A UNIFIED DESIGN OF DIELECTRIC RESONATOR OSCILLATORS FOR TELECOMMUNICATION SYSTEMS

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ABSTRACT

A unified design approach for improving the performance of both regular DRO & Voltage Tuned DRO (VTDRO) is presented with a step-by-step procedure. The novel designs of 23GHz DRO and 18GHz VTDRO are reported together with their experimental results showing superior performance over the previously published results; for example, the frequency-temperature stability at 23GHz has been improved by a factor of four, while the frequency tuning sensitivity at 18GHz by a factor of five.

INTRODUCTION

In this paper, a unified design approach is proposed to improve the performance of DRO and Varactor Tuned DRO (VTDRO). This proposed approach is verified by tests of a 23GHz DRO and an 18GHz VTDRO. The improved performance over previously published data are presented. A novel and simple 18GHz VTDRO is shown with significant improvement of frequency tuning range and sensitivity. Advantages and disadvantages of reflection, series feedback and shunt feedback types are also discussed in detail.

A UNIFIED DESIGN APPROACH OF DRO

The performance of a DRO is highly influenced by many factors: device characteristics, matching network, DR's temperature coefficient as well as dimensions and cavity, etc. Here, a unified step-by-step design procedure is proposed below with almost all of the above-mentioned factors.

Step 1: Select appropriate topology. The performance comparison among three types of DRO's in 23GHz are shown in Table 1.

Step 2: Use computer simulation and suitable configuration to make device unstable and determine the matching network of the various ports.

Step 3: Design and fabricate test circuit with computer-simulated results and measure the phase variation over temperature on the resonate port.

From [1]:

$$\frac{df}{fdT} \approx \frac{df_r}{f_r dT} + \frac{\beta+2}{4Q_r} \cdot \frac{\partial \phi}{\partial T} \Bigg|_{|\Gamma| = \text{const.}} \text{------}(1)$$

Where $\frac{df}{fdT}$ = temperature stability of DRO

f_r = DR resonate frequency

$\frac{df_r}{f_r dT}$ = DR temperature coefficient

β = coupling factor between DR and microstrip line

Q_r = DR's unloaded Q value

$\frac{\partial \phi}{\partial T}$ = phase variation of the resonate port over temperature

Table 1. Performance comparison among Reflection, Series Feedback and Shunt Feedback type DRO's.

Description \ Type	Reflection	Series Feedback	Shunt Feedback
Mechanic Tuning Range	Fair 200-600 MHz	Good 800-2500 MHz	Poor 50-200 MHz
FM Noise (100KHz away)	Fair * -105 dBc	Good -103 dBc	Good -108 dBc
Output Power	Good 12-15 dBm	Good 13-16 dBm	Fair 8-13 dBm
Circuitry Simplicity	Fair	Good	Poor
Voltage Push	Poor	Fair	Good
Load Pull (No Isolator)	Poor	Best	Good

* Over the mechanic tuning range, the FM Noise can deteriorate to about -95 dBc/Hz.

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Using the data measured from step 3, we can obtain the temperature coefficient of the DR from the equation above.

Step 4: Calculate the DR dimensions. If alumina substrate is used, low loss support sometimes has to be added between the DR puck and the substrate to increase the loaded Q value [2][3].

Step 5: Special attention should be directed toward DRO's cavity to assure good phase noise and to avoid interaction with other parts of the circuits [4][5].

Step 6: To modify a DRO into a VTDRO (Voltage-Tuned DRO), a varactor has to be added to the circuit. A model or equivalent circuit is established to describe the coupling effect between three parts of the FET oscillator circuitry, i.e. FET, DR and the varactor diode. With the aid of an appropriate matching network between the DR and varactor diode, tunable bandwidth and power variation can be readily predicted. Also the other parameters such as coupling coefficients and variation range of diode capacitance can be determined by using computer optimization.

23GHz DRO

With the step-by-step design procedures described above, we have successfully developed three types of 23GHz DRO's:reflection type, series feedback type and shunt feedback type. The schematics of these types of DRO's are shown in Fig. 1.

