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EFFECT OF POWER TUBE AGING ON PHASE SHIFT IN THE AGS HIGH FREQUENCY, HIGH LEVEL RF SYSTEM

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Technical Note

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Introduction

It has been noted that the phase delay of the rf station (power amplifier) changes with tube replacement (Fig. 1A & 1B). While observing the relation of the relative phase angle of each individual station to the vector sum of all rf stations, a phase variation from station to station as high as 50 deg. was observed. Since we do not have control of the phase for each individual power amplifier (PA), the stable phase angle from cavity to cavity (assuming running accuracy in all cavities) can vary. The angle of transition phase jump is the same for all cavities, therefore the position of the beam on the rf wave before transition will effect its position after.

AGS high frequency, high level (HFHL) rf system consist of 10 power amplifiers and two drivers, each utilizing two 100 kW triodes (8752) in a push-pull, grounded grid, configuration. The drivers are driven by a predriver. Each power amplifier output is transformer coupled to two 50 ohm transmission lines, and in turn, an accelerating station.

A laboratory test was performed to simulate actual running conditions. An rf system was assembled in Bldg. 925 consisting of a power amplifier, cavity, tuning system and predriver, as shown in Fig. 2. Since the output of the predriver is approximately 25 kW, and the power gain of the PA is about 10, a driver stage was not required.

Tube aging causes reduced emission which has two effects: first, causing the virtual cathode to shift closer to the filament surface, effectively changing the geometry of the tube; second, transconductance decreases. To simulate the aging process the filament voltage on a tube was changed from 12 volts, normal filament voltage, to 6 volts, approximating the state of the tube before its replacement.

Looking at the equivalent circuit of the grounded grid triode (Fig. 3), one can see that the input impedance will depend on the capacitance between the grid and the cathode (Cgk) and load impedance. This is true only for purely resistive load. In the case of a ferrite load we do have some reactive component, and, the input equivalent circuit will look like the parallel combination of Ri & Ci (Fig. 4).

$$Ci = Cgk + Cstray + Cfeedback;$$

$$Ri = \frac{1}{Gm}$$

$$Ci(min) = Cgk + Cstray; \qquad Cfb = \frac{Cgk}{(1+Gm*R1)}$$

$$Zin = \frac{(Ri*1/jwCi)}{(Ri+1/jwCi)} = \frac{Ri}{(1+RijwCi)}$$

Phase angle = arctan wRiCi

For AGS high frequency power amplifier Cstr = 100 pf; Cgk (8752) = 160 pf; Rl = 450 ohms.

The following data was measured in the laboratory:

Measurement data of transconductance (Gm) and feedback capacitance (Cfb) with various levels of filament voltage.

	New Tube		Used Tube	
Vfilament	Gm	Cfb	Gm	Cfb
12 V	0.168	2 pf	0.12	2.9 pf
10 V	0.15		0.12	2.9 pf
8 V			0.08	4.3 pf
6 V			0.019	16.7 pf

After the above measurements were made, phase delays were measured across the power amplifier.

Keeping the cavity in tune we changed the filament voltages while observing the phase shift across the power amplifier with a HP 3575A phase meter.

Taking the phase shift at Vfil. = 12 V as a reference we will get:

$$\Delta\phi = \phi(\text{reference}) - \phi(\text{Vfil})$$

Vfil.	Δφ					
	2.5 MHz		3.5 MHz		4.5 MHz	
	calc.	meas.	calc.	meas.	calc.	meas.
10 V	0 deg.	0 deg.	0 deg.	0 deg.	0 deg.	0.7 deg.
8 V	1	0	1.5	2.2	1.9	2.6
6 V	10.8	8.5	14.3	12	18.8	19

While taking data, another interesting event was observed: the change in filament voltage causes a phase shift not only across the power amplifier but also across the predriver. This can be explained by a change in power amplifier input impedance. That impedance variation mismatching the output of the predriver, causing the phase shift, as shown in the following table:

P.A. Vfil.	Measured phase shift across the predriver (input to output)		
	2.5 MHz	3.5 MHz	4.5 MHz
10 V	0.5 deg.	0.2 deg.	0.7 deg.
8 V	0.8 deg.	1.9 deg.	2.6 deg.
6 V	21.9 deg.	9.0 deg.	19.0 deg.

In the grounded grid configuration, there is no isolation between output and input of the triode. Therefore any mismatch in impedance in any power amplifier, of the AGS rf system, will get reflected all the way through the driver to the predriver which will cause the phase shift in all the rf stations.

