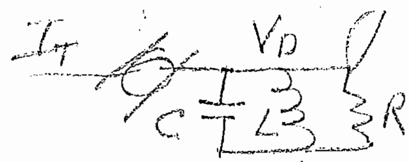
R.F. NOTE #[redacted] 214-0033-001-01_00 August 18, 1978
J. Riedel

1. The Turn On Problem

There exists a problem with our long transmission lines which connect the transmitter to the dees when we attempt "fast" turn on. This problem also occurs when the dee sparks, and, in fact, is the very reason why the existing cyclotron has sparking problems in the anode house and feed thru insulator. The latter problem can be solved by simply removing the drive when a spark occurs, or when a voltage somewhere becomes excessive.

Now the reason for desiring "fast" turn on is to permit the dee voltage to pass thru the multipactoring voltage thresholds fast, before too large a number of multiplying electrons have built up. How fast "fast" has to be is debatable, but in practice one tries to do it as fast as possible. Now the rate at which r f voltage builds up is linear, the equivalent circuit being:



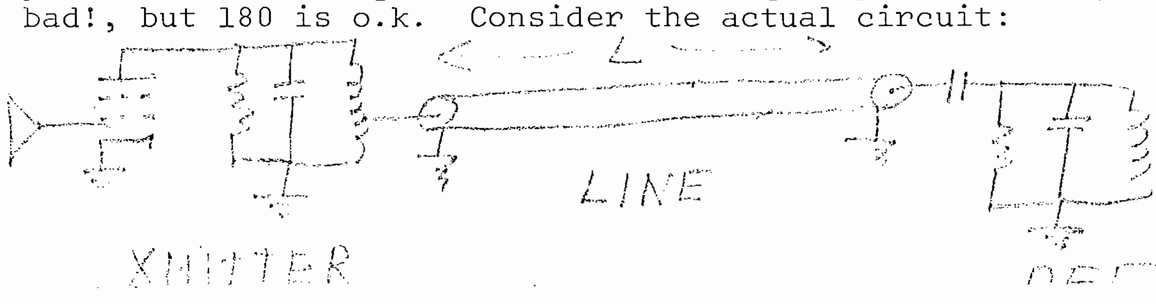
where the equivalent circuit of the dee is transformed down to the tube from which a constant current is delivered and $\frac{dV}{dt} = \frac{I}{C}$.

This is different from the decay time which is, initially,

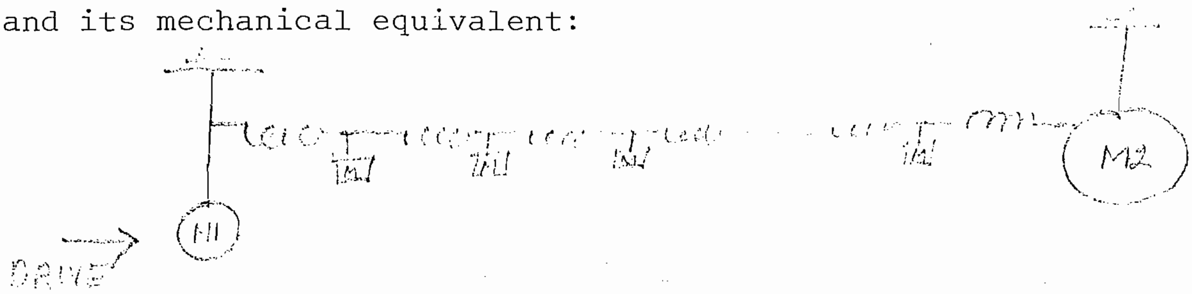
$$\frac{dV}{dt} = \frac{N}{2RC}$$

(The resistor only sees the voltage half the time, the rest of the time the energy is in the inductor). Usually, with a tube capable on demand of delivering twice the current required for steady state operation, the rise rate is about twice the initial fall rate. Since our initial decay rate is about 2×10^9 volts/sec we would expect a rise rate of about 4×10^9 volts/sec. or a total filling time of about 25 μs. This would be true if the tube current were effectively transformed to the dee. In practice, because of our transmission line, the minimum filling time as measured on the high Q model will be about 30 μs. Experiments on the Livermore MTA linac resulted on a figure of 10^6 v/s rise time as the minumum permissible for by-passing multipactor thresholds. So our simple fast turn on should be "fast" enough by a couple orders of magnitude, if some other consideration doesn't interfere.

