Y567B Power Amplifier Tests at 76 and 106 MHz

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1 Introduction

A perpendicular biased 2nd harmonic cavity for the Fermilab Booster is currently being constructed. We will use the same power tetrode (Eimac Y567B) which is used in the main (fundamental frequency) Booster cavities ($\sim$38 − 53 MHz), the Main Injector, and the Recycler ($\sim$53 MHz). The 2nd harmonic cavity will operate at twice the fundamental frequency, at injection ($\sim$76 MHz) and at transition or extraction ($\sim$106 MHz). Possible ramps are shown in Fig. 1.

According to the specifications for the Y567B (Eimac 4CW150000)[1], it can operate with up to 150 kW of power dissipated in the anode, and up to 108 MHz. In present Booster cavities, the output maximum is $\approx$ 100 kW, with an efficiency of $\approx 60 - 70\%$. The 2nd harmonic cavity is expected to have shunt impedances of 96 kΩ and 180 kΩ at 76 and 106 MHz, respectively. Here we use the definition for shunt impedance $R_{sh} = \frac{V_p^2}{2P}$, where V_p is the peak RF voltage across the gap and P is the average power loss. For the required peak voltage of 100 kV across gap, substantially less power will be needed by the Booster 2nd harmonic cavities when compared to the existing cavities operating at the fundamental frequency. Nevertheless, we must verify that the tetrode can produce the required output power at the frequencies of the 2nd harmonic.

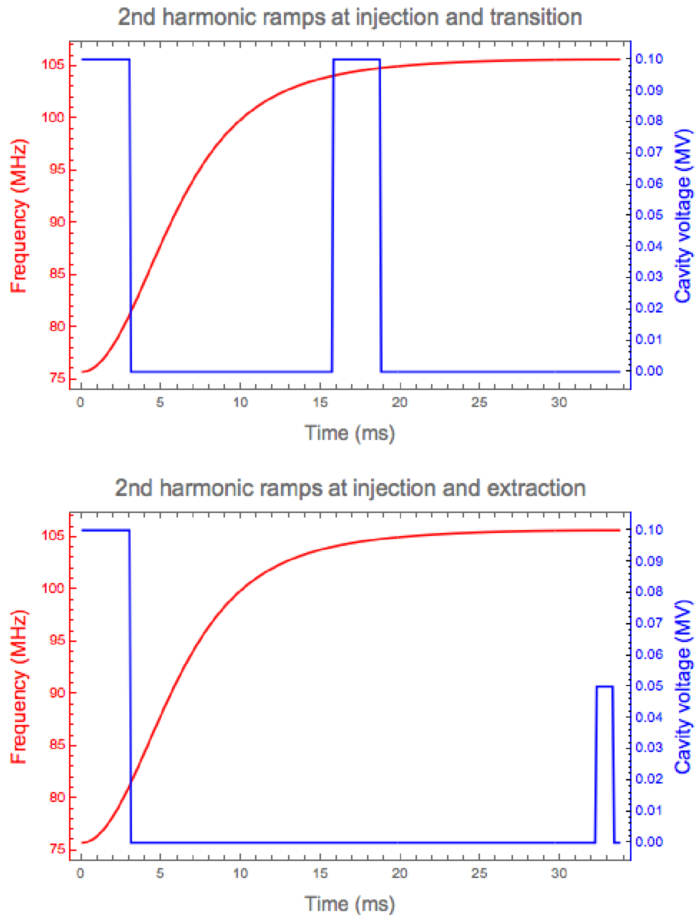


Figure 1: Possible scenarious for the time dependence of frequency and voltage in the 2nd harmonic cavity.

2 The Power Amplifier and Test Station

Testing and use of the tetrode at a given frequency requires a module (power module) to mechanically support the tube and supply voltage to its various electrodes, a drive resonator (cathode resonator), and an output resonator (anode resonator). The tetrode, power module, and cathode resonator together are referred to as the PA (power amplifier).

The power module is essentially a shell with the tube socket. The drive resonator is a coaxial line which looks inductive. This ideally should cancel the imaginary part of the tube input impedance, which is capacitive. "Swamper loads" (two 50 Ω loads in parallel) are connected to it so that the resonance is broad, and the tube can be driven over a wide frequency range by a solid state amplifier which would ideally see a purely resistive 50 Ω load.

The anode resonator serves as a (non-tunable) stand-in for a real cavity during PA testing. A water cooled 50 Ω load is attached to it to mimic the power dissipation in the ferrite of a real cavity with a tuner. The resonator and power module form a shorted transmission line; a different resonator must be constructed for each frequency at which we want to test the tube. Since a spare Booster power module was available, we used this for our testing. In the case of the real 2nd harmonic cavity, the design for the power module is smaller so that the input part of the cavity does not excessively detune it. For the PA testing we also use the same coupling scheme as the main Booster PAs. That is, a shroud is attached to the anode of the tetrode and inserted into a blocking (coupling) capacitor which is mounted on the anode resonator center conductor. This scheme will also be different in the real 2nd harmonic cavity, but it is suitable for testing the tetrode.

Given the components used, the 2nd harmonic test station looks very much like a fundamental Booster PA test station, except that the anode and cathode resonators are different sizes. The cathode resonator was constructed from a prototype fundamental cathode resonator by shortening it. (See Section 4 for more details.) A new anode resonator was constructed so that the complete setup would resonate at ∼76 MHz. A drawing and photograph are shown in Figures 2 and 3.

The first anode resonator was designed to test the PA at 76 MHz. The setup was modelled using a transmission line plus lumped circuit analysis with Agilent (now Keysight) Advanced Design System (ADS), and also with CST Microwave Studio. The simulations are discussed in Section 3.

After construction of the first resonator, the measured frequency was only 71.7 MHz. Power tests were done at this frequency, and then later the resonator was modified to test at exactly 76 MHz.

The PA was also tested at 106 MHz. Since a quarter wave resonator would have been too small to be practical (for instance, to connect the load), the 106 MHz resonator plus PA form a $3\lambda/4$ resonator. A picture is shown in Fig. 4.

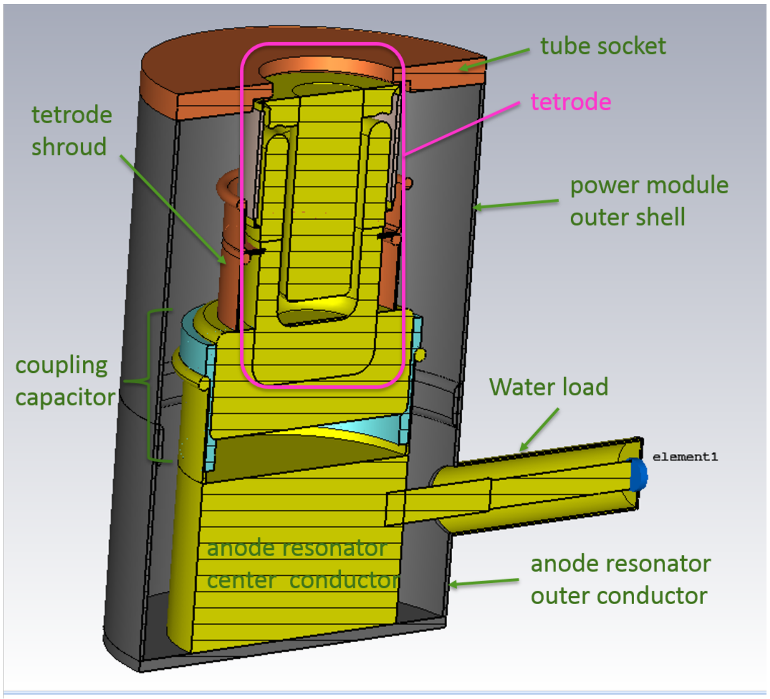


Figure 2: Drawing of the 76 MHz PA test setup.

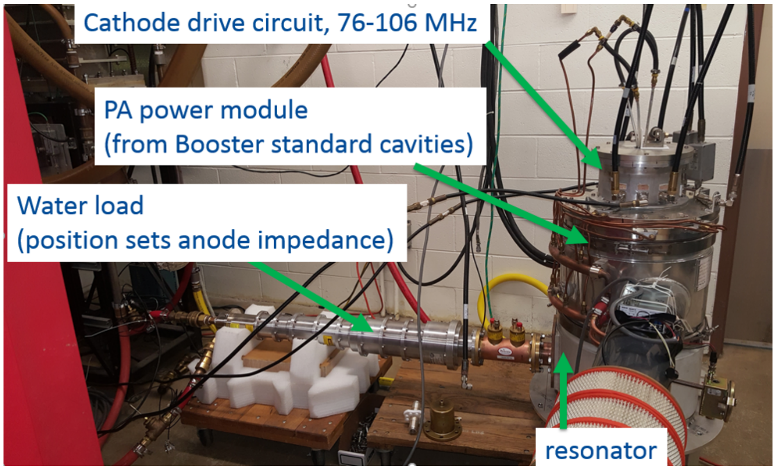


Figure 3: Photograph of the 76 MHz PA test setup.

Figure 4: Photograph of the 106 MHz PA test setup.

3 Simulations and Anode Resonator Design

To determine the geometry of the anode resonator such that the system would resonate at 76 MHz, a transmission line model of the existing setup for the fundamental Booster PA tests was constructed. The transmission line dimensions are determined by the diameters and lengths of the anode resonator inner and outer conductors, tube anode diameter, and power module outer shell diameter. The resonator is shorted at one end and the other end is foreshortened by the tube output capacitance of ≈60 pF. The blocking capacitor is represented by another lumped capacitance of 1000 pF. The model in the Keysight/Agilent Advanced Design System (ADS) software is shown in Figure 5. The simulation predicted a resonant frequency of 53 MHz and a Q of 60, which agreed with what was measured. The dimensions of the transmission line corresponding to the anode resonator part of the setup were then modified so that the frequency of the setup was 76 MHz. Changes are shown in Fig 6.

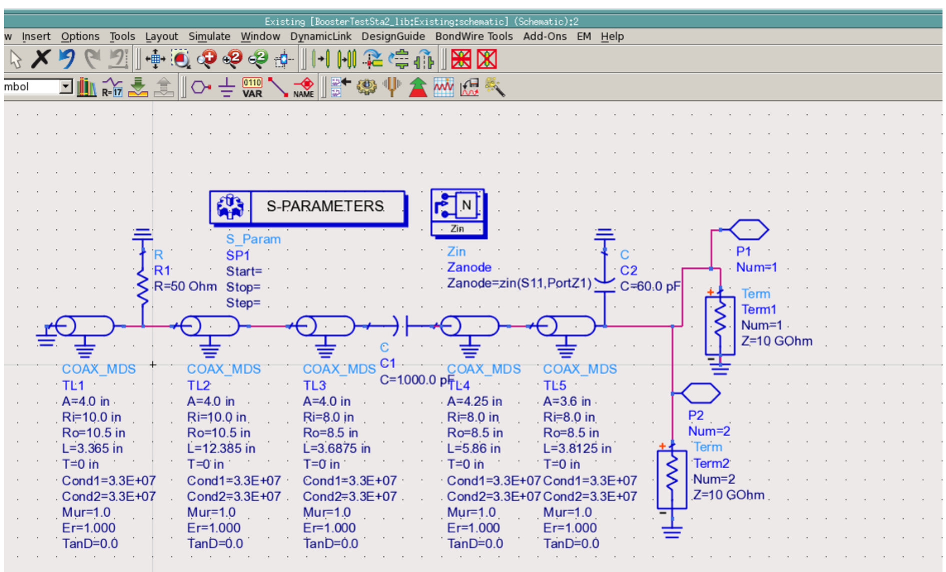


Figure 5: Transmission line model of Booster fundamental PA test setup in Keysight/Agilent ADS

As a check, the anode resonator and tube were also simulated in CST Microwave Studio. In the first (simplified) model the output capacitance of the tube was represented by a physical parallel plate capacitor at the end opposite the short. Again, the fundamental PA test station was modeled first and tuned (by adjusting the capacitor gap) until it predicted the correct resonant frequency. The model was then modified using the anode resonator dimensions which ADS had shown to give a resonant frequency of 76 MHz. The CST model predicted 78 MHz. It was decided that this was sufficient agreement, especially since the simulations were both using simplified models of the tetrode. (The coupling capacitor was simplified as well).

The anode resonator was constructed according the the calculated dimensions, however, the resulting resonant frequency of the system was 71.7 MHz and not the desired 76 MHz. We proceeded with power tests since it was likely that it was sufficient to test the PA near 76 MHz. In order to test the PA at exactly 76 MHz, a modification to the setup was designed. A ring was manufactured and bolted to the bottom of the anode resonator, making it effectively shorter and higher frequency. A modification to the load connection scheme was also made. In order that the impedance seen by the tube was optimal and similar to that in the 71.7 MHz tests, the connection scheme for the load was changed from a direct straight across connection to one in which the conductor attached to the load loops up and back down again, as shown in Figure 7. (In order to maintain the same impedance with the added ring and a straight across connection, the connection point would have had to be moved up further than the end of the anode resonator center conductor, into the coupling capacitor region.)

For the design of the 106 MHz test station, we again used a model similar to that shown in Fig. 5. The main differences were the following. First, the 106 MHz resonator and PA formed a three quarters wavelength resonator, instead of a quarter wavelength resonator. Second, the value of the tube output capacitance was changed from 60 pF to 73.1 pF, which is the capacitance, which, when used in the model for the initial 71.7 MHz resonator, gave the correct measured frequency. Nevertheless, we had seen before that extrapolating from 53 MHz to 76 MHz gave a cavity with a low frequency. In anticipation that this might happen again, we designed the 106 MHz cavity to have 2 inch long removable spacers on the inner and outer conductors. The cavity nominal predicted frequency was 106 MHz with the spacers in. If the frequency was too low, the spacers could be removed or shortened. As it turned out, the test cavity was exactly on resonance at 106 MHz with the spacers removed. The change in the design to 106 MHz is shown in Fig. 8, to be compared with Fig 6.