Conclusions:

Both these effects are changing the relative phase between one or more rf stations with respect to the beam. In the future tube Gm should be measured twice a year. Tubes with a Gm less than 0.06 (10A of tube current with plate voltage of 8.8 kV and grid at -100 v). This maintenance practice will reduce the undesirable phase shift across the rf station, reduce the deviation of the gap voltage at transition. Also working with the high gain tubes will make the tuning of the cavities much easier.

mif

STATION "JK" (old tubes)

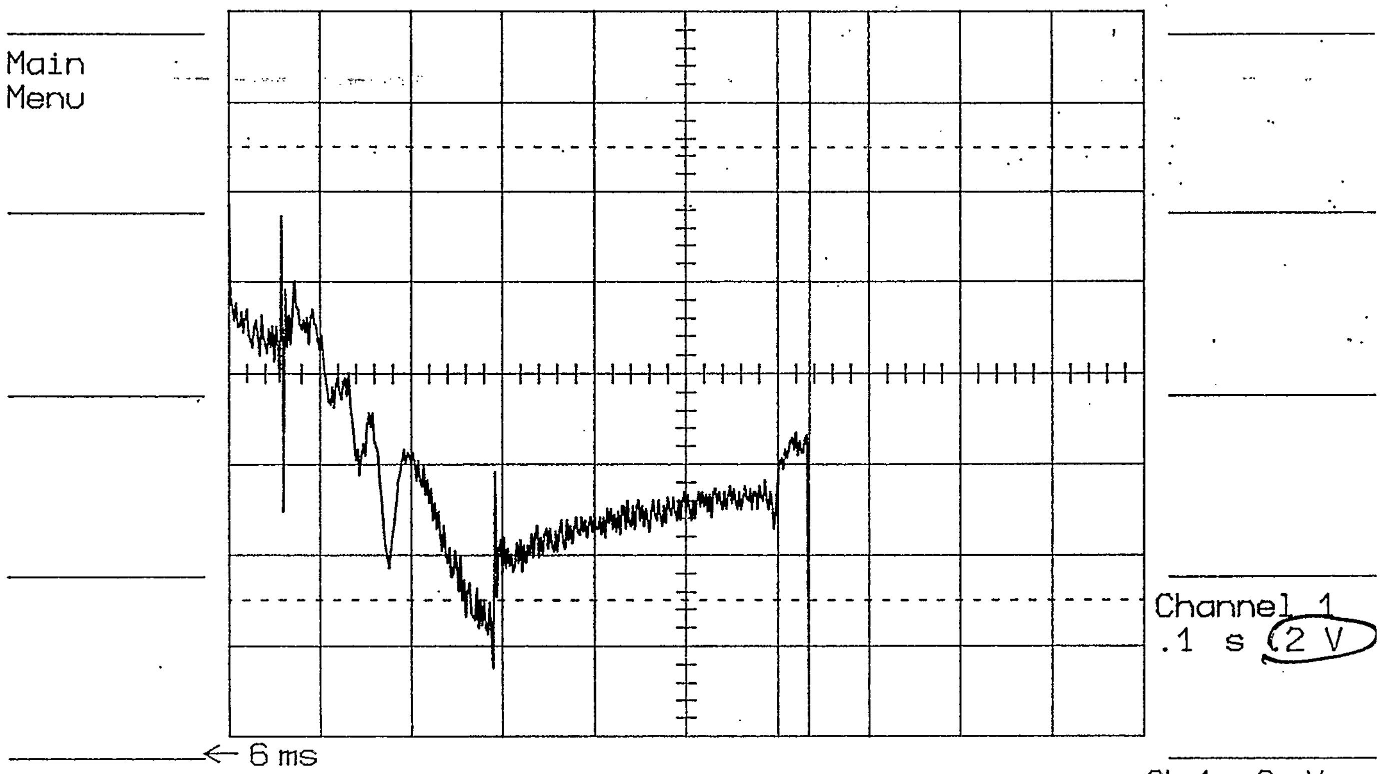

Fig. 1a

(10mV/°)

STATION JK (new tubes)

