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RECENT ADVANCES IN THE MODELLING AND PERFORMANCE OF MILLIMETER WAVE InP AND GaAs VCO's AND OSCILLATORS

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ABSTRACT

The use of a lumped element circuit form has provided a new means to model and quantify the equivalent circuit parameters of InP and GaAs Gunn VCO's and oscillators under large signal conditions. The modelling has resulted in excellent agreement between calculated and measured performance of wide-band VCO's and oscillators in the 26 to 60 GHz frequency range. New insights into device operation and performance will be presented.

INTRODUCTION

The realization of optimum performance characteristics from a Gunn VCO or oscillator mandates the use of an accurately characterized model, including the Gunn diode, under large signal conditions. The use of a distributed circuit for modelling and quantifying the equivalent circuit parameters of a Gunn VCO or oscillator at millimeter wavelengths is unsatisfactory due to uncertainties incurred in de-embedding the parameters from measured data in such a circuit, and to the limited frequency range of validity. These deficiencies have been overcome with a new large signal modelling means that is based on the use of a lumped element circuit form for millimeter wave Gunn VCO's and oscillators. The accuracy of the modelling is evidenced in the excellent agreement obtained between measured and calculated performance over oscillation frequency ranges as wide as 44 to 60 GHz. The lumped element modelling has also provided previously unavailable resolution into the values of RF voltage and power at the individual elements comprising a VCO or oscillator circuit. Thus, it has enhanced the understanding of device operation and performance, and provided new insights into VCO and oscillator design. This paper will describe the modelling technique and results obtained with both InP and GaAs Gunn VCO's and oscillators in the 26 to 60 GHz range. In addition, the performance of state-of-the-art VCO's will be presented.

TECHNICAL DISCUSSION

The lumped element concept is based on the use of circuit elements that are sufficiently small (electrically) so they can be characterized as lumped components (1). The layout of a lumped element circuit used for fundamental VCO's in the 26 to 60 GHz range is shown in Figure 1 and is intended to illustrate lumped element oscillator technology. The VCO circuit is a simple and low cost ensemble that has been reduced to an elemental form as evidenced by the minimal parts count and small circuit size (0.089 x 0.089 in.). The discrete circuit elements consist of a packaged Gunn diode, a GaAs chip varactor, and three chip capacitors. In fixed-frequency oscillators, the varactor and its choke and bias capacitor are replaced with a single fixed capacitor, and capacitor C_{TF} is eliminated. The inductive elements L_T and L_L are short lengths of line that provide the electrical connection between the discrete elements. The lines are sufficiently short so that they constitute lumped elements.

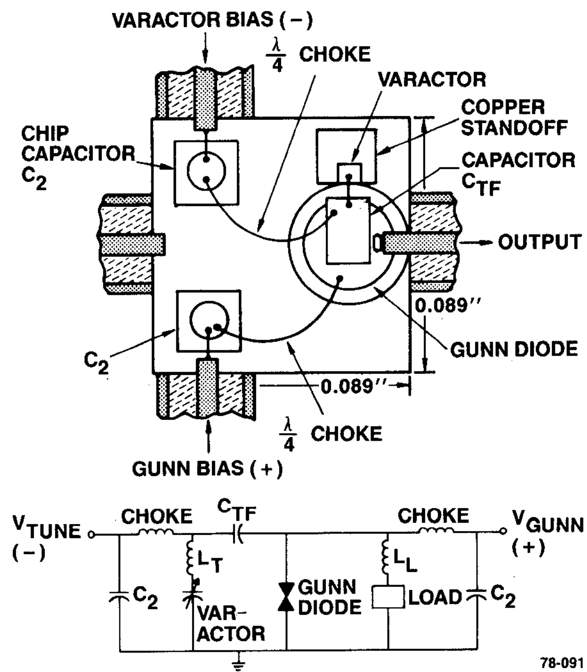

Figure 1. Layout of 55-GHz Lumped Element VCO

The measured tuning and output power characteristics of a lumped element InP Gunn VCO is shown in Figure 2. The VCO was built in the form shown in Figure 1 and used a Varian InP Gunn diode and an Eaton GaAs hyperabrupt tuning varactor.

