214-0102-01-01_00

RF NOTE # 101

June 23, 1985
by J. Vincent

Contents

1). On Decibels.

Those without an electrical engineering, or related, background may be confused about the concept of decibels. I am, and according to the first sentence here; should not be!

The concept of decibels was first used by Alexander Graham Bell to relate the power transfer characteristic of a network. He initially called this unit "bels"

$$\text{bels} = \text{Log}(P_2/P_1)$$

This unit was considered cumbersum so it soon became the "decibel".

$$\text{decibel} = \text{dB} = 10\text{Log}(P_2/P_1)$$

If P_1 and P_2 are referred to the same impedances ($Z_1 = Z_2$) then the decibel may be expressed as:

$$\text{dB} = 10\text{Log}(P_2/P_1) = 10\text{Log}[(V_2{}^2/Z_2)/(V_1{}^2/Z_1)] = 10\text{Log}(V_2{}^2/V_1{}^2) = 20\text{Log}(V_2/V_1)$$

It should now be apparent that if the input power and output power of a given network are referred to equal impedances, than the number of dB is the same regardless of whether we are speaking of voltage, current, or power. The method of converting back to the desired ratio is all that changes.

Due to the properties of logarithms that:

$$\text{Log}(ab) = \text{Log}(a) + \text{Log}(b)$$
$$\text{Log}(a/b) = \text{Log}(a) - \text{Log}(b)$$

Systems designers and the like have basically re-defined the decibel to be:

$\text{dB} = 20\text{Log}(a_1/a_2)$, where a_1 and a_2 have identical units.

This definition and the subsequent use has greatly reduced the work involved in analyzing and designing large systems. For example, a system function expressed in the frequency domain may have many terms in both the numerator and denominator. By taking the logarithm of the system transfer function, all of the multiplications and divisions are reduced to additions and subtractions. Bode diagrams of a system transfer function are a very common application of this technique.

Another thing commonly done with decibels now is to relate a variable quantity to a fixed reference quantity. Examples of this are noise related to some fixed noise level or power as related to some fixed power level. Following this idea, it has become common practice to express power in dBm or dBW. In this usage, the term "X dBm" or "X dBW" refers to 10 times the common Log of the ratio of the power level under discussion to 1mW or 1W respectively.

In conclusion, since the world has basically re-defined the decibel to be:

$$\text{dB} = 20\text{Log}(V_2/V_1)$$

I will go back to the original definition and crank out the following:

$$dB = 10Log(P_2/P_1) = 10Log[(V_2/V_1)^2(Z_1/Z_2)] = 20Log[(V_2/V_1)(\sqrt{Z_1/Z_2})]$$

$$= 20Log(V_2/V_1) + 20Log(\sqrt{Z_1/Z_2})$$

Now I re-define the original definition of dB as dBP such that:

$$dBP = 20Log(V_2/V_1) + 20Log(\sqrt{Z_1/Z_2}) = dB + 20Log(\sqrt{Z_1/Z_2})$$

Now if $Z_1 = Z_2$ then dBP = dB

Whenever I use decibels for anything now, I will state either dBP = dB or dBP ≠ dB. If dBP ≠ dB and power is important, I will state the impedances allowing you to compute dBP if you desire. I will never use the terms dBm or dBW unless you are to assume dB = dBP. So the following definitions are left according to the coresponding conditions.

$$dB = 20Log(V_2/V_1)$$

$$\text{and,}\quad dB = 10Log(P_2/P_1)\ ;\text{iff } dB = dBP$$

$$\text{where,}\quad dBP = dB + 20Log(\sqrt{Z_1/Z_2})$$

Enough on decibels.

2. K800 Transmitter Harmonic Distortion.

Now that decibels are more confusing then ever, I will use them to describe the harmonic distortion in the K800 final. Since we are testing the amplifier into a pure 50 Ohm load, all frequencies we are generating are referred to the same impedance; hence, dB = dBP.

$$\text{decibels of distortion} = 10Log(Pn/P_1)$$

where; P_1 = the power delivered to the load due to the fundamental frequency.
Pn = the power delivered to the load due to the nth harmonic.

