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Stopband Measurements in the AGS (I)

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Subject Stopband Measurements in the AGS (I)

I. Introduction

At high intensity, and at the present injection momentum of 0.65 GeV/c, the horizontal and vertical tunes are spread over a large region of tune space due to space charge detuning and non-zero momentum spread and chromaticity (see Figure 1 and Reference 1). Since this region crosses several resonance lines which can produce beam loss, it is necessary to correct those fields present in the machine which excite the resonances. (The present correction schemes are described in References 2 and 3.)

When the AGS Booster becomes operational, protons will be injected into the AGS at 2.25 GeV/c momentum and at 4 times the present high intensity. Assuming the normalized emittance of the beam remains the same, the region of tune space occupied by the beam will then be reduced by a factor of 2. Although this is a substantial reduction, it will still be necessary to correct some of the resonances shown in Figure 1. These will most likely be the $2Q_H = 17$, $2Q_V = 17$, $3Q_H = 26$, and $Q_H + 2Q_V = 26$ resonances.

The purpose of the present study and ones that follow is to isolate and investigate each of these resonances to determine the stopband widths and the amount of correction required at the Booster momentum.

II. Set-up Conditions

A 500 ms long flattop which started 100 ms from T_o was set up by J. Gabusi at a momentum of 1 or 2 GeV/c. (The resonances were studied at each of these momentum to determine the dependence of the correction on momentum. Also, the nuquads do not have enough strength to maneuver the tunes at higher momenta).

The radius was then adjusted so that beam survived on the flattop and was lost in the catcher afterwards. By reducing the Linac pulse width, we were able to reduce the intensity on the flattop to about 2 x 10^{12} ppp, but could go no further without losing the beam completely. To achieve an intensity of 5 x 10^{11} ppp, which ensures a negligible spread in tunes due to space-charge detuning, the following changes and adjustments in the low level rf were made by E. Gill:

1. The signals from the amplifier at PUE C18 were used in the radial loop.
2. 20 db of attenuation was taken out of the phase loop and 18 db gain was added.
3. The Boussard beam compensation was physically disabled.
4. The constant energy trigger TFHCE was disabled.
5. The manual phase was adjusted.

In addition, the vertical tune was lowered to compensate for the reduced space charge tune shift.

III. Programmable Corrections

The corrections labeled QN17, SN26, SN25, and 17S26 (see References 2 and 3) normally remain at their set values and do not cycle on and off during each machine cycle. To allow tuning of these corrections on the flattop without affecting injection and early acceleration, G. Cornish developed a program which provides two programmable levels for each correction. These are labeled QN17A, QN17B, SN26A, SN26B, SN25A, SN25B, and 17S26 in the ORTHO library of AGAST's TEST area. The program is invoked by running KIPS [307,307], and the switching between the two levels is enabled by turning KT1 and KT2 ON in the appropriate TEST area files. The time at which the corrections go from level A to level B is determined by the setting of KT2 (in ms from T_o) and the time at which the corrections go back to level A is determined by the setting of KT1 (also in ms from T_o). Level A for each correction is set to the values required during acceleration to the flattop momentum and level B is used to vary the settings of the corrections on the flattop. KT2 is normally set so that the transition from level A to level B occurs just after the beginning of the flattop, and KT1 is set so that the corrections return to level A sometime after the end of flattop. (For the flattop discussed above, KT2 = 100 ms and KT1 = 900 ms.)

IV. Procedures, Observations, and Results

A flattop as described above was first set up at a momentum of ~ 1 GeV/c (2000 Gauss clock counts) and level B of all the corrections was initially set to zero. The tunes were measured (see Reference 4) on the flattop and found to be $Q_H = 8.73$, $Q_V = 8.75$. The nu-quads were then programmed so that the tunes moved to $Q_H = 8.5$, $Q_V = 8.86$ approximately 100 ms after the start of the flattop. The resulting beam loss due to excitation of the $2Q_H = 17$ resonance is shown in Photo #1. (Here, and in Photos #2 and #3, the top, second, third, and bottom traces show respectively the backleg voltage, L-20 current transformer, nu-quad shunt voltage, and the shunt voltage for one of the quads in the QN17 correction scheme.) Level B of the QN17 corrections, cos 17X and sin 17X, was then tuned to eliminate the beam loss on the flattop as shown in Photo #2. The necessary corrections were found to be

