

DRO State of the Art

Dielectric resonator stabilized oscillators (DROs) can offer frequency stability below 3 ppm/C° without the size and cost of a frequency reference source. The authors provide design guides and give examples from 3 to 20 GHz.

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Dielectric resonator oscillators are used widely in today's electronic warfare, missile, radar and communication systems. They find use both in military and commercial applications. The DROs are characterized by low phase noise, compact size, frequency stability with temperature, ease of integration with other hybrid MIC circuitries, simple construction and the ability to withstand harsh environments.

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These characteristics make DROs a natural choice both for fundamental oscillators and as the sources for oscillators that are phase-locked to reference frequencies, such as crystal oscillators.

This paper summarizes design techniques for DROs and the voltage-tuning DRO (VT-DRO), and presents measured data for them including phase noise, frequency stability and pulsing characteristics.

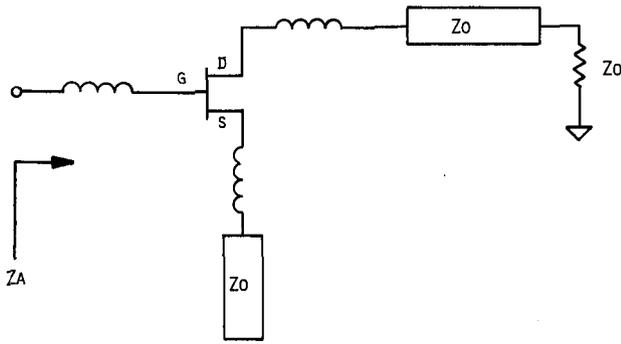


Figure 2. Circuit for series feedback topology.

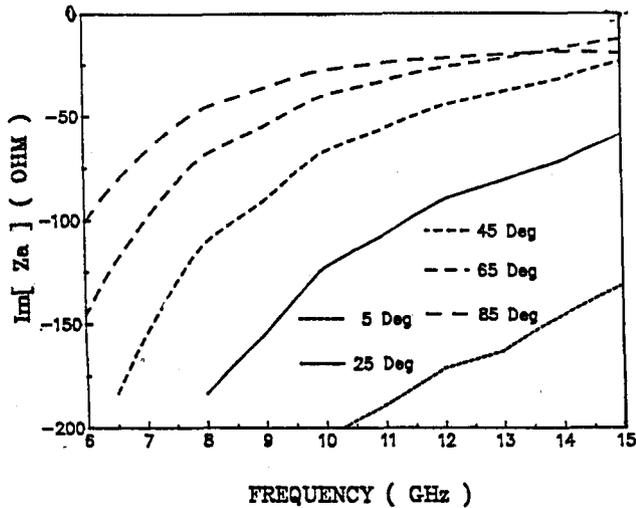


Figure 3a. Port resistance of the circuit shown in Figure 2.

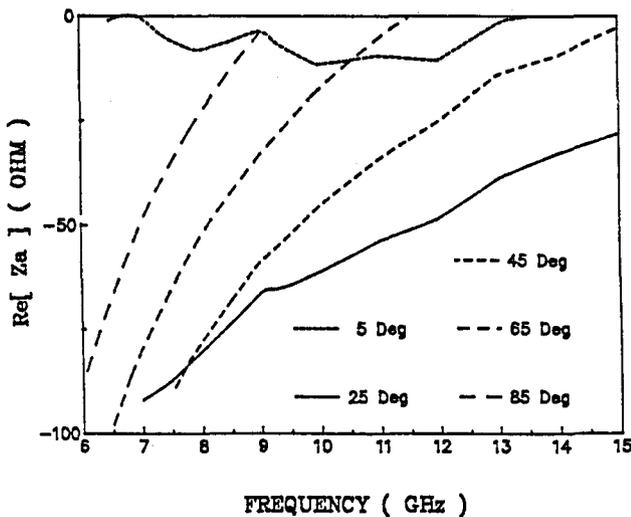


Figure 3b. Port reactance of the circuit shown in Figure 2.

ation, the length of the feedback stub is chosen as 45 degrees in this example, and the resultant input impedance of the active port is then $Z_a = -40.8 - j62.5$ ohms at the desired oscillation frequency of 10.4 GHz. The negative resistance of -40.8 ohms is

sufficient to allow the transistor to build up and sustain oscillation at the desired frequency.

It remains to determine the length of a 50 ohm terminated microstrip line between the coupling plane of the DR and the gate terminal of the active device. We know that the load must have a reactance $XI = 62.5$ ohms to resonate with the reactance of the active device input (gate) port.

Looking toward the DR from this port, the circuit appears as if it were an open circuited transmission line stub for which the open circuit appears at the equivalent coupling plane of the DR, about equal to the location of the DR's centerline drawn perpendicular to the line to which it couples. Accordingly, its reactance is $XI = Z_g \cot(\theta_g)$, from which the spacing of the DR can be determined. In the present series feedback example, the computed electric length is 141.3 degrees at 10.4 GHz. A photograph of the 10.4 GHz DRO is shown in Figure 4.