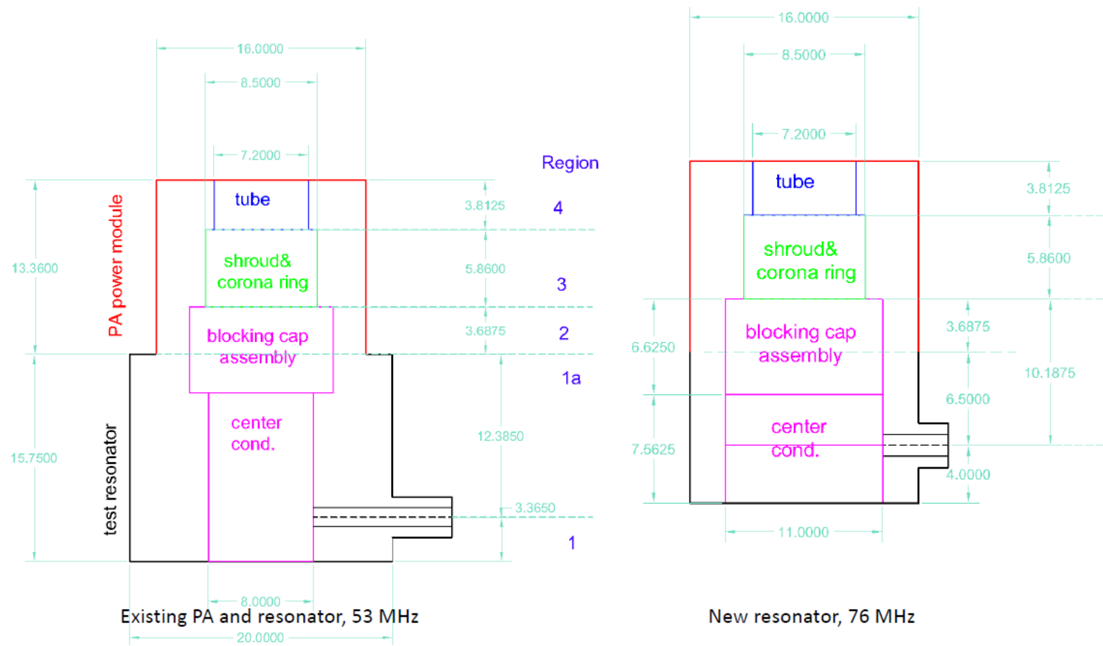


Figure 6: Modifications to PA test setup.

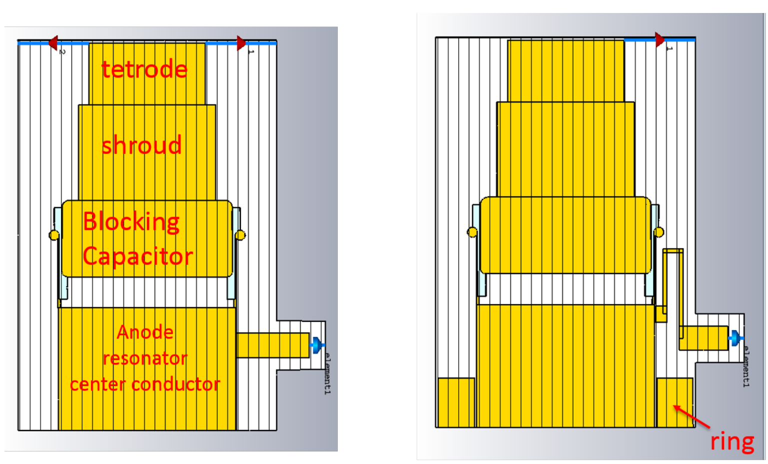


Figure 7: Original (left) and modified (right) anode resonator. The modified setup contains a ring at the bottom to increase the resonant frequency to from 71.7 to 76 MHz. In addition, the load connection geometry is changed so the tetrode sees the optimal impedance.

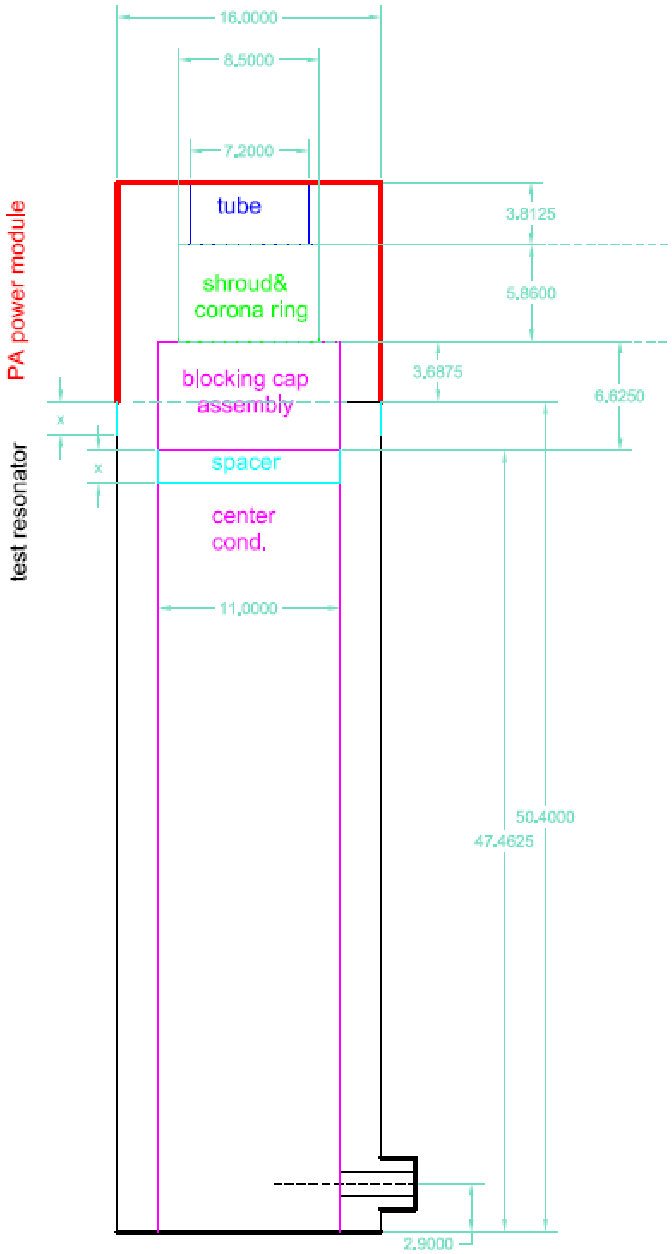


Figure 8: PA test setup at 106 MHz. A removable spacer (2 inches long) was included in the design.

4 Cathode Resonator

A schematic of the drive circuit is shown in Fig. 9. The amplifier, made by Tomco, has a maximum output power of 8 kW. It is meant to drive a 50 Ω load. To protect the amplifier components, forward output power is limited depending on the fraction of reflected power as shown in Fig. 10. However, the amplifier does not limit output unless the amount of reflected power is above the threshold for two seconds, for which it can withstand 100% reflected power at full output [1] Since we operate in pulsed mode with pulse widths substantially less than 2 seconds, this situation will never be realized.

Four 50 Ω Heliax cables connect the combiner outputs to the cathode resonator, through HN connectors and banana plugs (inside the resonator).

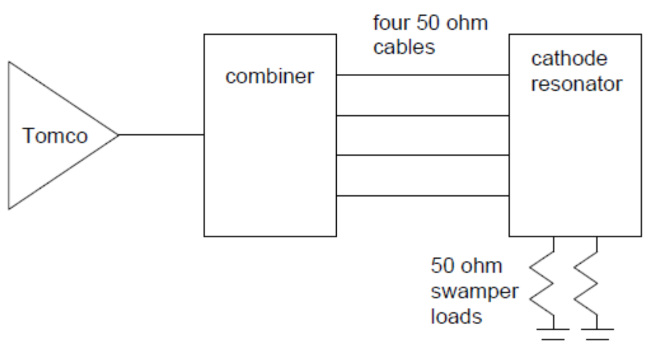


Figure 9: Schematic of the drive configuration.

The cathode resonator was modeled in a manner similar to that of the anode resonator, and is also discussed in [2]. That is, it is essentially a shorted quarter wave resonator foreshortened by the tube input capacitance

[1]The amplifier protection system monitors the reflected power level at all times. If the reflected power exceeds the maximum allowable level for more than two seconds the protection system activates and reduces the amplifier gain until the reflected power sits right at the maximum allowable level. At the same time, a 100-second timer is triggered. This disables the 2-second delay timer, meaning that if excessive reflected power is detected again within 100 seconds the reflected power limiter will activate immediately rather than waiting two seconds. When the 100 seconds has elapsed, the 2-second delay is switched back in and another 2-second burst of full-power full reflection will be permitted. This system ensures that there is sufficient time for the amplifier to completely cool down before allowing another high reflection event.

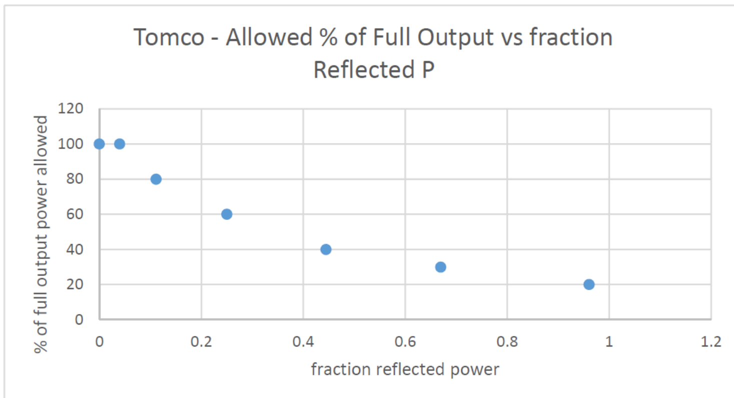


Figure 10: Percentage of maximum allowed output power vs. reflected power for the Tomco driver amplifier.

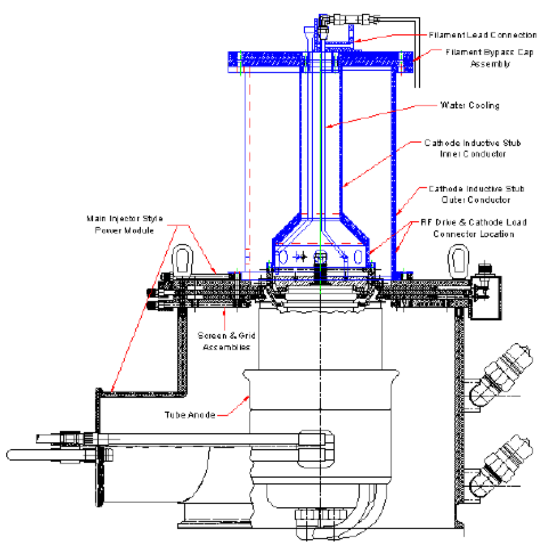


Figure 11: Cross section of the fundamental Booster PA. The cathode resonator is the blue structure on top.

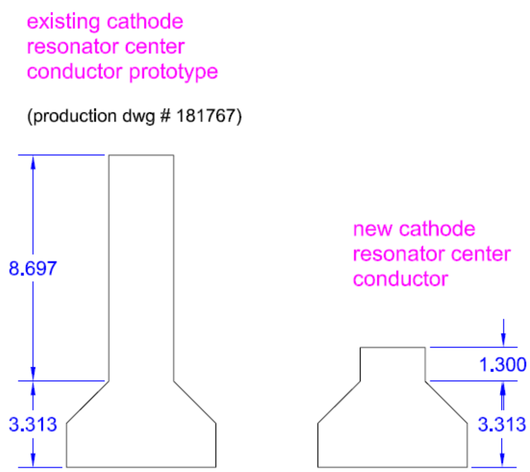


Figure 12: Modification of the fundamental Booster prototype cathode resonator for use at higher frequency. Only the inner conductor is shown. The outer conductors is also shortened accordingly.

of 250 pF. Note, according to [2], this includes both the tube interelectrode capacitance and the capacitance of the tube socket. The frequency of the new resonator, the "76 MHz cathode resonator", was shifted up by shortening the Booster prototype fundamental resonator (see Figs 11 and 12) so that its peak was near 76 MHz. As with the fundamental resonators, this frequency was chosen as the peak (as opposed to mid-range) since it is where the shunt impedance of the cavity is the lowest and thus where the most drive power would be needed.

The simulation predicted that the response would be down by only 1.1 dB at 106 MHz, compared to 76 MHz. Unfortunately, this turned out to not be true. In fact, with this cathode resonator, we have measured in low power tests that the fraction of reflected power is 77% at 106 MHz; at 76 MHz only 5-10% is reflected. The failure of the simulation to accurately predict the falloff in response/larger than expected reflection is possibly due to a frequency dependence of tube input impedance/capacitance.

One way to improve the situation, which has been studied at low power levels and has shown promise[2], is to attach an open stub (made from heliax cable) to the resonator to adjust the impedance. Here, we are shaping the response curve as a function of frequency to something which is more desir-

[2]thanks to Joe Dey

able. It turned out to be sufficient to slightly modify the design of cathode resonator - this time aiming for maximum response between 76 and 106 MHz as opposed to at 76 MHz. So the response at 76 MHz is inferior to that of the initial resonator, but is nevertheless workable at both frequencies. This "modified cathode resonator" was shorter than the 76 MHz cathode resonator by 0.18". Also, the center conductor was not tapered; the OD was constant (5.75"), and the same OD as the base (larger OD part) of the 76 MHz cathode resonator. Before building the modified cathode resonator, we constructed one out of sheet metal and measured the reflected power at low power levels. We then iterated upon this to obtain the best possible responses at both 76 and 106 MHz.

