Julia DiTomas
ECEN 5634
Lab 5 Report

Q1: The purpose of the coaxial choke is to prevent the RF wave from entering the DC bias input port. It is low impedance at low frequencies and high impedance at high frequencies. This protects the equipment connected to that port, and also keeps all of the signal in the waveguide cavity except for that which leaves through the coupling slot.

Part I

We first characterized the diode by applying different bias voltages and measuring I and V.

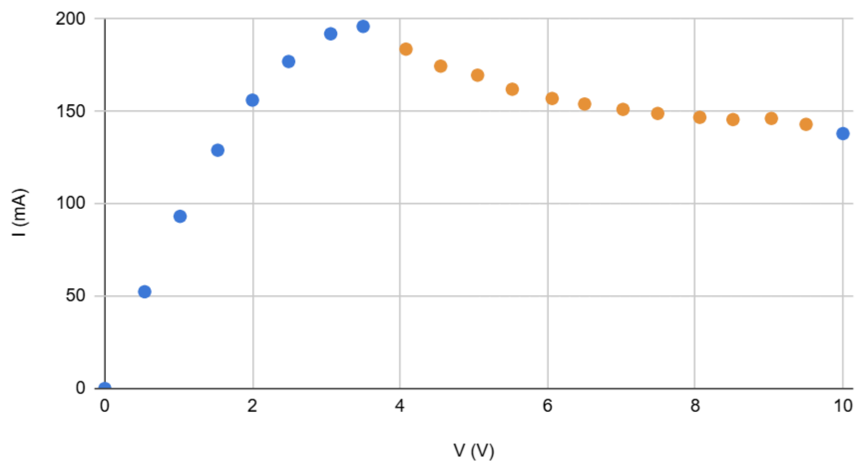

Figure 1: Gunn diode DC I-V curve based on our measurements. Points for which we observed oscillations are marked in orange.

Q2: We then calculated the DC power dissipated in the diode for each of our measurements.

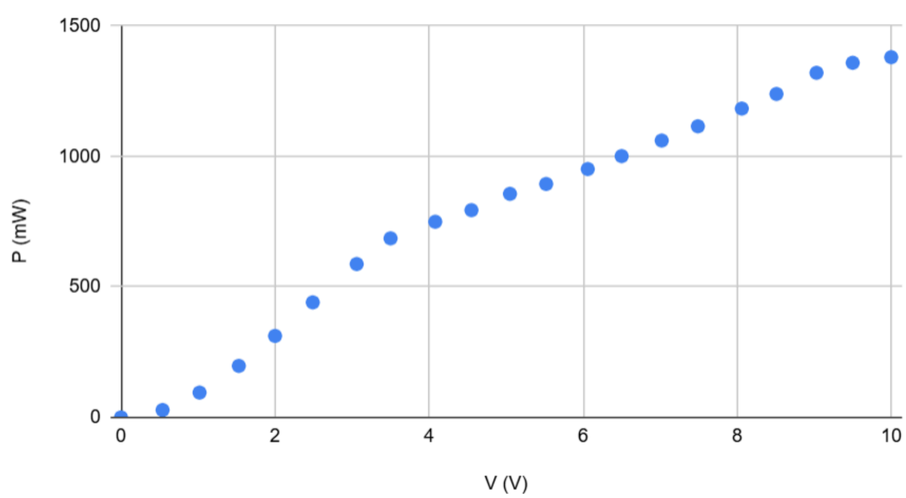

Figure 2: DC power dissipated in diode over DC bias voltage applied to diode.

Q3: Oscillations begin to appear on the spectrum analyzer where the diode's I-V curve begins to slope downward. Since the slope of the curve is conductance (or inverse resistance), the fact that the slope is negative means that the resistance is negative, which is what allows the Gunn diode to act as an oscillator.

Part III

Q5: We set the bias voltage to 4.48 V, and recorded oscillations at 9.77 GHz, 11.67 GHz, 13.58 Ghz, 14.65 GHz, 16.56 GHz, and 21.42 GHz. Figure 3 shows the peaks at these frequencies and their relative amplitudes. We found that the largest was that at 11.67 GHz (and this was the one that remained at higher bias voltages). None of the frequencies shown below correspond to the length of our resonator (2 cm). We believe that the actual resonant frequency is 5.84 GHz (half of 11.67 GHz) but that we might not see that on the spectrum analyzer because it is below the cutoff frequency of the waveguide. If we take 5.84 GHz to be our resonant frequency, then we find that it corresponds to a 5.1 cm wavelength, so the resonator length would be close to half a wavelength.