$$N_c = \cos 17X = -\ 550 \pm 20 \text{ counts},$$
$$N_s = \sin 17X = +\ 20 \pm 20 \text{ counts}, \qquad (1)$$

where the indicated error is the smallest amount of change in the corrections which produced observable beam loss. These corrections are a measure of the strength of the fields present in the machine which excite the $2Q_H = 17$ resonance. The width of the stopband opened up by these fields is proportional to $(N_c^2 + N_s^2)^{1/2}$ and can be calculated for the correction scheme described in Reference 2. The result is

$$\text{SBW (Stop Band Width)} = \frac{0.0271}{P} \frac{1}{1000} (N_c^2 + N_s^2)^{1/2} \qquad (2)$$

where P is the momentum in GeV/c. For the corrections given in (1), the SBW is therefore 0.015 at 1 GeV/c momentum.

To verify that the excitation of the $2Q_H = 17$ resonance is responsible for the beam loss seen in Photo #1, the cos 17X and sin 17X corrections were set to zero on the flattop and the horizontal tune was moved away from 8.5. Photo #3 then shows no beam loss on the flattop.

Photo #4 is a blow-up of the L-20 current transformer signal in the beam loss region of Photo #1. The observed periodicity of ~ 17 ms may be due to 60 Hz ripple in the nu-quad power supplies which could move the horizontal tune in and out of the $Q_H = 8.5$ stopband.

With the flattop momentum still at ~ 1 GeV/c and with level B of the SN26 corrections set to zero, the nu-quads were then adjusted so that the tunes measured on the flattop were $Q_H = 8.662$, $Q_V = 8.766$. Photo #5 shows that there is no observable beam loss under these conditions, indicating that the $3Q_H = 26$ resonance has not been excited. (The four traces shown in Photos #5 and #6 are the same as those of Photos #1-#3 except the bottom trace, which is the shunt voltage for one of the sextupoles in the SN26 correction scheme.) Even when the horizontal nu-quads were adjusted so that $Q_H = 8+2/3$, no beam loss was observed, apparently indicating that there were no fields present in the machine to excite the $3Q_H = 26$ resonance. (We did not check the auxiliary power supplies connected to the four drive sextupoles to see if they had been tuned to null the remanent fields of these magnets. This could account for our inability to excite the resonance and should not be overlooked in future studies.) Photo #6 shows the beam loss which occurred when the resonance was deliberately excited by setting the SN26 correction sin 26X = - 1500 on the flattop.

The flattop was next moved to 4190 Gauss clock counts (~ 2 GeV/c) and the horizontal tune was moved toward 8.5 on the flattop in a series of steps. To reduce the chromaticity (and thereby reduce the tune spread), the power supply which is normally connected to the horizontal high-field quads was connected to the horizontal sextupoles and pulsed on the flattop with sufficient current to reduce the width of the peaks in the FFT frequency spectrum from which the tunes are deduced (see Reference 4). Photos #7-#11 show the beam loss observed as Q_H was moved toward 8.5 (the top trace in each photo is the L-20 current transformer) and Table I summarizes the conditions on the flattop for each photo. Photo #8 shows that the first observable loss occurs when $Q_H = 8.533$, and Photos #9 and #10 show that a correction of cos 17X = - 500, sin 17X = - 100, is required when $Q_H = 8.519$. Using Equation (2) we see that this correction implies a SBW of 0.007. Evidentally, even when the measured horizontal tune is as far away as 8.533, some of the beam crosses this stopband. Since we have presumably reduced the tune spread with the horizontal sextupoles, it is not clear how the loss is occurring. (A close look at Photo #8 shows a small amount of 60 Hz structure in the region of beam loss. This, again, may be due to 60 Hz ripple in the nu-quad power supplies which could move Q_H in and out of the stopband.)

