APPLICATION NOTE 978

The Design of GaAs FET Oscillators

INTRODUCTION

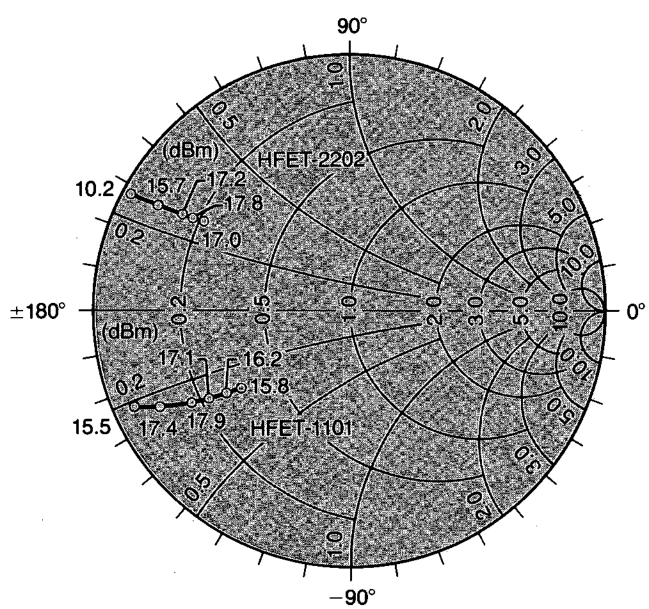
The design technique for bipolar transistor oscillators proposed in Hewlett-Packard Application Note 975 is shown to be applicable to GaAs FET oscillators also. In order to compare GaAs FET and bipolar oscillators, 4.3 GHz oscillators using the HFET-1101 (1 micron gate length) and the HFET-2202 (0.5 micron gate length) were built with a topology similar to the bipolar HXTR-4101 oscillator described in AN 975. Phase noise is compared, and the effect of matching element Q on noise performance is considered.

FET OSCILLATOR DESIGN

With the transistor represented by its measured S-parameters at 4.3 GHz, an initial topology using shorted 50Ω stubs in the source circuit and an open 50Ω stub attached to the gate was selected and computer optimized[1] in order to produce circuit dimensions that would provide an input impedance of −50Ω[2]. With this topology, however, there was no solution, so additional elements (open 50Ω shunt stubs) were utilized in the drain circuit. This topology provided solutions for both the HFET-2202 and HFET-1101.

These −50Ω microstrip networks were fabricated on RT/Duroid[3] 5880, FETs were installed and biased (see Appendix 1), and circuits were then analyzed on a Hewlett-Packard model 8410B network analyzer test system for optimum load impedance required to provide maximum oscillator power output at 4.3 GHz. To obtain this information the harmonic converter (8411A) was reversed so that the impedance observed on the polar display exhibited the impedance with its sign reversed. The incident and reflected powers were recorded as a function of incident power, and the impedance associated with each power level was noted. From this data the maximum added power (reflected-incident) and the related impedance were obtained. The power and impedance information are shown in Figure 1.

The displayed impedance at maximum added power is the optimum load impedance. The design was completed with the