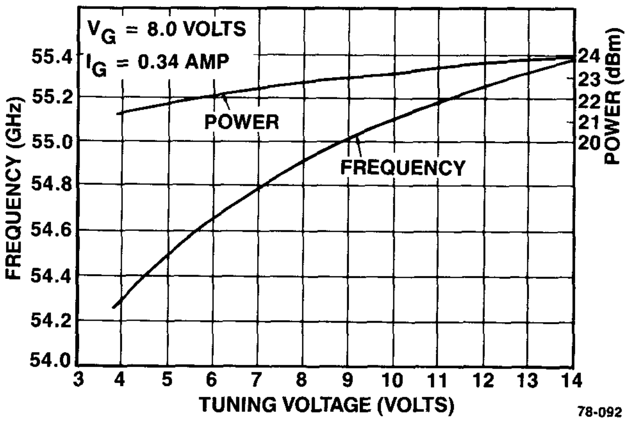

Figure 2. Lumped Element InP Gunn VCO

The VCO tuned from 54.25 to 55.38 GHz. Output power increased monotonically from a minimum of +21.2 dBm (132 mw) at the low-frequency end of the band to +23.8 dBm (240 mw) at the high end. The average power over the tunable band was +22.8 dBm (190 mw). In Ka-band, VCO performance over a tuning range of 35.3 to 40.7 GHz (5.4 GHz wide), with an average power of +19 dBm, has been demonstrated. These data illustrate the state-of-the-art performance capability of VCO's in miniature lumped element circuit form.

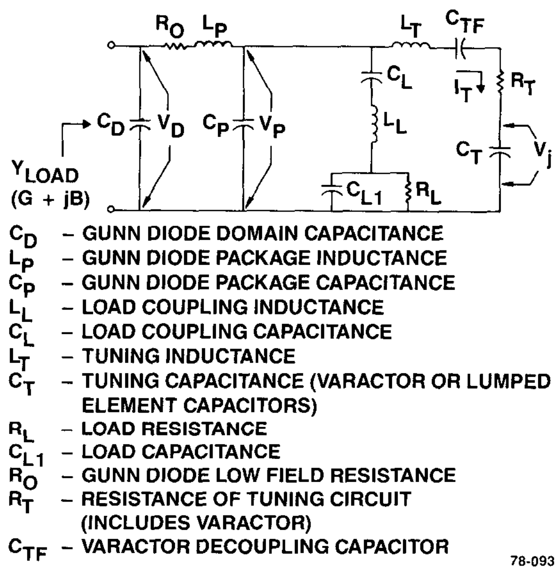

Figure 3. Equivalent Circuit Model of Loaded, Varactor-Tuned or Fixed Frequency, Lumped Element Gunn Oscillator

The design of lumped element VCO's and oscillators was based on the general design model shown in Figure 3. The elements in the model are those of the Gunn diode and its package parasitics and various circuit elements. The capacitive circuit elements C_{L1} and C_L were not present in the VCO circuit shown in Figure 1. The capacitive element C_T designates either a varactor or a resonator capacitor, corresponding respectively to VCO and fixed-frequency oscillator configurations.

The equivalent circuit elements C_D, L_P, C_P, L_L, and L_T in a VCO model were quantified from a measurement of oscillation frequency versus varactor capacitance C_T. In an oscillator model, these circuit elements were quantified from a measurement of oscillation frequency versus the capacitance of a series of resonator capacitors. The circuit elements C_T, R_T, and R_O were quantified from standard measurements at low frequency. A calculated value was used for miniature parallel plate capacitor C_{TF} and 50 ohms was used for R_L (based on calculation and indirect measurement).