Our transmission lines are about 20 ft long, thus at 32 mHz they are about 240° long and at 9 mHz about 66° long. So somewhere they will be 180° long and at another frequency be 90° long. 90 is bad!, but 180 is o.k. Consider the actual circuit:



and its mechanical equivalent:



where the coils are springs, M are masses.
M2 = 100 M1 = 1000 M. The lengths of the pendulum arms are equal. Now when drive is suddenly applied M1 quickly fills, that is, oscillates, but M2 takes 10 times longer to reach full amplitude. So meanwhile, and certainly at the start, the coupling capacitor is looking into a short, and reflections set in. Strange and complicated things can happen, and do.

Let us analyze two cases for the actual circuit. Case 1: The line is exactly $\lambda/2$ long and everything adjusted for normal steady state operation. We monitor the transmitter voltage, the voltage $\lambda/4$ along the line from the transmitter and the dee voltage. Then we square wave modulate the drive current at a low frequency and observe the envelopes of these three monitors. At "fast" turn on the rf quickly builds up at the anode (6 μs) but the $\lambda/4$ line position voltage and the die voltage build up in 20 μs. See figure 1 where the top wave form is the transmitter voltage, the second is the $\lambda/4$ monitor and the 3rd is the dee voltage. Figure 2 shows the fall time. Note that the anode voltage starts high and the $\lambda/4$ voltage low, showing that the dee is driving the line during the fall time and there are standing waves.

Now we adjust the line length to be $3\lambda/4$ and repeat. Fig. 3 & 4 show the rise and fall situation. Note that now the situation is reversed as regards the transmitter and $\lambda/4$ monitors. Now these pictures were taken with the high Q model resonator (Q = 5000) at 50 mHz where the Q of the RG 58U line was small (~50). Had it been high, (1000 for the 4 inch final lines)the $\lambda/4$ voltage in Fig. 2 would have been 20 times higher, or about 120 KV and the line would have sparked down. Similarly, on turn off, the $\lambda/4$ voltage of Fig. 4 would have caused a spark down.

So now we see why it is undesirable to feed a high energy storage load with a long transmission line unless we can adjust the line length to be a multiple of $\lambda/2$. You can't turn on "fast" and you can't turn off fast either. Well, with spark gaps placed periodically along the line so that one is always near a current node, one can turn off o.k. and allow the energy to be dumped in these sparks (1 Joule). And one can limit the rate of rise of drive rf to prevent sparking at turn on. Actually, since we can probably achieve 10^6 V/sec at turn on without excessive line voltages appearing even when the line is an odd multiple of $\lambda/4$ long I guess we are o.k.

To protect ourselves we propose to install voltage monitors at 2 ft. intervals along the line, each feeding a peak detector, comparator and logic chip to turn off the drive in the event of an overvoltage appearing at any one of them. Also we will dispose spark gaps along the line with photo detectors looking at them to indicate when and where a spark occurs. Finally, in our slow fast turn on scheme it seems we will have to limit the filling rate so that fill time will be about 100 μs or more.

Spark Gaps and Spark Detectors for the test stand

For the test stand we will use thesame length of transmission line as will later be used to feed the dees. This length is 22.5 ft at 32 mHz, 28.75 ft at 17 MHz where the line is λ/z long and 21.92 ft at 33 MHz where the line is $3\lambda/4$ long. The different lengths come about because of the different short positions in the transmitter for these frequencies, the short being one end of the line. We propose to install at 5 places along the line adjustable spark gaps, phototransistors to look at them, and voltage dividers to measure the voltage. Fig. 5 shows the line and the position of these devices along it. Fig. 6, below, shows a crude sketch of the spark gap and light sensor.

