FREQUENCY/TEMPERATURE COMPENSATED MILLIMETER-WAVE OSCILLATORS AND BROADBAND VCO'S IN LUMPED-ELEMENT AND PRINTED-CIRCUIT FORMS

by

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ABSTRACT

Frequency/temperature compensation of millimeter-wave, lumped-element, Gunn oscillators and broadband VCO's by use of a simple capacitive compensating element has been demonstrated with performance that includes ±1.5 ppm/$^{\circ}$C frequency stability at 30 GHz over a temperature range of -40° to $+71^{\circ}$C. A printed-circuit oscillator, in which the temperature compensating capacitor is printed in situ with the circuit elements, will also be described.

INTRODUCTION

Oscillators and varactor-tuned oscillators (VCO's) are used extensively in military applications as LO and transmitter sources. Frequency stability over a wide temperature range is a basic requirement for high-quality performance, concomitant with miniature size and low cost for such applications as missile seekers or smart munitions.

Frequency/temperature stabilization of a millimeter-wave oscillator by temperature compensation techniques is difficult, if not impractical, in practice due to the physical and electrical constraints imposed when conventional compensation technology is extrapolated from the microwave range. Temperature compensation of a broadly tunable VCO presents an even higher order of difficulty. These limitations have been overcome by the use of millimeter-wave oscillators and VCO's in a lumped-element circuit form in which a temperature compensating capacitor is located directly at the circuit element(s) (Gunn and/or varactor diode) to be compensated. This approach has resulted in devices that are frequency stable with temperature, inherently broadband, miniature in size, and potentially low cost. The design and performance of these sources will be described.

DISCUSSION

The lumped-element concept is based on the use of circuit elements that are sufficiently small (electrically) so that they can be functionally characterized as lumped components. This circuit form has reported use as fundamental and second harmonic oscillators and VCO's in the 25 to 75 GHz range (1).

An assembly drawing and circuit layout of a temperature compensated VCO with two possible placements of a compensating capacitor (C_C) are shown in Figure 1A. A compensating capacitor can be used in either placement shown for an average compensation, or at each diode for their individual compensation and a more exact offset of the frequency/temperature sensitivity of the VCO.

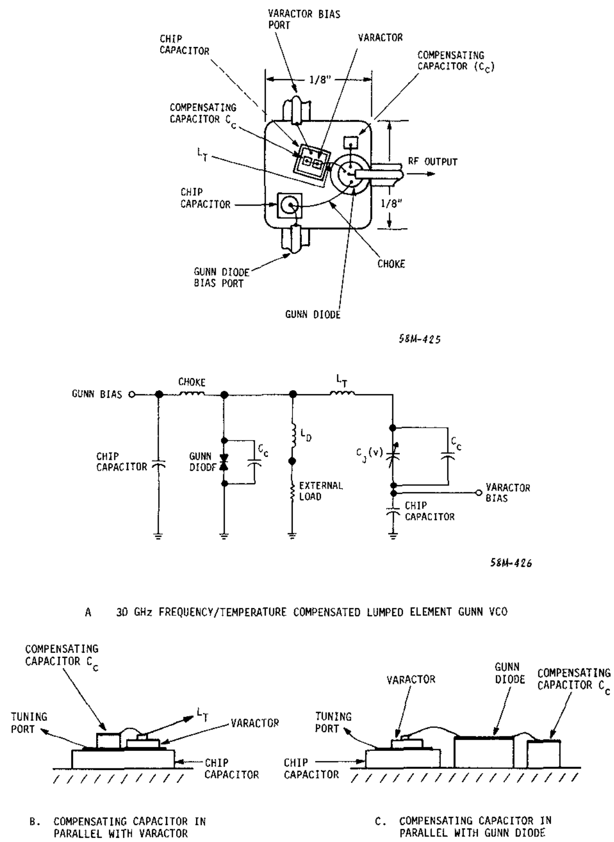

Figure 1. 30-GHz Frequency/Temperature Compensated, Lumped-Element, Gunn VCO

The discrete circuit elements constituting the VCO are a packaged Gunn diode, a chip varactor, two chip capacitors, and a lumped-element compensating capacitor(s). The open nature of the circuit provides easy access to the Gunn and/or varactor diode for their direct compensation. Functional use is made of the interconnections

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between the discrete components as the required inductive elements. The Gunn bias choke is a quarter wavelength long. The compensated VCO circuit is miniature in size (1/8 x 1/8 inch). The small size is evident in the photograph in Figure 2 where a Gunn VCO circuit assembly (uncompensated) is compared to a match head. The VCO circuit is assembled on the 0.118-inch diameter flange of a standard Gunn diode studded package.