Fig. 13 shows the setup used to measure the (low power) response of the cathode resonators with no high voltage on the tetrode. The filaments were on. Fig. 14 shows directional coupler measurements of the percentage of reflected power for the (1st) 76 MHz cathode resonator. As we will see in the next section, this is lower by up to around 5% when the tetrode is actually on, at 76 MHz. Fig. 15 shows the response of the modified cathode resonator with the same low power setup. At 76 MHz ∼32% of the power is reflected; at 106 MHz, ∼59% of the power is reflected.

The modified cathode resonator was the one used in the power test at 106 MHz. For high power tests at 76 MHz, the PA was initially tested using the 76 MHz cathode resonator, and was then tested a second time with the modified cathode resonator. Again, in the high power tests, the measured reflected power was less than or equal to that measured in the low level tests. (See the next section.)

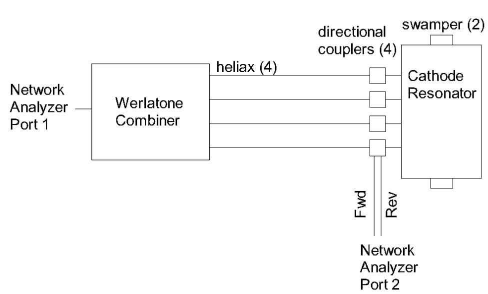


Figure 13: Low power measurement setup for 76 MHz cathode resonator reflected power.

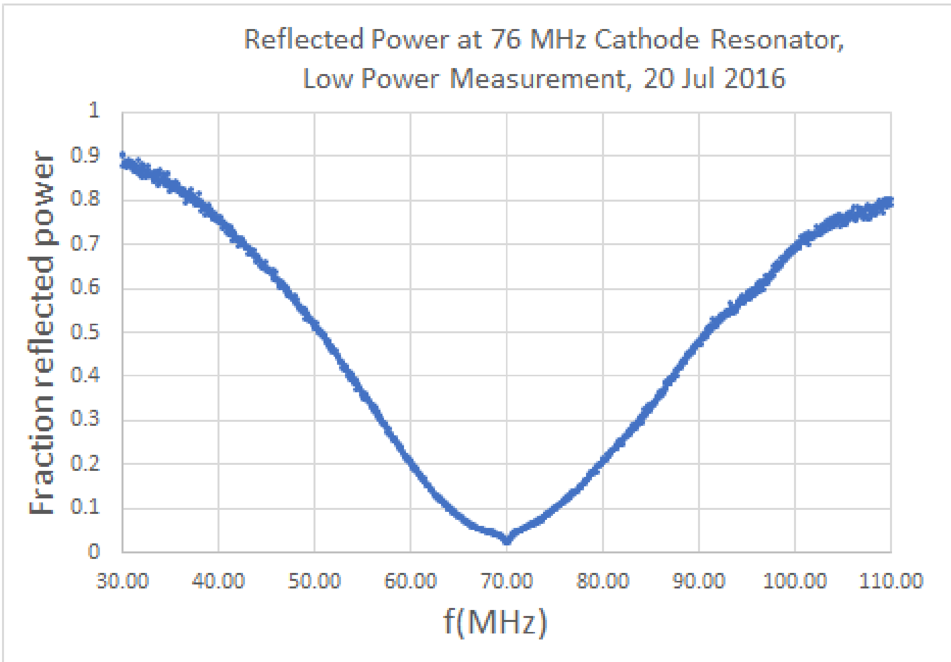


Figure 14: Measurement of 76 MHz cathode resonator reflected power.

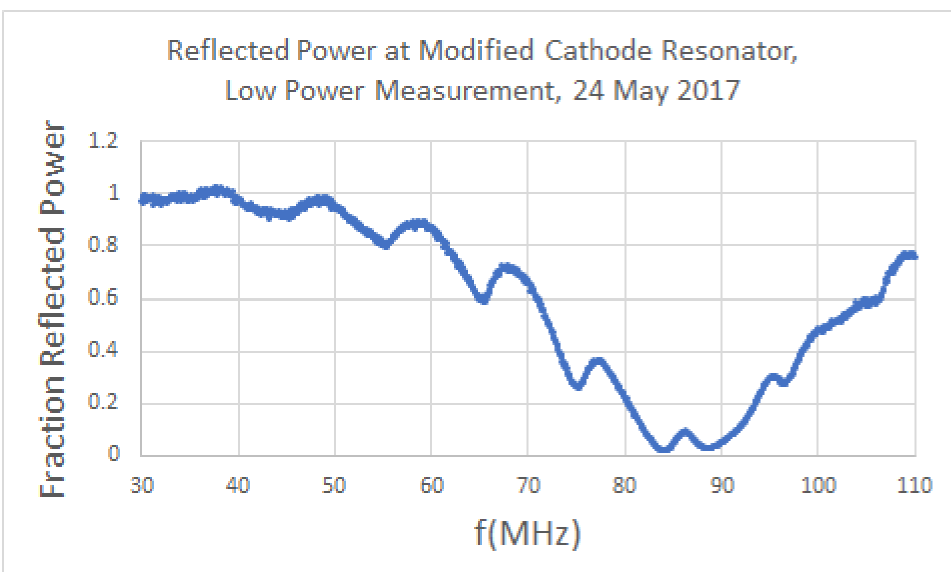


Figure 15: Measurement of 76 MHz cathode resonator reflected power.

5 High Power Tests

The PA was first tested at 71.7 MHz in April 2016 and then at 76 MHz, with a modification to the anode resonator, in January 2017. The impedance seen by the tetrode is set by the vertical position of the 50 Ω water load, which is adjustable. We aimed for $Z_0 = V_a(\mathrm{DC})/I_a(\mathrm{DC}) \approx 2$ kΩ, where V_a(DC) and I_a(DC) are the DC anode voltage and current. Following [3], by Fourier analysis for class B [3] operation, this corresponds to an impedance at the RF frequency of $Z_1 = \frac{2}{\pi} Z_0$.

The test was performed with $25 - 50\%$ duty factor and 40 ms wide RF pulses. Power dissipated in the anode and load were determined calorimetrically by measuring the flow to each and the temperature differential in the cooling water. As a cross check, power dissipated in the load was also measured using a directional coupler inline with it. Other measured quantities were DC anode voltage and current, forward and reflected drive power, and anode and cathode monitor response. Forward and reflected drive power were measured by one directional coupler on the output of the drive amplifier, and also by one of four directional couplers on the four inputs to the cathode resonator. A schematic of the test setup is shown in Fig. 16.

For the main study, several data points were taken starting at an anode voltage of 12 kV and increasing it to 21 kV. At each point, the drive power was adjusted so that the screen current was 300 mA. In this case the tetrode was operating with an efficiency of $\geq 70\%$. For another study (only at 76 MHz), the anode voltage was kept constant at 21 kV and the drive power was varied, regardless of the screen current or efficiency. This was done in the interest of measuring output power in the case where the drive power is small due to poor impedance matching to the cathode resonator.

Quantities of interest from the 76 MHz test, with the 76 MHz cathode resonator are plotted in Figs. 17 - 21. In these plots, 'dir cplr' refers to the directional coupler on the output of the drive amplifier. 'DC 1/4 x 4' refers to the power at one of four directional couplers on the input to the cathode resonator. The power in one of these has been multiplied by four.

A maximum output power of 138 kW was obtained at 76 MHz with an anode voltage of 21 kV and forward drive power of 3 kW. The tube efficiency was 70%. Similar results were obtained in the 71.7 MHz test. Scope and

[3] Technically, the amplifier is operated as class AB, but since the conduction angle is not very much more than 180°, this estimate can be used.

spectrum analyzer photos are shown in Appendix 6.

The tetrode was next tested at 106 MHz, with the modified cathode resonator (see Section 4). Plots are shown in Figs. 22 -25. Appendix 6 includes spectrum analyzer analysis of the cathode monitor signal.

The final test conducted was again at 76 MHz, but this time with the modified cathode resonator. Plots are shown in Figs. 26 - 29.

Given the predicted shunt impedances of 96 kΩ and 180 kΩ at 76 MHz and 106 MHz, respectively, we expect we will need 52 kW and 28 kW to produce a peak voltage of 100 kV in the cavity. Technically, for, extraction, only 30 kV is needed, in which case the PA output is only 2.5 kW. For transition, it is likely that more than one cavity is necessary. As shown in the plots referenced above, the tetrode can produce more than the required amount of power at both frequencies, using the modified cathode resonator. In addition, the drive powers (and associated fraction of power reflected) required to produce these output power levels are within the safe operating range for the drive amplifier, as shown in Fig. 10.

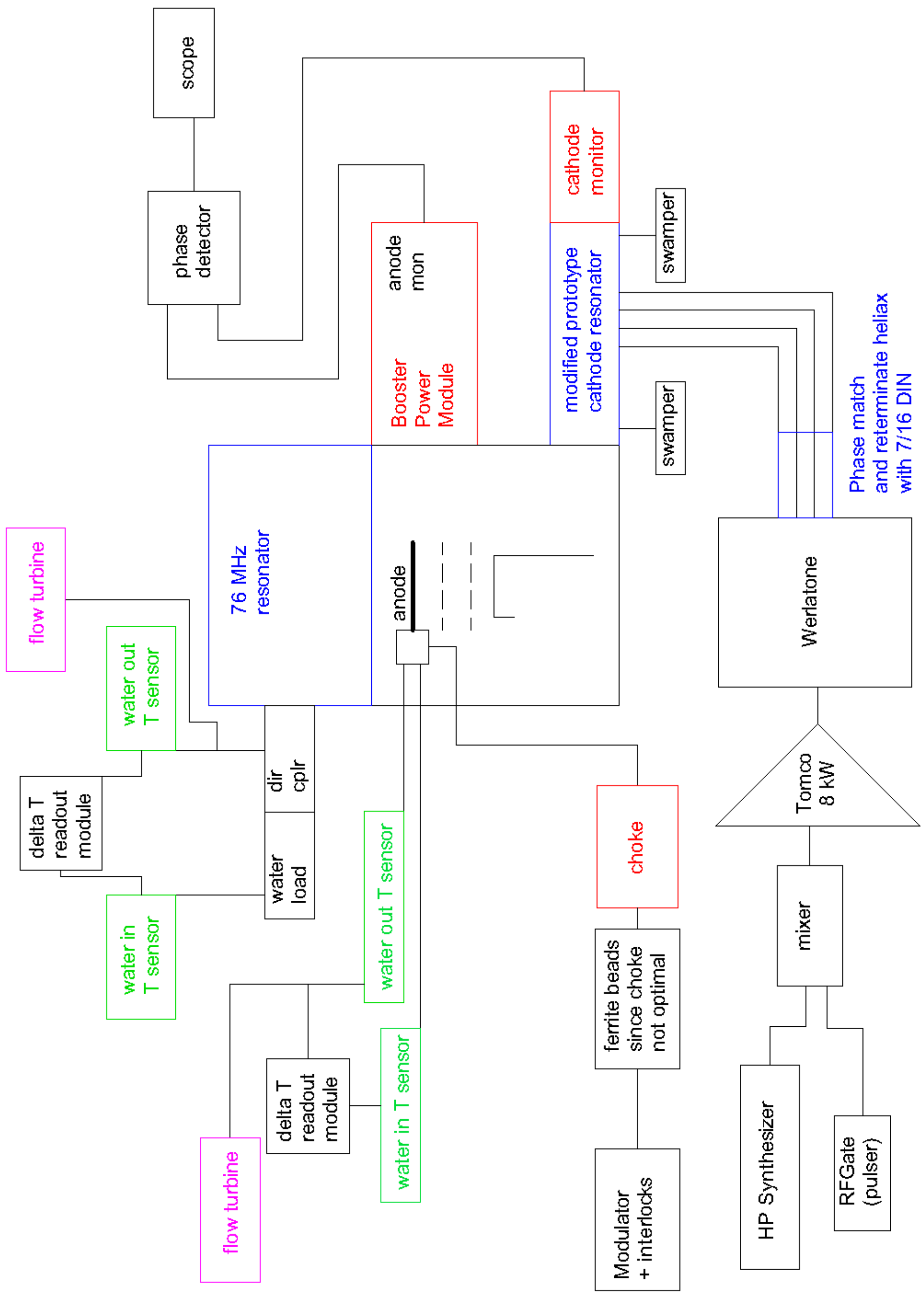


Figure 16: Schematic of the PA test setup.

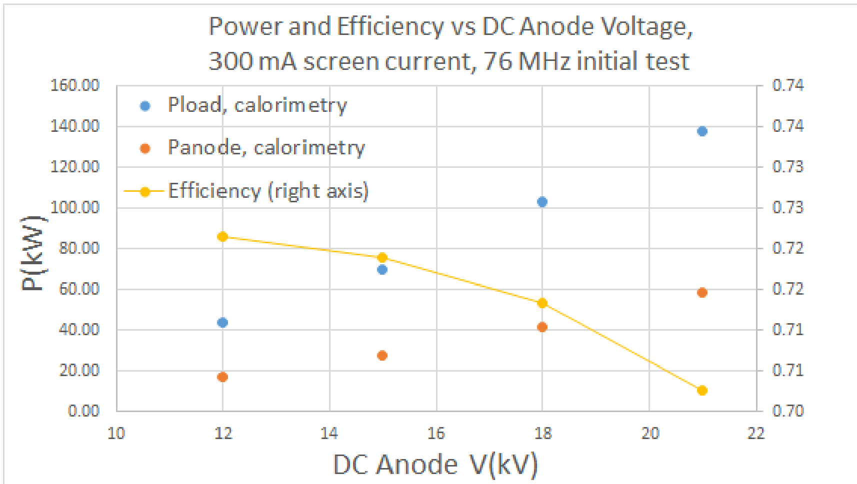


Figure 17: For initial 76 MHz test: Output (load) power, power dissipated in anode, and efficiency for each value of DC anode voltage. At each point the drive power was set to produce 300 mA of screen current.