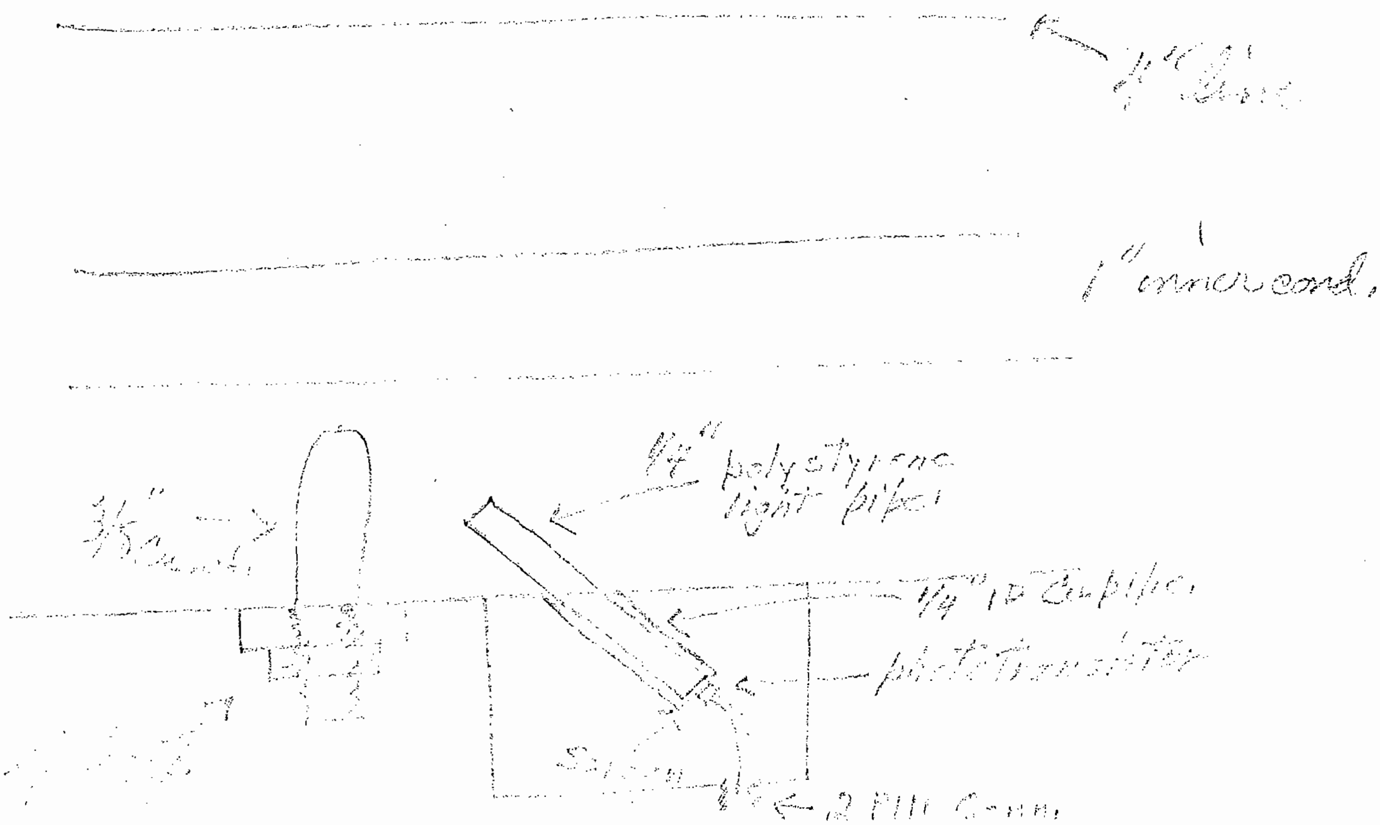