Notice from the above definition that the fundamental power expressed in decibels is 0.

Figure 1 displays the experimentally measured harmonic distortion as directly measured out of the directional coupler. The directional coupler coupling increases linearly with frequency such that; 10kW at 10Mhz will yield one fifth less signal than 10kW at 50Mhz. This makes the experimentally measured situation as shown in figure 1 appear much worse than it actually is. To compensate for the directional coupler, we must subtract the coupler gain out of the picture according to the following.

The coupler coupling transfer function is:

$$Vn/V_1 = Fn/F_1 = nF_1/F_1 = n$$

$$\text{decibels of gain} = 20Log(n)$$

The following table lists the number of dB of gain that must be subtracted out of the experimentally measured values.

n	#dB
0	0.00
1	6.00
2	9.54
3	12.00

Subtracting the above numbers from figure 1 leaves the actual harmonic distortion level shown in figure 2.

The worst case is now the third harmonic which is down by 16.54 dB at 14Mhz. For the third harmonic if P_1 = 300kW then, P_3 = 6.1kW. Figure 3 displays what you would see directly out of the directional coupler on an oscilloscope if the first and third harmonics were in phase, while figure 4 displays the same case after removing the directional coupler gain. All of these cases are for 14Mhz, which is the worst case.

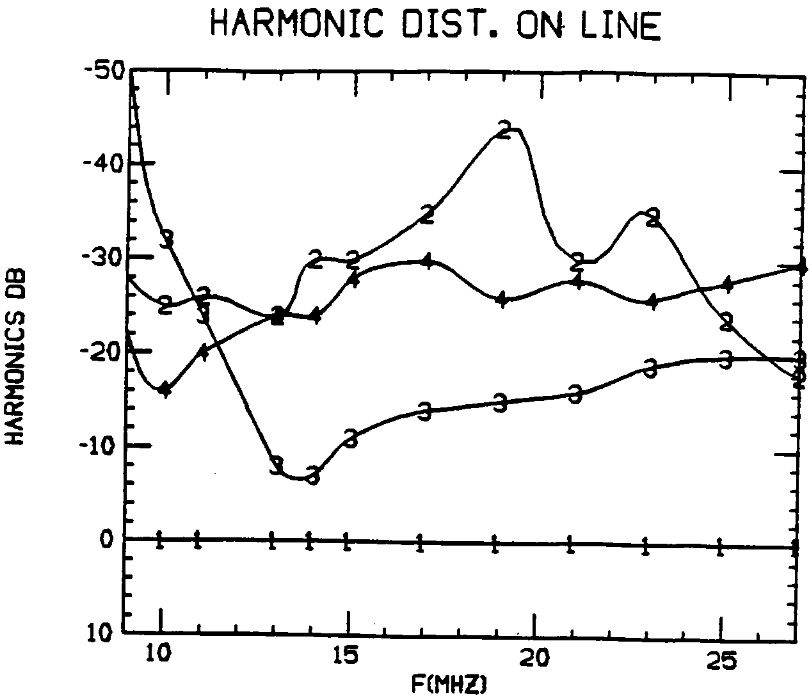


FIG. 1

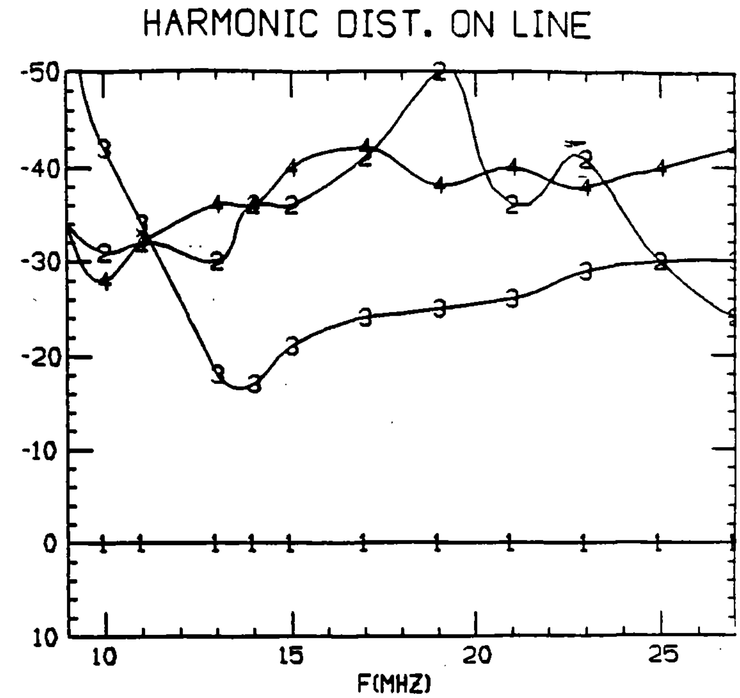


FIG. 2

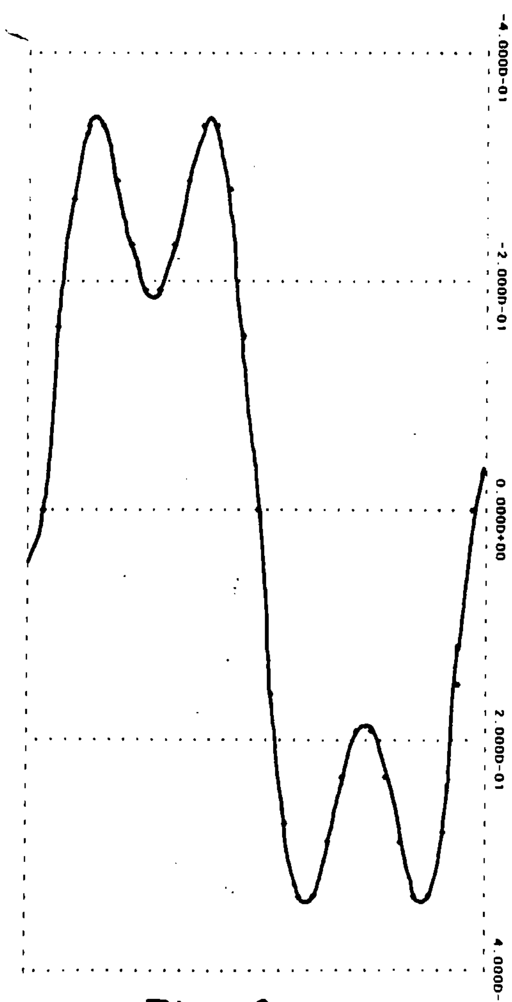


FIG. 3

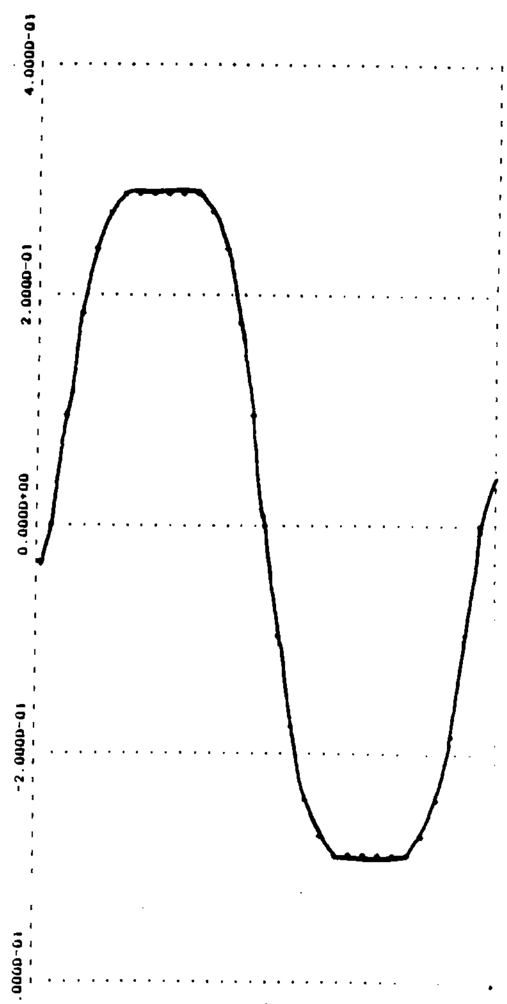
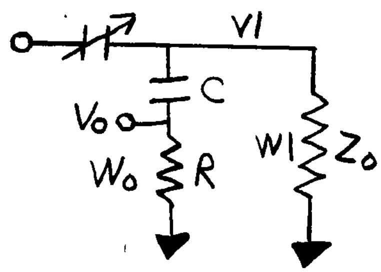


