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WIDEBAND ELECTRONICALLY TUNABLE GaAs GUNN VCO's AT W-BAND (75-110GHz)

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ABSTRACT

A series tuned GaAs VCO employing a second harmonic radial disk circuit has provided up to 10 percent electronic tuning bandwidth (ETB) at 94GHz. Packaged GaAs Gunn and Hyperabrupt Varactor Diodes are employed. Analysis of the series equivalent circuit provides insight into methods of controlling trade-off between output power and tuning bandwidth, e.g. by restricting the ETB to 1.5GHz around 92.3GHz an output power of 18 to 22mW was achieved; with tighter coupling an output power of 11 to 12.8mW from 91.5 to 95.5GHz resulted.

INTRODUCTION

The series resonant radial disk Gunn voltage controlled oscillator (VCO) design reported earlier [1] , [2] at Ka-Band (26.5 - 40GHz) and V-Band (60 - 75GHz) has been extended to the W-Band (75-110GHz) range. Advantage is taken of the inherently non-linear Gunn diode current waveform to generate useful power at the second harmonic frequency near 94GHz. Electronic bandwidths of 10% have been achieved by tuning the fundamental component (at 47GHz) using a radial disk series geometry similar to that shown in [2]. The frequency of operation is primarily controlled by the size of the radial disk and its position above the ground plane. Since the disk height 'h' is considerably less than a wavelength, the simple magnetic line and wall model, cf. e.g. [3], can be applied and the zero-order resonant frequency is found to be in good agreement with experimental measurements. The dominant TM_{nmo} mode is established along the disk diameter and radiates in the waveguide direction. The series resonant fundamental component is below the cut-off frequency of the W-Band waveguide and therefore does not propagate. Due to the inherently high Q of the radial disk second harmonic circuit [4] and wideband tuning features of series versus parallel configurations [5], this arrangement has been exploited over other possible designs. Novel features of the circular disk antenna are utilized in this oscillator; for example, the Gunn diode bias wire is intentionally aligned perpendicular to the disk and attached to the edge where the disk impedance is highest. Additionally, it is oriented to the point closest to the backshort; this guarantees that it is immersed in the region of maximum electric field established along the disk in the Z-direction and minimizes its interference with the second harmonic radial disk dominant mode fields. The degree of coupling between varactor and Gunn is conveniently controlled by varying the disk thickness and by enclosing a portion of the packaged Gunn diode (cap and ceramic ring) with a recess counter-bored in the disk face, which contacts the Gunn diode cap. A reduced height waveguide is needed to minimize the inductance of the series posts required to mount and bias both packaged devices, and to ensure that the associated parallel resonant waveguide mode [6] is far removed from the second harmonic series resonant mode. The resonant disk which establishes the dominant TM mode is suspended in air; its location above the ground plane, as well as its diameter, introduces the essential capacitive reactance required to resonate with the series inductances inherently introduced by both packaged devices as shown earlier [2], [7]. A compact miniature size unit was constructed by replacing the long linear taper of the output port with a two-step Tchebyschev transformer. Temperature performance of the initial design with long linear taper resulted in $\Delta P/\Delta T$ = 0.05dB/°C at + 54°C and $\Delta f/\Delta T$ = 5-10MHz/°C. Measured noise at 100kHz off the carrier was less than 90dBc/Hz in a laboratory environment and load pulling quality factors are typically 1,500 at the second harmonic frequency.

CIRCUIT ANALYSIS

The series arranged second harmonic oscillator as shown in Fig. 1a incorporates packaged Gunn and Varactor diodes which exhibit extremely low terminal impedance at the fundamental operating frequency (i.e. around 47GHz). A radial transmission line in the form of a resonant disk is placed over the Gunn diode. Because of the small height 'h' of the radial disk above the ground plane, no integral half-wavelength can be accommodated in the Z-direction of the cylindrical co-ordinate system shown in Fig. 2 for the frequencies presently used in this design. Consequently all fields in the resonator are TM modes and Stratton's [8] treatment can be used. The field components have only circumferential and radial variations but no

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variations in the Z-direction and are given on Fig. 2.