Photo #9 shows a large loss beginning when $Q_H = 8.519$ and lasting ~ 50 ms, after which the rf shuts off and no loss occurs on the remaining flattop. We believe this has the following explanation: the 2 GeV/c flattop has a positive slope of ~ 0.5 MeV/c per ms as shown in

Figure 2. As long as the beam is accelerated on this slope, at a fairly constant radius, the tunes will not change appreciably. However, when the intensity drops enough to shut off the rf, the beam momentum remains constant while the B-field continues to increase, so that even for a small chromaticity of say - 0.2, the horizontal tune will change by 0.015 in 35 ms. This would be enough to move the tune out of the stopband thereby preventing further beam loss.

The values of the cos 17X and sin 17X corrections, which produced the least beam loss when Q_H was moved to 8.504, are given in Table I. The fact that we were not able to eliminate the beam loss entirely in this case (see Photo #11) may be an indication of the resolution with which the QN17 correction scheme can reduce the SBW.

V. Conclusions

The measurements of the QN17 corrections required to cancel the fields present in the machine which excite the $2Q_H = 17$ resonance indicate that the corrections should be adequate at the Booster momentum of 2.25 GeV/c. We should, however, test the reproducibility of the measurements in another study.

When the horizontal tune was moved to 8+2/3, no beam loss was observed and it was therefore not necessary to apply any SN26 corrections. This result is consistent with the fact that these corrections were not required during the recent high intensity SEB tuning done by E. Gill, and seems to indicate that any fields present in the machine which can excite the $3Q_H = 26$ resonance are small. We should, again, test the reproducibility of this result in another study and also explore the effect of tuning the auxiliary power supplies used to null the remanent fields in the drive sextupoles.

Another study is also clearly needed to try to find out why beam loss is seen when the measured tune is outside the SBW calculated from Equation (2). More precise control of the chromaticity on the flattop and a measurement of the ripple from the nu-quad power supplies should shed some light on this question.

