HIGH EFFICIENCY MICROWAVE TRANSISTOR OSCILLATOR

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ABSTRACT

A high efficiency oscillator was designed and simulated using a high frequency linear CAD program called PUFF. The transistor used was an Agilent MESFET, ATF-10736, operating at a DC bias of 2V and 25mA. The oscillator was designed linearly using the 1/3 oscillation rule because of its effectiveness and simplicity. Oscillation feedback was connected to the MESFET in a common source configuration using a simple 76.2° transmission line in order to provide a negative resistance of -90Ω looking into the drain. An output power of 15 dBm was recorded from the data sheet of the transistor, and was used to calculate a conversion efficiency of 63.2%. Using the circular function, the oscillator was found to oscillate at a frequency of 10.79 GHz.

INTRODUCTION

The unmanned nature of space-related applications has always dictated the need for highly efficient interplanetary devices. High efficiency devices not only require less power to operate, but they also lower the cost of interplanetary missions, since extra resources are not needed to compensate for losses in power.

A microwave oscillator converts DC power to RF power, and is therefore one of the most basic and essential components in a microwave system [Fig. 1]. Without an RF signal to place the message onto, wireless communications, like those between earth and space stations, would not be possible. Therefore, the prevalence of oscillators in communication systems, along with the need for efficient components, dictates the need for efficient oscillators.

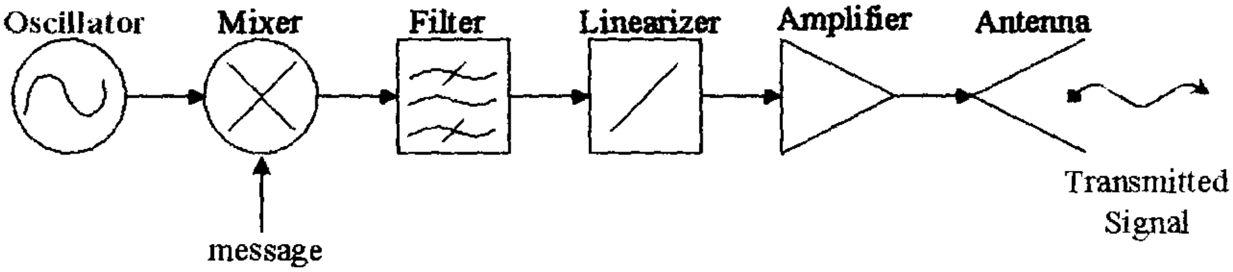


Fig. 1: Sample schematic of a transmitter microwave system

At the heart of any oscillator is an active device, such as a transistor, which produces a sinusoidal steady-state RF signal from a DC source. In order for a transistor to oscillate, however, it must have a negative input resistance at the output. This allows the internal signal reflections to increase in power. If the transistor does not have a negative input resistance, feedback is usually added to change the resistance of the transistor.

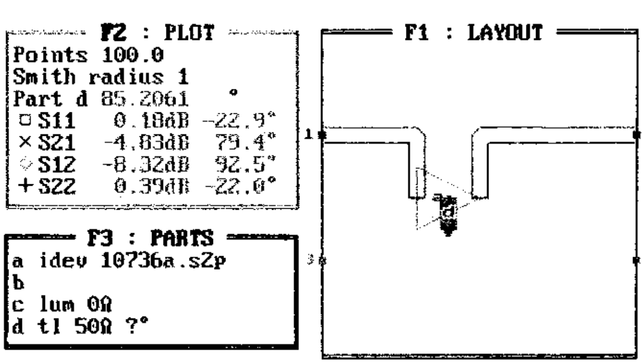
When negative resistance of the transistor is achieved, the transistor will then be able to oscillate. At the startup of DC to RF conversion, oscillation is triggered by noise in the system, which continues to build. As the power builds, the input resistance of the transistor will becom less negative until it finally reaches a stable oscillation state, at which point it will continue to oscillate at a specific frequency and output power.

The main difficulty in designing an oscillator is that the operation of an oscillator is inherently non-linear. This means that the characteristics of an oscillator are not easily predictable, and is not easily simulated using a linear CAD program. There are, however, many linear design methods that have been created which are acceptably accurate.

One linear method that is used to increase the output power of an oscillator is the 1/3 rul [Pozar], named as such because the input resistance of the oscillator load is designed with a resistance that is 1/3 the magnitude of the transistor input resistance. Using this method, the efficiency of an oscillator can be increased, since the oscillator will produce more output power with the same amount of DC bias. Although the operation of an oscillator is non-linear, this linear design method is popular because it has a high rate of success and it is very easy to implement.