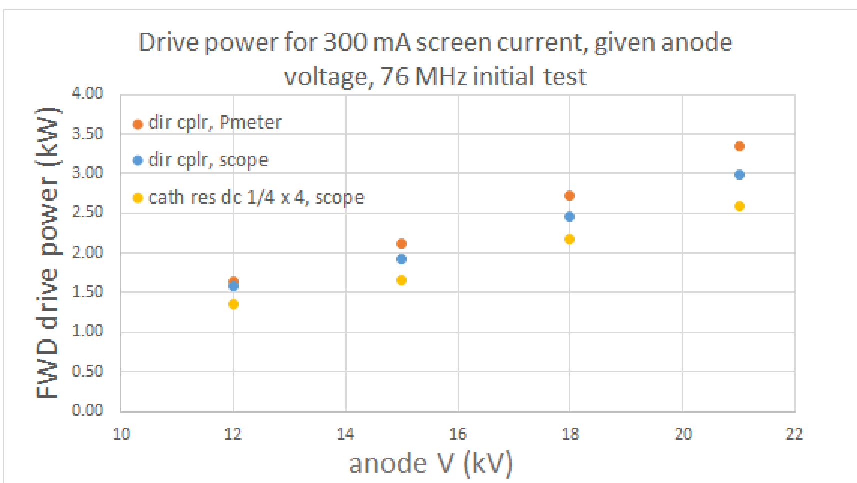


Figure 18: For initial 76 MHz test: Drive power used at each anode voltage setting to produce 300 mA of screen current. The measurements using the dedicated power meter (Pmeter) are more accurate. Additional measurements of the voltage were taken on the oscilloscopes, and power was calculated. This serves mainly as a cross check.

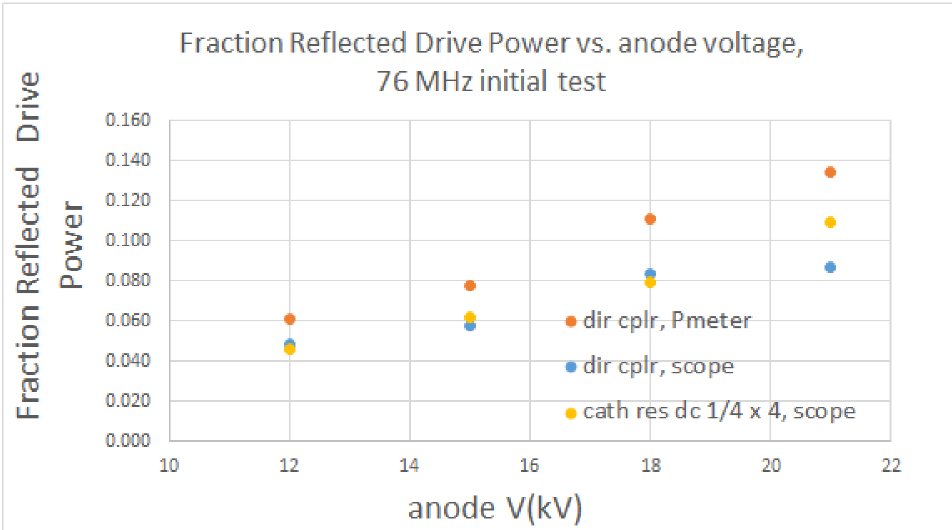


Figure 19: For initial 76 MHz test: Fraction of reflected power, measured in several ways, for each DC anode voltage.

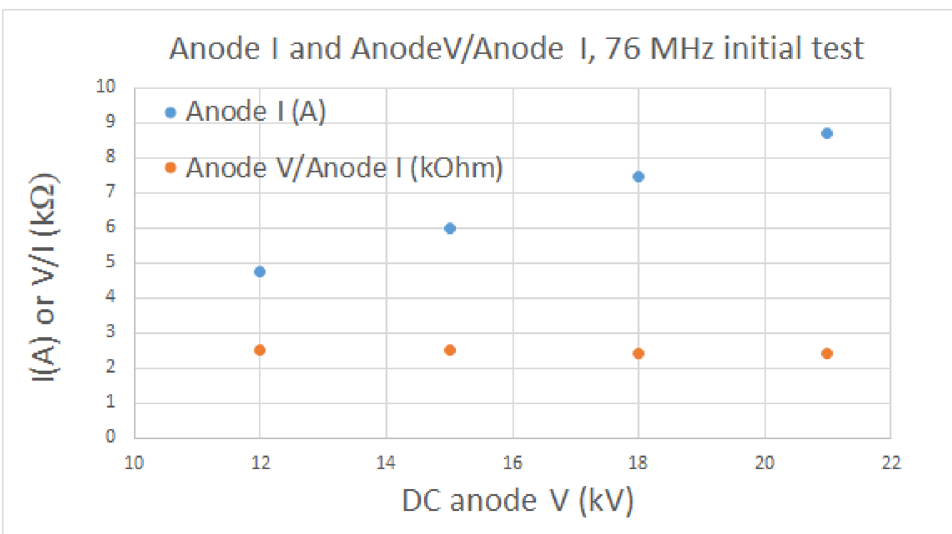


Figure 20: For initial 76 MHz test: DC anode voltage and current for 300 mA screen current.

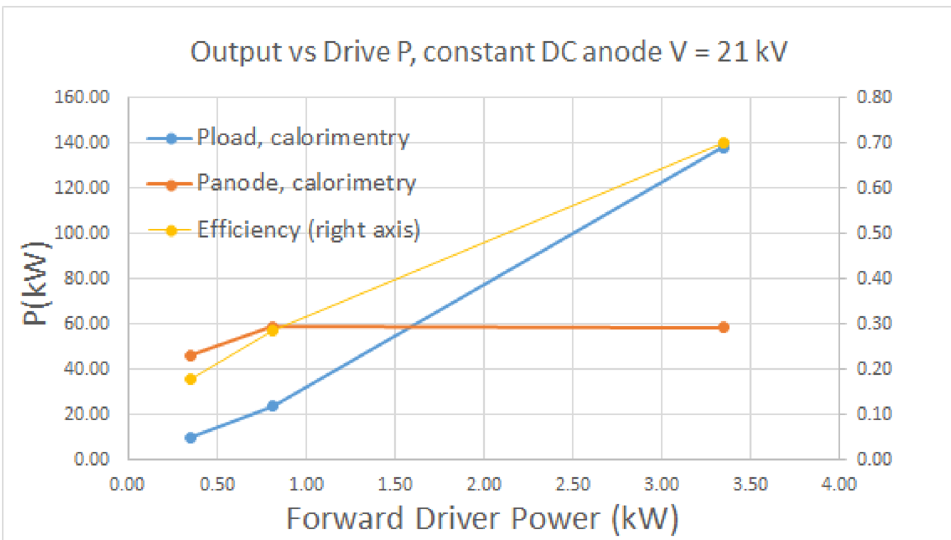


Figure 21: For initial 76 MHz test: Output power as a function of drive power for an anode voltage of 21 kV. The two lower points here have smaller values than those producing a screen current of 300 mA, which were used in the previous plots. Note that the efficiency is also poor.

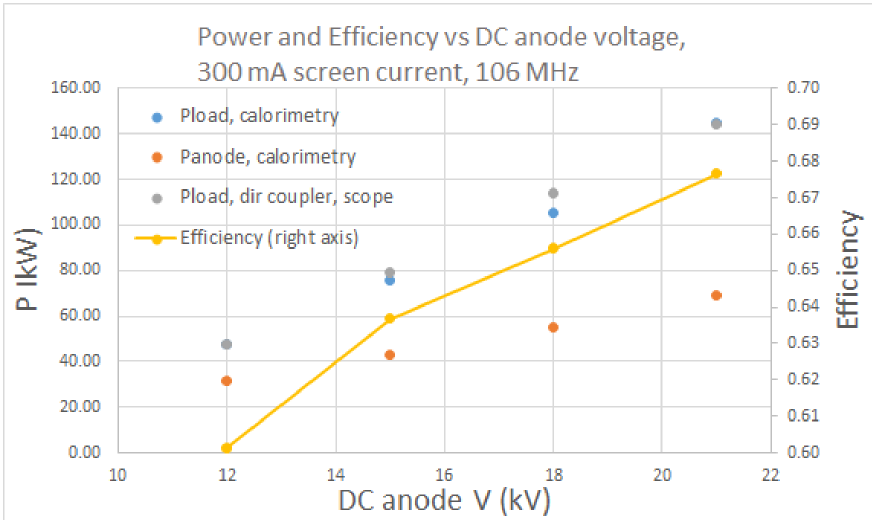


Figure 22: For 106 MHz test: Output (load) power, power dissipated in anode, and efficiency for each value of DC anode voltage. At each point the drive power was set to produce 300 mA of screen current.

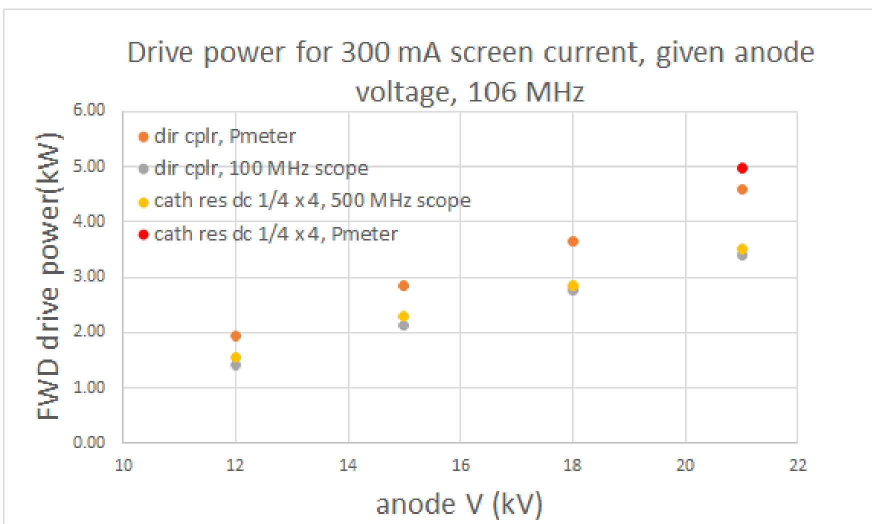


Figure 23: For 106 MHz test: Drive power used at each anode voltage setting to produce 300 mA of screen current. The measurements using the dedicated power meter (Pmeter) are more accurate. Additional measurements of the voltage were taken on the oscilloscopes, and power was calculated. This serves mainly as a cross check.

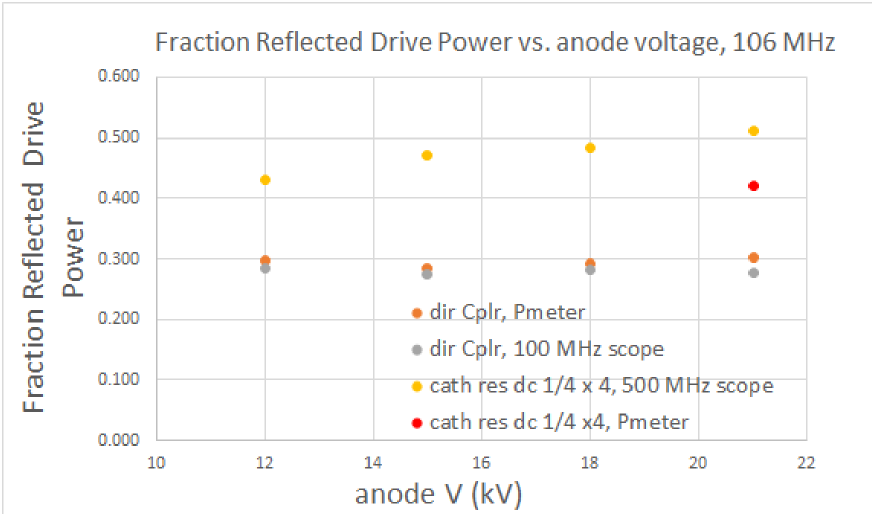


Figure 24: For 106 MHz test: Fraction of reflected power, measured in several ways, for each DC anode voltage.

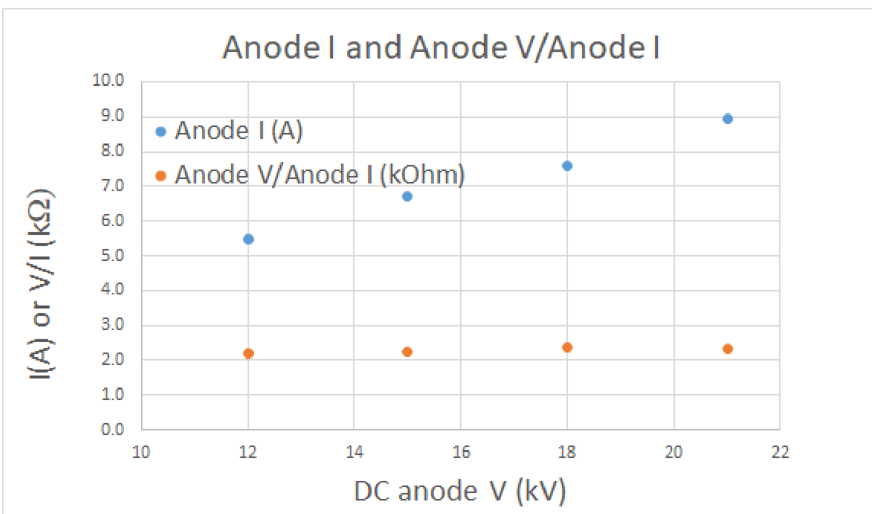


Figure 25: For 106 MHz test: DC anode voltage and current for 300 mA screen current.

