HIGHLY STABLE 15 dBm LOW NOISE GaAs MESFET SOURCE AT 45 GHz USING A GaAs PHEMT AS A FREQUENCY DOUBLER

A P S Khanna, Carl Creamer, Ed Topacio* & Edmar Camargo**

ABSTRACT

A highly stable GaAs MESFET dielectric resonator oscillator with a GaAs PHEMT frequency doubler, operating at 45 GHz, has been developed. The oscillator presents + 15 dBm minimum output power, ±0.01% temperature stability and -82 dBc/Hz phase noise at 10 Khz from the carrier. The design approach is discussed and practical test results are presented.

INTRODUCTION

The rapid increase in applications for millimeter wave technology has resulted in the need for efficient, reliable and highly stable oscillators. Until recently a Gunn oscillator was the only choice for a low noise source with reasonable power output at frequencies beyond 30 GHz. The advancement of the GaAs MESFET and PHEMT technology has made it possible not only to generate signals at millimeter wave frequencies, but to process them through frequency multipliers and amplifiers at levels not attainable without the bulk devices till recently. This paper describes the design approach and practical realization of a 45 GHz source. Using a low noise GaAs MESFET DRO at 22.5 GHz, followed by a GaAs PHEMT frequency doubler and GaAs MESFET buffer amplifier, + 15 dBm power has been achieved at 45 GHz. The phase noise of - 82 dBc/Hz at 10 kHz and frequency stability of better than ± 4 MHz from -30^{o} to +60^{o} C represent the best results reported till date in this frequency band. The compact packaging and low power dissipation are other attractive features of this approach compared to the alternatives. The technology used is capable of being implemented as a GaAs MMIC to perform all the functions.

DESIGN APPROACH

The block diagram of the 45 GHz source as depicted in figure 1, comprises three main parts: Dielectric Resonator Oscillator (DRO), Frequency Multiplier and Amplifier. The design approach of each of these components is described next:

* Avantek Inc., 481 Cottonwood Drive, Milpitas, CA. 95035, USA.

** University of Såo Paulo C.P. 8174 - CEP 01051 Såo Paulo, Brazil.

GaAs MESFET DRO

The GaAs MESFET DRO uses an Avantek low noise 0.3 um GaAs MESFET with gate width of 600 um. High quality vapor phase epitaxial material was used and devices were fabricated using AuGe/Ni/Au as the contact metal, double recesses and refractory metal in the gate step and silicon nitride in the device passivation layer. The F_t and F_{max} estimated from the S-parameters of typical devices are 40 GHz and 80 GHz respectively. The dielectric resonator, manufactured by Trans Tech has a dielectric constant of 29.

The series feedback oscillator shown in Figure 2, was designed with conventional techniques employing S-parameters to determine the circuit parameters that satisfy the oscillating conditions at 22.5 GHz. Low phase noise was obtained by first selecting a device that presented a low 1/f noise and then by calculating the dielectric resonator coupling to the transmission line that optimizes the loaded Q as well as temperature stability[1]. The important test parameters are described in table I

Frequency	22.5 GHz
Power output	13.0 dBm
Frequency pulling	$\pm$ 2MHz into 2:1
Phase Noise	-88/Hz dBc at 10 KHz
Frequency stability	$\pm$ 2 MHz from -30^{o} to $+60^{o}$ C

Table I - DRO Electrical Characteristics

This low noise results represents 6 to 8 dB improvement in phase noise over typical commercial GaAs MESFET dielectric resonator oscillators.

FREQUENCY MULTIPLIER

The frequency multiplier uses an Avantek GaAs Pseudomorphic HEMT (PHEMT) with a sub 0.2 um as gate length and 250 um gate width, fabricated on MBE material[2]. The gates were defined using electron-beam lithography resulting in gate lengths ranging from 0.2 to 0.25 um. These devices have an F_t of 80 GHz, F_{max} of 160 GHz and are capable of delivering +17 dBm linear power with 8 dB gain at 18 GHz. Their main static characteristics are shown in Figure 3. Note that the device has a high non-linear transconductance which is adequate for harmonic generation[3]. Currently available non-linear models are not able to accurately represent the non-linear characteristics for this type of device, which means that the design has to rely on experimental results. For the sake of comparison an investigation was carried out on a multiplier test circuit operating in the 6 to 12 GHz range and the results compared to a typical MESFET of similar area. It was verified that, biased at V_{GS} = -1.2V; V_{DS} = 5.0 V the PHEMT presented a multiplication gain of 9 dB and an output power of

+13 dBm. The multiplication gain is roughly the same presented by MESFET multipliers with a 1 dB advantage to PHEMTs, but the improvement in second harmonic output power exceeds 4 dB.