By imposing the appropriate boundary conditions at the edge of the disk its minimum diameter, which corresponds to the dominant TM_{110} mode [9],

$$\text{Disk Diameter (inches)} = 2a = \frac{6.922}{f(\text{GHz})} \qquad (1)$$

can be computed (e.g. 1.88mm = .074"at f = 94GHz). If the spatial distribution of the fundamental and second harmonic components are chosen so that λ_g (fo) = 3λ_g (2fo)as in [10] it can be shown that

$$\text{Disk Diameter} \approx \frac{\lambda_g(2fo)}{2} . \qquad (2)$$

If the packaged varactor is embedded in the bias filter, cf. Fig. 1a, it will be located at a low impedance point (voltage mode) and its prong can be used to provide the essential inductance required to series resonate with the capacitive disk-Gunn components [2]. The varactor, located as shown effectively 'modulates' the length of the inductive post at the fundamental operating frequency. The entire series structure is immersed in a reduced height WR-10 (WG-27) waveguide to avoid the parallel resonant waveguide mode [6]. The equivalent circuit for the series geometry is shown in Fig. 1b. A dual of the graphical analysis done in [11] for the mechanically tunable harmonic disk oscillator can be applied to this circuit to illustrate the fundamental operating mode.

MEASURED RESULTS

Electronic tuning characteristics and output power versus varactor bias voltage are shown in Figs.3 through 5 for some of the W-band series VCO's described above. A typical value of resonant disk diameter 1.905mm (0.075") was used in these oscillators in accordance with (1). Hyperabrupt tuning varactors were employed in these sources. The results shown in Fig. 3 are for a disk having no recess for Gunn diode embedding. An ETB of 9.4GHz (10%) centered at 94GHz with output power ranging from 0.2 to 2.0mW resulted. In another arrangement, with a portion of the Gunn diode partially embedded in the disk face and ETB of 6.5GHz with output power variations between 7 and 12.8mW resulted; a 4GHz ETB centered at 93.5GHz provides output power from 11 to 12.8mW, cf. Fig. 4. With the Gunn diode further embedded in the disk face, the trade off between ETB and power output is apparent, as shown in Fig. 5. Several Gunn diodes providing from 20 to 26mW in standard fixed frequency test oscillators were assembled in VCO's. The varactor was inverted with its prong extended from the choke as discussed previously. The reduced degree of coupling of the Gunn diode fields resulted in an ETB of 1.5GHz centered at 92.3GHz with the output power variations extending from a minimum of 18mW to a maximum of 22mW for one device (#31). For this device the nominal rated Gunn diode power was 22mW. For the other devices greater than 10mW output power over approximately 1GHz ETB resulted without further circuit optimization, cf Fig. 5.

When the hyperabrupt varactors are replaced with silicon abrupt varactors, a reduction in tuning bandwidth results due to reduced varactor capacitance variations. One arrangement exhibited an ETB of 2.1GHz around 93.5GHz and output power between 4.2 and 6.0mW [9]. Similar performance was attained with other silicon abrupt tuning varactors showing that these diodes are useful when very wide tuning ranges are not required.

Temperature behaviour of the series VCO's having reduced height WR-10 waveguide with long linear taper transitions to full height have been measured over the range from 0°C to +60°C. The power variation $\Delta P/\Delta T$ is less than 0.05dB/°C at +54°C and the frequency change $\Delta f/\Delta T$ is typically 5MHz/°C with maximum excursions of 10MHz/°C. The noise performance measured at 100kHz off the carrier is less than 90dBc/Hz using standard power supplies and laboratory test facilities. Measured load pulling quality factors at the second harmonic frequency are typically 1,500 with one unit exhibiting $Q_L \approx 10,000$!