FIG. 4

3. Transmission Line Damper.

The last section briefly described the harmonic distortion present on the transmission. The ratios observed there are only true when the transmission line is ideally terminated for all frequencies of interest. When we couple to the dee resonators, the transfer function will change significantly for all higher order harmonics. To hold the Q of these harmonics down so that a standing wave is not allowed to build significantly, we need to damp the line. The following lumped equivalent circuit will be used.



R and C are picked to hold the fundamentals power lost in the resistor to a minimum acceptable level, while simultaneously having a cut-in frequency of just below the transmitter second cavity mode. The frequency where we need to deliver the most power is 27Mhz.

$$F_o = 27\text{Mhz}$$

We allow 10kW to be disapated in the damper at 27Mhz and 250kW delivered.

$$W_o = 10\text{kW}$$

The transmitter second cavity mode begins at 40Mhz, hence a cut-in frequency of 38Mhz is acceptable.

$$F_c = 38\text{Mhz}$$

$$V_o/V_1 = 1/\sqrt{1+(1/\omega RC)^2} \Rightarrow W_o = V_1^2/R[1+(1/\omega RC)^2]$$

$$V_1^2 = Z_o W_1 \Rightarrow W_o = Z_o W_1/R[1+(1/\omega RC)^2]$$

$$F_c = 1/(2\pi RC) \Rightarrow \omega_C = 1/(RC) \Rightarrow C = 1/(\omega_C R)$$

$$\text{therefore; } W_o = Z_o W_1/R[1+(F_c/F_o)^2]$$

solving for R leaves:

$$R = Z_o(W_1/W_o)/[1+(F_c/F_o)^2] \text{ , then } C = 1/(2\pi F R)$$

Putting in the numbers leaves the following element values:

$$R = 50(250/10)/[1+(38/27)^2] \approx 420\ \Omega$$

$$C = 1/(2\pi 38Mhz420) \approx 10\ pF$$

There must be a million "what ifs" to contend with here, and suffice it to say I have considered many of them. My contention is to see what happens when we couple into the dee resonators, and use that data to modify this design if necessary. The available condensers that will work here are the "CF3C 12F" from Comet or the "CFHD 12" from Jennings. The resistor will be a standard $3^{1}/_{8}$ inch flanged, water cooled, 50 kW version from Atronics Research. This apparatus will be placed just after the output coupler mounted on one end of a $6^{1}/_{8}$ inch tee.

4. 4648 Final Grid Circuit.

Early on, during the conception and first computations of the power requirements for the K800 dee resonators, it was assumed that we would need less then 180 kW of drive power for each resonator. Later, more detailed and exhausting calculations showed the original resonators needed closer to 300 kW. We then re-designed and optimized the resonators leaving a current theoretical figure of 190 kW. Since there always exists some uncertainty to the exact power requirements, we have decided to adjust the amplifier strings for 300 kW each. We will downgrade the amplifiers to bring the efficiency back up to an acceptable level for the actual maximum power necessary when we experimentally measure it.