The multiplier prototype operating from 22.5 GHz to 45 GHz was constructed on an alumina substrate, employing the same bias conditions as used in the 6 GHz circuit. A 90^{o}@ 22.5 GHz open stub was connected to the drain for blocking the fundamental and at the same time presenting the necessary drain reactance for maximum gain. The capacitive input impedance was inductively matched by means of wire bonds. The results for the mm-wave doubler are shown in table II.

Frequency input	22.5 GHz	
Frequency output	45.0 GHz	
Power input	13 dBm	
Power output	@45 GHz	7 dBm
	@22.5GHz	-10 dBm

Table II - PHEMT multiplier characteristics

These impressive results were obtained over the temperature range of -30^{o} to $+60^{o}$ and confirm the adequacy of PHEMTs as mm-wave frequency multipliers.

GaAs MESFET AMPLIFIER

The amplifier section uses two balanced amplifiers using an Avantek GaAs MESFET with 0.2 um gate length and 75 um gate width. The balanced amplifier substrates are mounted on a Kovar carrier for better heat sinking and module testability. The GaAs MESFETs are self biased from a single power supply on the drain side, with the gate being grounded for DC. The design details for this amplifier are explained elsewhere[4], and its performance is described in table III.

Frequency band	44 - 46 GHz
Small signal gain	10 dB
Power output (@ 1 dB)	+ 15 dBm
In/Out return loss	< 12 dB

Table III - MM-wave amplifier performance

EXPERIMENTAL RESULTS OF THE MILLIMETER WAVE ASSEMBLY

The oscillator, multiplier and amplifier are constructed on .254 mm thick alumina substrates with thin film hybrid circuitry and are housed in a compact package measuring 50mm x 50mm x 7mm. The output is connected to the WR22 waveguide with a feedthru. The experimental results for the 45 GHz source operating at 25^{o} C are listed in table IV.

Frequency	44.810 GHz
Power Output	+ 15 dBm

Frequency Pushing	<0.1MHz/V
Frequency Drift (-30^{o} to + 60^{o} C)	3.7 MHz
Phase Noise at 10 KHz	-82 dBc/Hz
Bias supply	12V, 175 mA

Table IV - Performance of the 45 GHz source.

The frequency stability as a function of temperature is represented in Figure 5. The phase noise was measured after downconverting the 45 GHz signal to 3.8 GHz using a cavity stabilized Gunn source as the reference source at 10 GHz. The results are plotted in Figure 6. Figure 7 shows a picture of the 45GHz low noise source mounted on a WR22 waveguide output test fixture.

CONCLUSIONS

This paper presented a successful oscillator design that confirms the validity of the approach followed for obtaining low phase noise. Also presented are the results of investigation on non-linear characteristics of PHEMTs and the application of PHEMTs as a highly efficient harmonic generator.

Finally, it can be said that this paper explored the capability of different state-of-the art devices namely GaAs MESFET 0.3um x 600um^2; PHEMT 0.2um x 250 um^2 and GaAs MESFET 0.2um x 75 um^2, in order to develop a new low phase noise, highly stable and medium power 45 GHz source.

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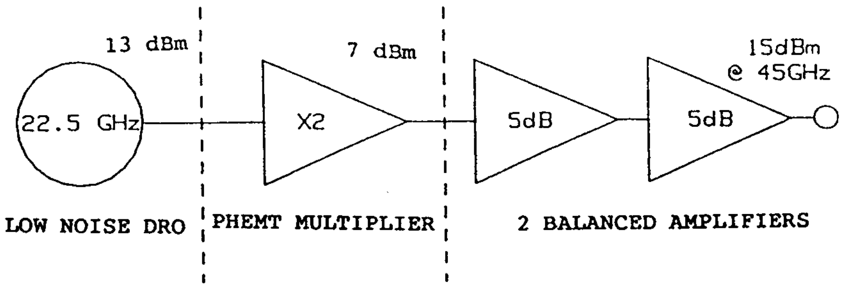

