A FAST-LOCKING X-BAND TRANSMISSION INJECTION-LOCKED DRO*

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ABSTRACT:
A novel wideband configuration for a transmission injection-locked DRO is presented. An example of a 9.5 GHz ILDRO with a locking time of less than 100 ns for the final frequency to be within ±1 ppm of the reference frequency is described.

INTRODUCTION:

Fast-locking microwave oscillators are a necessity in certain pulsed radar/EW applications, where the minimum usable pulse width is determined by the locking time of the oscillator. Oscillator locking time also limits the maximum usable modulation rate in injection-locked FM amplifier applications, and is an important parameter in a number of other military/communication systems as well.

The small size, low noise, low cost and high temperature stability make dielectric resonator oscillators a practical component for many commercial/military applications[1]. However, even using properly-selected dielectric mixes and using other temperature compensation techniques, the frequency stability of a free-running DRO is limited to approximately ±150 ppm over the -55° to +85°C military temperature range. The phase noise of free running DROs is also very sensitive to the vibration level of the system in which it is being used--another important consideration in some applications.

In order to achieve greater frequency-vs.-temperature stability, a reduction in vibration-induced phase noise, or to provide coherence in a multi-oscillator system, DROs are generally locked to a harmonic of a highly-stable crystal oscillator.

Locking can be achieved by using injection or phase-locking techniques. While phase locking is required for phase coherency, phase-locked oscillators are not only complex and expensive but also have excessive locking times. The locking time in phase locked oscillators is typicaly of the order of milliseconds. Injection locking of microwave oscillators is simple, elegant and can provide locking times, orders of magnitude faster, compared to phase locking. Injection locking however, in reality, is frquency locking as opposed to phase locking. Little has been reported on the injection locking of the dielectric resonator oscillator[2].

In this paper a novel wideband configuration is presented for an X-band transmission injection-locked DRO. This configuration eliminates the need for the ferrite circulator and bandpass filter normally used in a reflection injection-locked oscillator. For a sample 9.5 GHz oscillator built using this design, locking times were measured as a function of the resonator quality factor and injection gain: the DRO locked to the reference frequency within ±1 ppm in 100 ns for an injection gain of 11 dB. The theory and design approach of the ILDRO is presented and the locking time measurement approach and performance is discussed.

THEORY:

Figure 1 is a typical block diagram for a reflection injection-locked DRO. In this design, the selected harmonic from a crystal-controlled reference signal is applied to the output of the DRO through a bandpass filter and a ferrite circulator. The bandpass filter rejects unwanted harmonics generated by the step-recovery comb generator, and the circulator isolates the injection signal from the signal produced by the locked oscillator.

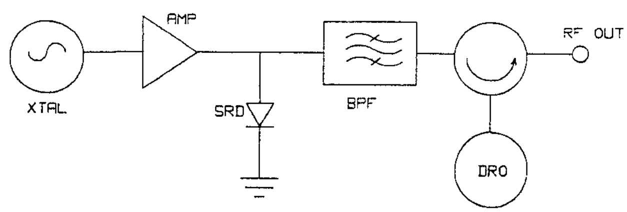

Fig.1 Standard Reflection Injection Locked DRO.

* U.S. Patent approved October, 1987

Transmission injection locking of a two-port GaAs FET oscillator is known to provide a higher injection bandwidth, while eliminating the need for a ferrite circulator[3]. The injection-locking bandwidth for the reflection and transmission case is given in equations 1 and 2 respectively.

$$\Delta f = 2.f_o/Qext_{.} \sqrt{P_i/P_o} \qquad 1)$$

$$\Delta f = 2.f_o/Q_ext. \sqrt{P_i/P_o}. G_s/G_p \qquad 2)$$

where G_s is the stable gain of the device and G_p is the ratio of the power at the output port Po to the power at the input port.
Pi is the injection power and Qext is the external Q of the oscillator.

Figure 2 represents the newly-developed configuration for a transmission injection-locked DRO. In this configuration the dielectric resonator functions simultaneously as:

1. The frequency determining element for the DRO,

2. A narrow bandpass filter, rejecting the spurious frequencies generated by the comb; and as an

3. Injection locking circuit path connecting the reference signal with the oscillating device.

DESIGN:

The device is an Avantek silicon bipolar transistor. The base inductance of the transistor was determined using a computer aided design program to create instability (S_{11}>1) looking in the emitter terminal of the device. The position of the dielectric resonator is then calculated to satisfy the oscillation condition S_{11} x T1=1. The dielectric resonator is modeled as a bandpass filter, and the input terminal J1 (Fig. 2) is considered loaded with 50 ohms for the oscillator analysis.