Small signal S parameters are used in the design, whereas in reality the oscillator's voltage amplitudes increase until saturation, at which the DRO reaches its steady state output power. This saturation, by definition, corresponds to the high level S parameter case. Nevertheless, designs based upon the small signal behavior are found to yield a good first order solution, requiring minor adjustment for high level operation at the desired frequency.

The frequency stability of the DRO over temperature, which mainly depends on the temperature characteristics of the DR, is also affected by the temperature characteristics of the supporting circuit structure, the epoxy with which the DR is attached to it, the transistor and the circuit hous-

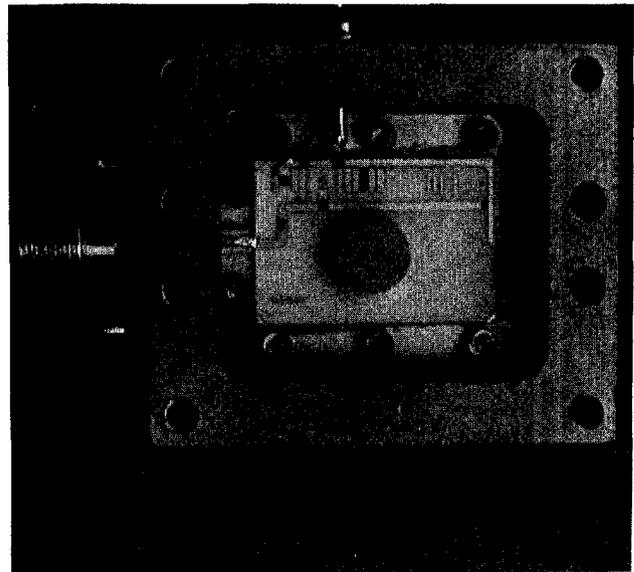


Figure 4. Photograph of the DRO.

ing. Generally, the most effective approach is to select a DR which itself has a variation of resonance frequency with temperature that counteracts the temperature variation of the other elements of the oscillator.

The frequency stability with temperature depends mainly on the dielectric resonator selected.

A frequency stability of 3 parts per million per degree Centigrade (3 ppm/C) for a DRO operating around 10 GHz is typically achievable. This corresponds to a frequency shift of 30 kHz per Centigrade degree shift. By comparison, aluminum has a thermal expansion coefficient of about 20 ppm/C, thus an aluminum microwave cavity resonant at 10 GHz would undergo a resonant frequency shift of about 200 kHz/C.

Besides temperature coefficient, the DR is selected for its size and dielectric constant. Figure 5 shows that the size of the DR (the thickness to diameter ratio of a DR is generally kept to 0.4 for the widest mode separation) is inversely proportional to the frequency of the DRO for the same dielectric material. On the other hand, Figure 6 shows that dielectric resonators of almost the same size but with different dielectric materials can be used for DROs of various frequencies. The 12 GHz DRO with integral amplifier shown in Figure 6 has the smallest size (0.515" x 0.535" x 0.375") ever reported using hybrid MIC techniques, yet it delivers more than 20 dBm of output power at 105 C.

Frequency Tuning

Frequency tuning of a DRO can be achieved by using voltage controlled diodes (varactors) [4], [5]. The circuit configuration for coupling the varactors to the DR consists of an additional line paralleling that which couples the DR to the active device, and placed on the opposite side of the DR (Figure 8a). In the example shown in Figure 7a two varactors are attached to the ends of a microstrip half wavelength resonator having characteristic impedance Z_1 .

At the DR plane of coupling, the transmission line can be treated as two quarter-wavelength impedance transformers (or, more precisely two impedance inverters) terminated with two tuning varactors. The varactors' capacitive variation at the end of the inverter is transformed into inductive variation at the plane of the coupling by the imped-

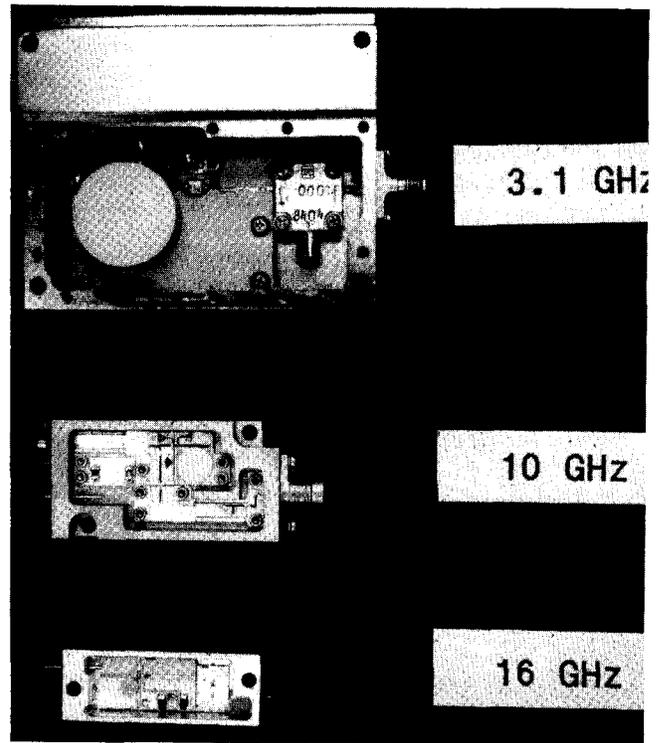


Figure 5. DROs of different frequencies with the same dielectric material used for the DRs.

ance inverter (Figure 7b). The equivalent circuit of the tuning is that shown in Figure 8b.

