# Silicon-Carbide High Efficiency 145 MHz Amplifier for Space Applications

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## 1 – Introduction

This paper describes a 40 W high efficiency 145 MHz amplifier to be used in a spacecraft like AMSAT Eagle. It utilizes a silicon carbide (SiC) field effect transistor manufactured by Cree, in Durham, NC. SiC is cutting-edge semiconductor technology that together with gallium nitride (GaN) is allowing power amplifier designers to achieve higher efficiency over wider bandwidths. The two major advantages of these two semiconductors is their high electron mobility and breakdown voltage.

SiC and GaN are junction devices, and do not suffer from the problems associated with LDMOS devices in high radiation environments. However, to the best of my knowledge, no SiC or GaN devices have been flown into space to date. AMSAT will be breaking new ground (once again) by doing this.

The main goal of this design is to achieve high efficiency by operating the amplifier in class E. Such an amplifier can be used in an envelope elimination and restoration system in order to allow the amplification of signals with a non-constant envelope.

The amplifier was simulated and optimized using the nonlinear harmonic balance feature of AWR Microwave Office.

## 2 – Design

The schematic diagram of the amplifier appears in Fig. 1. The active device is a CRF24060 SiC MESFET, operating with 40 V at the drain. MESFETs require a negative gate-source voltage to set the operating point. In the case of class E, the device is biased well below pinch-off.

The input matching circuit is implemented with a high pass network comprised of C1, L1 and C2. A high pass network was chosen since that configuration does not attenuate the harmonics of the input signal generated by clipping at the input of the device.

The gate-source voltage necessary for proper class E operation is –14 V. This voltage is applied to the gate through a large value inductor (L2). The drain voltage was fixed at 40 V, and it is applied to the drain through the inductor L3. The breakdown voltage of the MESFET is 120 V. Since class E operation produces a peak drain voltage much higher than class AB operation, the device needs to be operated at reduced drain voltage. Typically, the class AB drain voltage is 48 V. Fig. 2 shows the drain voltage waveform as a function of time. The maximum drain peak voltage is just below 100 V.