SUMMARY

The theory of operation of resonant radial disk series VCO's has been successfully applied to oscillators operating at W-Band (75-110GHz) frequencies. Electronic tuning of 10% at 94GHz has been achieved. Trade-off between gain and bandwidth occurs by controlling the degree of coupling of varactor and Gunn circuits through embedding of the packaged Gunn diode in the face of the disk resonator. With relatively weak coupling the power output can be made to approach that obtained in a standard fixed frequency test oscillator and typical tuning bandwidths of 2GHz result. If silicon abrupt tuning varactors are used in place of hyperabrupt GaAs varactors, the ETB is correspondingly reduced along with power output; however, useful sources having nominally 5mW power outputs over a 2GHz range have been constructed. Typical temperature behaviour, noise performance, and load pulling quality factors of the series VCO's approach that of conventional fixed frequency second harmonic sources having radial disk geometries.

ACKNOWLEDGEMENT

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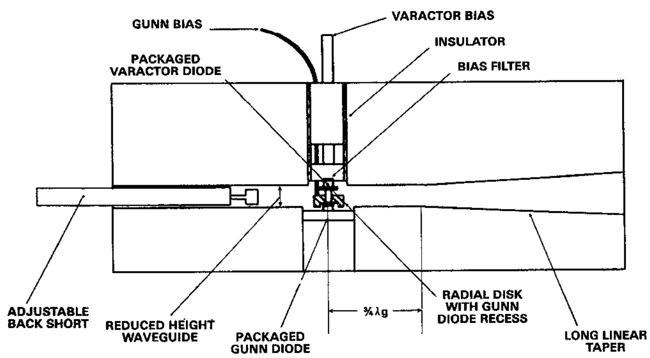


Fig. 1(a) INTERNAL DETAILS OF SECOND HARMONIC SERIES ARRANGED RADIAL DISK OSCILLATOR WITH PACKAGED GUNN AND VARACTOR DIODES.

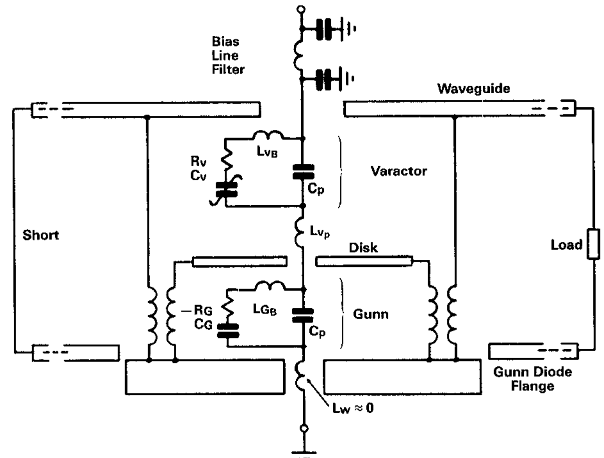
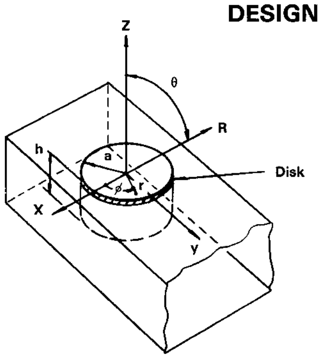


FIG. 1(b) EQUIVALENT CIRCUIT OF PACKAGED GUNN DIODE, RADIAL DISK, PACKAGED VARACTOR AND BIAS FILTER.