By increasing the coupling between the DR and the tuning microstrip line, the tuning bandwidth of

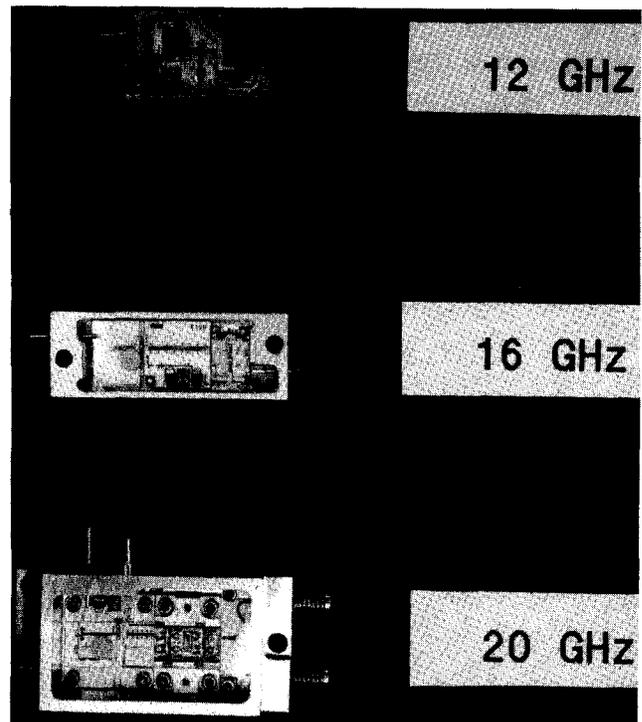


Figure 6. DROs of different frequencies with different dielectric material used for the DRs.

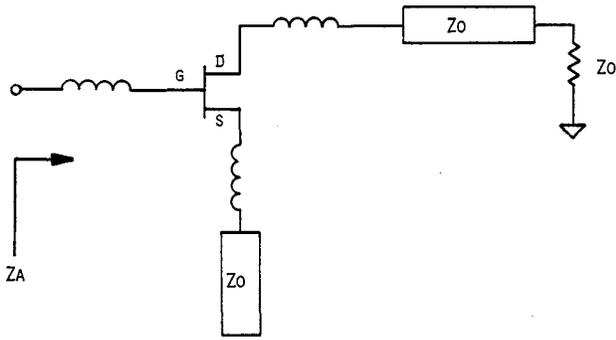


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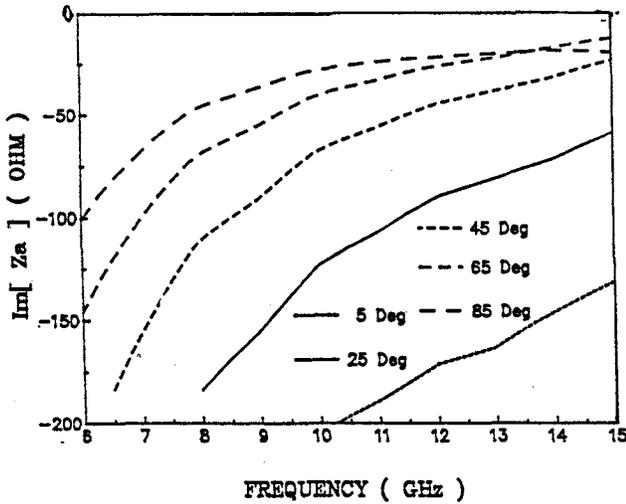


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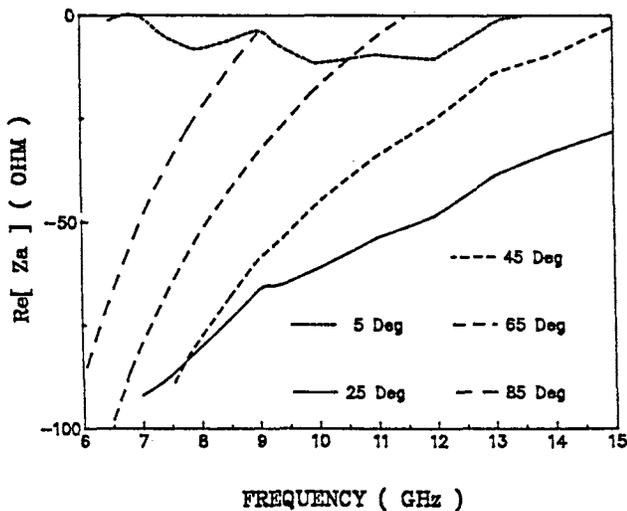