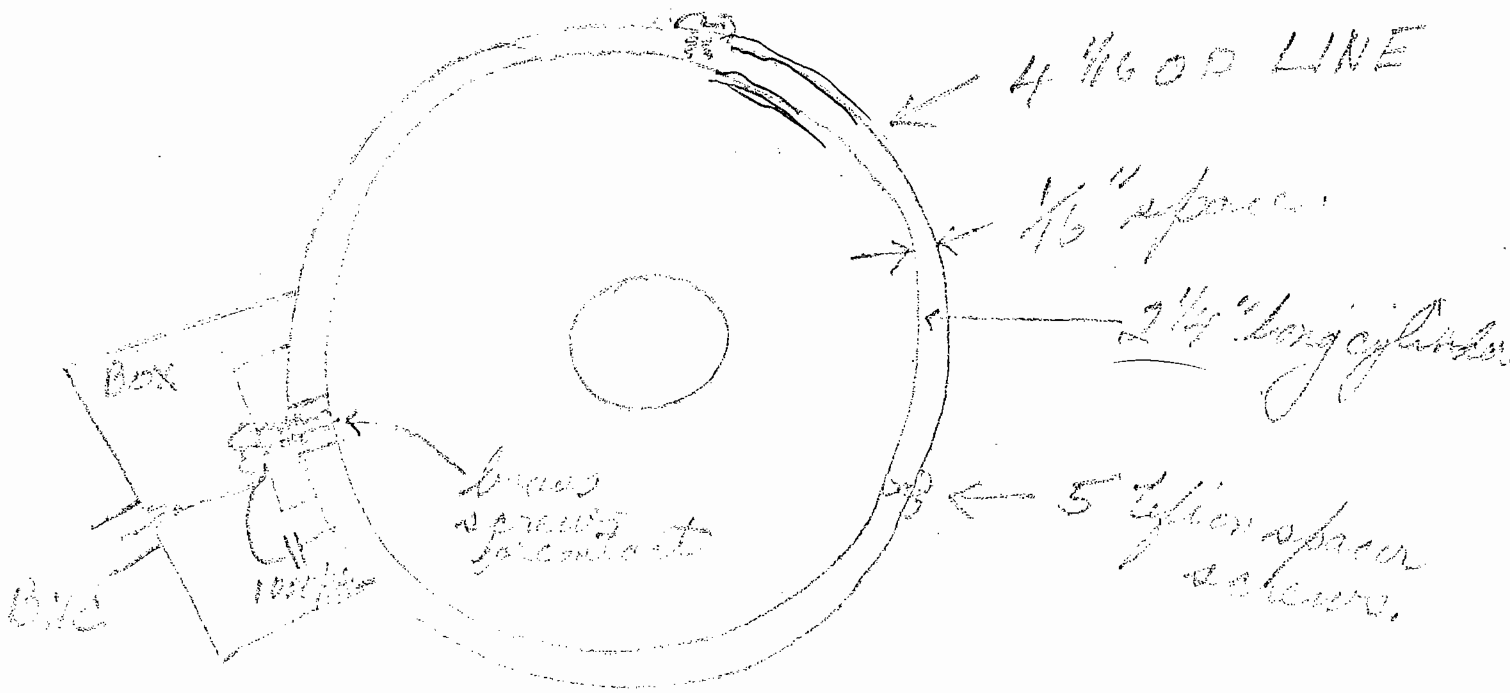