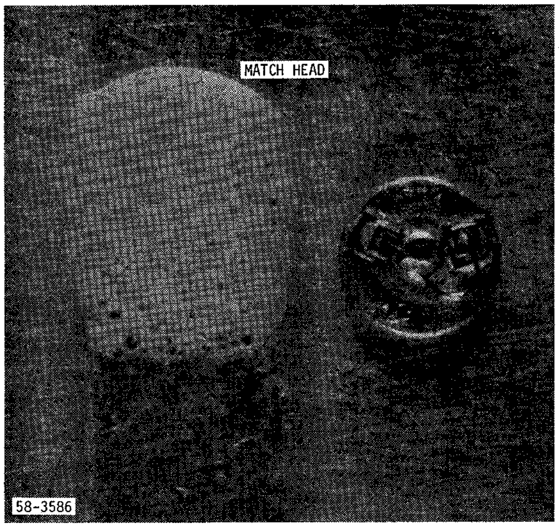

Figure 2. Ka-Band, Lumped-Element, Gunn VCO Assembled on the Flange of a Gunn Diode Studded Package (Flange Dia. = 0.118")

A material parameter of interest for a compensating capacitor is the temperature coefficient of dielectric constant. Frequency/temperature compensation is achieved by offsetting the capacitance/temperature characteristic of the Gunn and/or varactor diode with that of the compensating capacitor. Materials with a negative temperature coefficient of dielectric constant are used for compensation of oscillators and VCO's exhibiting a negative frequency/temperature coefficient. Positive coefficient materials are appropriate for compensation of oscillators and VCO's that have a positive frequency/temperature coefficient. Broadband frequency/temperature compensation was achieved with this approach because a lumped-element circuit is inherently more broadband than a distributed circuit and direct capacitance compensation is used.

Candidate materials for a compensator capacitor for a lumped-element or printed-circuit millimeter-wave VCO or oscillator are shown in Table 1. These materials are also suitable for use as a substrate for oscillators and VCO's in printed-circuit (MIC) form. With the exception of silicon (ε_r = 11.8) and sapphire (ε_r = 11.5), the dielectric constant of all the materials is in the range of 2.2 to 10. Material with low dielectric constant is advantageous for use in the millimeter range. Because the material for a compensating capacitor can also serve as a substrate material for printed oscillator and VCO circuits (i.e., transmission mediums as microstrip or fin line), the compensator can be printed in situ with the circuit elements. Temperature compensation with a high dielectric constant titanium oxide dielectric has been reported (2) for an avalanche diode oscillator at 9.2 GHz in a waveguide circuit. This material is not suitable for in situ printing of compensated oscillators and VCO's or for use at millimeter wavelengths.

Table 1. Temperature Coefficient of Dielectric Constant of Various Materials

Dielectric Material	Temperature Coefficient of Dielectric Constant (PPM/^{o}C)
Epsilam-10 (1)	-570
Kapton (2)	-950
Quartz	+45
Silicon	+260
Sapphire	+1100
RT Duroid 5500 (3)	-110
RT Duroid 6010.5 (3)	-370
RT Duroid 5880 (3)	-100

(1) 3M Company
(2) Du Pont Company
(3) Rogers Corporation

MEASURED PERFORMANCE (-40^{o} to +71^{o}C TEMPERATURE RANGE)

A. Compensated, Lumped-Element, Gunn Oscillator

The lumped-element Gunn oscillator was built in the form shown in Figure 1, except that the varactor was replaced with a chip resonator capacitor. The compensating capacitor was fabricated from 10-mil thick copper-clad Epsilom-10 material and was placed in parallel with the Gunn diode package. A comparison of the performance of this oscillator with and without a lumped-element compensating capacitor is shown in Figure 3 and is summarized below:

Parameter	Uncompensated	Flat Compensated
Frequency (GHz) at 25^{o}C	33.7	30.3
Power (dBm) at 25^{o}C	+15.5	+13.0
Frequency/ Temperature Stability (MHz/^{o}C) Over -40^{o} to +71^{o}C	2.45 (73 ppm/^{o}C)	0.045 (1.5 ppm/^{o}C)

The performance with compensating capacitor values that resulted in over and under compensation is also shown. The compensating capacitor was sequentially trimmed in place from an over compensated value to the flat and under compensated values in order to characterize the compensation capability of the technique. With flat compensation, the frequency/temperature sensitivity of the oscillator was reduced to 45 kHz/^{o}C (1.5 ppm/^{o}C), which corresponds to a near 50 times improvement over that of the uncompensated oscillator. The frequency of the compensated oscillator can be restored to its initial frequency (before compensation) by a resizing of inductance L_T (see Figure 1).

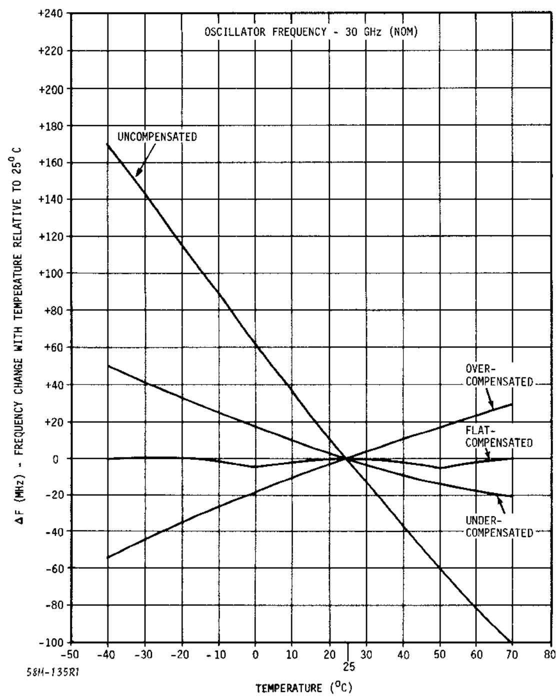

Figure 3. Measured Performance of Temperature Compensated and Uncompensated Millimeter-Wave, Lumped-Element, Gunn Oscillator