References

1. E. Raka, et al., IEEE NS-32, 3110 (1985).

2. E. Raka, Second and Third Order Stopband Corrections in the AGS, AGS Technical Note, to be published.

3. C. Gardner, AGS/AD/OP Note No. 17, February 4, 1988.

4. W. van Asselt, AGS/AD/Tech. Note No. 292, January 13, 1988.

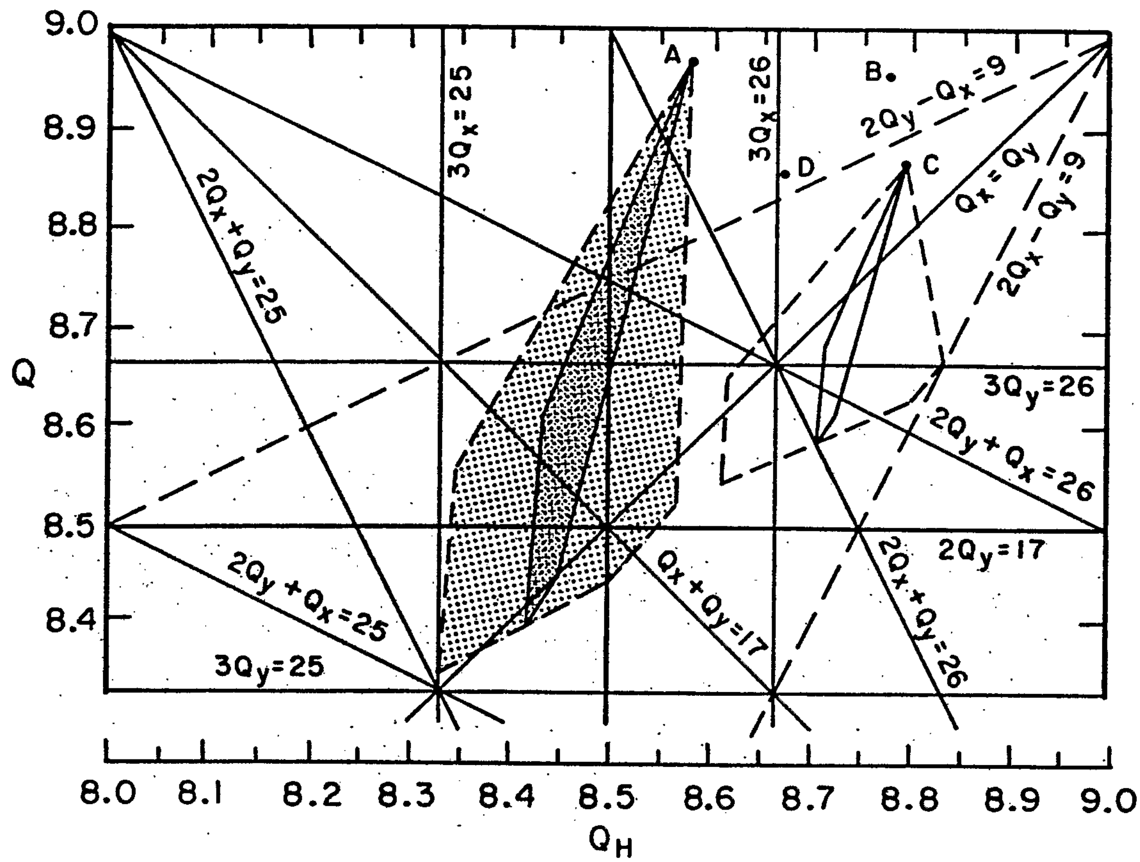
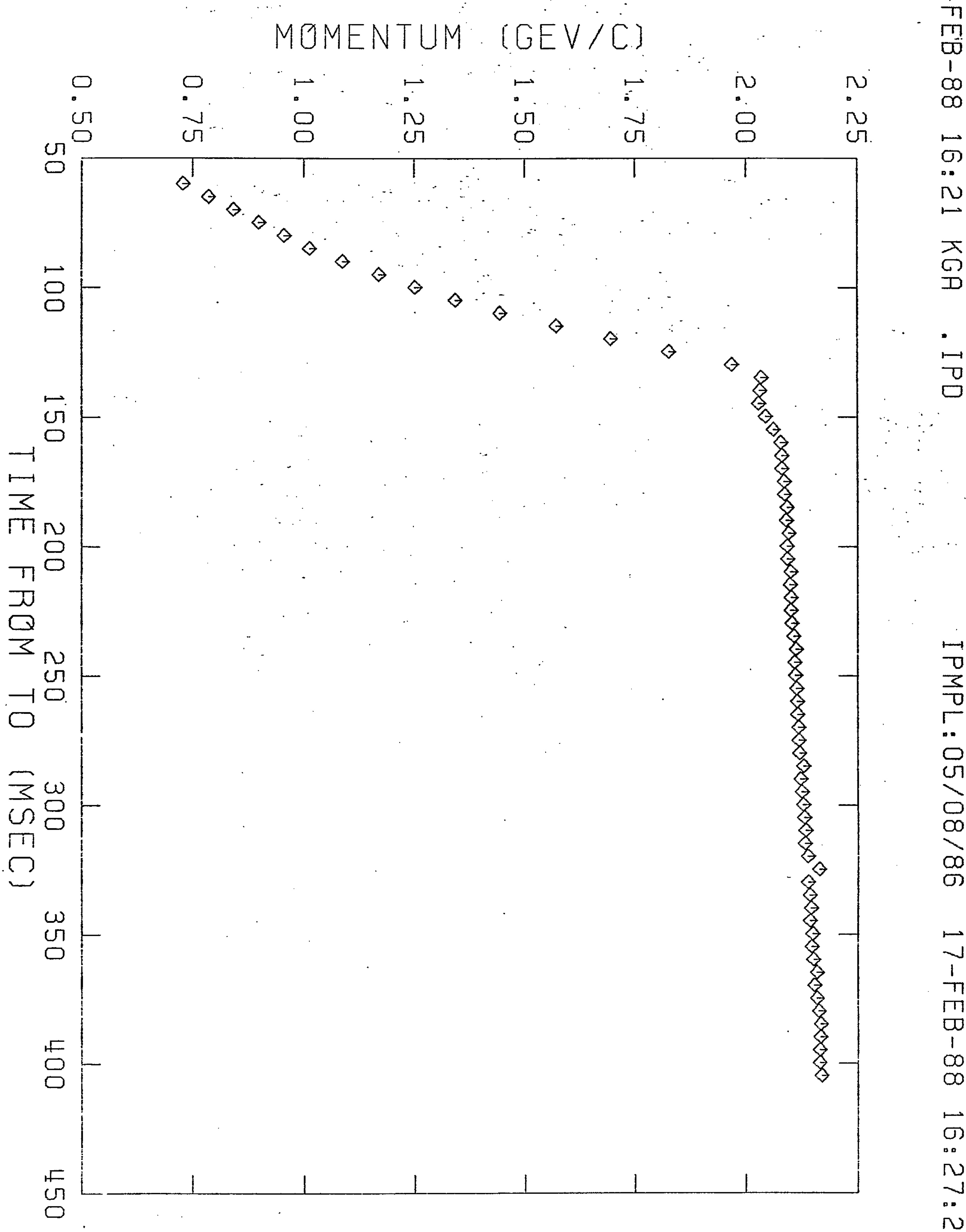