1. Reflection Type:

A common gate configuration is used with the drain as the output port as shown in Fig.1(a).

The typical test results of the 23GHz reflection type DRO's are below: Output power of 14 dBm, temperature stability of +/-4MHz over -40°C to +80 °C, and FM noise of -105 dBc/Hz (100 KHz away carrier). Taking advantage of voltage pushing characteristics, a thermistor is added to compensate the frequency drift over temperature, thereby enhancing the temperature stability as shown in Fig. 1(a)

2. 23GHz Shunt Feedback Type DRO

A shunt feedback type DRO with DR coupling feedback between gate transmission line and drain transimission line is designed and fabricated as shown in Fig. 1(c).

Because of the difficulty of exact analysis, the design of this 23GHz shunt feedback type of DRO is actually done on a experimental basis [6]. This oscillator exhibits extremely low FM noise and highly temperature stabilized performance. FM noise of -108 dBc/Hz at 100KHz away from carrier and +/-1MHz temperature stability over -40°C to +80°C at 23GHz have been achieved.

3. 23GHz Series Feedback Type DRO

Although the reflection type and shunt feedback type DRO's exhibit significantly improved FM noise and temperature stability over those of a conventional oscillator, they still have several major drawbacks as follows.

A. For reflection type:
 (1) Poor pulling figure
 (2) Mode hopping phenomenon
 (3) Poor voltage push figure
 (4) Temperature stability and FM noise may change substantially over the mechanical tuning range

B. For shunt feedback type:
 (1) Complication for analysis and realization
 (2) Narrow frequency tuning range
 (3) Relatively low output power

These disadvantages can be improved by the use of a series feedback type DRO [7].

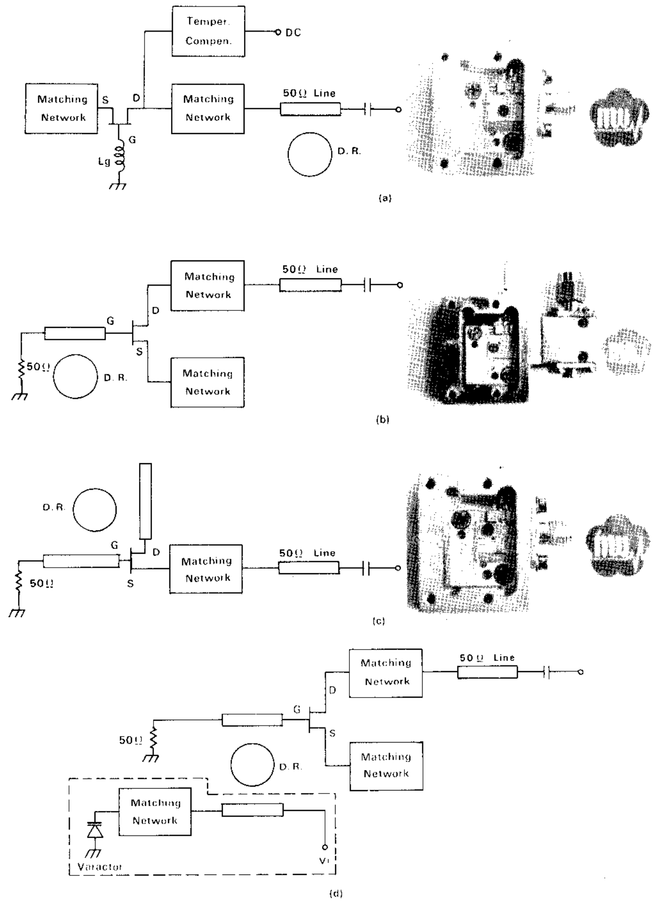
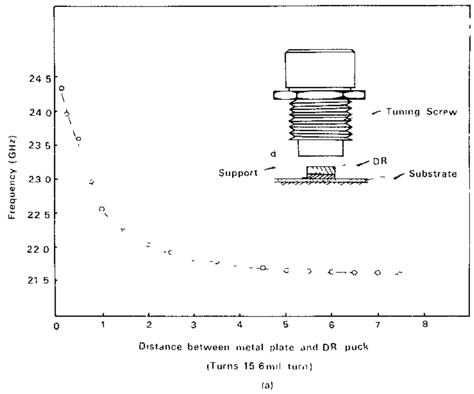