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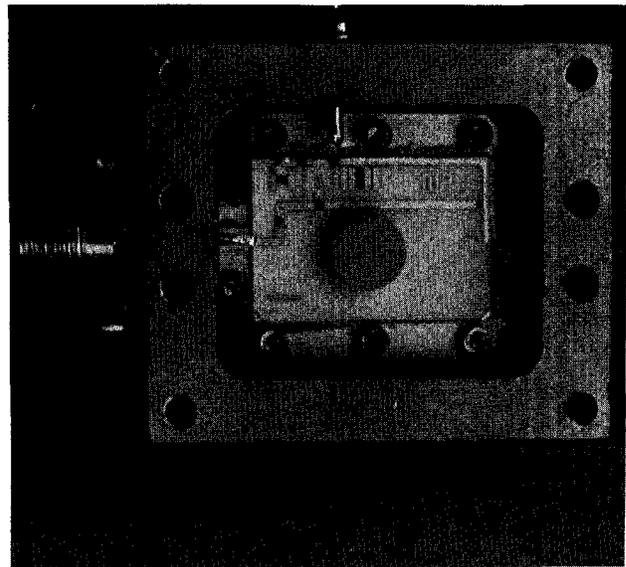


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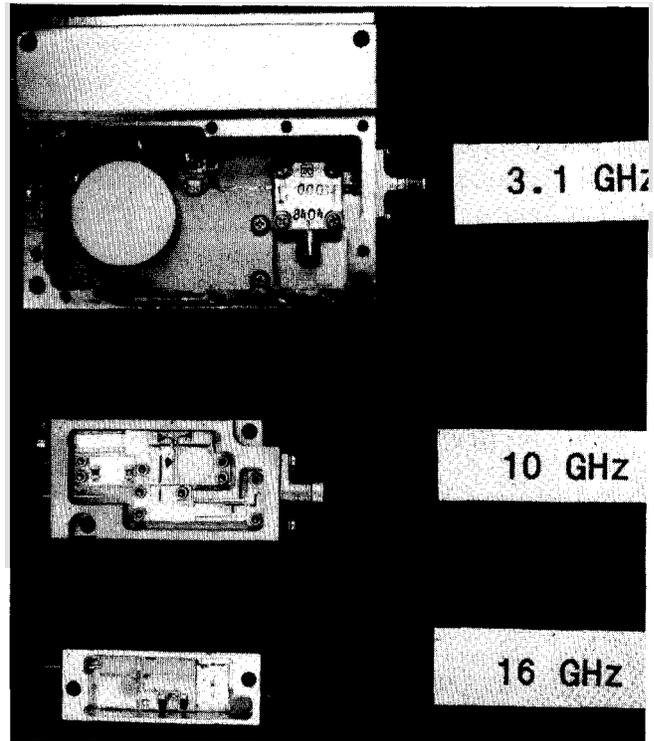


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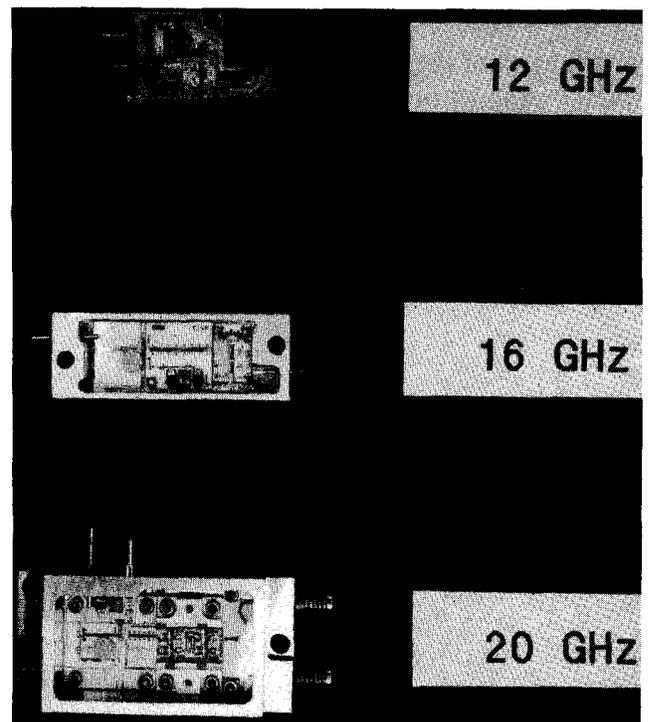


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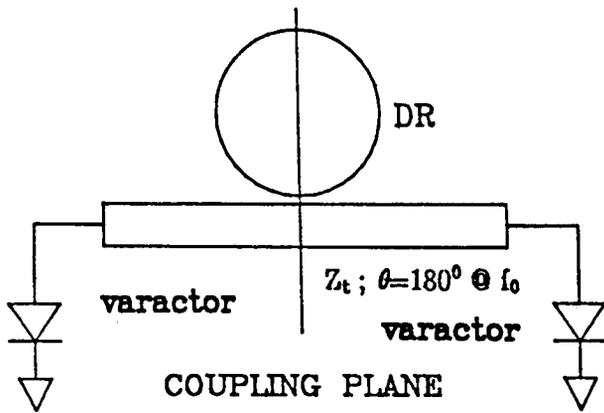


Figure 7a. Coupling scheme for varactors with DR.