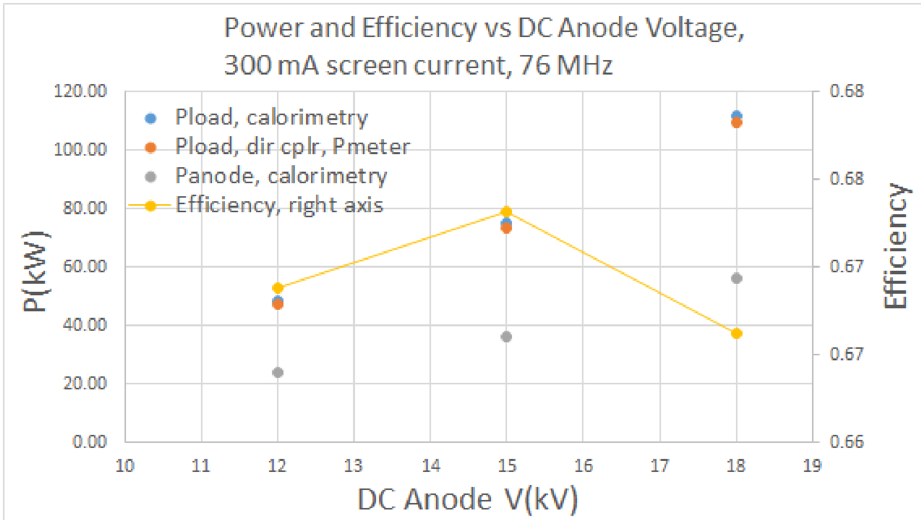


Figure 26: For final 76 MHz test: Output (load) power, power dissipated in anode, and efficiency for each value of DC anode voltage. At each point the drive power was set to produce 300 mA of screen current.

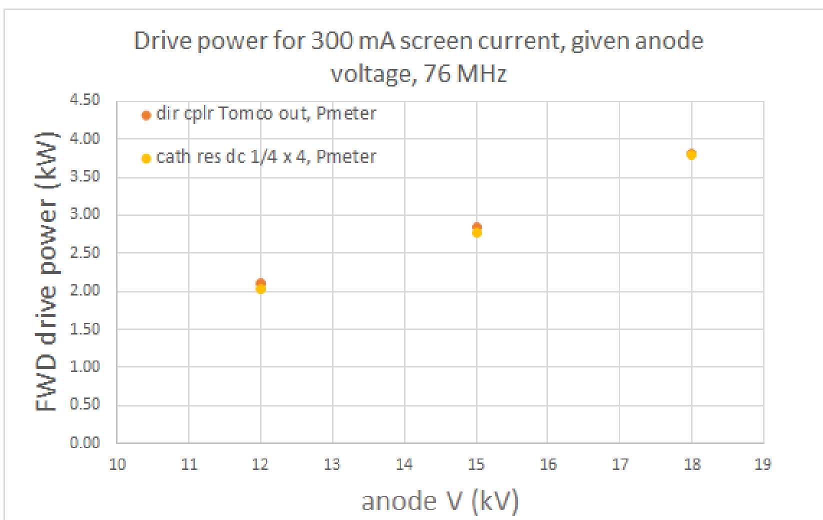


Figure 27: For final 76 MHz test: Drive power used at each anode voltage setting to produce 300 mA of screen current. The measurements using the dedicated power meter (Pmeter) are more accurate. Additional measurements of the voltage were taken on the oscilloscopes, and power was calculated. This serves mainly as a cross check.

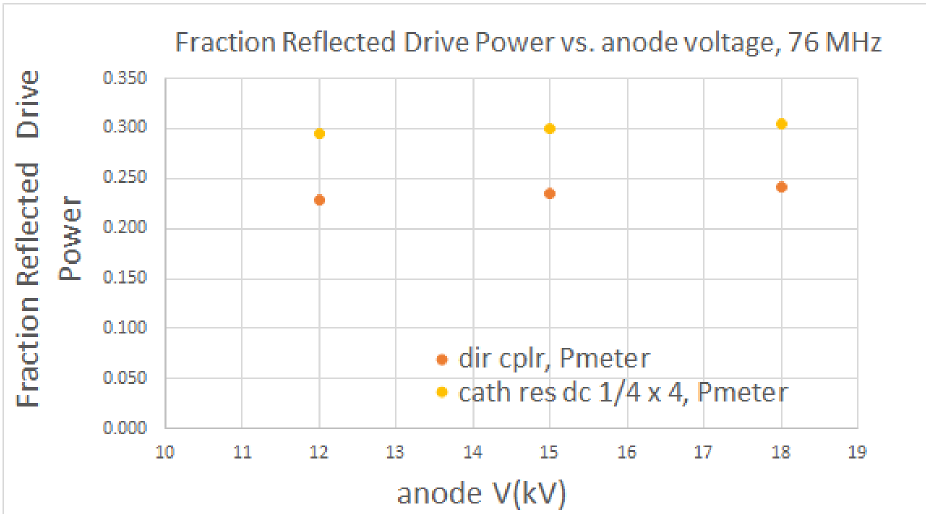


Figure 28: For final 76 MHz test: Fraction of reflected power, measured in several ways, for each DC anode voltage.

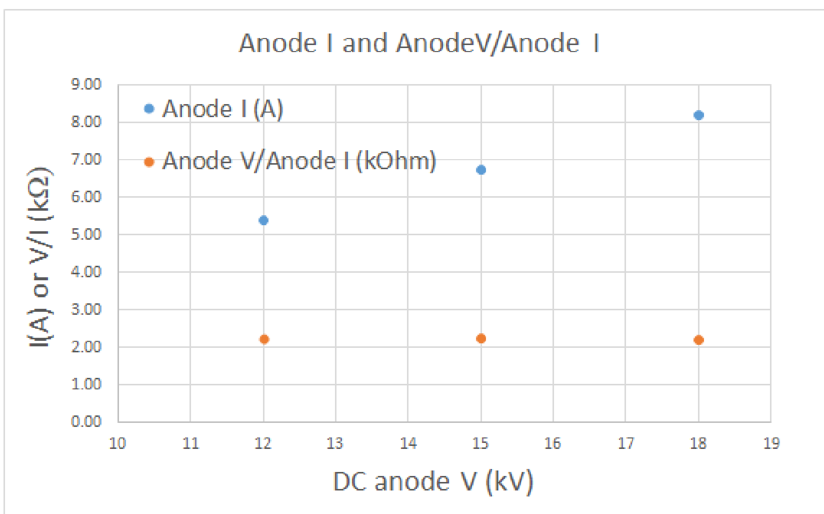


Figure 29: For final 76 MHz test: DC anode voltage and current for 300 mA screen current.

References

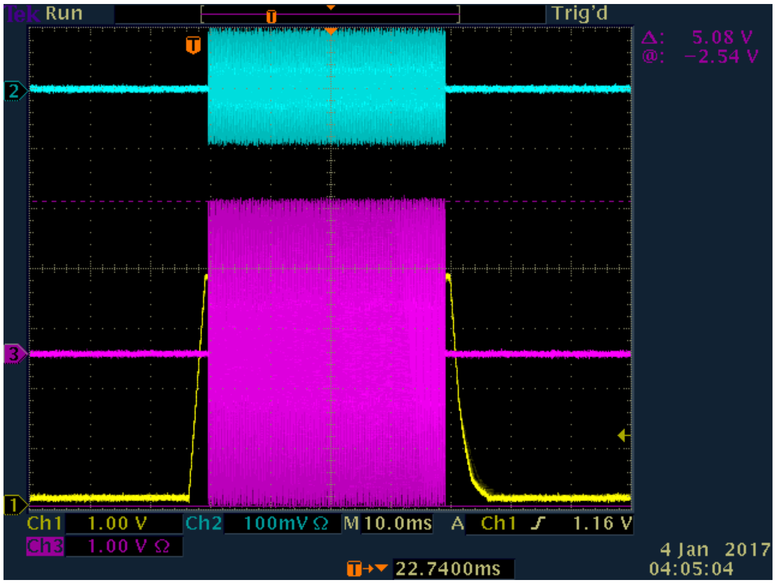
[1] http://www.relltubes.com/filebase/en/src/Datasheets/4CW150000E.pdf.

[2] T. Berenc and J. Reid. A solid-state driven power amplifier design for the Booster RF cavities. http://rf.fnal.gov/global/technotes/TN/TN023.pdf, 2001.

[3] R. G. Carter. Review of RF power sources for particle accelerators. In *CERN - Rutherford Accelerator School: RF Engineering for Particle Accelerators Oxford, England, April 3-10, 1991*, pages 269–300, 1991.

6 Appendix - Scope and Spectrum Analyzer Photos

Modulator Voltage = 12 kV



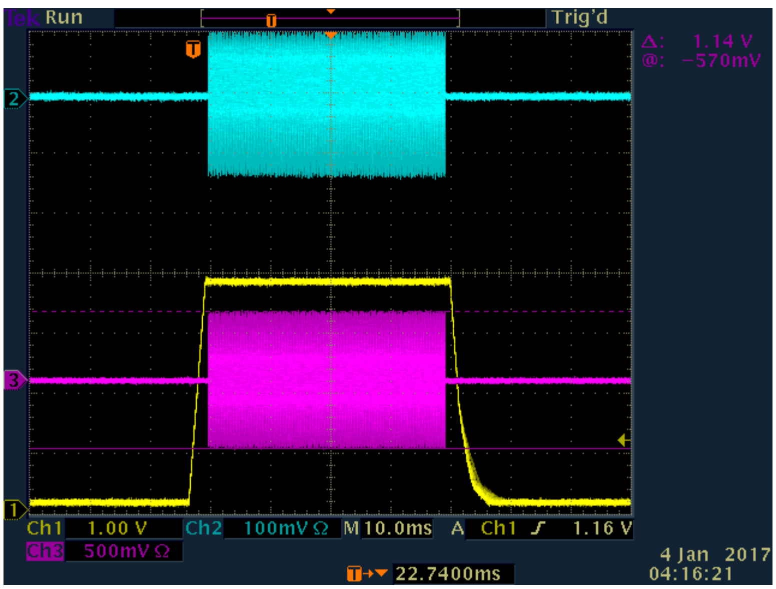
Water Load Directional Coupler

Blue Trace Reflected Power -56.719dB

Violet Trace Forward Power -56.758dB

Yellow Trace Anode DC Voltage = 12kV

RF On = 40mSec, RF Off = 40mSec

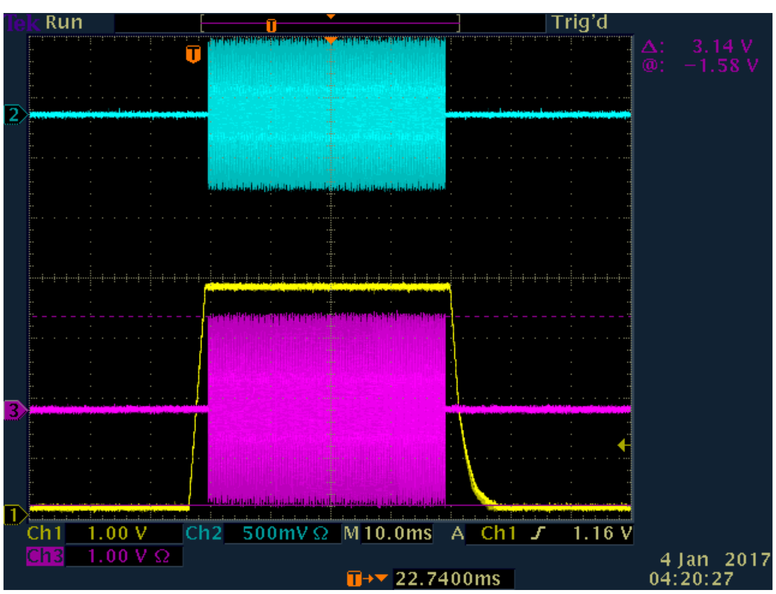


Cathode RF Drive Directional Coupler

Yellow Trace Anode DC Voltage = 12kV

Blue Trace Reflected Power -50.404dB

Violet Trace Forward Power-50.266dB



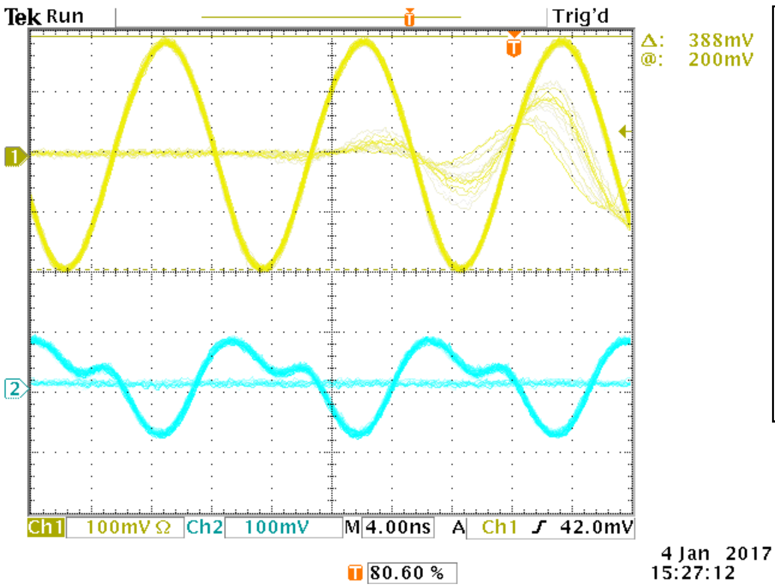
Cathode & Anode Monitors

Yellow Trace Anode DC Voltage = 12kV

Blue Trace Anode Mon

Violet Trace cathode Mon

Modulator Voltage = 12 kV (cont'd)



SSA Output Directional Coupler

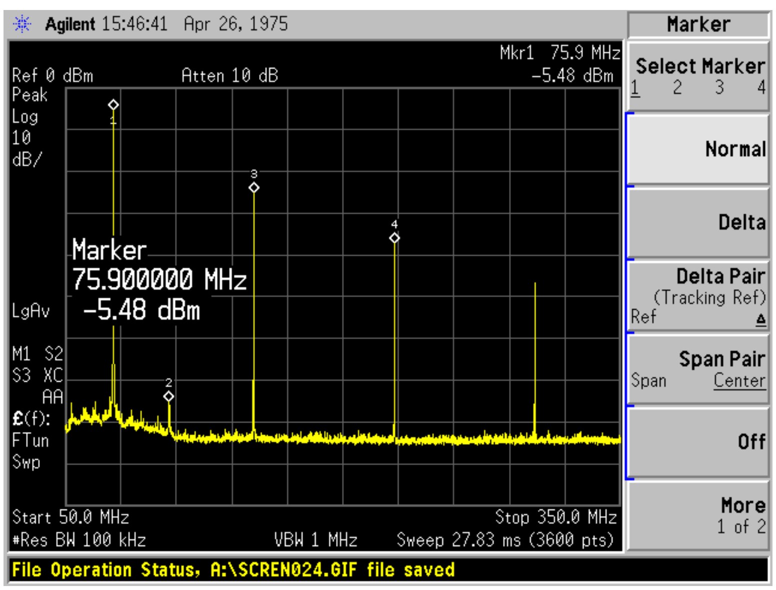
Anode DC Voltage = 12kV

Yellow Trace Forward Power -66.0312dB

.388vpp

Blue Trace Reflected Power -65.834dB

.087vpp



Cathode RF Mon Harmonics SSA with 10 db pad on input to analyzer.