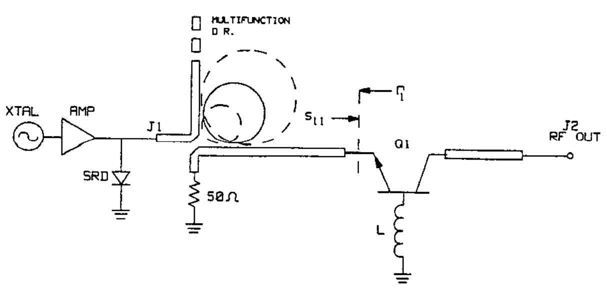

Fig.2 New Wideband Configuration for Transmission Injection Locked DRO.

Using the **unique quadrature coupling configuration**[4] shown in Fig. 2 provides two significant design advantages over the usual parallel-line coupling structure. The first is its capacity for accommodating dielectric resonators of varying diameters (as shown in Fig. 2), which makes it possible to use the same substrate for a wide range of frequencies. The quadrature coupling configuration also provides for independent adjustment of the coupling coefficients between the dielectric resonator and the two perpendicular microstrip lines.

The drain output matching circuit was designed using the load pull method in order to optimize the power output on the drain. Since the injection bandwidth is proportional to the loaded Q of the resonator, the dielectric resonator coupling to the microstrip is calculated based on the available injection power.

It must always be kept in mind in designing an injection-locked oscillator that, for the minimum available injection power, the injection locking bandwidth should far exceed the frequency drift of the DRO due to all possible variations of temperature, load and power supply. This is taken care of by carefully selecting the resonator material, device bias and load circuit, as well as adjusting the degree of coupling of the resonator to the microstrip lines.

Fast locking to the reference frequency is an important feature of the injection-locked oscillators. Injection gain and the resonant circuit Q are the main factors controlling the locking time. A higher-Q resonant circuit results in slower settling or locking of the oscillator to the reference oscillator. On the other hand, the use of a lower-Q resonant circuit increases the frequency drift over temperature and the phase noise, particularly at frequencies away from carrier by more than the injection bandwidth. Optimization of the resonator Q is essential.

PERFORMANCE RESULTS:

An X-band injection-locked DRO was realized using the design approach discussed above. The main parameters were measured to be:

Center Frequency:	9496 MHz
Power at J1:	+2 dBm
Power at J2:	+7 dBm
Frequency drift over -55 to +85 C:	4 MHz
Freq. Pulling into 2:1 VSWR:	2 MHz
Injection Bandwidth:	16 MHz for -13 dBm.
Qext:	125

Locking time was measured as a function of the injection power. For an injection gain of 11 dB the settling time of 100 ns was measured using the delay line discriminator setup shown in Fig. 3. Figure 4 shows the variation of settling time with injection gain, and Fig. 5 represents a typical settling time plot showing the final frequency time required for settling within ±1 ppm of the nominal final frequency.

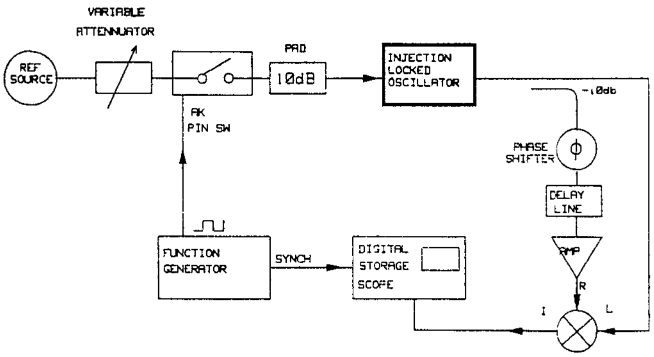

Fig.3 Locking-Time Measurement Set-up.

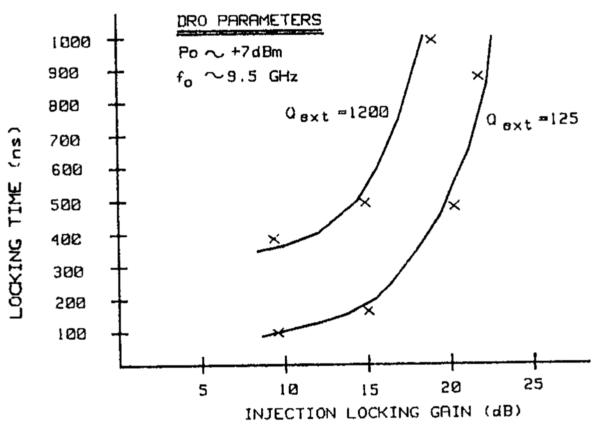

Fig.4 Locking-Time as a function of Injection Gain & Osc. Qext.