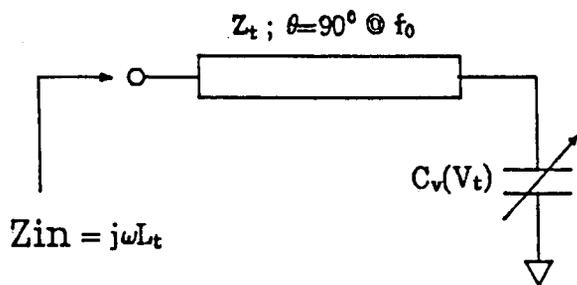


Figure 7b. Impedance inverter effect.

the DRO can also be increased. There is a trade-off for wider tuning bandwidth in that degraded phase noise and poorer frequency stability results, mainly due to the resultant equivalent degradation in the unloaded Q of the dielectric resonator.

Nevertheless, it is necessary that the electrical tuning band of the DRO be wider than the anticipated frequency drift of the oscillator over its operating temperature range. Using this condition, tuning bandwidth of 0.3% has been employed [4] at 18 GHz without significantly degrading the phase noise characteristics.

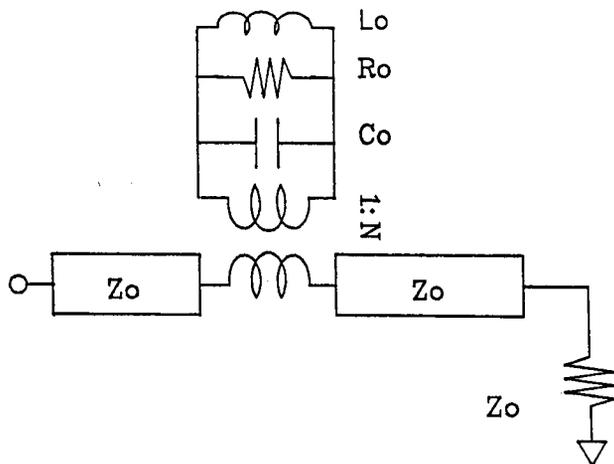


Figure 8a. DR equivalent circuit in ideal transformer.

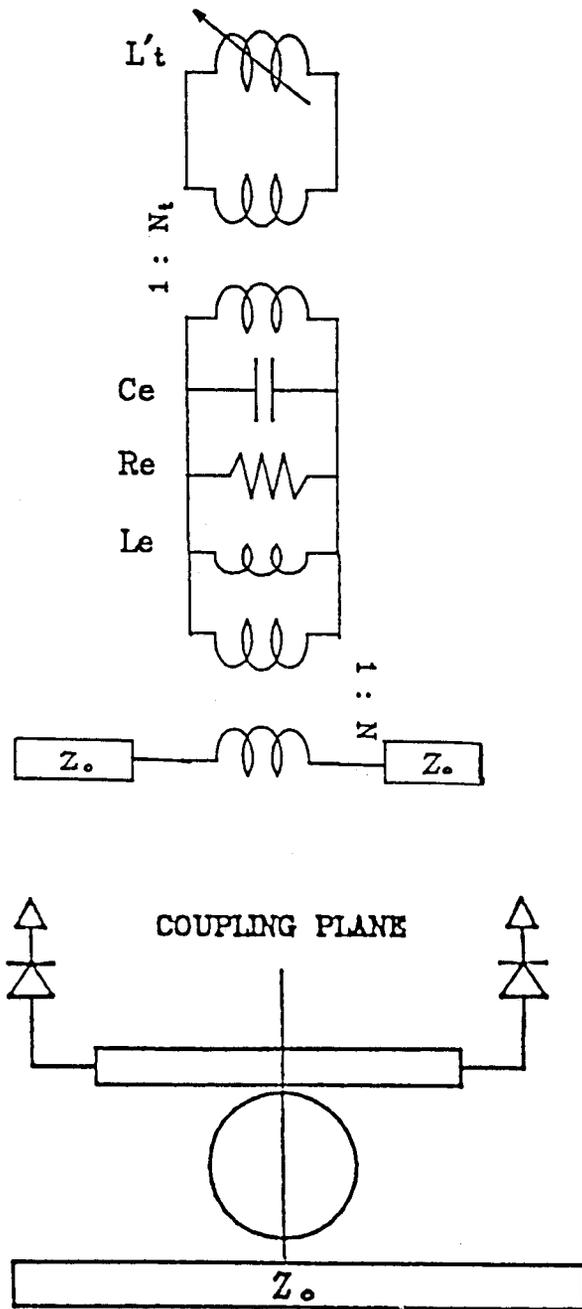


Figure 8b. Model of the tuning mechanism.