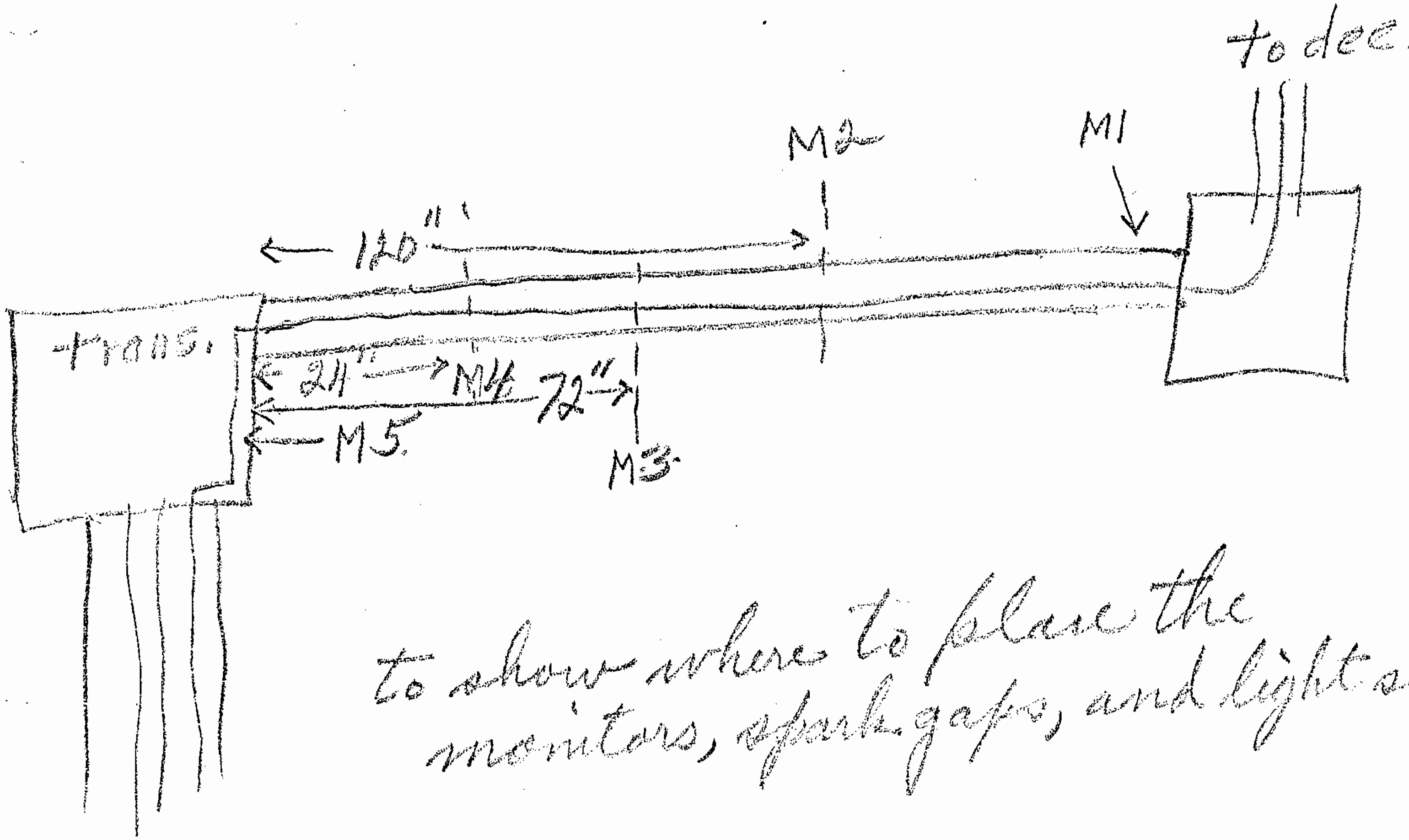