DESIGN PRINCIPLES



When $h \ll \frac{\lambda g}{2}$

- Only TM modes exist
- Field components have circumferential and radial variations (No Z-Direction variations)

$H_Z = E_\theta = E_r = 0$

$E_Z = E_0 J_n(kr)\cos(n\phi + \theta)$

$H_r = -j\frac{\omega\varepsilon n}{k^2 r} E_0 J_n(kr)\sin(n\phi + \theta)$

$H_\phi = -j\frac{\omega\varepsilon}{k} E_0 J_n'(kr)\cos(n\phi + \theta)$

- Surface currents

$K_\phi = -H_r,\ K_r = H_\phi$

$K_r = 0$ At $r = a \therefore J_n'(ka) = 0$

FIG. 2 COORDINATE SYSTEM, FIELD COMPONENTS AND BOUNDARY CONDITIONS FOR RADIAL DISK IMMERSED IN WAVEGUIDE

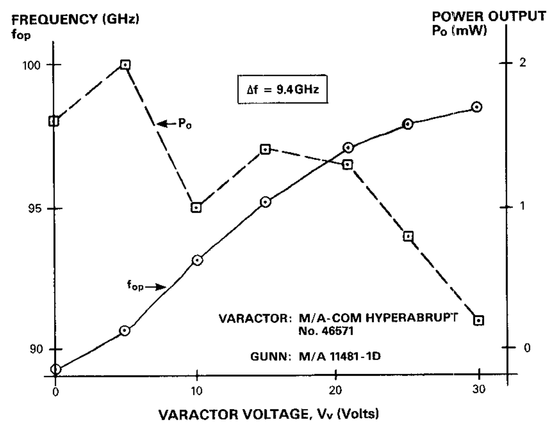


FIG. 3 W-BAND (75-110GHz) SERIES TUNED VCO FREQUENCY AND POWER OUTPUT VERSUS VARACTOR VOLTAGE. DISK WITHOUT GUNN DIODE RECESS.

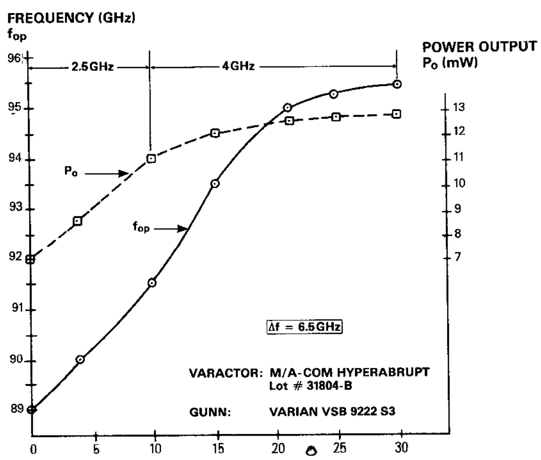


FIG. 4 W-BAND (75-110GHz) SERIES TUNED VCO FREQUENCY AND POWER OUTPUT VERSUS VARACTOR VOLTAGE. GUNN DIODE PARTIALLY EMBEDDED IN DISK SURFACE

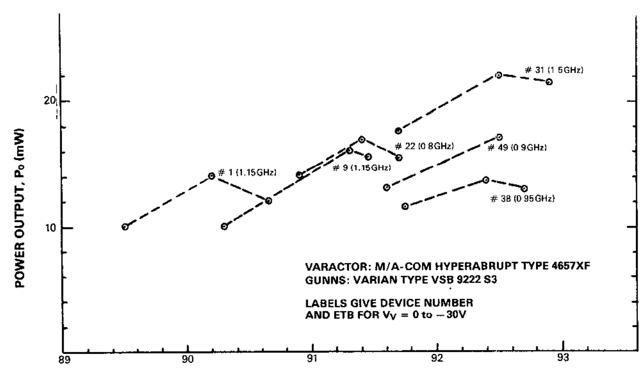


FIG. 5 POWER AND TUNING PERFORMANCE FOR VCO CIRCUIT WITH HIGH POWER GUNN DIODES. GUNN DIODE EMBEDDED IN DISK FACE. HYPERABRUPT TUNING VARACTOR WITH PRONG EXTENDED.

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