B. Compensated, Lumped-Element, Varactor-Tuned, Gunn Oscillator (VCO)

Frequency/temperature compensation of a broadband, lumped-element, Gunn VCO with a center frequency of 28.5 GHz was demonstrated using the circuit configuration shown in Figure 1. A lumped-element compensating capacitor fabricated from 5-mil thick metallized Kapton was used in parallel with the Gunn diode package.

The frequency/temperature characteristics of the uncompensated VCO over a temperature range of -40° to +71°C is shown in Figure 4. The performance of the compensated VCO is shown in Figure 5 and shows the effectiveness of the compensator in reducing frequency change with temperature over the 2.8 GHz VCO tuning range. A comparison of the performance of the uncompensated and compensated VCO is summarized below:

Parameter	Uncompensated	Compensated
Center Frequency (GHz)	28.7	28.5
Tuning Range (GHz)	2.4	2.8
Power (dBm) at midband and +25°C	+7	+5
Frequency/ Temperature Stability (MHz/°C) Over -40° to +71°C at Midband	3.35 (117 ppm/°C)	0.79 (27.7 ppm/°C)

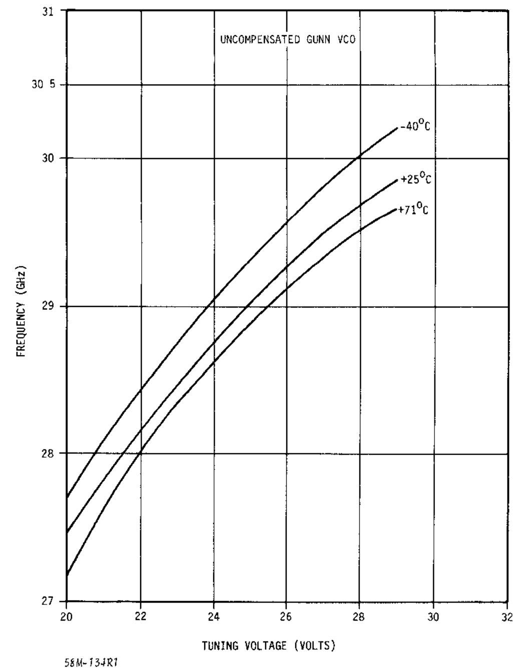

Figure 4. Measured Frequency Versus Tuning Voltage as a Function of Temperature of an Uncompensated Gunn VCO

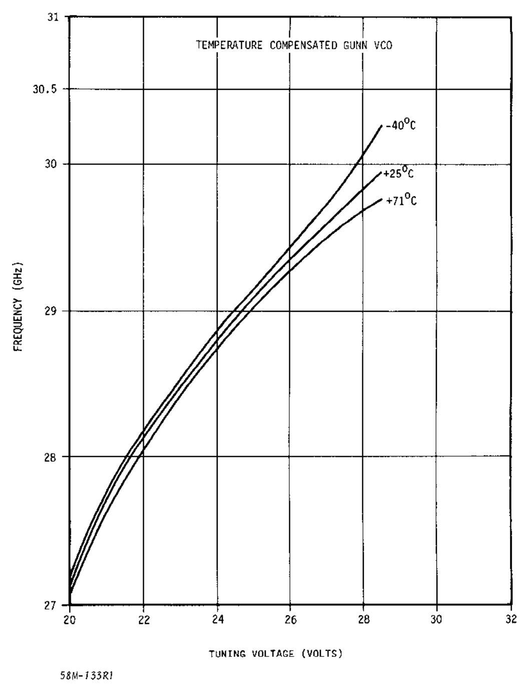

Figure 5. Measured Frequency Versus Tuning Voltage as a Function of Temperature of a Compensated Gunn VCO

The improvement obtained in the frequency/temperature coefficient of the VCO would be further enhanced by optimization of the value of the compensating capacitor. Optimization is accomplished by a simple trimming of the capacitor.

SUMMARY

A new approach to the frequency/temperature stabilization of millimeter-wave VCO's and oscillators has been described. Compensation over a broad frequency and temperature range can be obtained by use of a compensating capacitor(s) located directly at the active device and/or varactor in a lumped-element or printed VCO or oscillator circuit.

ACKNOWLEDGMENTS

This work was performed at the Eaton Corporation AIL Division, Melville, New York, under the direction of J. Whelehan and G. Irvin. Technical consultations with E. Sard and the contributions of E. Dolphy, E. Barksdale, and A. Pentecoste to device assembly are gratefully acknowledged.

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