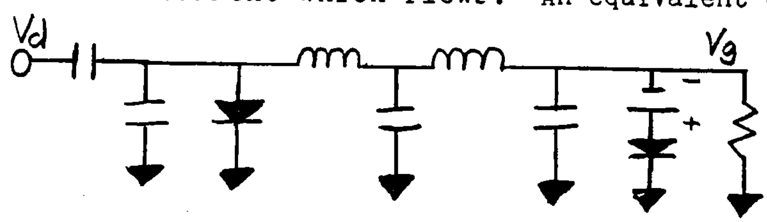
At power levels of less then 200 kW (with our load impedance) the RCA 4648 tetrode draws little or no grid current. Due to this fact, and the thoughts mentioned in the first paragraph, no consideration was made for much, if any, grid current. Now, with the new goal of 300kW, we must compensate for this current.

The gain of a tetrode becomes greatest when the grid passes through zero volts and goes positive. The tube efficiency also goes up. We need at least 75% efficiency to deliver 300 kW simultaneously from all three amplifiers. When the grid of a tetrode goes positive, it begins to draw current due to a diode effect. The instantaneous power disapated in the grid, due to this current, is cheifly due to the absorbsion of kenetic energy of each electron as it strikes the grid. This energy is equal to Vd(t) + Vg , where Vd(t) is the time instantaneous drive voltage and Vg is the negative dc bias voltage. So the power lost in the grid due to this current is basically equal to:

$$Pl = \frac{1}{T}\int_0^T Ig(t)[Vd(t) + Vg]dt = \frac{1}{2\pi}\int_0^{2\pi} Ig(\theta)[Vd(\theta) + Vg]d\theta$$

The above power is supplied by the driver.

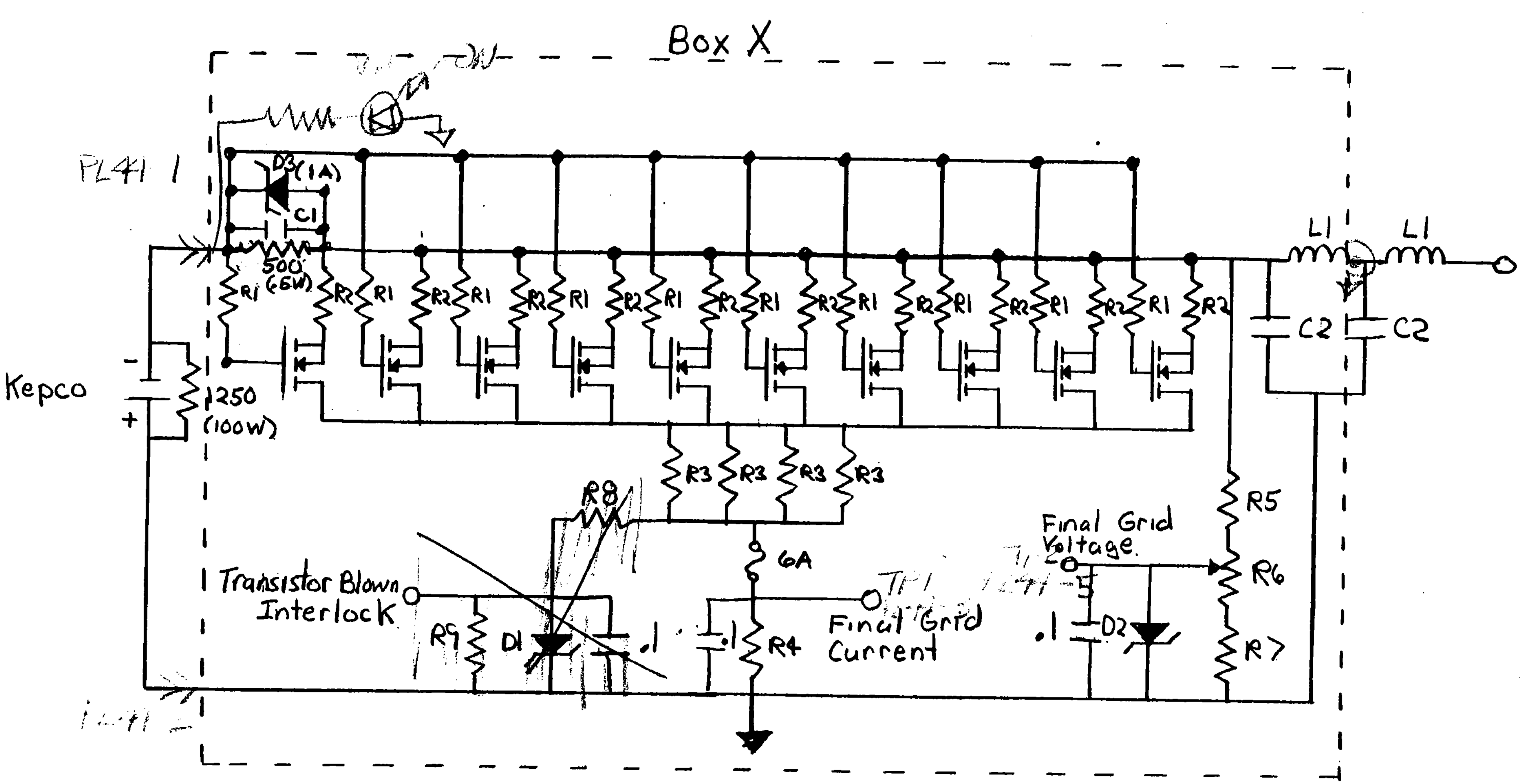
Aside from the grid losses due to this current, we must also contend with this rectified current which flows. An equivalent circuit for this looks like:



The diode has characteristics as specified on the tube grid voltage/current curves. This circuit is obviously now behaving as a negative peak detector when [Vd(t) + Vg] > 0. Since the grid bias supply is voltage regulated, then the current through its shunt resistance decreases as the rectified current from the grid increases. This process continues, as a function of increasing drive, until the grid bias supply current is exhausted. Notice at the point when the grid bias supply current goes to zero, the grid bias is completely supplied by the driver. Also notice, once the grid bias supply current is exhausted, then increasing the drive will increase the negative grid voltage. This process bucks out the increased drive from the driver leaving us with a almost perfect amplitude limiter.

Two methods exist to prevent this from happening. One involves placing a powerful enough grid bias supply in the circuit along with an appropriate resistance to supply more then an adequate amount of grid current for any drive level. This method isn't very desirable because the available current is a function of grid bias for any given shunt resistance value, and when we aren't drawing any grid current, power into this shunt resistance goes down the drain. The other method involves inserting a automatically variable shunt resistance into the circuit whose resistance is a function of the bias supply current drawn into the grid. This method allows us to use a much less hefty power supply, and we only dissapate power when the grid draws current.

Since we have already purchased these less hefty supplies, and since the second method above makes more sense anyway; we will build and install this shunt regulator. Figure 5 displays the circuit diagram of the shunt regulator we will be building. We have already tested this circuit on the prototype amplifier and it behaves beautifully.



R1 100Ω, .25W, ± 5%
R2 10Ω, 3W, ±1%
R3 80Ω, 250W, ±1%
R4 1Ω, 10W, ± 1%
R6 1K
R7
R8
R9

C1
C2
L1
D1
D2
D3

4648 GRID #1
Circuit Diagram

FIG 5

J. Vincent

June 22, 1985

5. Conclusion.

The K800 rf amplifier is now approaching completion rapidly. We still have to solve the magnetic interactions problem, since our last attempt did little to improve the situation. Another item which should be given our immediate attention is getting parts detailed and ordered from wherever for the new low z sections. During the next couple weeks the rf group will be working on the Aydin power supply and building the shunt regulator for the grid circuit as previously mentioned. During our next meeting we should lay down what will happen in the next couple of weeks to the rf amplifier to get it closer to the final product.