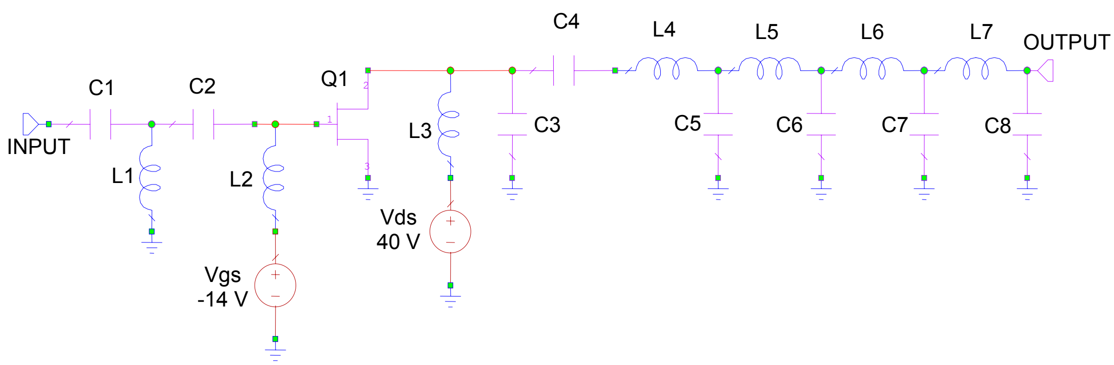


**Fig. 1 – RF power amplifier schematic diagram**

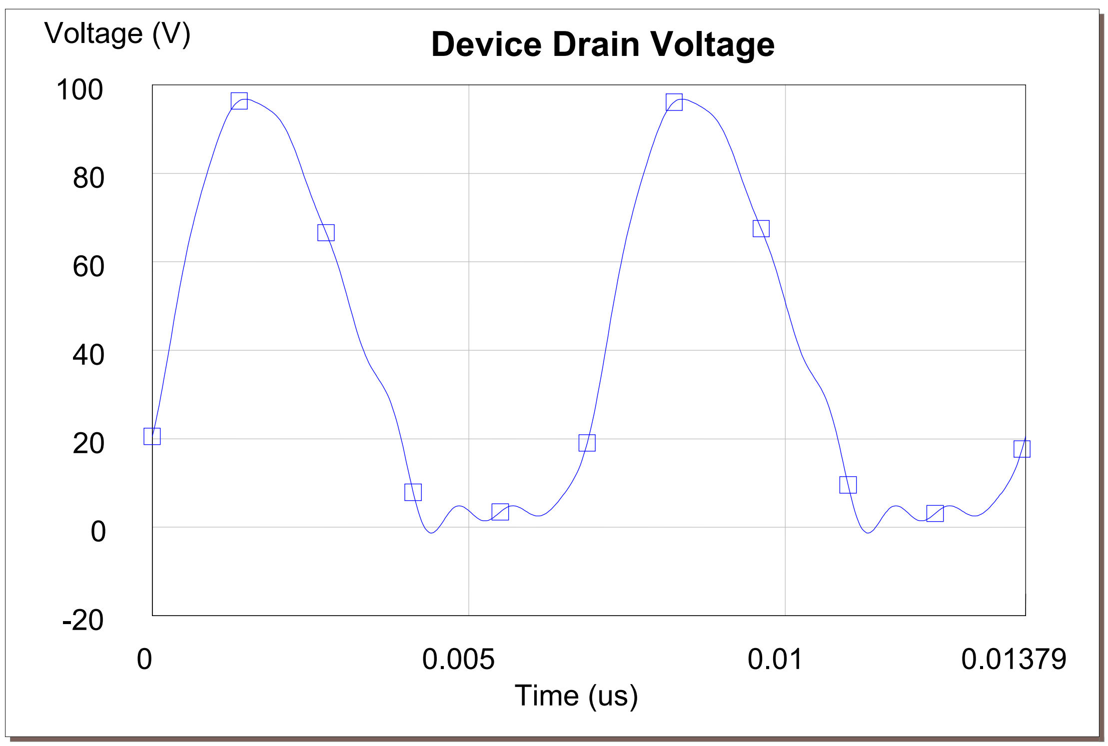


**Fig. 2 – Active device drain voltage**

The output matching network performs three functions:

1) It shapes the drain current and voltage so the power dissipation in the device is minimized

2) It performs the impedance matching between the device and the antenna

3) Attenuates the harmonics.

The capacitors C3 and C4 together with the inductor L4 comprise a classic class E output network. The impedance at this point is around 10 ohms. The inductor L5 and the capacitor C5 match this 10 ohm impedance to 50 ohms. The rest of the inductors and capacitors are used to implement a 5 element Chebyshev low pass filter.

The output spectrum of the amplifier is shown in Fig. 3. The second harmonic is the strongest one. However, its level is approximately 60 dB below the fundamental.

The amplifier output power was calculated to be 40 W at a drain voltage of 40 V. The required drive level for this output power is 29 dBm or 800 mW. As a result, the gain of the amplifier is around 17 dB.

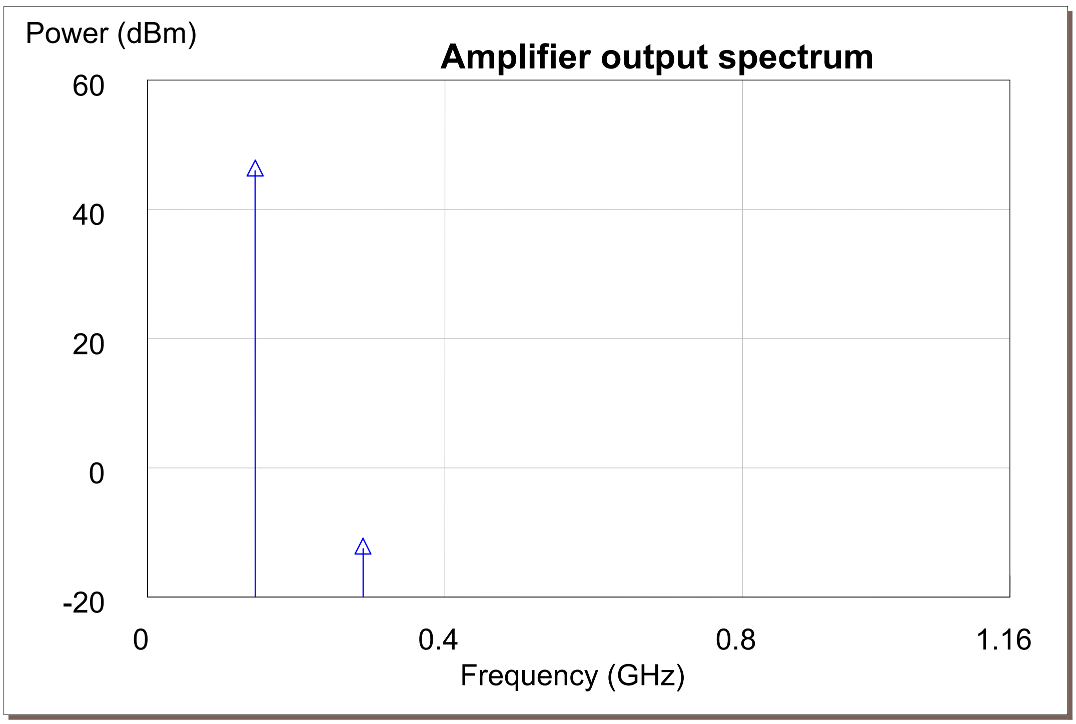


**Fig. 3 – Amplifier output spectrum**

### 3 – Efficiency and output power vs. drain voltage

Fig. 4 shows the amplifier efficiency as a function of drain voltage for a constant drive level of 29 dBm. The efficiency is approximately 90%, and it quickly degrades at very low drain voltages. This happens when the output power is lower than the drive level. If the drive level is reduced, the efficiency can be maintained very high at all output power levels. However, the degradation of efficiency at very low output power is not an issue that needs to be addressed since the dc power involved is very low also. This can be appreciated in Fig. 5, where the dc power and the RF power as a function of drain voltage are shown.