The measured tuning characteristic of a VCO (Figure 2), or the measured oscillation frequency versus resonator capacitance characteristic of an oscillator (Figure 4), was the basis for the process of de-embedding the unknown circuit elements C_D, L_P, C_P, L_L and L_T in the model. A computer program, in conjunction with a SuperCompact optimization, was used to obtain a best fit to the measured tuning characteristic and thereby establish the value of these circuit elements. In the case of a VCO, the varactor capacitance was corrected for large signal effects. The measured output power characteristic of a VCO (Figure 2) was subsequently used as input data in a computer program to delineate the RF voltage and power values at the various elements in the model (Figure 3). The output power characteristic of an oscillator tuned and characterized with a series of resonator capacitors was similarly used. The output power versus frequency characteristic of a GaAs Gunn oscillator tuned with a series of resonator capacitors is shown in Figure 5 and is complementary data to the tuning characteristic shown in Figure 4.

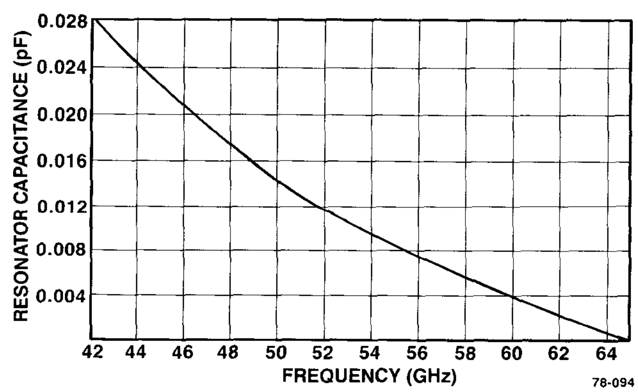

Figure 4. Lumped Element InP Gunn Oscillator Tuned with a Series of Resonator Capacitors

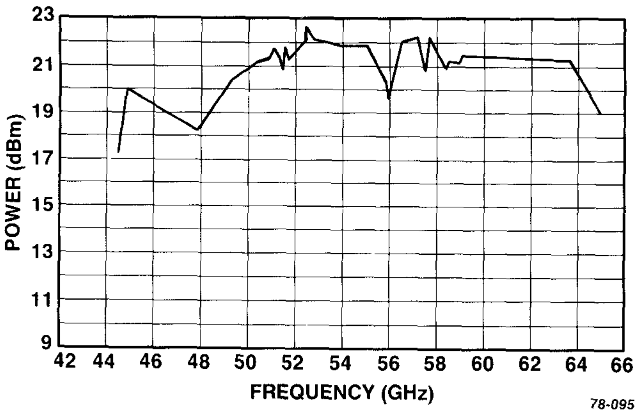

Figure 5. Lumped Element InP Gunn Oscillator Tuned with a Series of Resonator Capacitors

Typical values of the equivalent circuit parameters of 55-GHz GaAs and InP Gunn oscillators and VCO's are shown in Figure 6. The accuracy of the modelling is exemplified in Figure 7 by the excellent agreement, over the very broad frequency range of 44 to 60 GHz, between the measured and calculated tuning characteristics of an InP Gunn oscillator that was tuned with a series of resonator capacitors. The model also provided a level of resolution, not previously realizable, into the RF voltage and power conditions internal to a VCO or oscillator circuit. A printout from a VCO program that delineates the peak RF voltage and power level at various circuit elements in the model (Figure 3) is shown in Figure 8 for a Ka-band GaAs Gunn VCO. An input summary of the equivalent circuit parameter values is at the top of the printout. The listing of measured load power, P_L, shows that this VCO exhibited nearly flat output power with frequency. The power