Anode Voltage = 12kV

Marker 1 75.9MHz -5.4 dBm

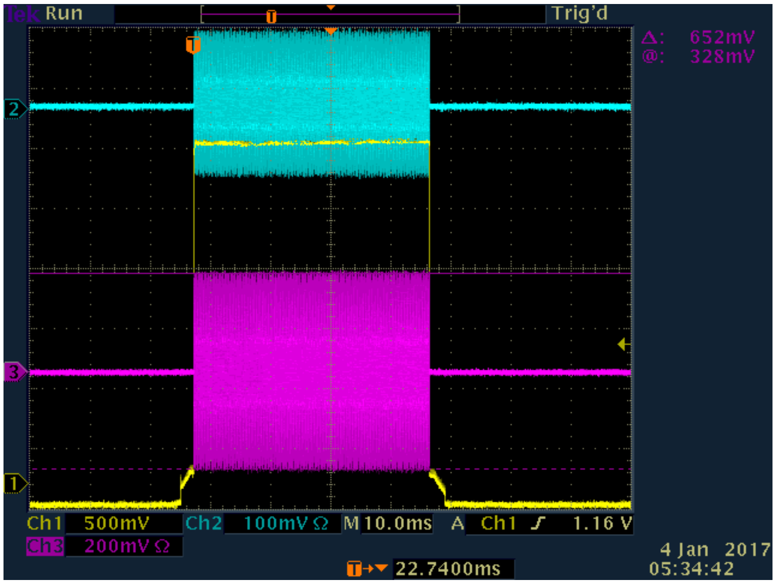
Marker 2 106 MHz -74.95dBm

Marker 3 151.9MHz -25.23dBm

Marker 4 227.9MHz -37.17dBm

Marker 5 303.8MHz -46.54dBm

Now raising modulator voltage to 15kV

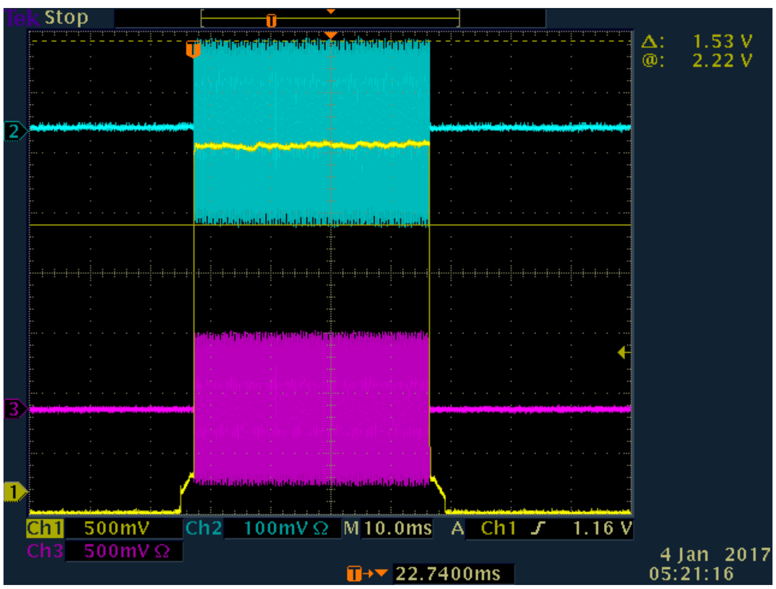


Water Load Directional Coupler

Anode Voltage = 15kV

Blue reflected Power = 0.242vpp

Violet forward Power = 6.58 Vpp trace has 20dB pad



Cathode RF Drive Directional Coupler one of four couplers

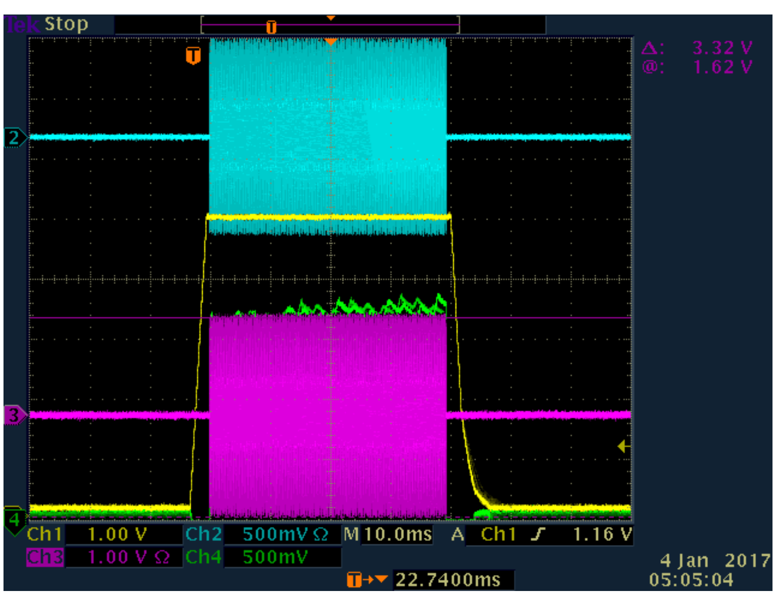
Yellow Trace Anode DC Voltage = 15kV

Blue Trace Reflected Power -50.404dB

.306vpp

Violet Trace Forward Power-50.266dB

1.25vpp



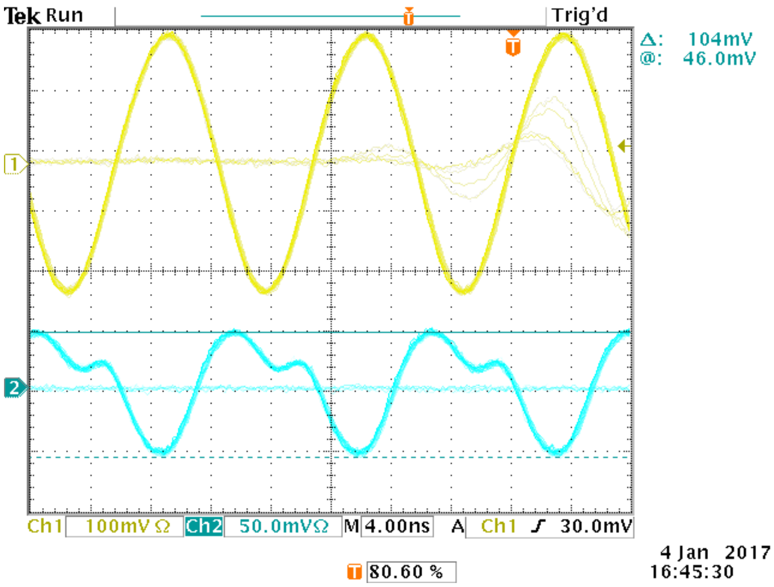
Cathode & Anode Monitors

Yellow Trace Anode DC Voltage = 15kV

Blue Trace Anode Mon = 3.32vpp

Violet Trace cathode Mon = 1.61vpp

Modulator Voltage = 15 kV (cont'd)



SSA Output Directional Coupler

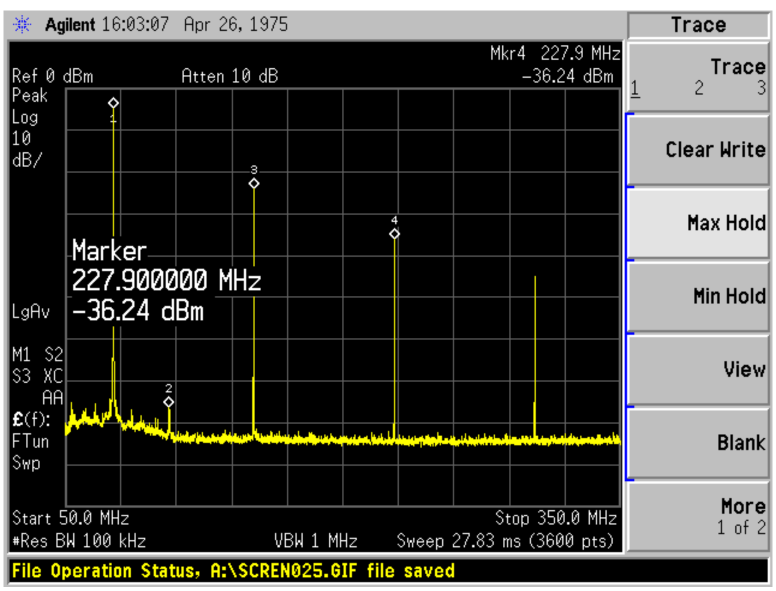
Anode DC Voltage = 15kV

Yellow Trace Forward Power -66.0312dB

.425vpp

Blue Trace Reflected Power -65.834dB

.104vpp



RF Cathode Mon at 15kV with 10db pad on input to analyzer.