DESIGN

Transistor ATF-10736 was selected for the design of the oscillator because the required negative input resistance of the device was easily attainable using a simple 85.2° transmission line as feedback [Fig. 2 and eq. (1) and (2)], the transistor was inexpensive and in supply, and th output power it produced was satisfactory for our purposes. The transistor itself didn't provide the negative resistance that was required, so feedback was placed in a common-source configuration in the form of an 85.2° transmission line. In this configuration, the output power of the oscillator was designed so that it would be delivered from the drain of the transistor.



```
Points 100.0
Smith radius 1
Part d 85.2061   °
 □ S11    0.18dB -22.9°
 × S21   -4.83dB  79.4°
 ◇ S12   -8.32dB  92.5°
 + S22    0.39dB -22.0°
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```
a idev 10736a.s2p
b
c lum 0Ω
d tl 50Ω ?°
```

Fig. 2: PUFF CAD simulation showing the S-parameters of the ATF-10736 transistor in a common source configuration with an 85.2° transmission line (part d) providing feedback.

Since all the power was to be delivered from the drain of the transistor, an open circuit [$\Gamma_T = 1$ in eq. 1] was left at the gate of the device to prevent power dissipation at the gate. Using the new feedback s-parameters of the transistor [F2 window, Fig. 2], the cascaded s-parameters of the network were determined using equation 1. The input resistance of the device was then calculated using equation 2. The feedback network was chosen so that the resistance was approximately –90 ohms, a value which was chosen because it would be easy to implement using the 1/3 rule (30 ohms at the load).

$$\Gamma_{in} := S_{22} + \frac{S_{21} \cdot S_{12} \cdot \Gamma_T}{1 - S_{22} \cdot \Gamma_T} \qquad \text{eq. (1)}$$

$$Z_{in} := (-Z_o)\left(\frac{\Gamma_{in} + 1}{\Gamma_{in} - 1}\right) \qquad Z_{in} = -90.047532 - 335.874566i \qquad \text{eq. (2)}$$

The impedance needed for the load was then calculated using the 1/3 rule, and a matching network of the load was designed using a Smith chart. A schematic of the oscillator, with a pictorial description of the 1/3 rule, is shown in Fig. 4. Notice that the resistance of Z_{load} is 1/3 the resistance of Z_{in} and the reactance of Z_{load} is of equal magnitude but opposite in sign from Z_{in}.

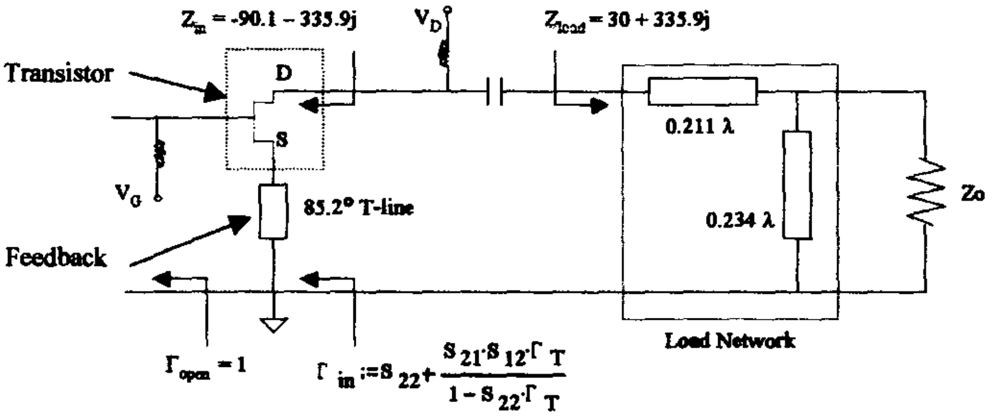
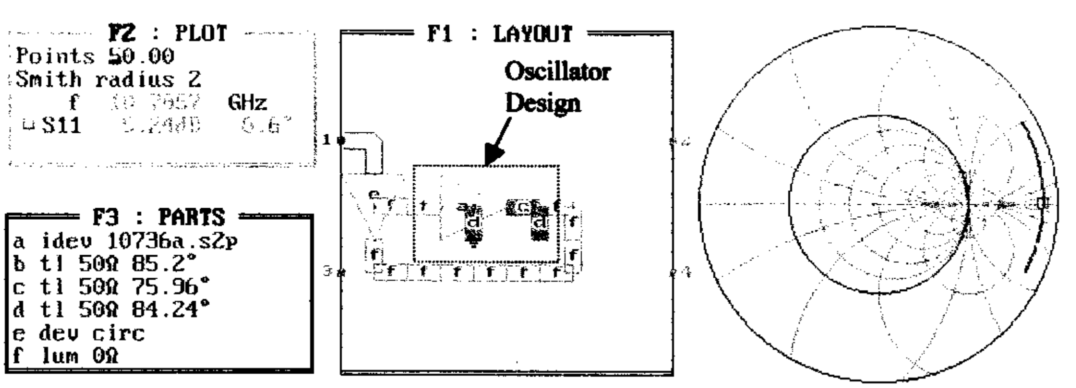


