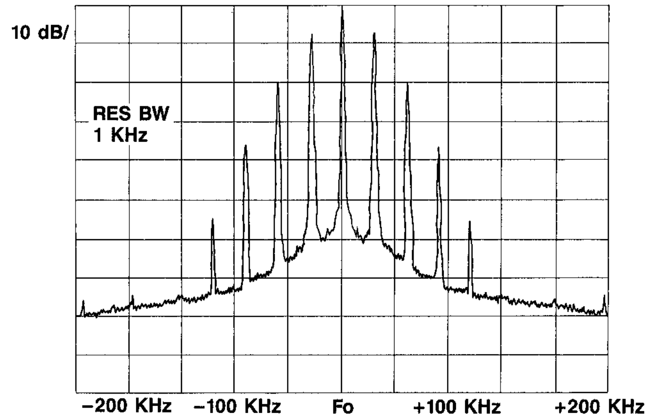

Figure 6. The measured FM sidebands of the frequency locked loop.

FM Noise Spectrum Improvement

As noted earlier, the ability of the frequency locked loop to improve the noise spectral density of an oscillator is limited by the equivalent input noise of the loop amplifier, the noise contribution of the discriminator detector diodes (1/f or flicker noise), and the available signal level at the output of the discriminator. To calculate the theoretical improvement over a range of offset frequencies, one may tabulate the various contributions of noise together with the discriminator gain constant and the low index approximation for FM noise, -20 LOG[F/Frms]. The results of this procedure are shown in Table 1.

TABLE 1
NOISE LIMIT OF FREQUENCY LOCKED LOOP

Fm *Hz*	*Ea* *nV/ Hz*	*Ed* *nV/ Hz*	*Frms* *Hz*	*Frms/Fm*	*NOISE* *DBC/Hz*
10E+2	15	101	102	1.02	-46
10E+3	15	11	19	0.19	-81
10E+4	15	2.4	15	0.15	-102
10E+5	15	1.2	15	0.15	-122
10E+6	15	1.2	15	0.15	-142

The data for the table are available from the OP37 data sheet, equivalent input noise and typical 1/f noise Schottky diode data [3]. A discriminator gain constant of 0.10 Mhz volt was used to convert the rms noise voltage to frequency deviation at the given offset frequency. The following nomenclature is applicable:

Fm is modulation or offset frequency,
Ea is the loop amplifier equivalent input noise,
Ed is the output noise of the Schottky diode, and,
Frms is the frequency deviation.

Acknowledgment

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References

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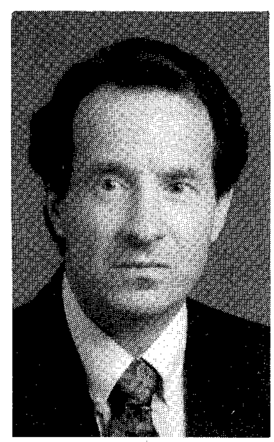

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From 1965 to 1966 he was with the Laboratory for Electronics, Inc. and engaged in the design and development of a two-frequency read system. He was also responsible for the miniaturization of peripheral electronics for a random access, high speed, mass memory system.

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Mr. Puglia joined M/A-COM in 1971 as a design engineer. Since that time he has designed a variety of microwave stripline components, solid state oscillators and amplifiers. These experiences were obtained with such programs as AMRAAM AIM-120, Phoenix AIM 54C, MILSTAR and the Combat Talon Receivers.

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