Figure 6

Voltage monitors

The voltage monitors will be capacitor dividers. The nominal line voltage is 3KV so a 400 to 1 divider seems about right. To make these fairly frequency independent, we use 1000 pf for the ground capacitor and 2.5 pf to the line.
For a Zo = 75 r line we have $\frac{2.5}{3\text{x}10^{10} \text{ x } 75}$ = 1.11 pf per inch, so we need a cylinder 2.25 inches long. Below is a sketch.





to show where to place the monitors, spark gaps, and light sensors.

Figure 5

On Modes in Transmitter & Feed Line

Fig. 7 shows many things and in a future RF note will be expanded to show even more! Curve A (the same as in RF note 23) shows the freq. vs. short position in the transmitter. To get down to 9 mHz we switch in a 100 pf capacitor at the anode, generating curve B for frequencies below 12.5 MHz. The other curves show, for the short lengths associated with curve A the $\lambda/4$, $\lambda/2$, $3\lambda/4$ and $5\lambda/4$ modes in the combined transmission line. Where curves intersect we are in for trouble, particularly at 33 mHz, where the $3\lambda/4$ mode can be excited at turn on, at 27 mHz where the second harmonic of the tube current will excite the $3\lambda/4$ mode (3 x the $\lambda/4$), at 17.5 MHz where we will excite the λ mode of 35 MHz, and a raft of still higher order modes.

All this will be investigated with our test stand, and solution found. These solutions involve using a 10 pf vaiable condensor at the anode to move the intersections apart by .1% in frequency.