Marker 1 79.5 MHz -4.84 dBm

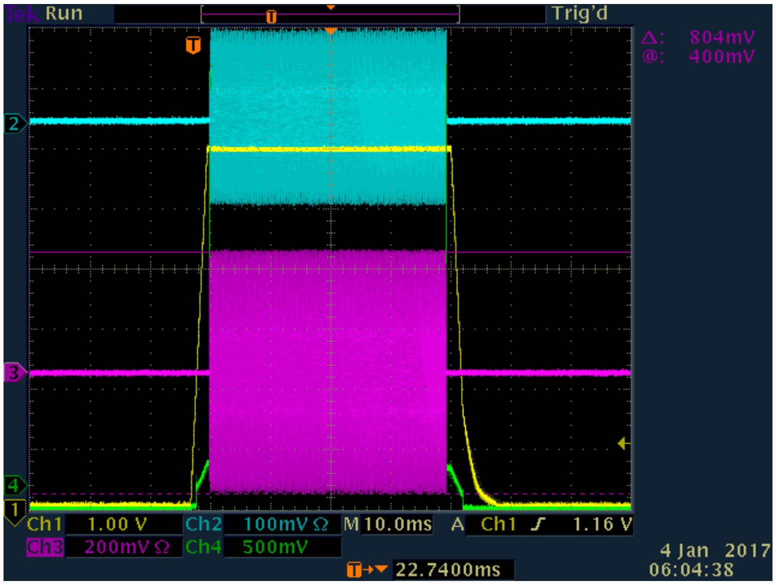
Marker 2 106.2 MHz -76.88

Marker 3 151.9 MHz -24.14

Marker 4 227.9MHz -36.24

Marker 5 303.8MHz -45.04

Now raising modulator voltage to 18kV



Water Load Directional Coupler

Blue Trace Reflected Power -56.719dB

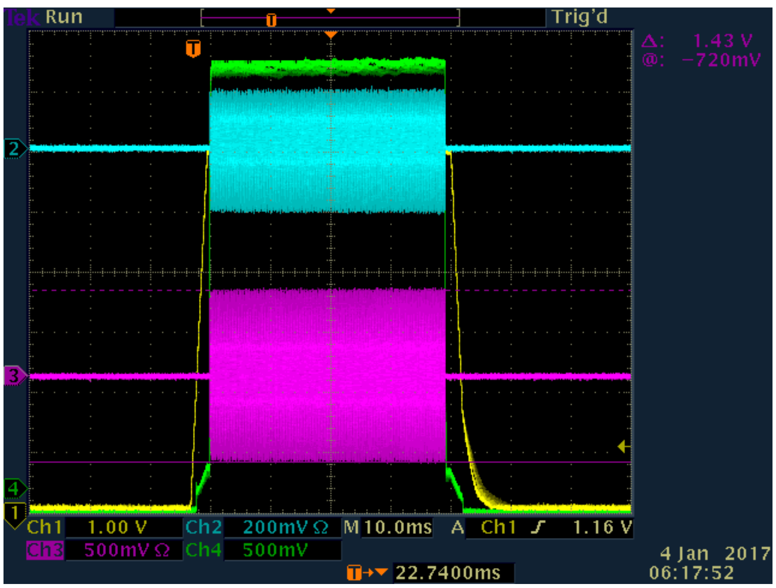
0.228vpp

Violet Trace Forward Power -56.758dB

8.04vpp

Yellow Trace Anode DC Voltage = 18kV

RF On = 40mSec, RF Off = 40mSec



Cathode RF Drive Directional Coupler

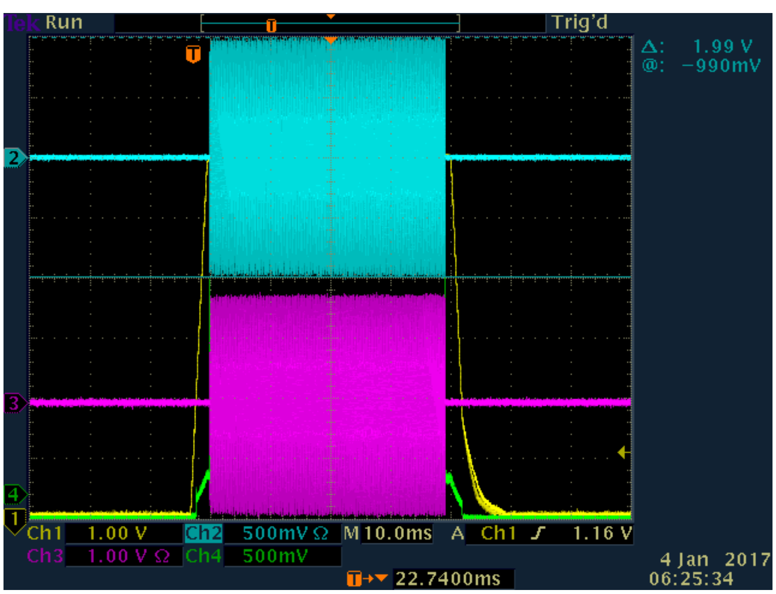
Yellow Trace Anode DC Voltage = 18kV

Blue Trace Reflected Power -50.404dB

0.396vpp

Violet Trace Forward Power-50.266dB

1.43vpp



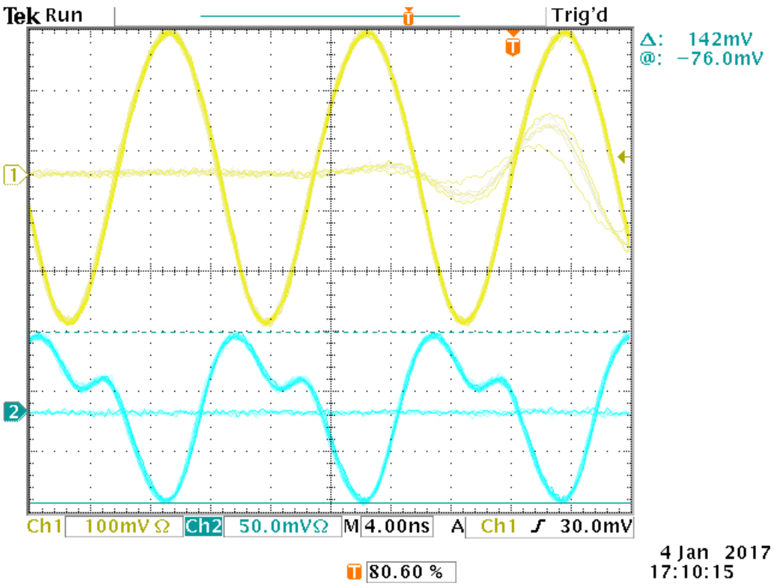
Cathode & Anode Monitors

Yellow Trace Anode DC Voltage = 18kV

Blue Trace Anode Mon 1.99vpp

Violet Trace cathode Mon 3.66vpp

Modulator Voltage = 18 kV (cont'd)



SSA Output Directional Coupler

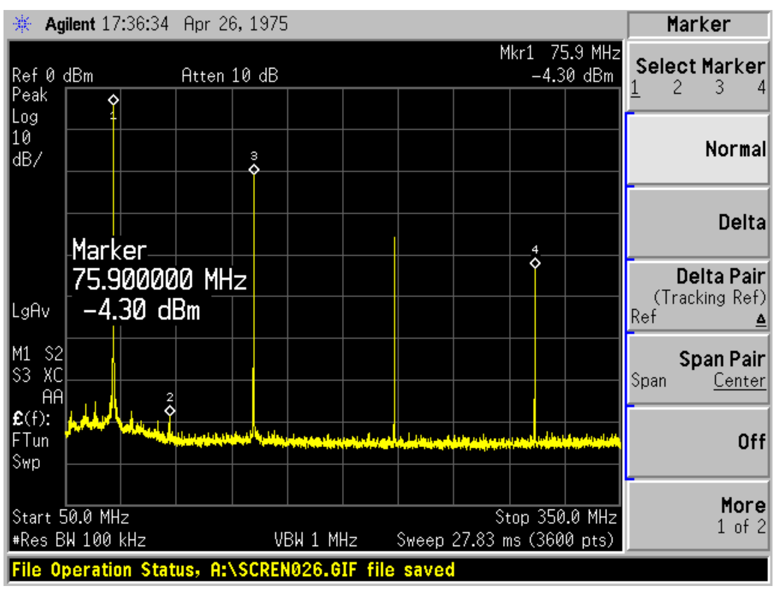
Anode DC Voltage = 18kV

Yellow Trace Forward Power -66.0312dB

.482vpp

Blue Trace Reflected Power -65.834dB

.142vpp



Cathode Spectrum at 18kv with 10db pad on input to analyzer

Maker 1 75.9 MHz -4.3dBm

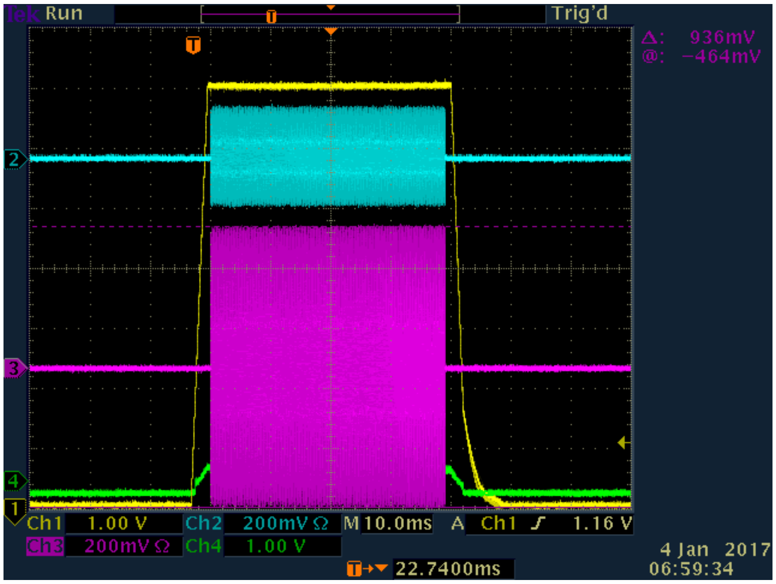
Marker 2 106.2MHz -78.46

Marker 3 151.9MHz -20.99

Marker 4 227.9MHz -35.64

Marker 5 303.8MHz -43.39

Now raising modulator voltage to 21kV



Water Load Directional Coupler

Blue Trace Reflected Power -56.719dB

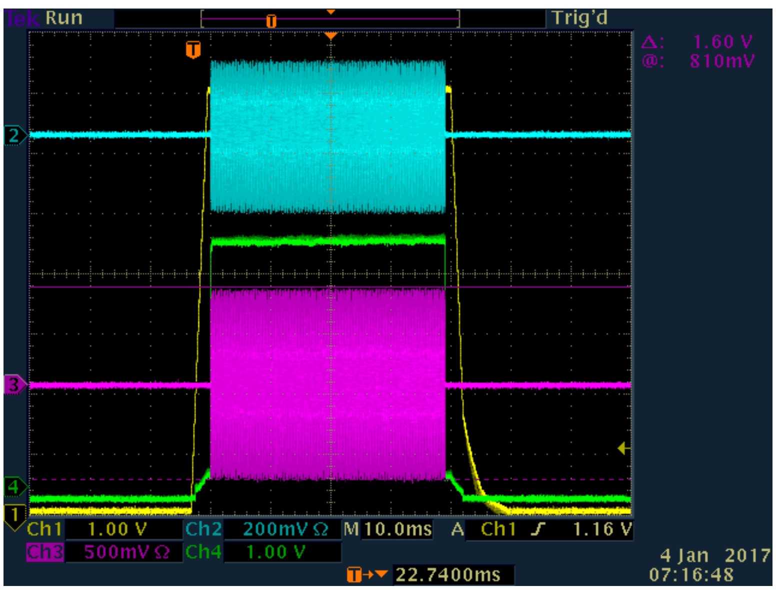
0.328vpp

Violet Trace Forward Power -56.758dB

9.28vpp

Yellow Trace Anode DC Voltage = 21kV

RF On = 40mSec, RF Off = 40mSec



Cathode RF Drive Directional Coupler

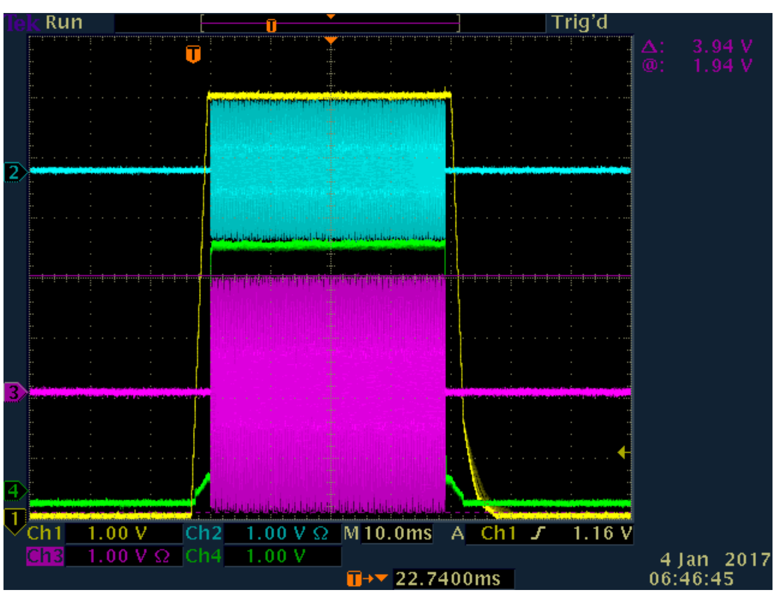
Yellow Trace Anode DC Voltage = 21kV

Blue Trace Reflected Power -50.404dB

0.508vpp

Violet Trace Forward Power-50.266dB

1.56vpp



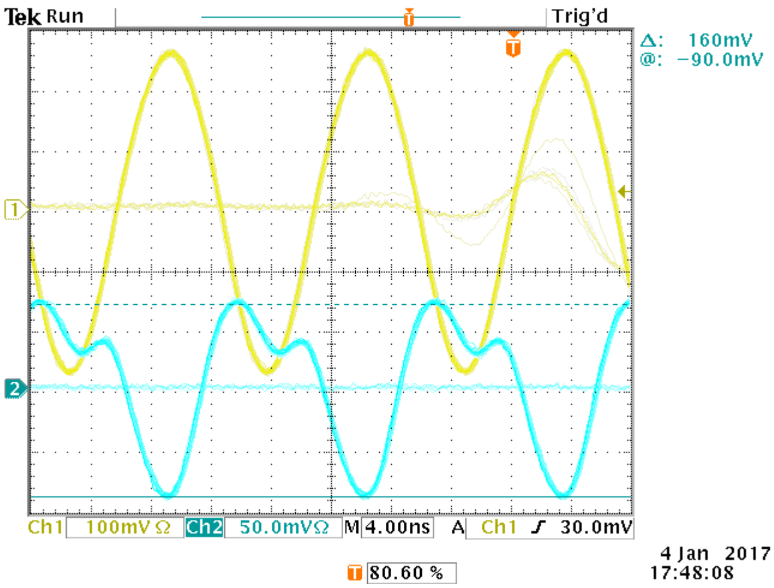
Cathode & Anode Monitors

Yellow Trace Anode DC Voltage = 21kV

Blue Trace Anode Mon 2.29vpp

Violet Trace cathode Mon 3.94vpp

Modulator Voltage = 21 kV (cont'd)