Electrical tuning of a DRO can be used to compensate for frequency drift over temperature. Temperature sensor information is converted into proper tuning voltage and is fed into the tuning port of the DRO. This tuning voltage can also be used as the correction loop should the DRO serve as the output oscillator of a phase-locked source. The tuning sensitivity ratio (frequency change/control voltage) may change in slope by as much as three to one for an X-band VT-DRO over the tuning voltage range and over temperature. A linearizer circuit may be used to linearize the characteristic. The low phase noise and small circuit size make the VT-

DRO very attractive in phase-locked source applications.

Varactor diodes can provide voltage tuning of DROs over limited ranges.

To increase the operating frequency of a DRO, one may use the conventional push-push oscillator design approach [7]. Output power of 3 dBm has been obtained at 35 GHz, with a phase noise level of -100 dBc/Hz at an offset frequency of 100 kHz. Similar power levels have been achieved for a 20.5 GHz DRO with phase noise level of -110 dBc/Hz at an offset frequency of 100 kHz [6].

The frequency tuning mechanism shown in Figure 7 has been added to the push-push DRO design, resulting in a tuning band of over 1% at 21.8 GHz [6]. The photograph of the voltage-tuned push-push DRO is shown in Figure 9a, and the measured tuning characteristics are depicted in Figure 9b.

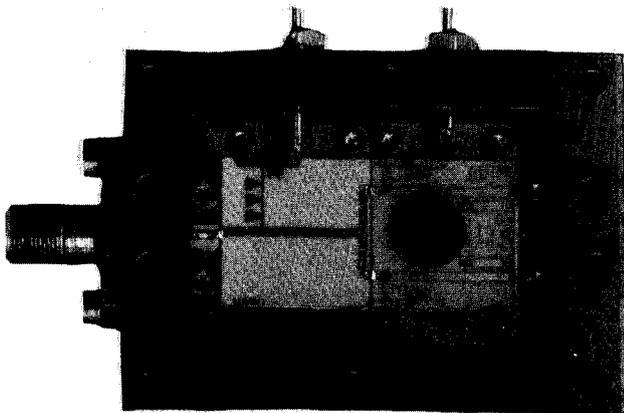


Figure 9a. Photograph of the voltage-tuned push-push DRO.

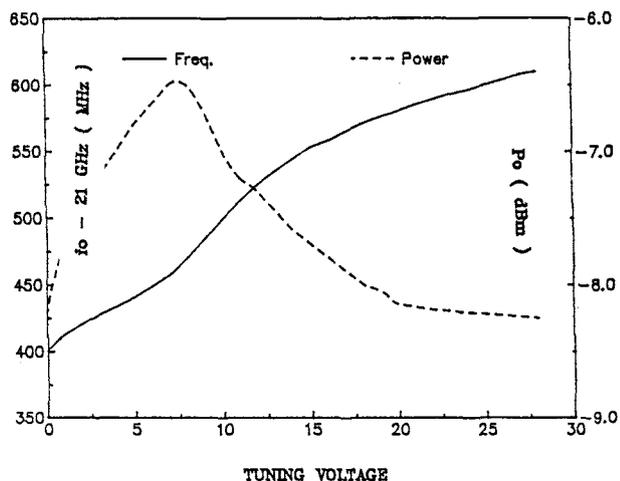


Figure 9b. Tuning performance of the voltage-tuned push-push DRO.

Phase Noise

One of the important characteristics of a DRO is its phase noise at 10 kHz or higher away from the carrier. The phase noise of a DRO is dependent upon the active device used, the coupling of oscillation power to the DR, and the amount of power delivered to load. Figure 10 shows the typical phase noise characteristics of a DRO using Si-bipolar transistors and GaAs FETs. The Si-bipolar transistor provides about a 10 dB improvement in phase noise, which is generally believed to be contributed by 1/fm noise of the GaAs FETs. Phase noise increases with the square of operating frequency, thus to obtain the phase noise level of a DRO at frequencies other than 10 GHz, add $20 \times \log_{10}[f(\text{GHz})/10]$ to the values shown in Figure 10. For example, corresponding phase noise will be 6 dB greater for a 20 GHz DRO.

There is a trade-off between tuning range and phase noise for DROs.

As more energy is stored in the dielectric resonator, the temperature characteristic of the DRO more closely follows that of the DR, however more of the active device's power is dissipated in the DR, leaving less for output. Also the phase noise of the DRO also may degrade. Therefore, some compromise often must be made between the DRO's temperature stability and phase noise.

Frequency Stability with Temperature

Without external compensation for frequency variation over temperature, DRO frequency stability of 3 ppm per degree C typically is obtained. Temperature compensation for frequency drift of a DRO has been achieved by using either an analog control voltage or a programmed digital signal, both from a temperature sensing element correct the DRO frequency through its tuning circuit. Schematic diagrams of these two approaches are shown in Figure 11. The temperature compensated DROs using the analog approach exhibit ± 0.3 ppm per degree C stability with DRO output frequencies up to 20 GHz from and over the temperature range -54 C to +105 degrees C [8].