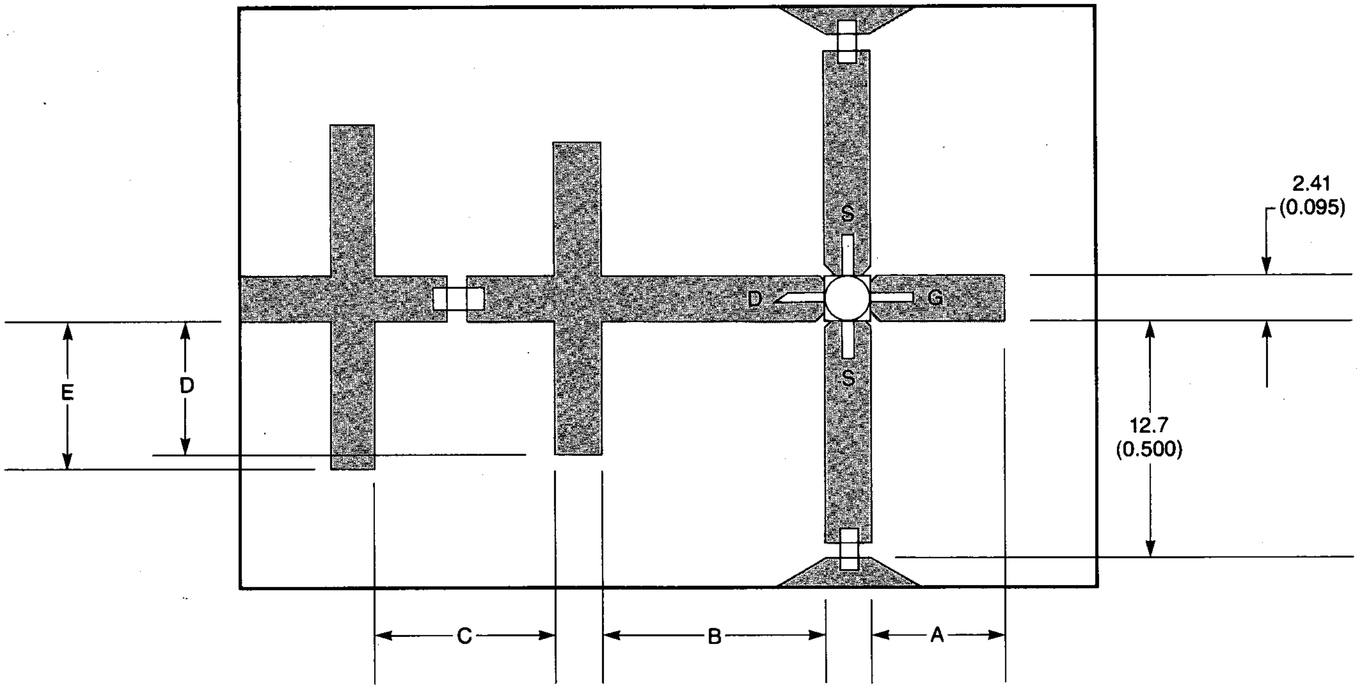
FREQUENCY = 4.3 GHz		
	HFET-1101	HFET-2202
$V_{DS(V)}$	4.0	3.5
$I_{DS(mA)}$	45	84

Figure 1. Load Impedance Versus Added Power for HFET-1101 and -2202 Non-Oscillating Circuits.

fabrication of matching networks (see Appendix 2) involving two 50Ω open shunt stubs placed the required distance away from the reference plane of the impedance measurement.

OSCILLATOR PERFORMANCE

Circuits were then tested, and the HFET-1101 circuit oscillated without any tuning adjustment with an output power of



	HFET-1101 LENGTH	HFET-2202 LENGTH	
	COMPUTED AND ACTUAL	COMPUTED	ACTUAL
A	8.03 (0.316)	7.62(0.300)	8.13(0.320)
B	14.0 (0.552)	14.0 (0.550)	14.0 (0.550)
C	8.18 (0.322)	14.0 (0.550)	14.0 (0.550)
D	6.63 (0.261)	7.65(0.301)	6.48(0.255)
E	5.44 (0.214)	6.50(0.256)	6.60(0.260)

DIMENSIONS IN MILLIMETERS (INCHES)
MATERIAL: RT/DUROID 5880
THICKNESS: 0.079(0.031)

Figure 2. Computed and Actual Dimensions for the HFET-1101 and -2202 Oscillators.

17.7 dBm. The HFET-2202 required slight adjustment of the gate and drain stubs after which it produced an output power of 17.6 dBm. The maximum added power for the -50Ω circuits were 17.9 and 17.8 dBm for the HFET-1101 and HFET-2202 respectively. This shows good agreement between measured and predicted power levels. A comparison of computed versus final circuit dimensions is shown in Figure 2.

PHASE NOISE

Figure 3 compares the phase noise of these GaAs FET oscillators to that of a similarly designed HXTR-4101 oscillator (Figure 4). The GaAs FET oscillators are about 16 dB noisier. This result is similar to that obtained for microstrip voltage controlled oscillators[4] at X-band.

PHASE NOISE WITH AIR DIELECTRIC SLUG TUNERS

The same transistor units used in the microstrip tuned oscillators were placed in -50Ω non-oscillating microstrip circuits. The load impedances required to permit oscillation were then provided by air dielectric slug tuners. It was possible to obtain output power levels of 17.3, 17.1, and 19.8 dBm at close to 4.3 GHz for the HFET-1101, HFET-2202, and the HXTR-4101 oscillators respectively. These values are very close to those obtained above with microstrip matching stubs. Figure 5 shows the phase noise performances of these oscillators. The HXTR-4101 oscillator is still the best performer. However, the HFET-1101 and HFET-2202 oscillators show greater improvement in performance when compared to their microstrip stub tuned counterparts. The HXTR-4101 oscillator's noise