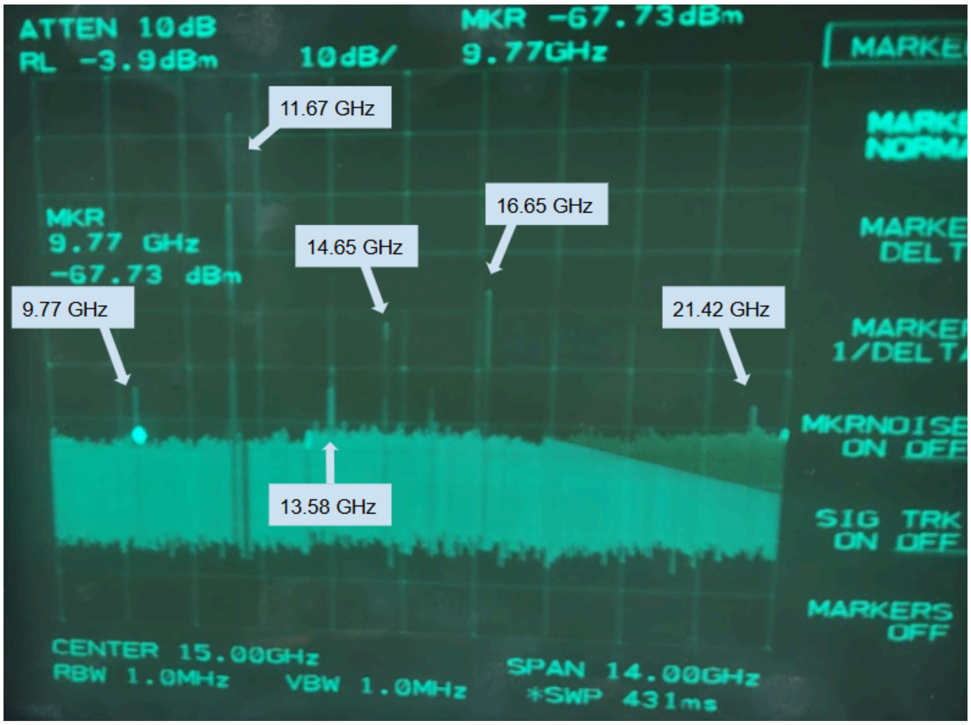

Figure 3: Spectrum analyzer output for DC bias voltage of 4.48 V from 8 GHz to 22 GHz.

We think that the diode is generating a nonlinear waveform, because of the presence of oscillations at harmonic frequencies and other frequencies. The total wave is a sum of sinusoids of the frequencies and relative amplitudes shown in Figure 3 (and others that are not in the displayed spectrum analyzer span). Because the harmonic oscillation (11.67 GHz) exists and has a much higher amplitude than the oscillations at non-harmonic frequencies, the quasi-harmonic approximation is valid.

Q6: The DC power delivered to the diode at this operating point is 4.48*0.175 = 0.784 W. The power in the fundamental frequency (which we assume to be 11.67 GHz) is 3 dBm, or 2 mW, from our measurements with the spectrum analyzer and compensated for the attenuation of the waveguide. This means that the efficiency is 0.002/0.784 = 0.26%.

Q7: We believe that the presence of other frequencies is due to imperfections in the waveguide cavity and nonlinearity, which cause harmonics and intermodulation distortion. Furthermore, we think that the Gunn diode is not at its intended operating point, which also contributes to the other frequencies, due to the voltage and temperature being below where it was designed to operate. This is supported by the fact that when we previously increased the voltage to move further into the negative resistance region, we witnessed the other frequencies disappear.

Q8: We then varied the DC bias voltage from 0 V to 10 V and recorded the fundamental frequency. Our results are shown in Figure 4. Note that we only plotted over voltages for which we observed oscillations, which was 4 V to 9 V. We found that f_{osc} slightly increases as more voltage is applied, but does not strongly depend on the DC bias voltage.