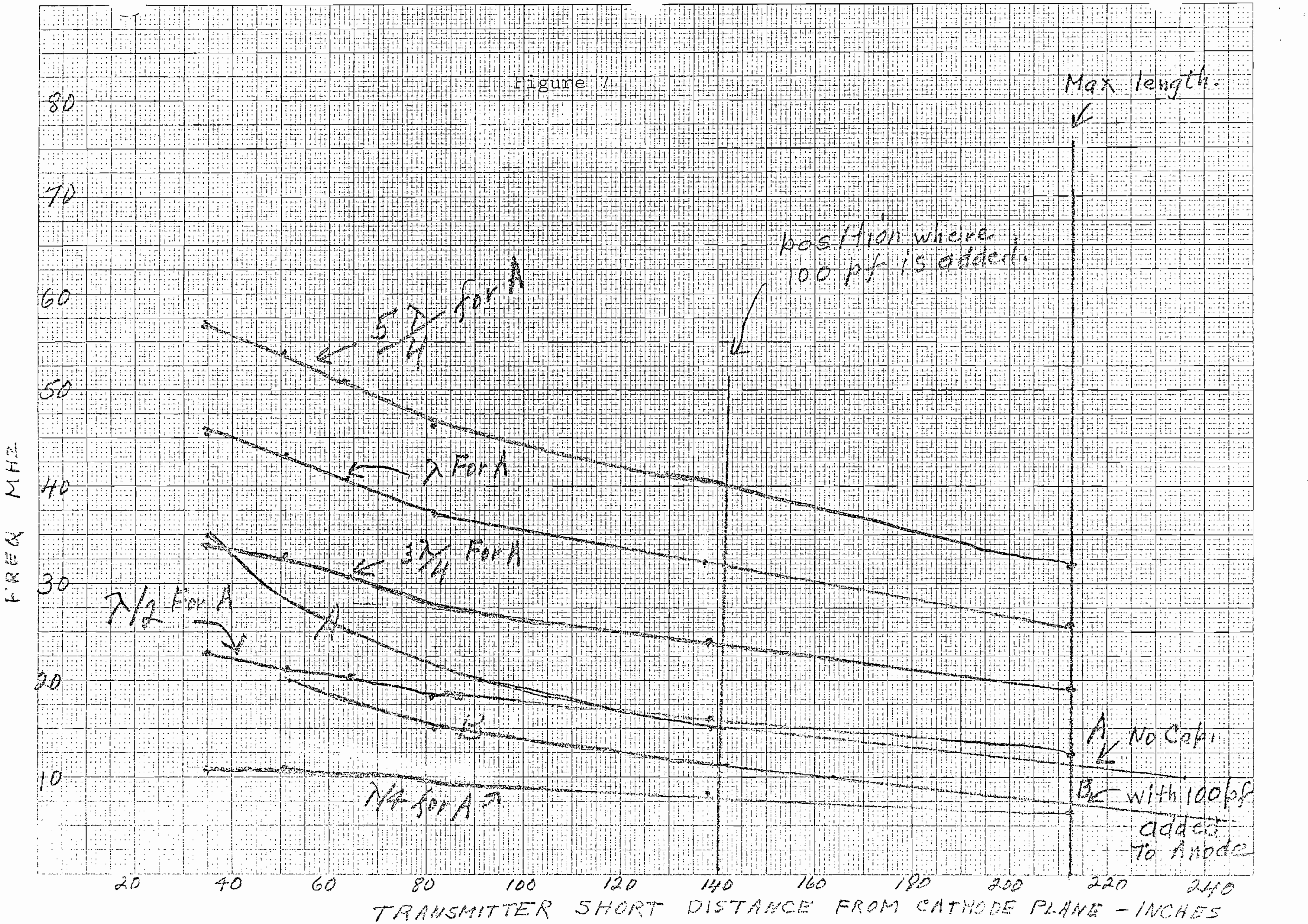


Figure 7
Max length.
position where 100 pf is added.
5λ/4 for A
λ For A
3λ/4 For A
λ/2 For A
A
B
λ/4 for A
A No Cap
B with 100pf added To Anode
FREQ MHZ
10
20
30
40
50
60
70
80
20
40
60
80
100
120
140
160
180
200
220
240
TRANSMITTER SHORT DISTANCE FROM CATHODE PLANE - INCHES

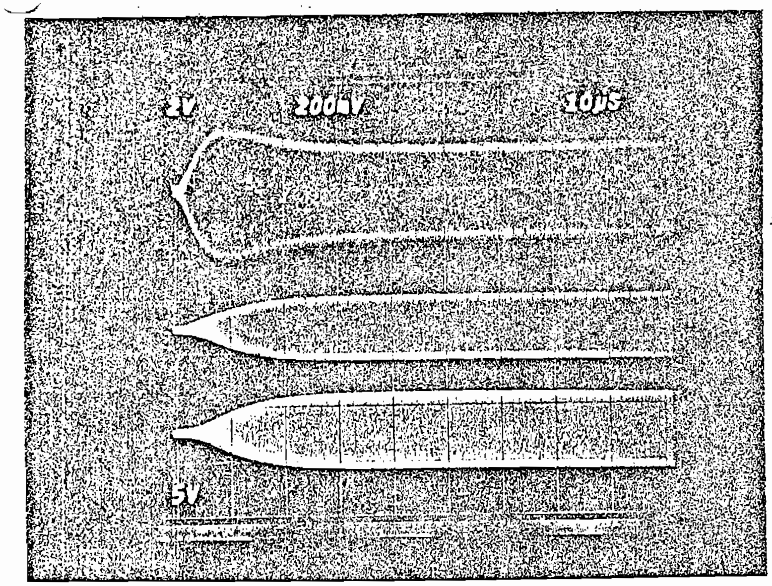
Modules

We have reviewed our NIM module requirements, and they are as follows.

Module Title	Width	Quantity
Oscillator	3	1
L P Filt	2	1
A Buffer	1	4
B Buffer	2	3

Module Title	Width	Quantity
Motor Servos	1	8
Δ ϕ	1	1
ϕ Det	1	5
Mixer	1	5
Amp. Reg	2	4

which add up to 23 singles, 8 doubles, 1 triple or equivalent of 42 inches, or 4 NIM BINS, which means, one master NIM BIN for the modules above the double line (Gress' responsibility) and one for each dee of the times below the line (Birket's responsibility), although when Birkett returns to his vacation in Harlem, Gress will have everything.