SSA Output Directional Coupler

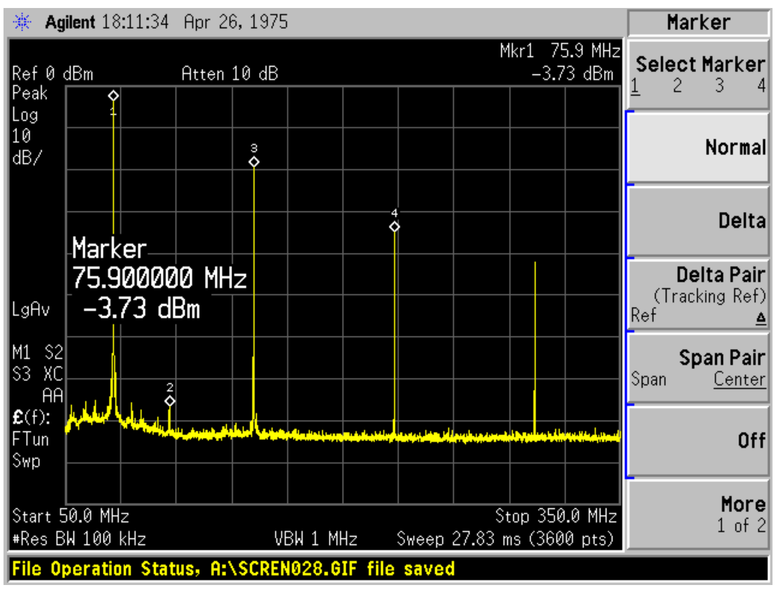
Anode DC Voltage = 18kV

Yellow Trace Forward Power -66.0312dB

0.532vpp

Blue Trace Reflected Power -65.834dB

0.160vpp



Cathode Spectrum at 21kv with 10db pad on input to analyzer

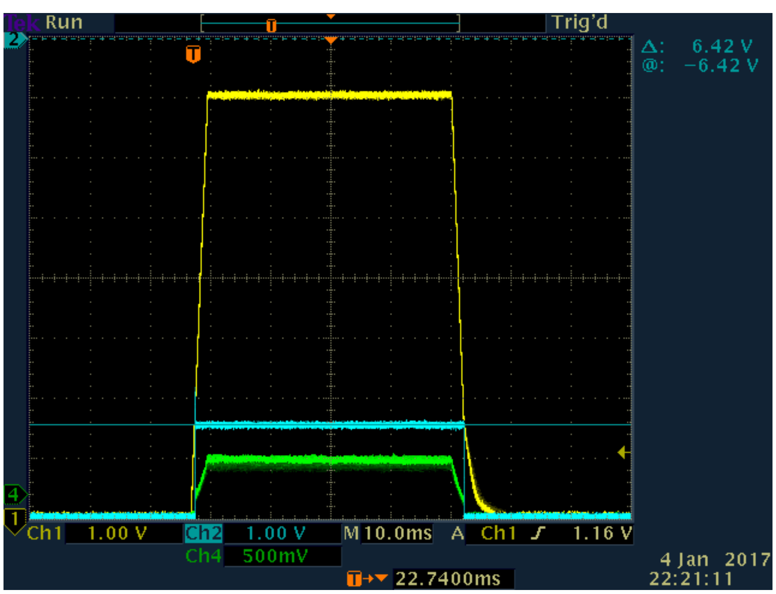
Maker 1 75.9MHz -3.73dBm

Maker 2 106.2MHz -76.57

Maker 3 151.9MHz -19,38

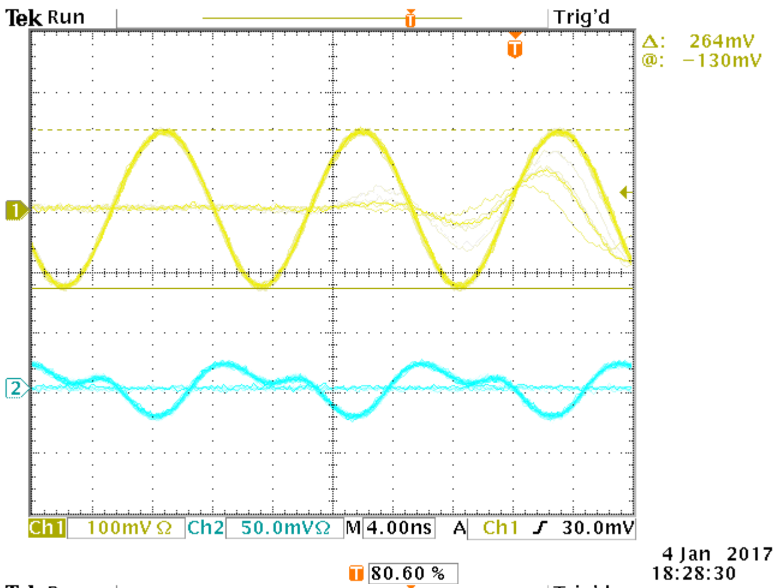
Marker 4 227.9MHz -34.81

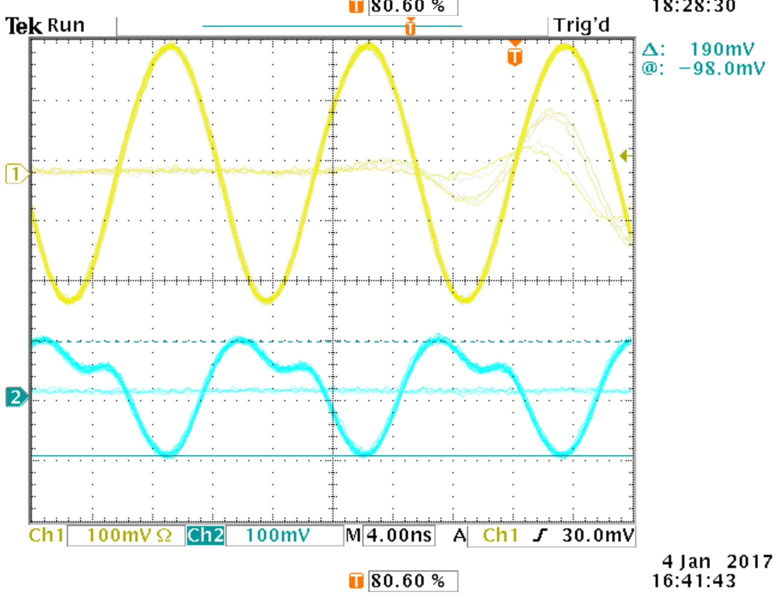
Maker 5 303.9MHz -42.43

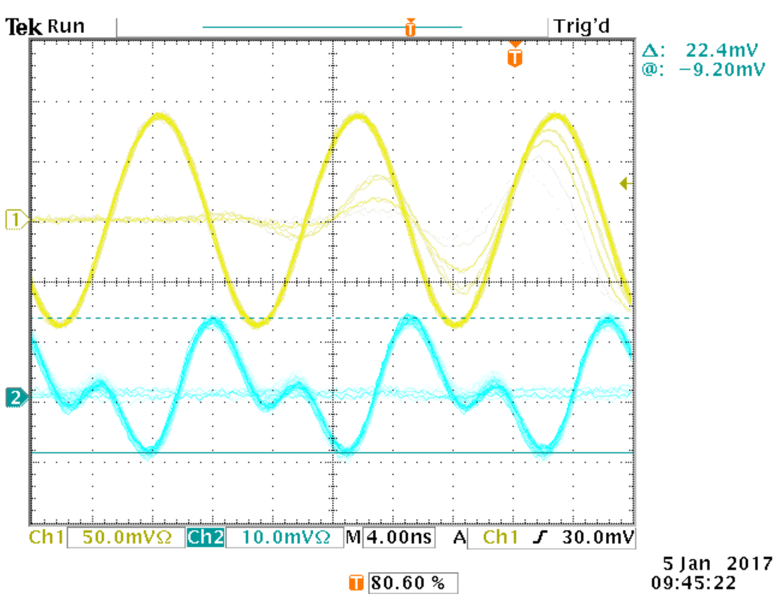


PA Grid Volts -321v with dial setting of 3.5

Low power drive, Modulator Voltage = 21 kV







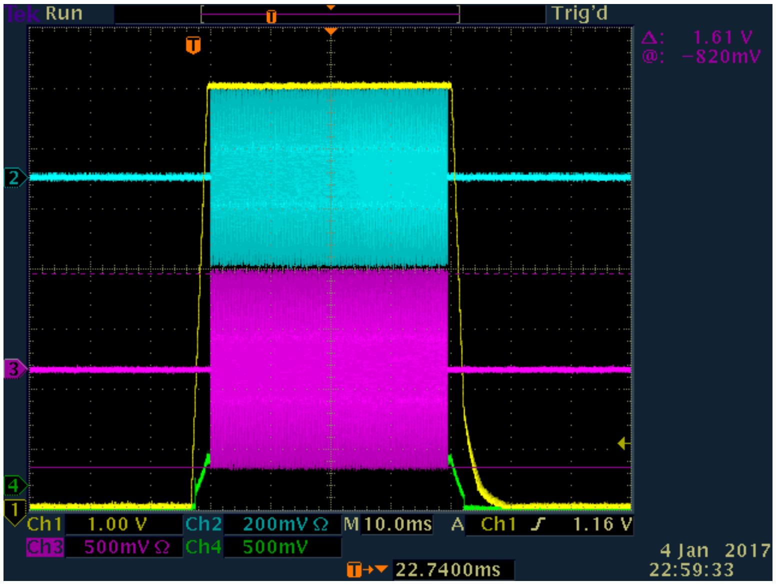
Drive at about 380 Watts PA Power Out =.9 degrees C for Water Load and 4.56 degrees for PA water

PA water Load = 10 kW

PA Anode water = 46kW

SSD Drive from PM = 360 Watts

Low power drive, Modulator Voltage = 21 kV (cont'd)

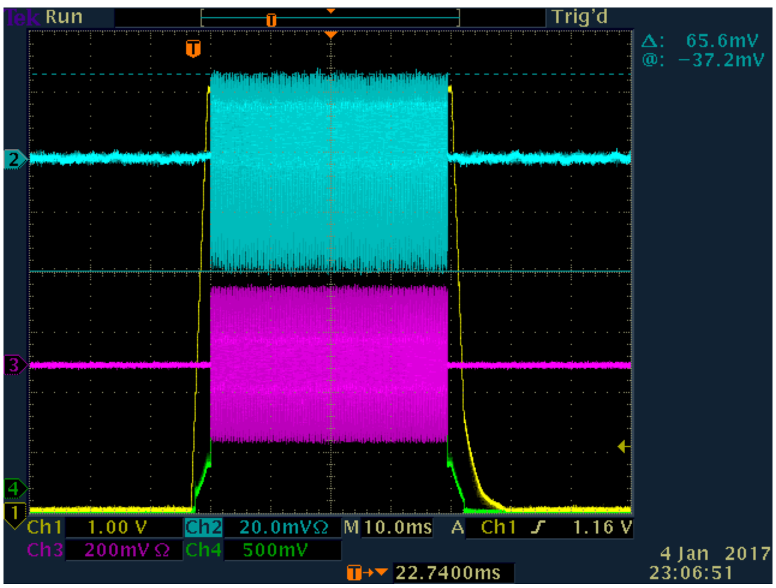


Cathode & Anode Monitors

Yellow Trace Anode DC Voltage = 21kV

Blue Trace Anode Mon .576vpp

Violet Trace cathode Mon 1.61vpp



Cathode RF Drive Directional Coupler

At ~380 Watt drive

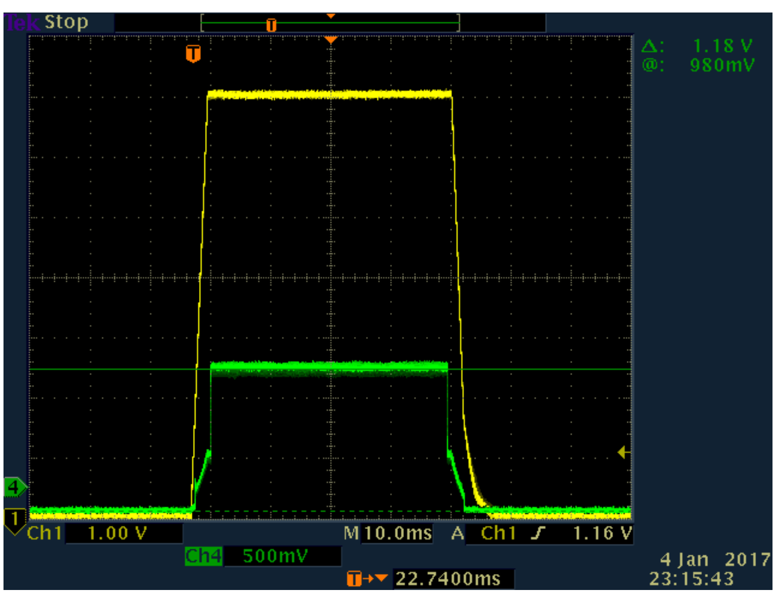
Yellow Trace Anode DC Voltage = 21kV

Blue Trace Reflected Power -50.404dB

.056vpp

Violet Trace Forward Power-50.266dB

5.16vpp



Modulator V & I at low rf drive of about 380W

Mod V = 21kv

Mod I = 2.36 A

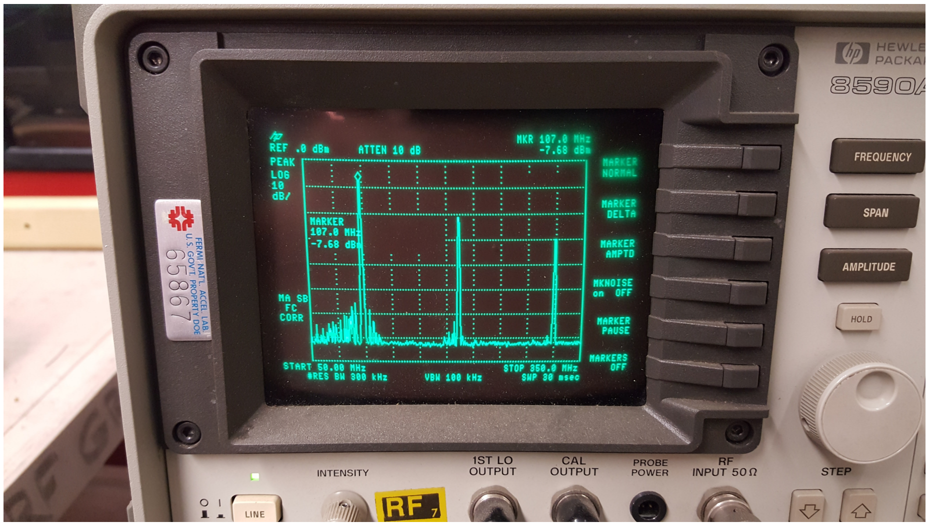


Figure 30: 106 MHz PA test: cathode resonator signal with 20 dB pad. The first and second harmonics are down by 15 and 23 dB respectively.

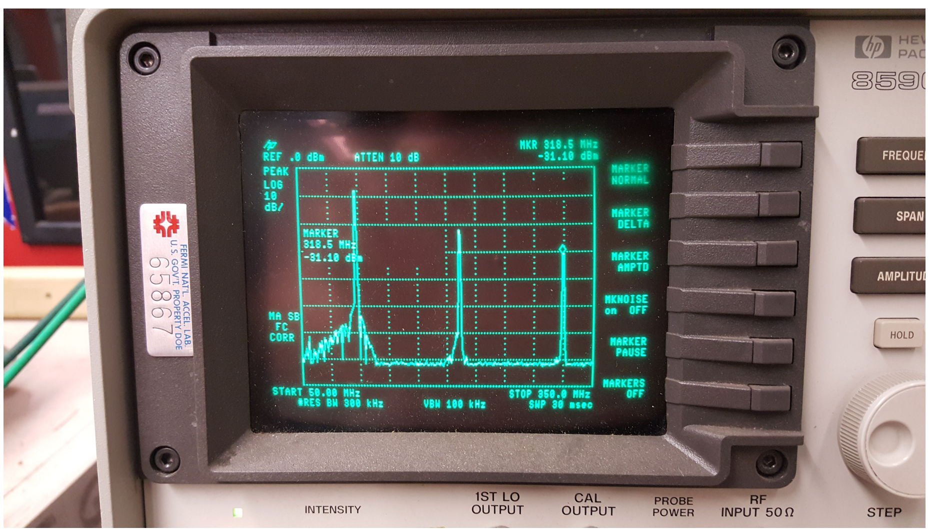


Figure 31: 106 MHz PA test: cathode resonator signal with 20 dB pad. The first and second harmonics are down by 15 and 23 dB respectively.