Fig.1 Block Diagram of the 45GHz Source

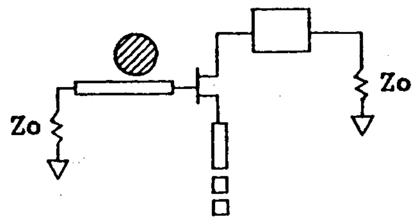

Fig.2 GaAs FET DRO

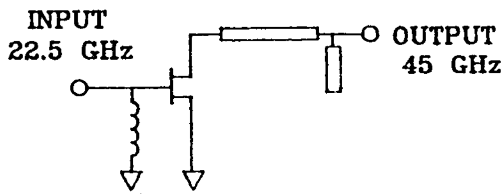

Fig.4 PHEMT Frequency Multiplier

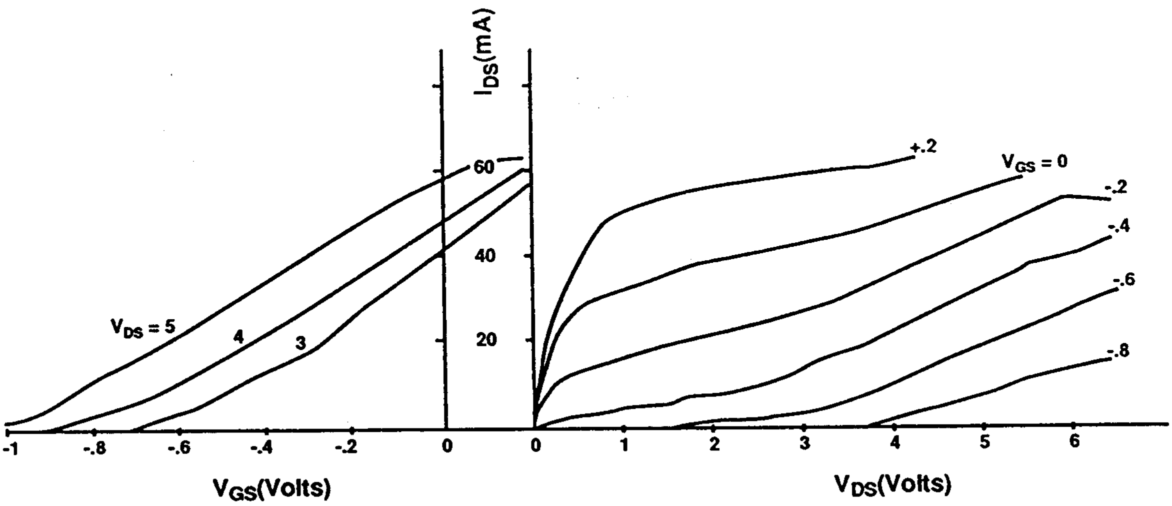

Fig.3 PHEMT Static Characteristics