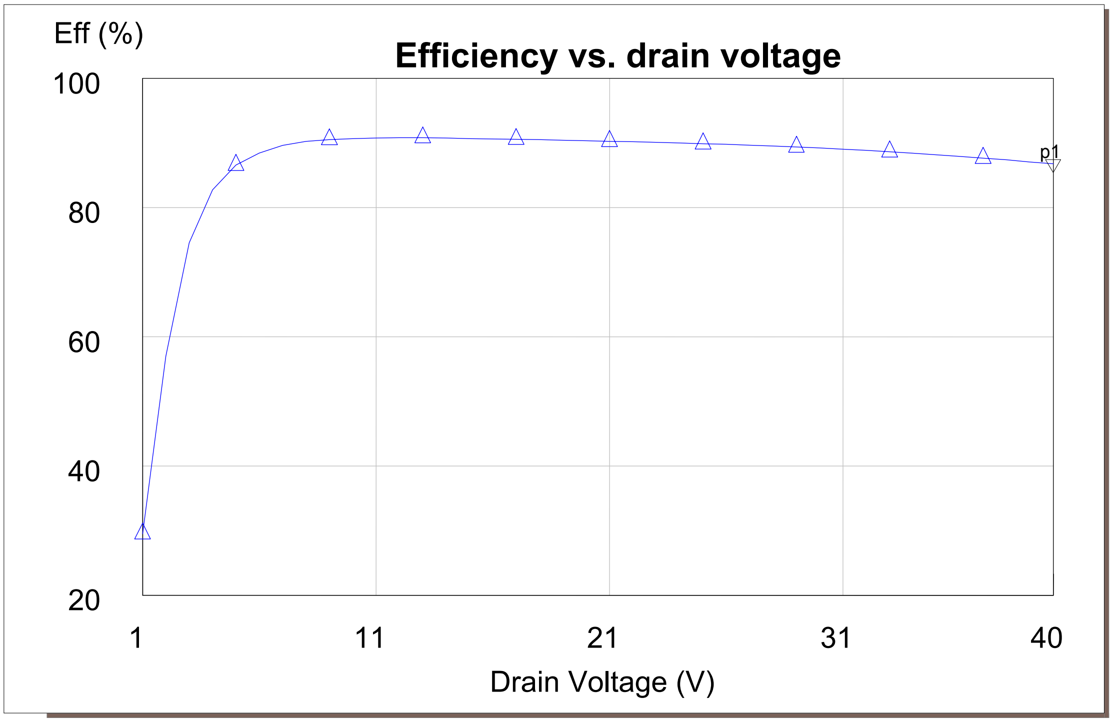


**Fig. 4 – Amplifier efficiency vs. drain voltage**

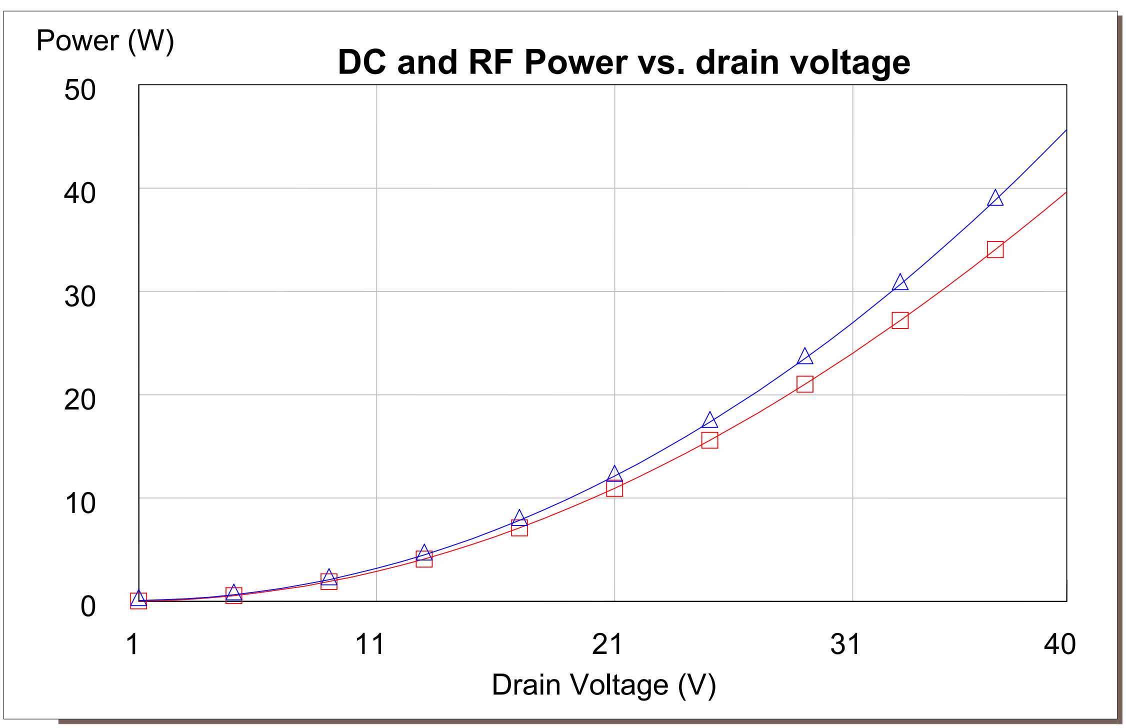


**Fig. 5 – Amplifier output power (red) and dc power (blue) vs. drain voltage**

Table I shows in more detail the dc input power, RF output power and efficiency as a function of the drain voltage.

**Table I**

| Drain voltage [V] | DC input power [W] | RF output power [W] | Efficiency [%] |
|---|---|---|---|
| 1 | 0.09 | 0.03 | 29.51 |
| 2 | 0.14 | 0.08 | 57.00 |
| 3 | 0.25 | 0.19 | 74.56 |
| 4 | 0.42 | 0.34 | 82.74 |
| 5 | 0.64 | 0.55 | 86.58 |
| 6 | 0.92 | 0.81 | 88.44 |
| 7 | 1.26 | 1.13 | 89.61 |
| 8 | 1.65 | 1.49 | 90.23 |
| 9 | 2.10 | 1.91 | 90.54 |
| 10 | 2.62 | 2.37 | 90.69 |
| 11 | 3.19 | 2.89 | 90.77 |
| 12 | 3.81 | 3.46 | 90.84 |
| 13 | 4.50 | 4.09 | 90.84 |
| 14 | 5.25 | 4.76 | 90.76 |
| 15 | 6.06 | 5.49 | 90.68 |
| 16 | 6.92 | 6.27 | 90.62 |
| 17 | 7.84 | 7.11 | 90.58 |
| 18 | 8.82 | 7.99 | 90.52 |
| 19 | 9.87 | 8.92 | 90.43 |
| 20 | 10.97 | 9.91 | 90.34 |
| 21 | 12.12 | 10.94 | 90.26 |
| 22 | 13.34 | 12.03 | 90.20 |
| 23 | 14.61 | 13.17 | 90.11 |
| 24 | 15.95 | 14.35 | 90.00 |
| 25 | 17.34 | 15.59 | 89.89 |
| 26 | 18.80 | 16.88 | 89.79 |
| 27 | 20.31 | 18.21 | 89.67 |
| 28 | 21.89 | 19.60 | 89.53 |
| 29 | 23.52 | 21.03 | 89.38 |
| 30 | 25.22 | 22.50 | 89.23 |
| 31 | 26.98 | 24.02 | 89.05 |
| 32 | 28.80 | 25.59 | 88.85 |
| 33 | 30.68 | 27.20 | 88.65 |