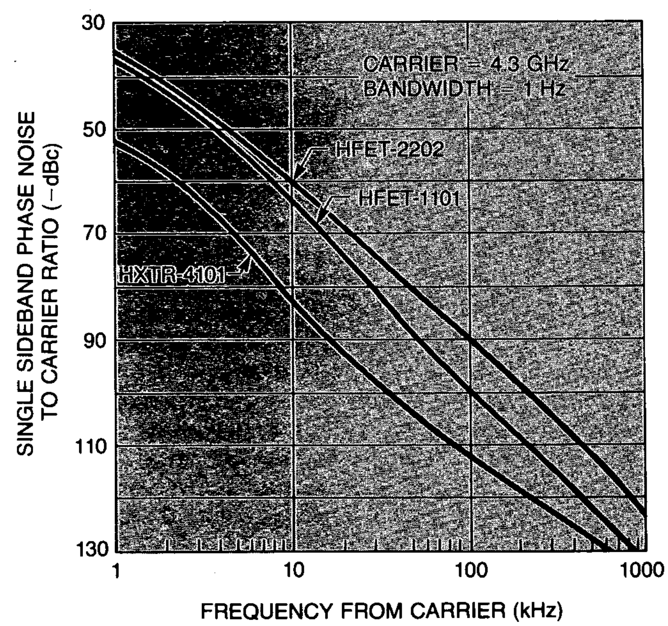
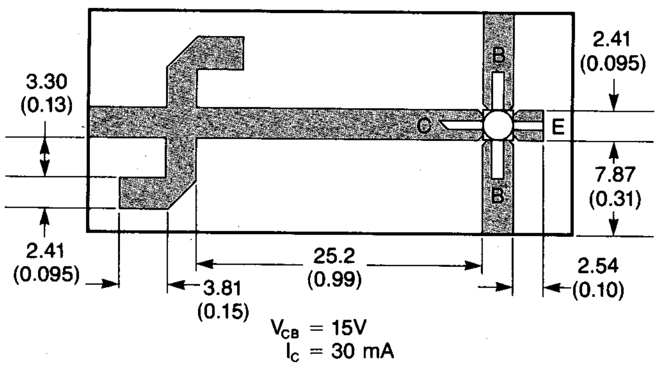


Figure 3. Phase Noise of HFET-1101, -2202 and HXTR-4101 Oscillators.



DIMENSIONS IN MILLIMETERS (INCHES)

Figure 4. HXTR-4101 Oscillator Circuit.

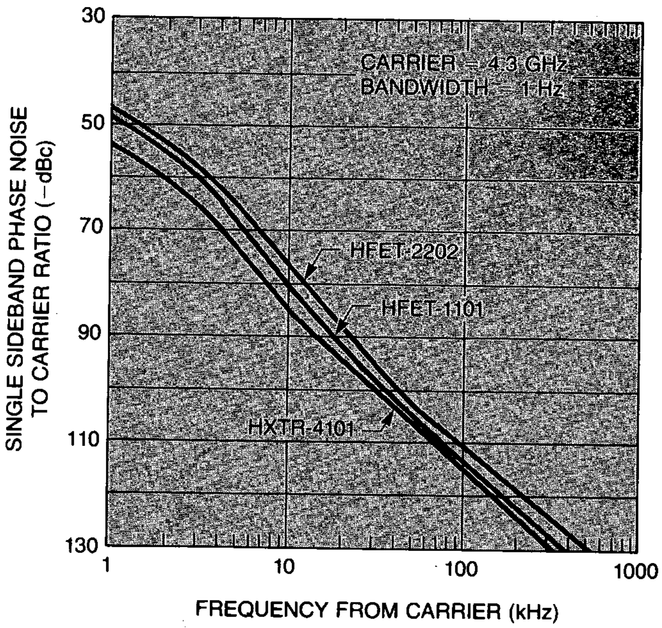


Figure 5. Phase Noise of HFET-1101, -2202 and HXTR-4101 Oscillators with Air Dielectric Slug Tuners.

performance only improved by approximately 2.0 dB while the FET oscillators' noise improved by about 14 dB. Since phase noise is related[5] to Q, the higher Q of the simpler bipolar oscillator circuit may explain this difference.

CONCLUSIONS

The oscillator technique described in AN 975 for bipolar transistors is also applicable to GaAs FETs. FET oscillators do seem to have higher phase noise than bipolar oscillators; however, the FET oscillator noise appears to be more sensitive to the matching circuit. It was also observed that the 1 micron gate FET (HFET-1101) exhibited slightly lower phase noise than the half-micron device (HFET-2202).