ig. 1

$\lambda/2$ LINE TOP → ANODE
MIDDLE → $\lambda/4$ position
BOTTOM → DEE

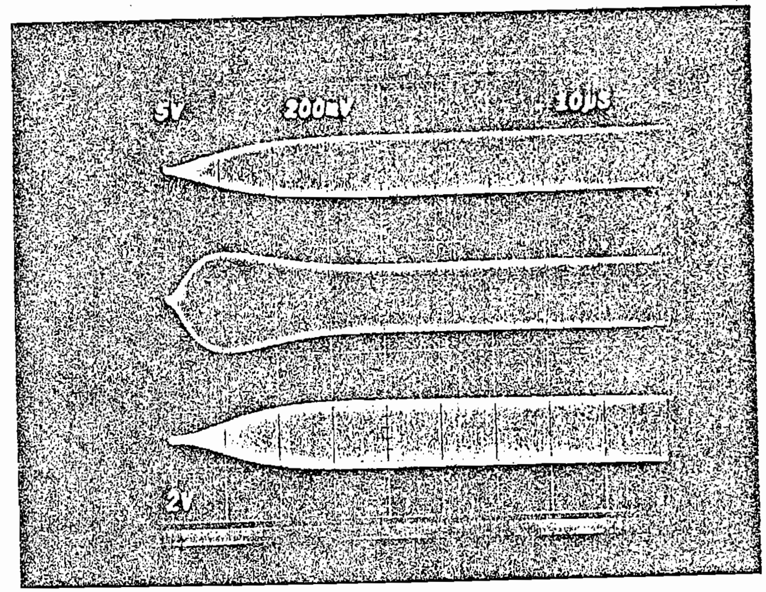
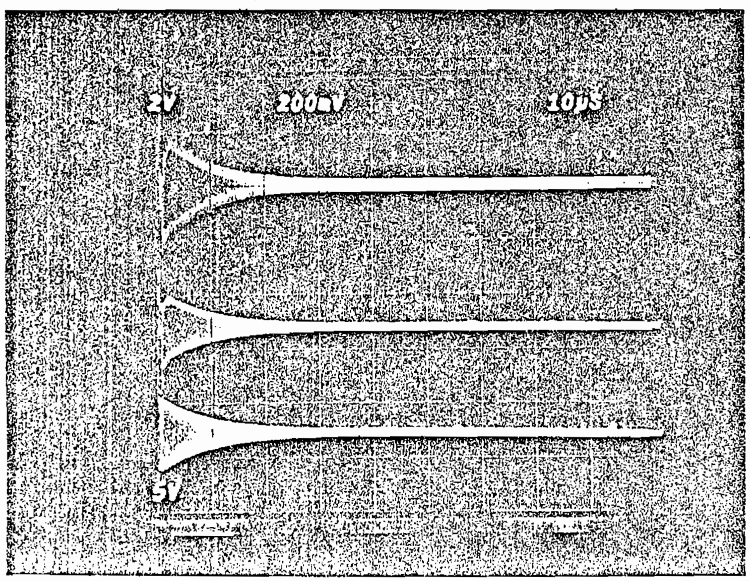


Fig. 3

$3\lambda/4$ LINE



g. 2

$\lambda/2$ LINE

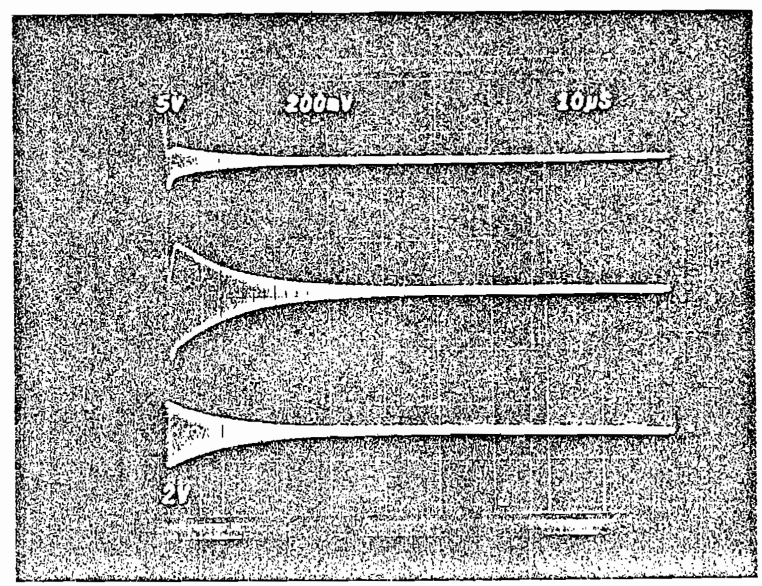


Fig. 4

$3\lambda/4$ LINE