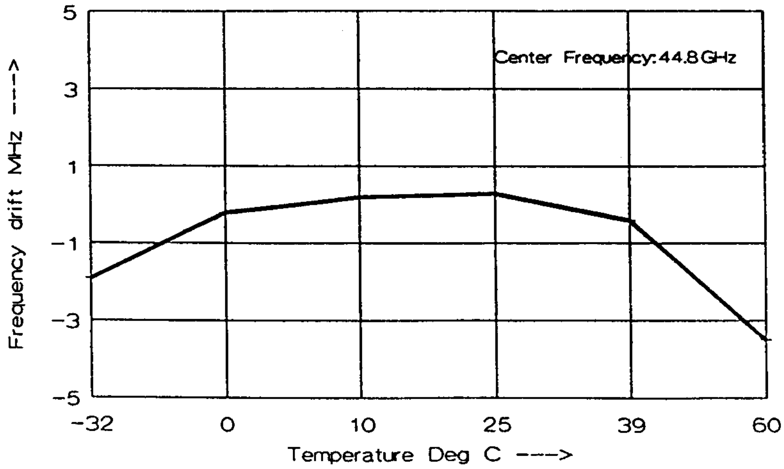

Fig.5

Temperature Stability of the 45GHz Source

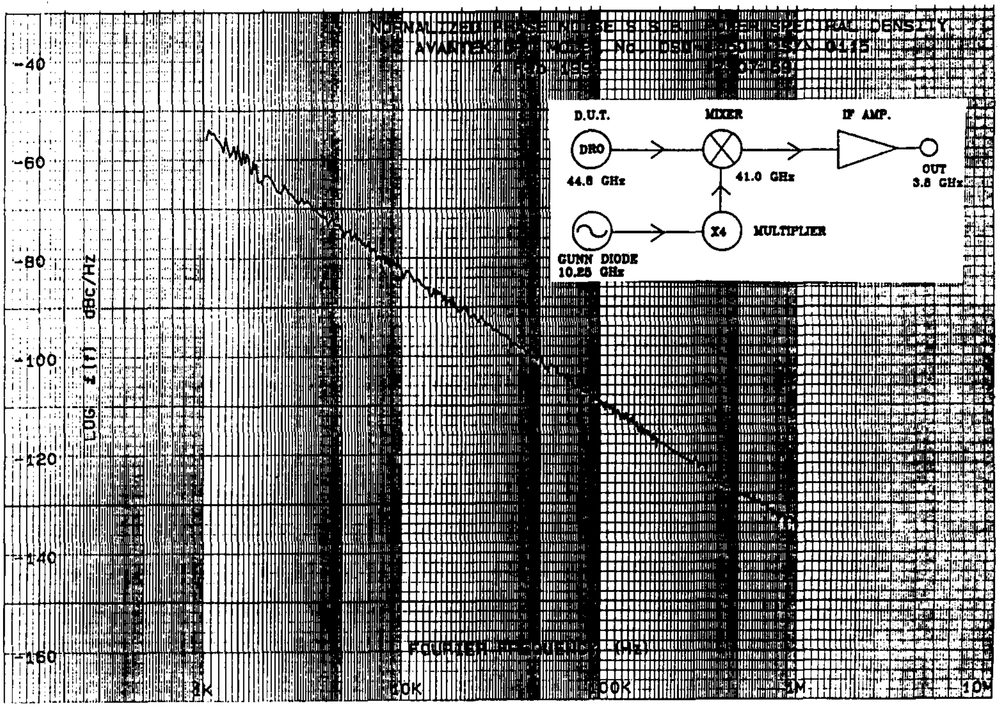

Fig.6 Phase Noise of the 45GHz Source.

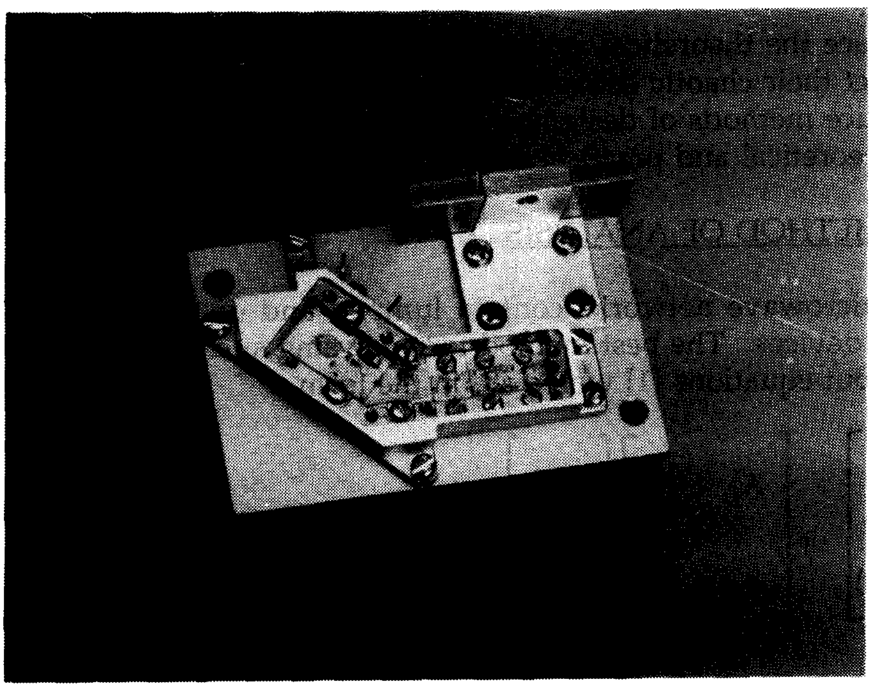

Fig.7 GaAs FET/PHEMT Millimeter Wave Source