APPENDIX 1
BIASING THE HFET-2202 AND HFET-1101

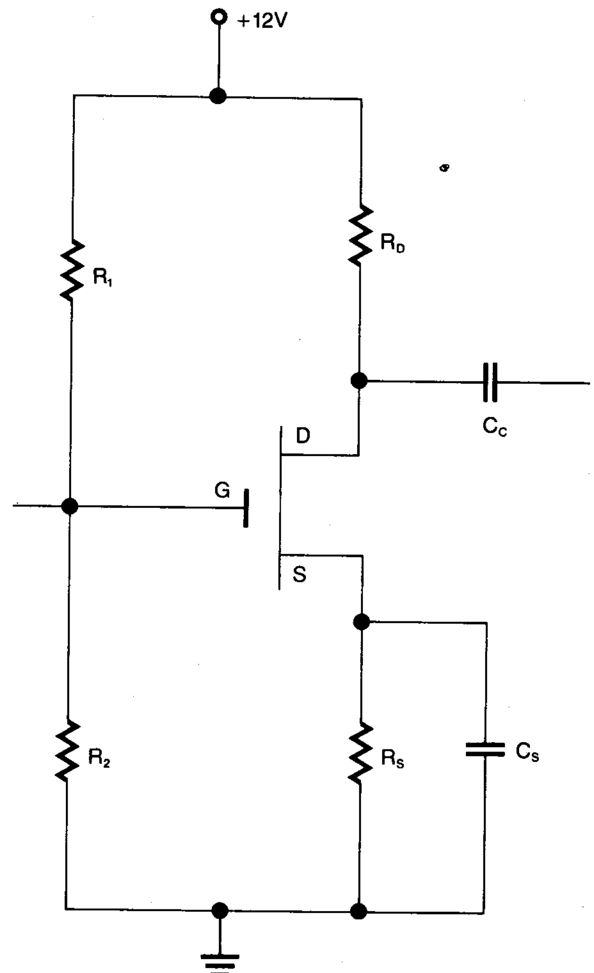
The configuration selected is shown in Figure 6. This configuration was selected because it utilizes a single power supply, yet it is stabler than other configurations. The oscillator, being a high gain device, should be biased as a high gain amplifier, i.e., at $I_{DSQ} = I_{DSS}$ and V_{DSQ} = 3.5V for HFET-2202 and 4.0V for HFET-1101. The remaining values for the biasing circuits were obtained as follows:

FOR THE HFET-2202

1. Selecting V_{DD} = 12V, V_{GS} = 0, I_{DSS} = 84 mA (measured) and $R_D = R_S$, the values of R_D and R_S were computed from:

$$V_{DD} = I_{DSQ}(R_D + R_S) + V_{DS}$$

to yield $R_D = 51\Omega$.



	HFET-1101	HFET-2202
$V_{DS(V)}$	4.0	3.5
$I_{DS(mA)}$	45	84

	HFET-1101	HFET-2202
COMPONENT	VALUE	
C_C	10 pF	10 pF
C_S	10 pF	10 pF
R_1	100 kΩ	100 kΩ
R_2	51 kΩ	61.9 kΩ
R_D	90.9 kΩ	51Ω
R_S	90.9 Ω	51Ω

Figure 6. HFET-1101, -2202 Oscillator Bias Circuits.

2. Selecting $R_1 = 100\ k\Omega$, R_2 was found by solving these equations:

$$(I_{DSQ})\, R_S = V_{GG}$$

$$\left(\frac{R_2}{R_1 + R_2}\right) V_{DD} = V_{GG}$$

for $R_2 = 55.5\ k\Omega$ (closest available value = $61.9\ k\Omega$). The values for the HFET-1101 were similarly obtained and are shown in Figure 6.

APPENDIX 2
MATCHING NETWORK CALCULATIONS

The matching network required must transform the admittance corresponding to the center of the Smith Chart, Y_O (see Figures 7 and 8), to the optimum load admittance, Y_A. This was done by first transforming to a point, Y_B, on the unit conductance circle at the same radial distance as the load admittance by the addition of shunt lines with susceptance determined by Y_B. This point was selected to be in the capacitive half of the Smith Chart because Y_B corresponds to an easily adjustable open line, whereas the corresponding point in the inductive half of the Chart corresponds to the more difficult to adjust shorted line. Finally, Y_B was transformed to the optimum load admittance, Y_A, by a rotation towards the generator.