The analog approach is smooth and continuous with no thermal toggling. The digital approach of temperature compensation also can provide similar frequency stability but much more complex circuitry is required [9].

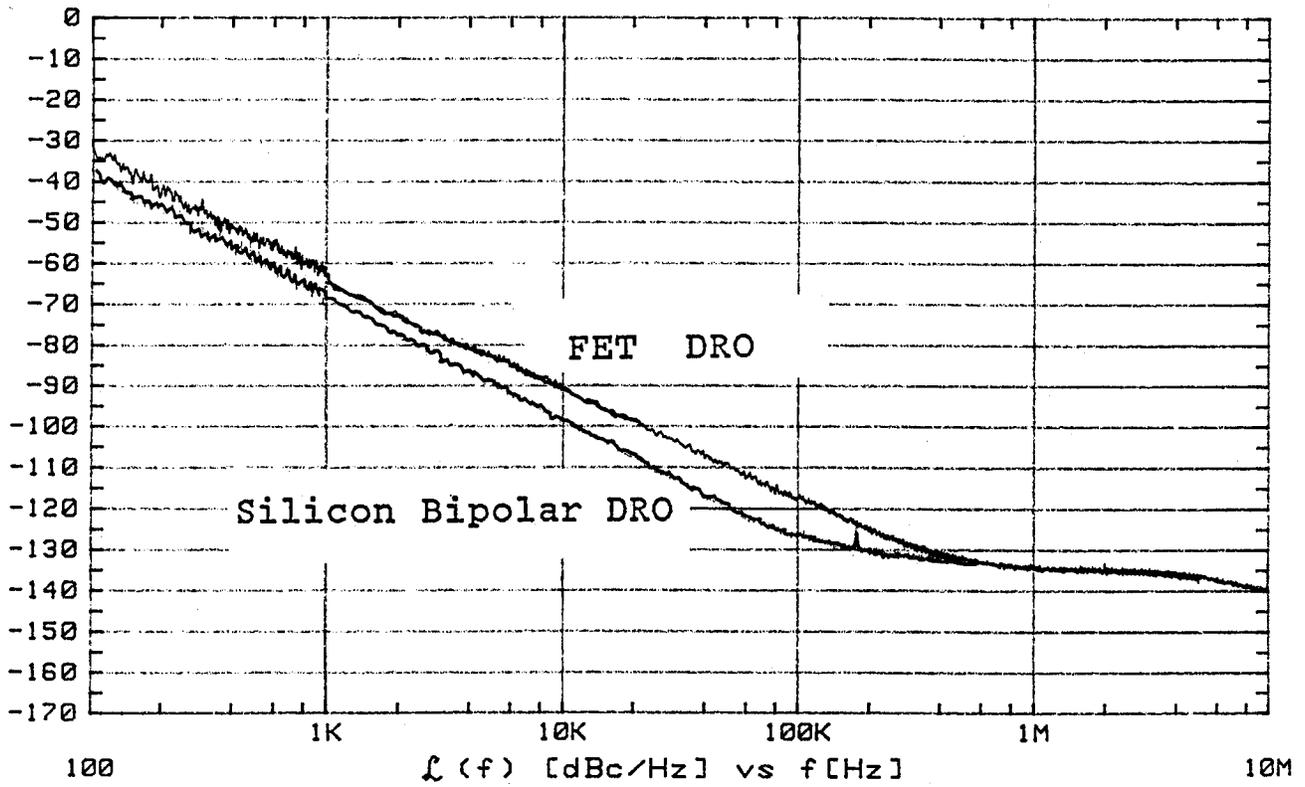


Figure 10. Typical phase noise characteristics of a DRO.

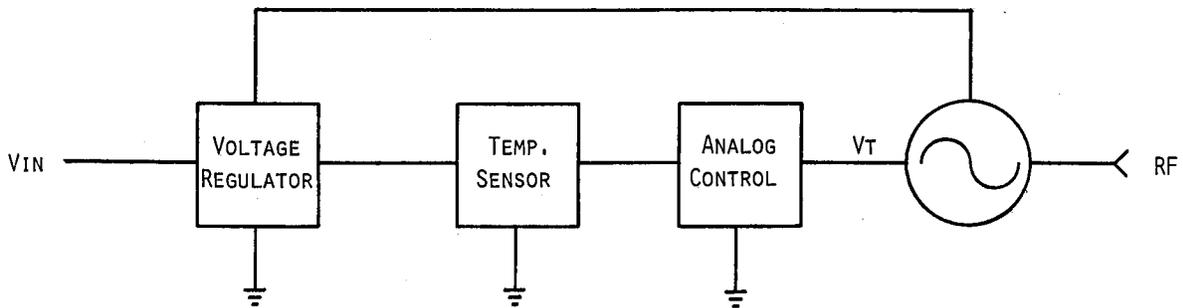


Figure 11a. Analog voltage control.