	InP GUNN OSC	GaAs GUNN VCO
DOMAIN CAPACITANCE, C_D (pF)	0.071	0.103
PACKAGE INDUCTANCE, L_P (nH)	0.126	0.110
PACKAGE CAPACITANCE, C_P (pF)	0.096	0.123
TUNING INDUCTANCE, L_T (nH)	0.191	0.172
COUPLING INDUCTANCE, L_L (nH)	0.083	0.096
DECOUPLING CAPACITANCE, C_{TF} (pF)	NONE	0.017
GUNN DIODE DISSIPATIVE RESISTANCE, R_O (OHMS)	5.5	0.69
VARACTOR SERIES RESISTANCE, R_T (OHMS)	5.0	5.0
LOAD RESISTANCE, R_L (OHMS)	50.0	50.0

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Figure 6. Equivalent Circuit Parameters of a 55-GHz Lumped Element InP Gunn Oscillator and a GaAs Gunn VCO

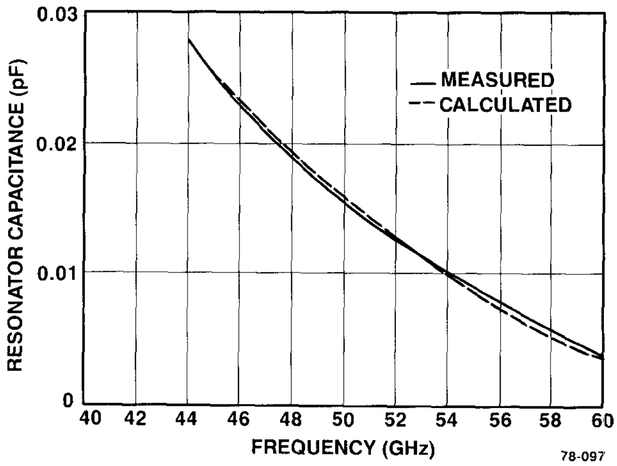

Figure 7. Lumped Element InP Gunn Oscillator Tuned with a Series of Resonator Capacitors

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INPUT SUMMARY
CD(PF)= 0.2622   RO(OHM)=  0.34   LP(NH)= 0.1576
CP(PF)= 0.1520   LL(NH)= 0.2550   CL1(PF)= 0.0000  CL(PF)= 0.10E+09
RL(OHM)=  50.0   LT(NH)= 0.1550   RT(OHM)=  5.0    CTF(PF)= 0.448E-01

ENTER NO.(50 MAX) OF TUNING CAPACS.:VALUES(PF)
12 .0545 .053 .0488 .0452 .0424 .0389 .038 .0371 .0362 .0349 .0331 .0322

ENTER CORRESPONDING LOAD POWERS(DBM)
20.65 4*20.75 7*20.85
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CT (PF)	PL (DBM)	FREQ (GHZ)	GLOAD (MS)	VD (PVOLT)	VP (PVOLT)	VJ (PVOLT)	IT (PMA)	PO (DBM)	PT (DBM)	PEX (DBM)
0.05450	20.65	39.215	34.15	2.73	5.47	3.21	43.11	8.25	6.67	21.05
0.05300	20.75	39.241	34.40	2.75	5.54	3.29	42.96	8.33	6.64	21.15
0.04880	20.75	39.315	35.19	2.72	5.55	3.40	41.04	8.27	6.24	21.13
0.04520	20.75	39.380	35.96	2.68	5.55	3.51	39.27	8.21	5.86	21.12
0.04240	20.75	39.431	36.65	2.65	5.56	3.60	37.80	8.17	5.53	21.11
0.03890	20.85	39.494	37.65	2.64	5.62	3.76	36.25	8.20	5.17	21.19
0.03800	20.85	39.509	37.93	2.63	5.63	3.79	35.72	8.19	5.04	21.19
0.03710	20.85	39.525	38.23	2.62	5.63	3.82	35.17	8.17	4.90	21.18
0.03620	20.85	39.540	38.54	2.61	5.63	3.85	34.62	8.15	4.77	21.18
0.03490	20.85	39.561	39.03	2.59	5.63	3.90	33.80	8.12	4.56	21.17
0.03310	20.85	39.588	39.77	2.56	5.63	3.96	32.62	8.08	4.25	21.16
0.03220	20.85	39.600	40.17	2.55	5.63	4.00	32.01	8.06	4.08	21.16