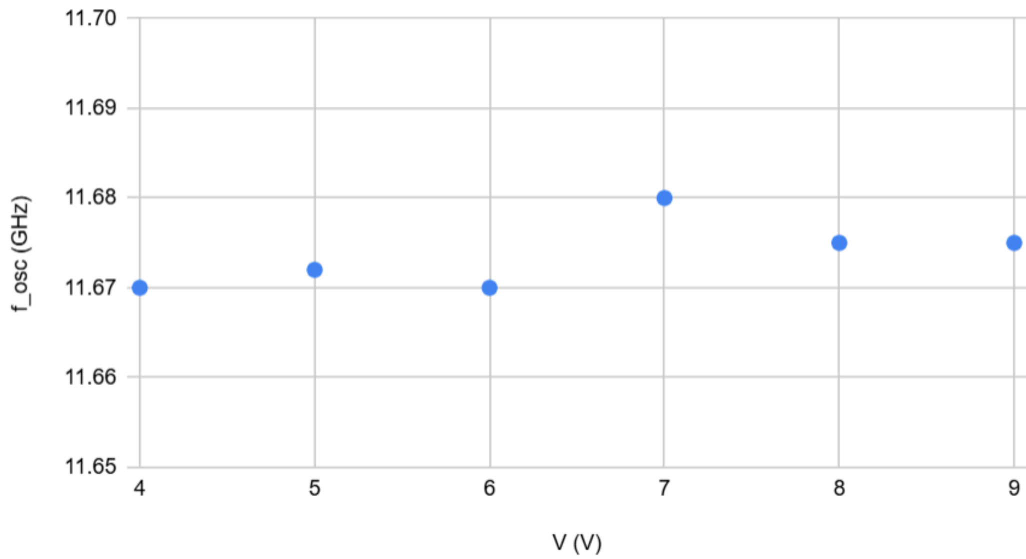

Figure 4: Fundamental frequency vs DC bias voltage.

Q9: We then set the DC bias voltage to 7.64 V and computed the efficiency. We found that the DC power input to the system was 7.64*0.148 = 1.131 W, and that the power in the fundamental frequency was 24.5 mW. Thus, the efficiency at this operating point is 0.0245/1.131 = 2.17%.

Part IV

Q10: We then connected a signal generator to the Gunn diode, first outputting a 1 MHz square wave, and then a 1 MHz sine wave. For the square wave, we saw oscillations at the resonant frequency of the waveguide oscillator, 11.681 GHz, and at odd harmonic frequencies away from this center frequency (11.678 GHz, 11.68 GHz, 11.682 GHz, and 11.684 GHz), which are the sinusoids that make up a square wave. For the sine wave, we observed the same oscillations except that the ones at 11.678 GHz and 11.684 GHz went away, so we had only the waveguide resonant frequency, and oscillations at the frequencies 1 MHz away from this.

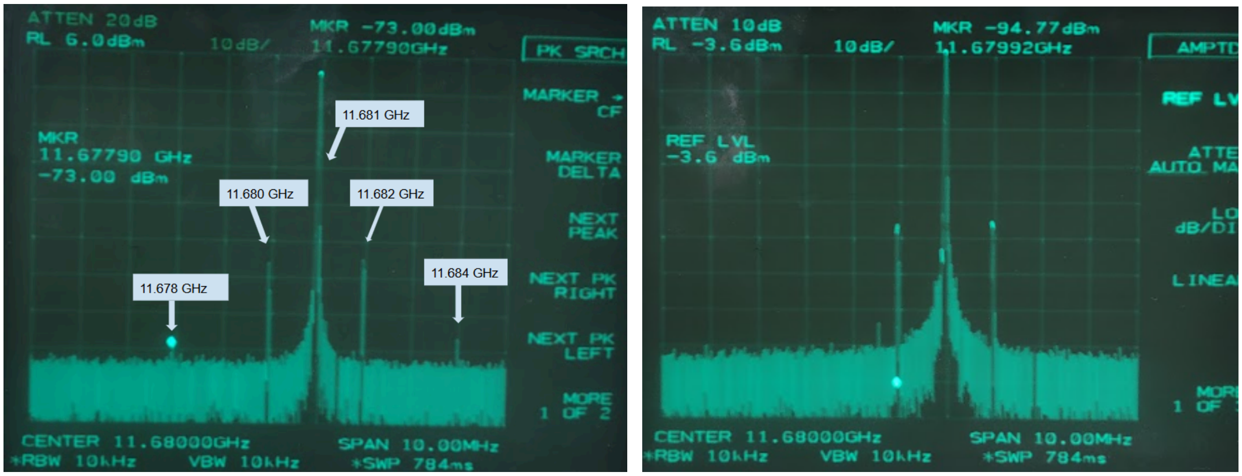

Figure 5: Spectrum analyzer display with bias modulation of 1 MHz square wave (left) and 1 MHz sine wave (right).