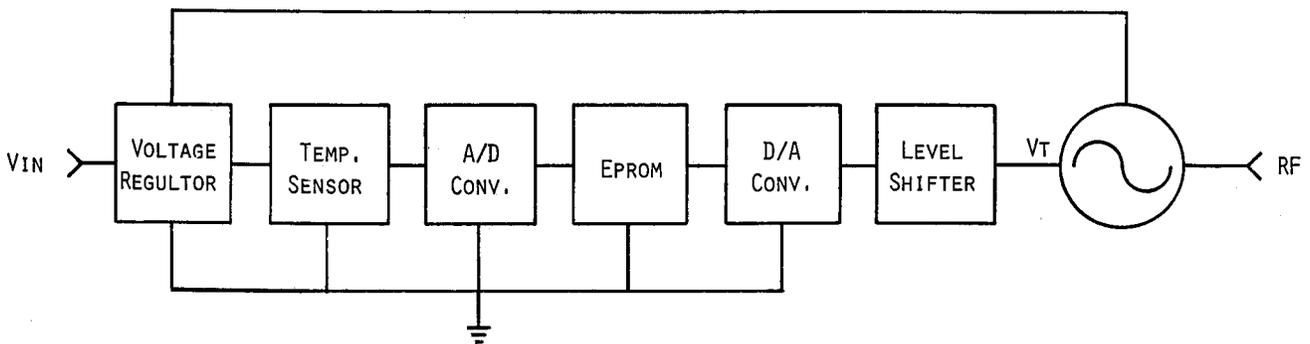
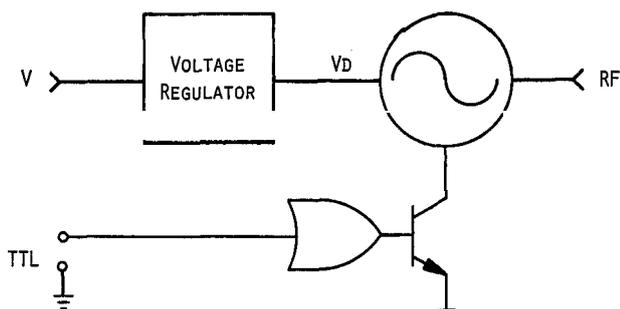
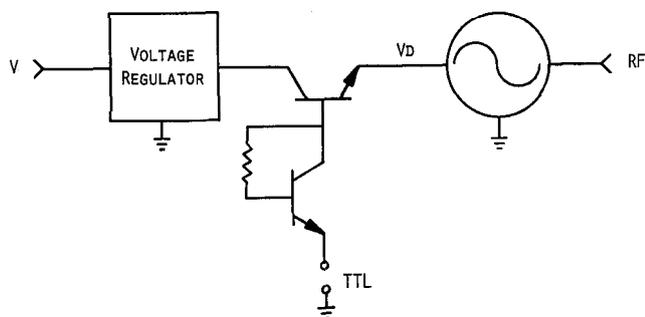


Figure 11b. Programmed digital control.

Pulsing Characteristics

For some applications it is desirable that the output power of the DRO be turned on and off, subjected to pulsing from TTL control signals. Pulsing circuitries can be placed at the drain (Figure 12a) or at the ground (Figure 12b). Both circuits yield similar pulsing risetime, defined as the time between 50% TTL input and 90% RF output. A risetime 600 nsec has been obtained for a 16 GHz DRO with 20 dBm output power and phase noise of 86 dBc/Hz at 10 kHz from the carrier. The high Q_u nature of the DR requires longer time to build up the energy in the resonator compared a free running oscillator.



To increase the pulsing speed, relatively high loss dielectric resonator material can be used together with tighter coupling of the microstrip line to the DR, at the expense of reduced unloaded Q and significant impact on phase noise and frequency stability. While the frequency stability of a DRO can be compensated by using a DR of proper temperature characteristics, the phase noise appears to be the parameter that must be traded off for faster risetime pulsing. A similar design of a DRO at 16 GHz, when optimized for pulse risetime, exhibits less than 100 nsec risetime but a phase noise degraded to 73 dBc/Hz at 10 kHz from the carrier.

The settling time of the fast pulsing DRO is less than 100 nsec when the frequency is measured with

+/-100 kHz referenced to the frequency measured at 500 nsec and drift within +/-100 kHz from 500 nsec to 1 sec.

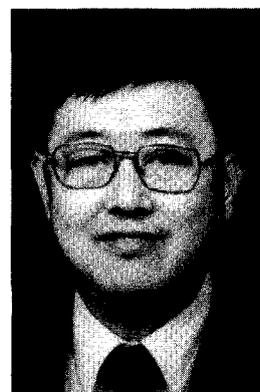
Acknowledgment

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Tim Kajita is a staff engineer with M/A-COM's Active Assemblies Division. He is responsible for the design and development of stable, narrow-band microwave sources, including DROs and DRO subsystems. Kajita has 19 years of microwave experience, all with M/A-COM.