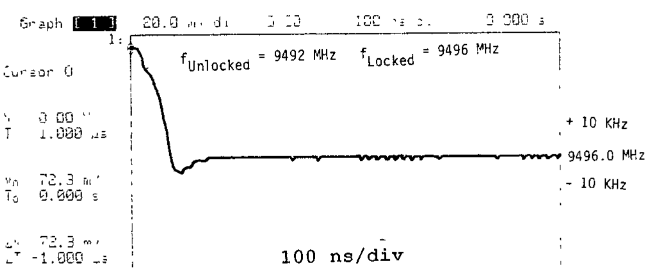

Fig.5 Typical Locking-Time for Qext= 125 & Injection Gain= 10dB.

A similar DRO using a smaller coupling coefficient between the DR and the microstrip lines, which increased the Qext to 1200, was also built for comparison. The result was a greatly increased locking time, as shown in Fig. 4. The dependence of the locking time on Q makes it necessary to optimize the Qext for each application. In order to verify the broadband feature of the quadrature coupling configuration, ILDROs were realized using the same substrate covering 8 to 12 GHz frequency range.

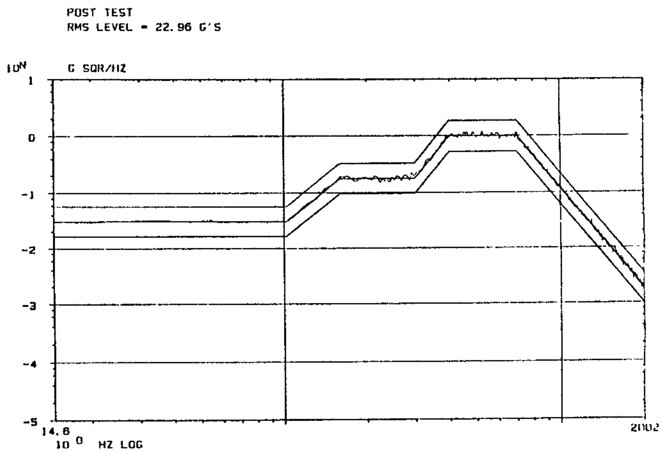

Fig. 6 Vibration density curve.

As noted before, the phase noise of a free-running DRO is very sensitive to the vibration levels of the package. Injection locking of the DRO to a reference source eliminates the problem of phase noise degradation under vibration. With initial measurements, there was no noticeable degradation in the phase noise of an ILDRO under vibration. The free-running DRO, on the other hand, had greater than 20 dB degradation in the close-in phase noise for vibration density shown in figure 6. Figure 7a and 7b show the spectra of the free-running & injection-locked DRO under vibration, respectively.

CONCLUSION:

Analysis and design of an X-band transmission injection locked DRO is presented. Wideband feature of the unique quadrature coupling configuration is explained. Effect of the injection gain & resonator Q on the locking time has been shown and isolation of the DRO performance from vibration is demonstrated.

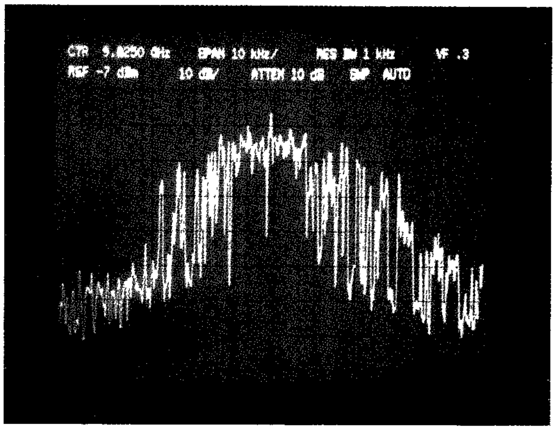

Fig. 7a Frequency spectrum of free running DRO under 20G vibration.

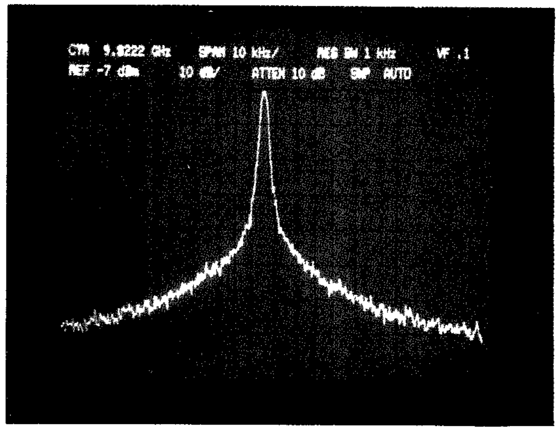

Fig. 7b Frequency spectrum of an injection locked DRO under 20G vibration.

ACKNOWLEDGEMENTS:

Authors would like to thank Bob Oyafuso of Avantek for technical discussions and Rolf Weglein of Hughes Aircraft Company(MSG) for help in verifying the locking time measurements and valuable discussions.

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