Q11: We repeated our observations with the frequency of the square wave signal set to 10 MHz, and then 80 MHz (the maximum of our signal generator). Figure 6 displays our results. We found that in each case, the center frequency was unchanged, because we did not change the DC bias voltage. It remained at 11.681 GHz and always had the greatest amplitude. For the 10 MHz square wave, we observed oscillations at 11.671 GHz and 11.691 GHz, which are both 10 MHz away from the resonant frequency. For the 80 MHz square wave, we observed oscillations at 11.601 GHz and 11.762 GHz, which are 80 MHz and 81 MHz away from the resonant frequency, respectively.

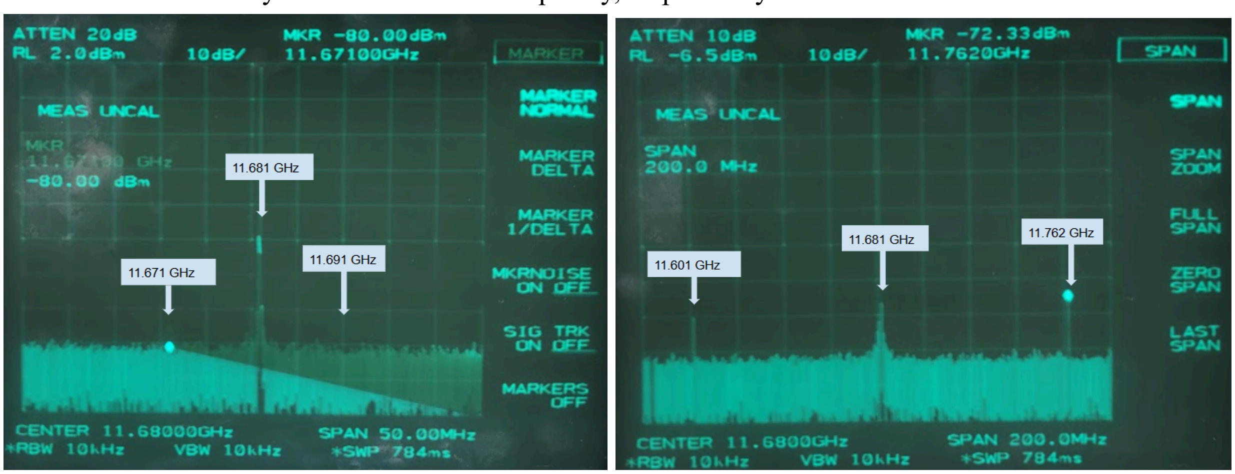

Figure 6: Spectrum analyzer display with bias modulation of 10 MHz square wave (left) and 80 MHz square wave (right).

Part V

Q12: When we brought the RF output close to the Gunn diode frequency, we observed the two frequencies combine into one after a transition state, which was at the frequency set by the sweep oscillator. This is when we had successfully injection locked the Gunn diode oscillator. If we were near enough to the fundamental oscillation, we could use the RF output to control it. Because of the limited bandwidth, this does not affect the other frequencies. Figure 7 shows the spectrum analyzer display at the fundamental frequency with the RF signal off, and then with the RF signal at the minimum frequency to injection lock the Gunn diode oscillator. We found that the signal purity was not greatly affected, but that the amplitude did decrease from -4.60 dBm to -6.60 dBm.

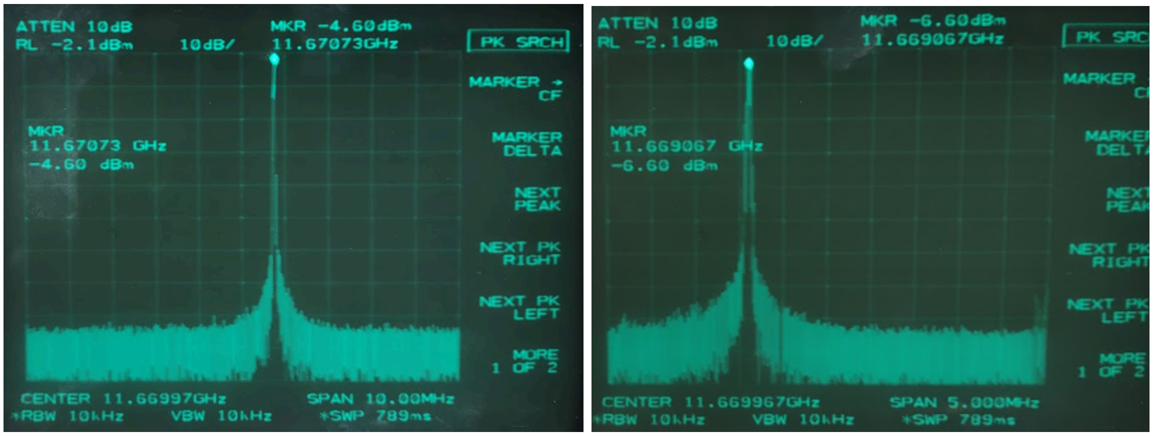

Figure 7: Spectrum analyzer display for 4 V DC bias, no injection locking (left) and injection locking with a -20 dBm RF output at the minimum frequency able to move the fundamental frequency (right).