Fig 1. Schematics and hardware photographs of DRO and VTDRO.
(a) 23GHz Reflection Type DRO.
(b) 23GHz Series Feedback Type DRO.
(c) 23GHz Shunt Feedback Type DRO.
(d) 18GHz Series Feedback Type VTDRO.

To avoid the mode hopping phenominon, the circuit is designed not to oscillate before the DR puck is coupled to 50 ohm microstrip line. Fig. 2 shows the test results of the 23GHz series feedback type DRO. It's found that the mechanical tuning is about 2.5GHz, while the temperature stability +/-500KHz from -40°C to +80°C.

18GHz Voltage-Tuned DRO

As shown in Fig.3(a) & (b), a dielectric resonator magnetically coupled to two microstrip lines simultaneously is represented by parallel RLC resonate circuit [8]. Redrawing the equivalent circuit in Fig.3(c) by taking into account the two facti-



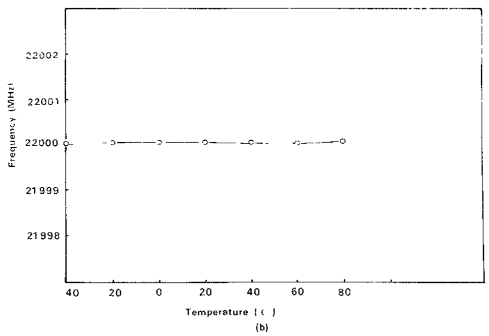


Fig 2. (a) Mechanical tuning and (b) Temperature stability of a Series Feedback Type DRO used in 21.2-23.6GHz Local Area Network Application.

tious transformers with turn ratios n_1 and n_2. Assume that the load admittance $Y_L = G_L + jB_L$ where $n_2^2 B << \omega C$, while the generator admittance is G. Then the new resonance frequency ω_o' of the dielectric resonator can be induced to be

$$\omega_o' = \omega_o(1-n_2^2 B_L / 2Q_o G) \text{---------(2)}$$

If we set $Y = Y_o$, and $\beta_2 = n_2^2 Y_L/G = n_2^2 Y_o/G$ as defined,

$$\omega_o' = \omega_o(1-\beta_2 B_L / 2Q_o Y_o) \text{-------(3)}$$

The second term in the parenthesis gives the fractional frequency change.

If Y_L is replaced by a varactor, ΔB_L and $\Delta\omega_o'$, which mean the difference of susceptance B_L and electrical tuning range of frequency respectively, can be obtained from equation (3).

Using the concept outlined above and the design procedure described in step 6, we have successfully developed an 18GHz VTDRO with an electrical tuning range about 50MHz that is superior to earlier results obtained with a 10GHz VTDRO[9]. In frequency stability, +/-0.5 MHz from -40°C to +80°C is observed whereas 10 GHz VTDRO [9] exhibits +/-3.0 MHz over same temperature range.

Similarly, frequency tuning range and tuning sensitivity are improved at least two times and five times respectively (Fig.4). When the FET has better heat sink, the FM noise is improved more than 15dB to about -115 dBc/Hz (100KHz away), as shown in Fig.5. This is the best FM noise performance of DRO known to the author.