| 34 | 32.62 | 28.85 | 88.43 |
| 35 | 34.64 | 30.54 | 88.18 |
| 36 | 36.71 | 32.28 | 87.92 |
| 37 | 38.85 | 34.06 | 87.66 |
| 38 | 41.05 | 35.88 | 87.39 |
| 39 | 43.33 | 37.73 | 87.08 |
| 40 | 45.67 | 39.63 | 86.76 |

## 5 – Conclusion

This VHF power amplifier was simulated using real parts models. All the capacitors and inductors have a finite Q and the associated parasitics. As a consequence, the simulation results are expected to be reasonably accurate.

No instability was observed in this amplifier. However, further analysis is being carried out in order to confirm that.

All capacitors used are American Technical Ceramics (ATC) type 700B, and the inductors are air core surface mount made by Coilcraft. The power supplies have not been decoupled since the Microwave Office model already has zero impedance at all frequencies. The decoupling networks can be added and considered in the simulation before the amplifier is implemented.

The simulation results are encouraging. This amplifier can be used in an envelope elimination and restoration scheme (also known in the amateur radio literature as HELAPS) to provide linear amplification of non-constant envelope signals. The efficiency holds very well over a wide range of drain voltages. If the output power of 40 W is excessive for any reason, it can simply be reduced by applying a lower drain voltage.

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