PRINTOUT LISTINGS

- C_T – MEASURED VARACTOR CAPACITANCE (pF)
- P_L – MEASURED LOAD POWER (dBm)
- FREQ – OSCILLATION FREQUENCY (GHz)
- G LOAD – LOAD CONDUCTANCE AT GUNN DIODE NEGATIVE RESISTANCE (mSEC)
- V_D – PEAK VOLTAGE ACROSS GUNN DIODE NEGATIVE RESISTANCE (VOLTS)
- V_P – PEAK VOLTAGE ACROSS GUNN DIODE PACKAGE (VOLTS)
- V_J – PEAK VOLTAGE ACROSS VARACTOR JUNCTION (VOLTS)
- I_T – PEAK VARACTOR CURRENT (mA)
- P_D – POWER D'SSIPATION IN GUNN DIODE PASSIVE RESISTANCE (dBm)
- P_T – POWER DISSIPATION IN VARACTOR CIRCUIT RESISTANCE (dBm)
- P_{EX} – POWER GENERATED BY GUNN DIODE (dBm)

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Figure 8. Computer Printout of the RF Voltages and Power Levels at the Circuit Elements Comprising a Ka-Band, Lumped Element, GaAs Gunn VCO

dissipated in the Gunn diode and varactor, as a function of frequency, is listed in the printout and shown plotted in Figure 9. This information gives insight into the understanding and control of VCO performance, for example, post-tuning drift with a step in VCO tuning voltage. To minimize post-tuning drift, a VCO can be designed for flat power dissipation with frequency at the varactor. Another example is that knowledge of the RF voltage swing at the Gunn diode gives insight into the operating mode. Thus, the modelling and fabrication of VCO's and oscillators in lumped element circuit form provides unique opportunities for their analysis and design and for the realization of optimum VCO performance.

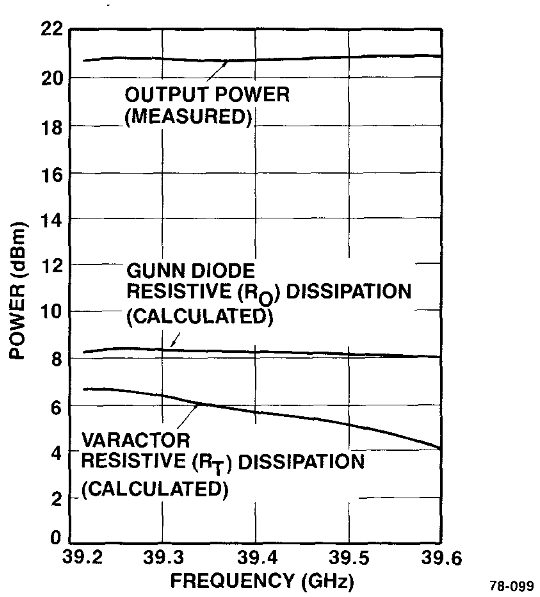

Figure 9. Varactor and Gunn Diode Power Dissipation in a Ka-Band VCO as a Function of Frequency

SUMMARY

The modelling, fabrication and performance of millimeter wave, lumped element, InP and GaAs Gunn VCO's and oscillators have been described. The lumped element circuit form has provided a unique means to accurately quantify the equivalent circuit parameters of the model, including the packaged Gunn diode, under large signal conditions. It has also given previously unavailable resolution into the operating conditions internal to a VCO or oscillator circuit by delineating the RF voltage and power values at the individual circuit elements. This new capability provides enhanced opportunities in analysis, design and synthesis for the advancement of the state-of-the-art in VCO and oscillator technology.

ACKNOWLEDGMENTS

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REFERENCE

(1) L.D. Cohen and N. King, "Frequency-Temperature Compensated Millimeter Wave Oscillators in Lumped Element and Printed Circuit Forms," 1986 IEEE-MTT-S International Microwave Symposium Digest, pp 169-172.