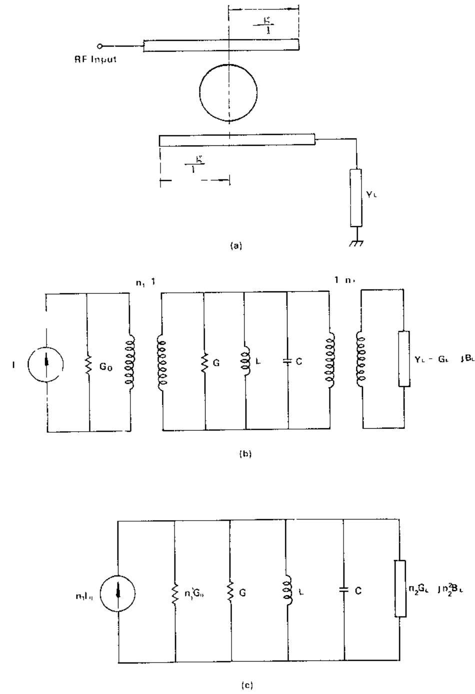


Fig 3. (a) Diagram of a DR magnetically coupled to two transmission lines simultaneously.
(b) Equivalent circuit.
(c) simplified equivalent circuit.

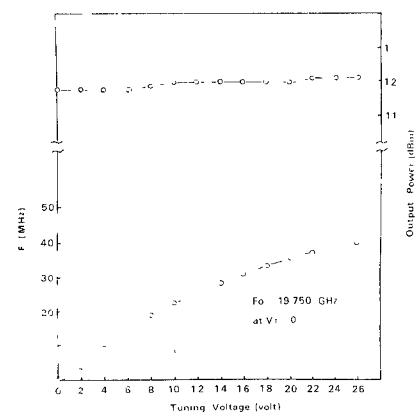
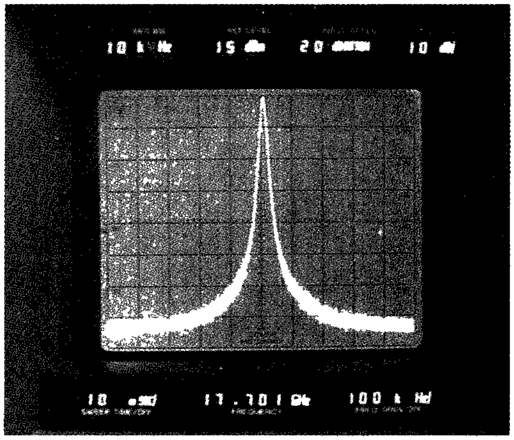
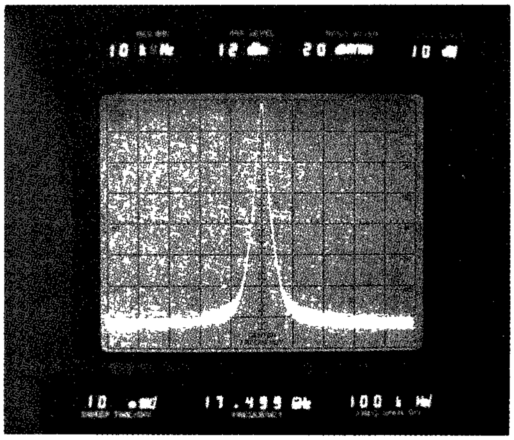


Fig 4. Frequency deviation and output power as a function of tuning voltage for 18GHz VTDRO.



(a)



(b)

Fig 5. FM Noise of an 18GHz VTDRO with
(a) poor thermal resistance and
(b) improved thermal resistance of FET device.
Note: Vertical : 10dB/div
Horizontal:100KHz/div

CONCLUSION

Significant improvement in the performance of two types of Dielectric Resonator GaAs FET Oscillators have been reported for 23GHz and 18GHz digital radio systems using this unified design approach.

Experimentally, the series feedback type 23GHz DRO has been shown to be superior to other types. The presented data indicated only +/-0.5 MHz, frequency change over 120℃ temperature range, with a mechanical tuning range improved by factor of four.

Using this newly developed design approach, an 18 GHz VTDRO is reported. Along with excellent temperature stability, significant phase noise improvement and good power variation,the design shows much wider tuning range (by factor of two) and better tuning sensitivity (by factor of five) than the known data.

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