Figure 1 (from Ref 1)



7-FEB-88 16:21 KGA .IPD
IPMPL:05/08/86 17-FEB-88 16:27:21
MØMENTUM (GEV/C)
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
50
100
150
200
250
300
350
400
450
TIME FRØM TO (MSEC)

Figure 2

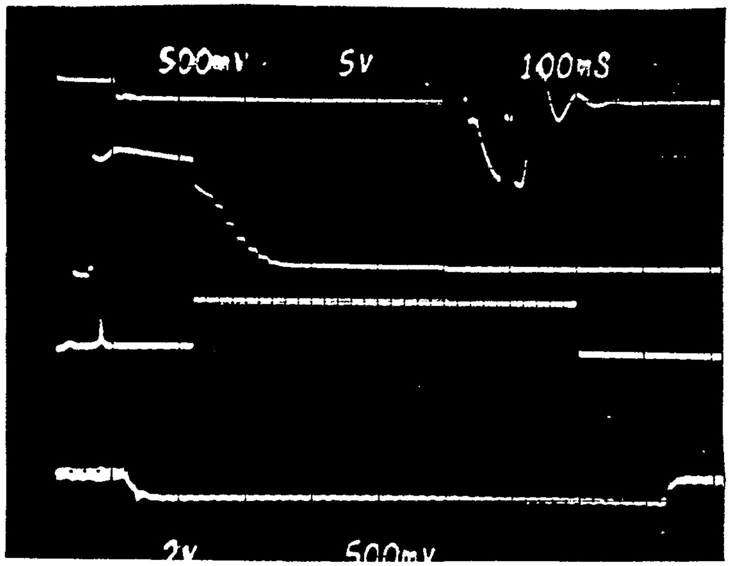
Photo 1

Backleg

L20

Nuquad

Aux Quad

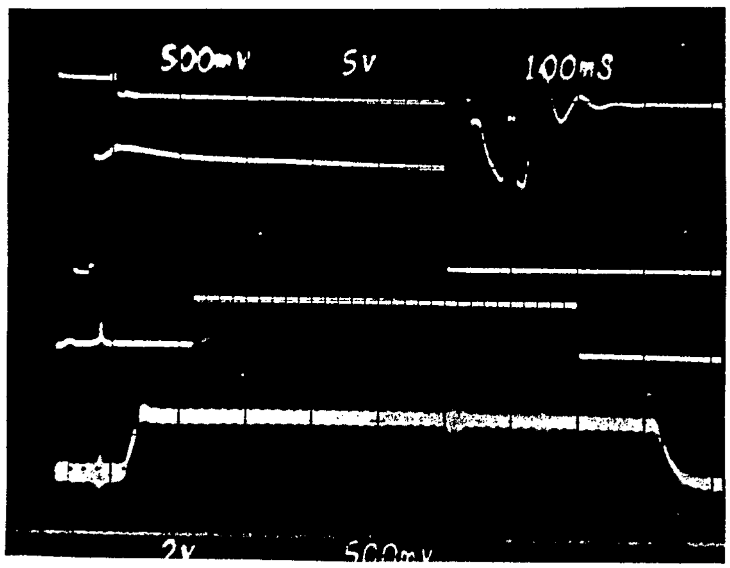


$Q_H = 8.5$

COS 17X = 0

SIN 17X = 0

Photo 2

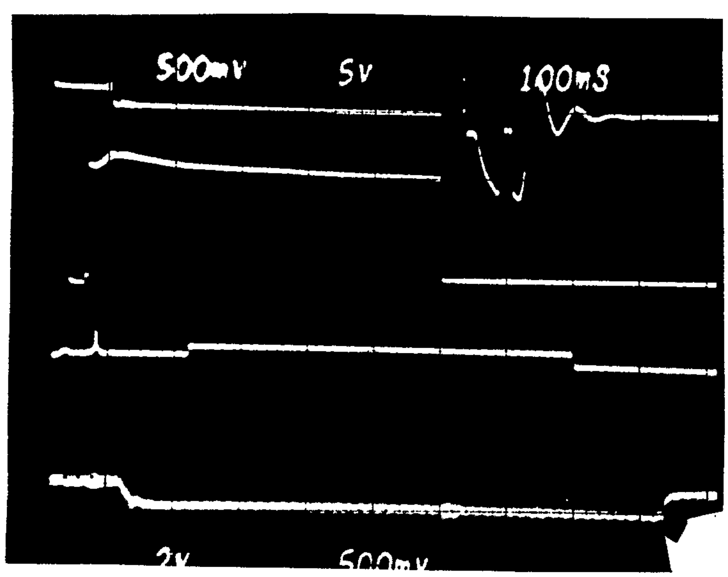


$Q_H = 8.5$

COS 17X = −550 ± 20

SIN 17X = 20 ± 20

Photo 3



$Q_H \neq 8.5$

COS 17 = 0

SIN 17X = 0

Photo 4

$Q_H = 8.5$

COS 17X = 0

SIN 17X = 0

L20

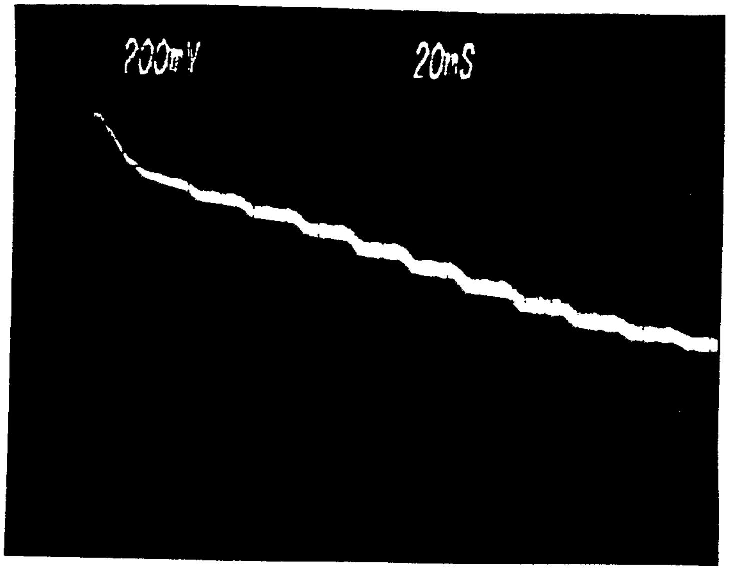


Photo 5

$Q_H = 8\frac{2}{3}$

SN26B = 0

Backleg

L20

Nuquad

Aux. Sext.