Fig. 3: Schematic of the oscillator showing the necessary resistances at the input and the load for the 1/3 rule. The gate of the transistor is open, and the matching network matches the load to the necessary resistance.

SIMULATION

The oscillator design was simulated using PUFF, a linear analysis high frequency CAD program. Since the program only provided linear analysis, the steady state oscillation conditions, such as the output power, could not be accurately simulated. Instead, the output power of the transistor was taken from the manufacturer's specifications, which was listed on the transistor datasheet provided to us. The output power of the transistor at 1dB of gain compression is 17 dBm when biased at V_{DS} = 2V and I_{DS} = 25mA, but to be conservative, the simulated output power of the transistor was taken at 15 dBm. This corresponds to a 37% decrease in simulat output power when compared to the 1dB compression output power.

The frequency of operation of the oscillator was simulated in PUFF using the circulat function. The input and output of the oscillator was connected to the circulator, and the reflections (S11 measurements) from the circulator were measured and graphed on a Smith c The frequency at which S11 crosses the x-axis outside of the smith chart unity circle [Fig. 5] the frequency at which the oscillator will oscillate. From the simulations, the oscillator was found to operate at a frequency of 10.79 GHz.



```
F2 : PLOT
Points 50.00
Smith radius 2
   f   [illegible]   GHz
 S11   [illegible]   [illegible]
```

```
F3 : PARTS
a idev 10736a.s2p
b tl 50Ω 85.2°
c tl 50Ω 75.96°
d tl 50Ω 84.24°
e dev circ
f lum 0Ω
```

Fig. 5: Puff simulation of the circular function method in determining the oscillation frequen

ANALYSIS AND DISCUSSION

The conversion efficiency of the oscillator was calculated using the ratio of the RF ou power to the DC power. The DC power of the oscillator was calculated using the biasing conditions of the ATF-10736 transistor given in the transistor technical data sheet. In this ca $V_{DS} = 2V$, and $I_{DS} = 25mA$, so the total DC power is 0.05W. Since the oscillation condition the 1/3 rule were met in the design and simulation, the output power was recorded at 15dBm The following calculations show the derivation of the oscillator efficiency, listed at 63.2%.

$$P_{out\_dBm} := 15 \quad V_{ds} := 2 \quad I_{ds} := 0.025$$

$$P_{out\_lin} := \left[10^{\left(\frac{P_{out\_dBm}}{10}\right)}\right] \cdot 10^{-3} \qquad P_{out\_lin} = \blacksquare$$

$$P_{DC} := V_{ds} \cdot I_{ds} \qquad P_{DC} = \blacksquare \quad \text{Watts}$$

$$\text{Efficiency} := \left(\frac{P_{out\_lin}}{P_{DC}}\right) \cdot 100 \qquad \text{Efficiency} = \blacksquare$$

CONCLUSION

A high efficiency oscillator has been designed and simulated using PUFF, a microwave CAD program. S-parameter data provided by Agilent was used to linearly design the oscillator using the 1/3 rule. The oscillator operated at a frequency of 10.8 GHz, and according to the data sheet, generated 15 dBm (0.032W) of output power. The DC power being fed to the oscillator was 0.05W, which led to an overall efficiency of 63.25%.

Future improvements would be to simulate the oscillator non-linearly using a more powerful microwave CAD program such as Microwave Office or ADS. This would, however, require us to change our transistor since an accurate non-linear model of a transistor would be needed. With the model, we would then be able to simulate the output power from the transistor and the oscillation frequency non-linearly.

ACKNOWLEDGEMENTS

First of all, I would like to thank NASA and the Hawai'i Space Grant Consortium staff for allowing me to conduct my research, and for being very helpful and understanding during the research process. I'd also like to thank my parents for being supportive of my research, and helping me with research errands whenever I needed their help. And last but not least, I'd like to thank my mentor, Dr. Wayne Shiroma, who has been one of the most influential person in my life, and who I credit for helping me to achieve all that I've done since I begun working with him as a sophomore in college. Thank you.

REFERENCES

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