Q13: For DC bias voltage of 4 V and RF Power level at -20 dBm, we found that the minimum frequency we could use for injection locking was 11.669067 GHz, and the maximum was 11.670533 GHz, which meant that the bandwidth for this power level was 1.466 MHz. We then experimented with RF sweeper power levels of -15, -10, -5, and 0 dBm, and recorded the injection locking bandwidths. Our results are shown in Table 1. We discovered that as we increased the power of the injected signal, we were able to move around the fundamental oscillation to a wider range of frequencies.

RF Signal Power (dBm)	Minimum Injection Locking Frequency (GHz)	Maximum Injection Locking Frequency (GHz)	Bandwidth (MHz)
-20	11.669067	11.670533	1.466
-15	11.6689	11.67095	2.05
-10	11.668167	11.671833	3.666
-5	11.666942	11.672642	5.7
0	11.66537	11.67597	10.6

Table 1: Dependence of injection locking bandwidth on injected RF power for DC bias voltage of 4 V.

Q14: Finally, we changed the DC bias voltage to 7.5 V and repeated our experiment. We found that we could still use injection locking to pull the oscillation frequency around in the same way that we did in the previous part, but to a lesser extent. We think that this is because at this operating point, since the Gunn diode is outputting more power and giving a more stable oscillation, it would take more injected power to be able to move the fundamental frequency around by the same amount. In other words, the same amount of injected power is less, proportional to the higher Gunn diode power. For example, the injection locking bandwidth at -20 dBm of injected power is now (11.68123-11.68077) GHz = 0.46 MHz, which is about a third of what it was at the 4 VDC operating point.

Again, however we still see the bandwidth increase as the injected power increases. Table 2 displays our measurements, and Figure 8 shows the trend of the injection locking bandwidth as injected RF power changes for both DC operating points tested.

RF Signal Power (dBm)	Minimum Injection Locking Frequency (GHz)	Maximum Injection Locking Frequency (GHz)	Bandwidth (MHz)
-20	11.68077	11.68123	0.46
-15	11.6805	11.68143	0.93
-10	11.68017	11.68183	1.66
-5	11.6795	11.6825	3
0	11.67823	11.6837	5.47

Table 2: Dependence of injection locking bandwidth on injected RF power for DC bias voltage of 7.5 V.

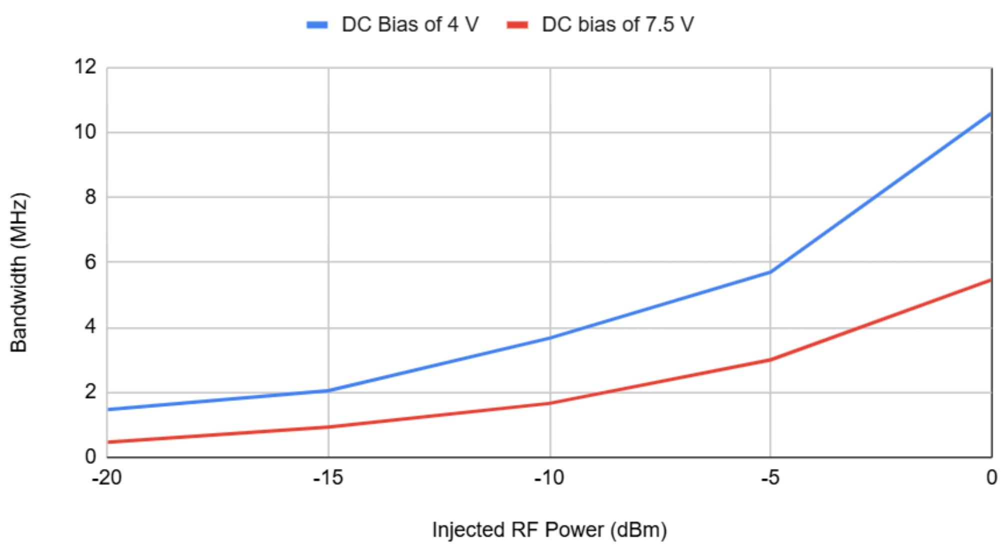

Figure 8: Injection locking bandwidth over injected power for DC bias voltages to the Gunn diode of 4 V and 7.5 V.