For the HFET-1101 the normalized load admittance at point Y_A in Figure 7 is 1.9 + j2.1, and the admittance at Y_B is 1 + j1.6. The susceptance required to transform Y_O to Y_B was obtained by using two 50Ω open shunt stubs. The length of each line was obtained as follows:

$$\frac{Y}{Y_O} = j \tan \theta = j\,\frac{1.6}{2}$$

$$\theta = 38.7^\circ$$

$$\text{Length} = 5.44\ \text{mm}\ (0.214\ \text{inch})$$

Transformation from Y_B to Y_A was done by adding a 50Ω line of 0.026 wavelength (see Figure 7) or 1.32 mm (0.052 inch). The 50Ω shunt stubs were located 1.32 mm towards the generator with respect to the reference plane used in measuring the optimum load admittance.

Similarly, the lengths of the two 50Ω shunt stubs for the HFET-2202 were found to be 0.104 wavelength or 6.50 mm (0.256 inch) and located 5.26 mm (0.207 inch) from the reference plane towards (away from the FET) the generator (see Figure 8).

REFERENCES

1. Compact Engineering, Inc., 1070 East Meadow Circle, Palo Alto, CA 94303.
2. Hewlett-Packard Application Note 976, "A 4.3 GHz Oscillator Using The HXTR-4101 Bipolar Transistor."
3. Rogers Corporation, Chandler, Arizona.
4. Edward C. Niehenke and Ricky D. Hess, "A Microstrip Low-Noise X-Band Voltage Controlled Oscillator," IEEE Trans. MTT, Vol. MTT-27, No. 12, pp 1075-1079 (December 1979).
5. Dieter Scherer, "Learn About Low Noise Design," Microwaves, Vol. 18, No. 4, pp 120-122 (April 1979).

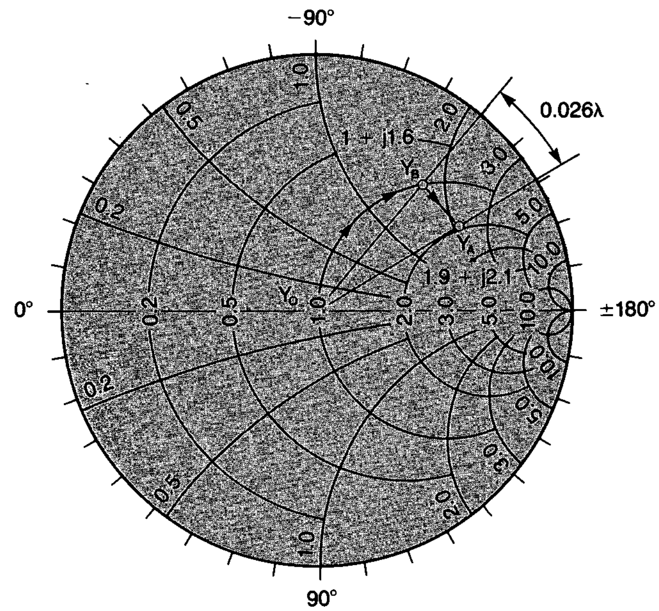


Figure 7. Matching Network Design for HFET-1101 Oscillator.

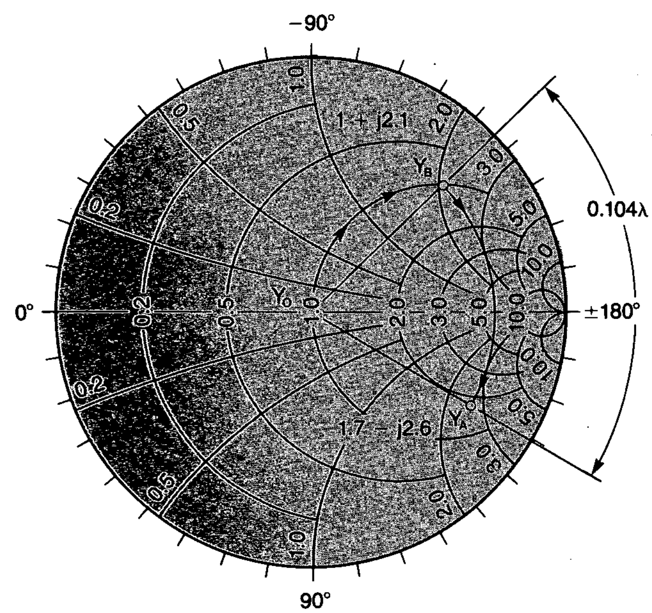


Figure 8. Matching Network Design for the HFET-2202 Oscillator.

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