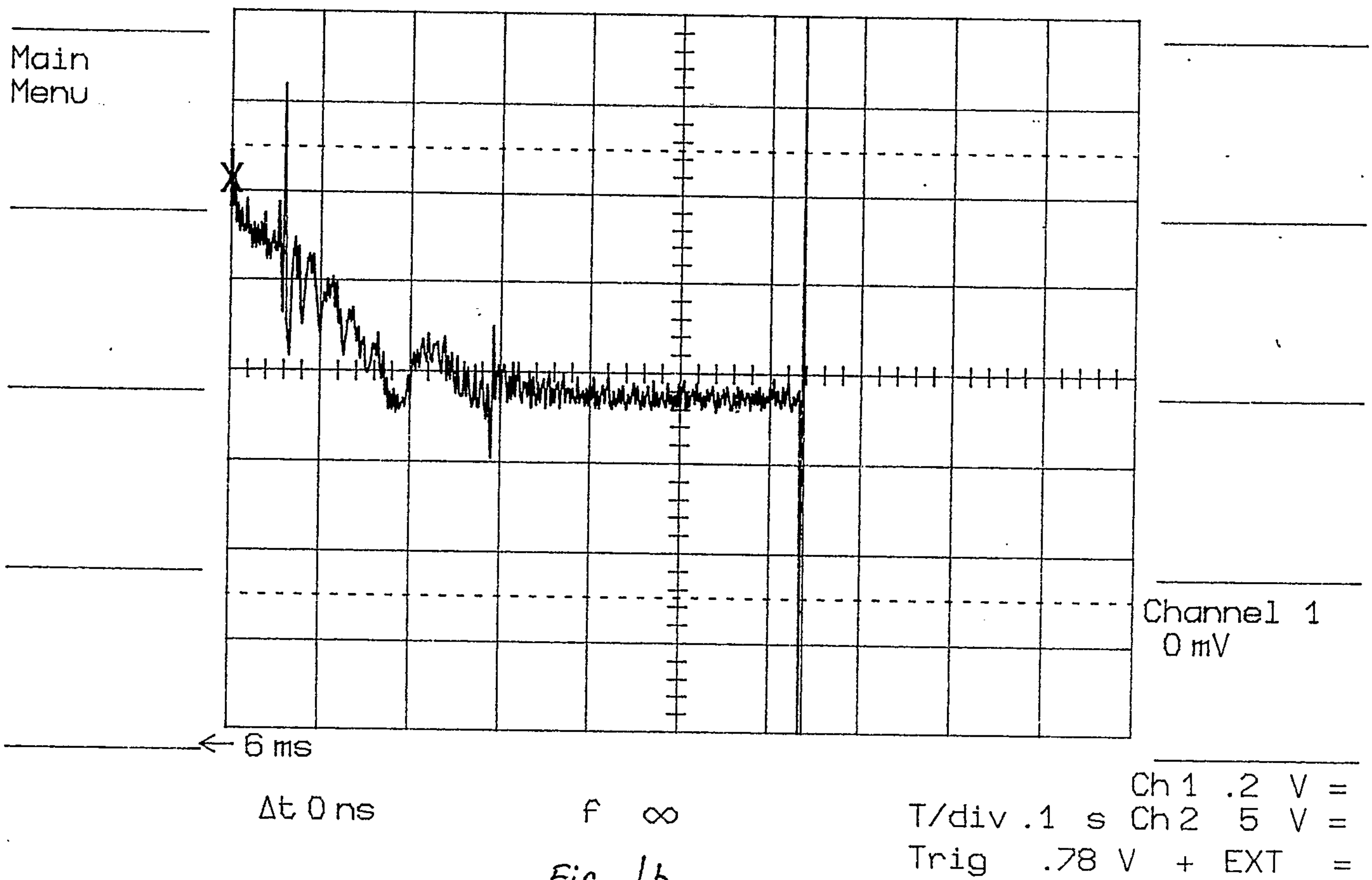

Fig. 1b
(10mV/°)

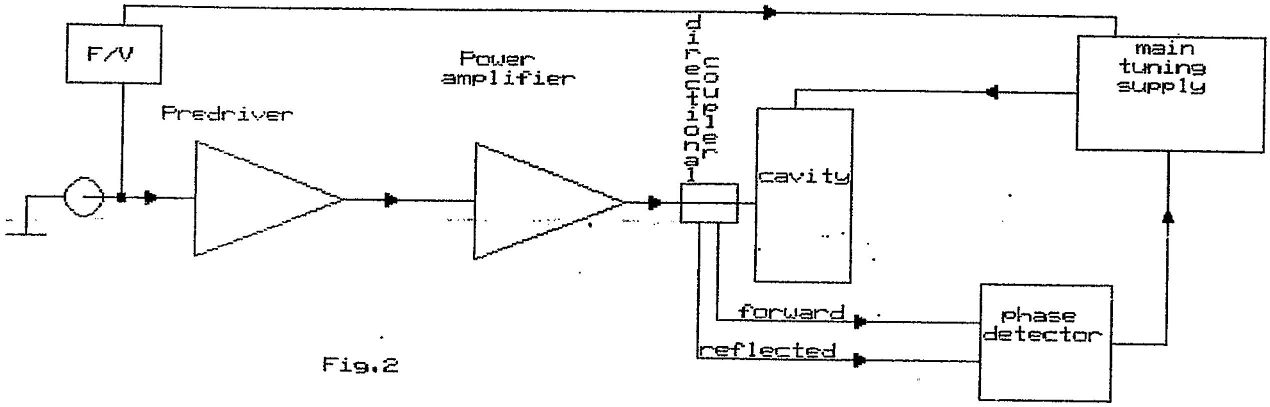

Fig.2

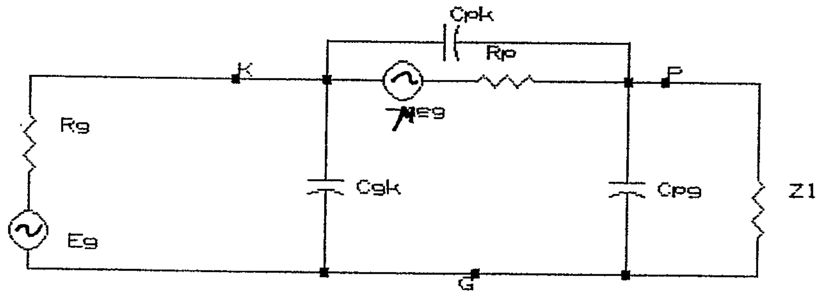

Fig.3

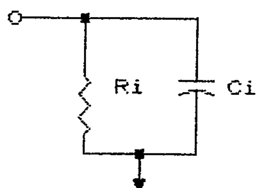

Fig.4