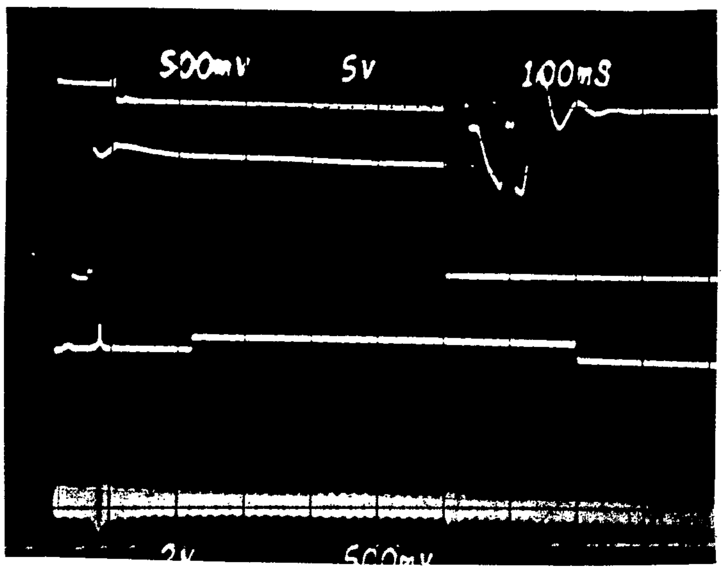
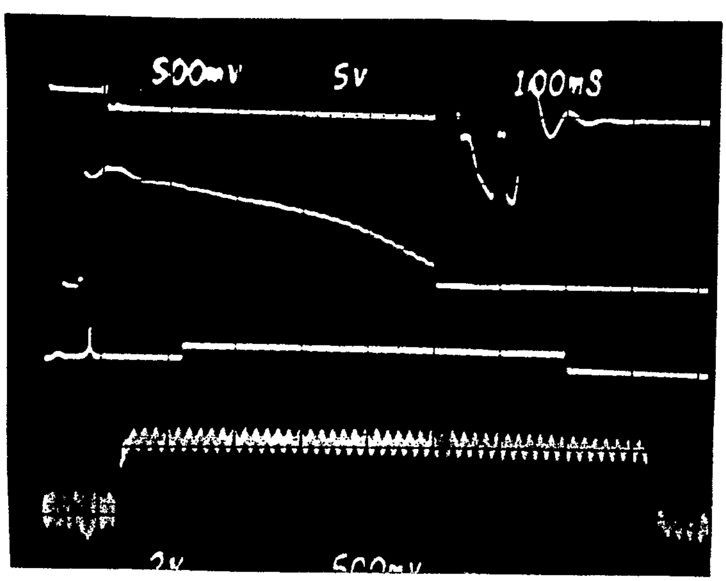


Photo 6

$Q_H = 8\frac{2}{3}$

SIN 26X = -1500



L20

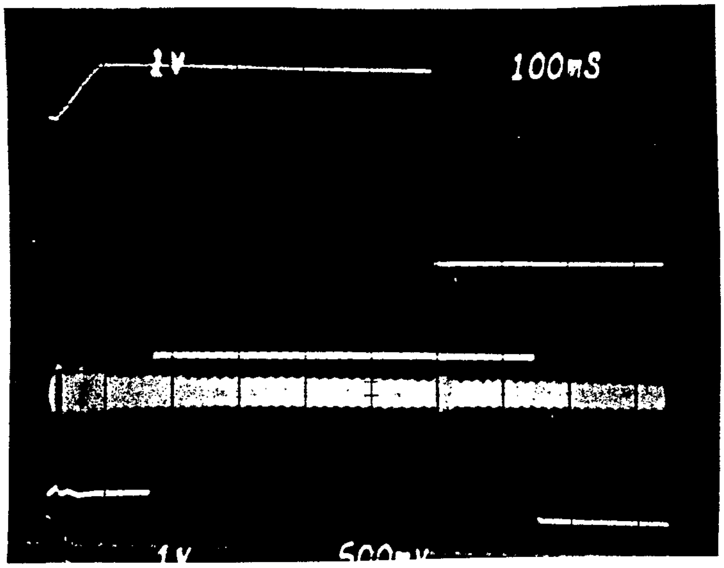


Photo 7

$Q_H = 8.548$

$\cos 17X = 0$

$\sin 17X = 0$

L20

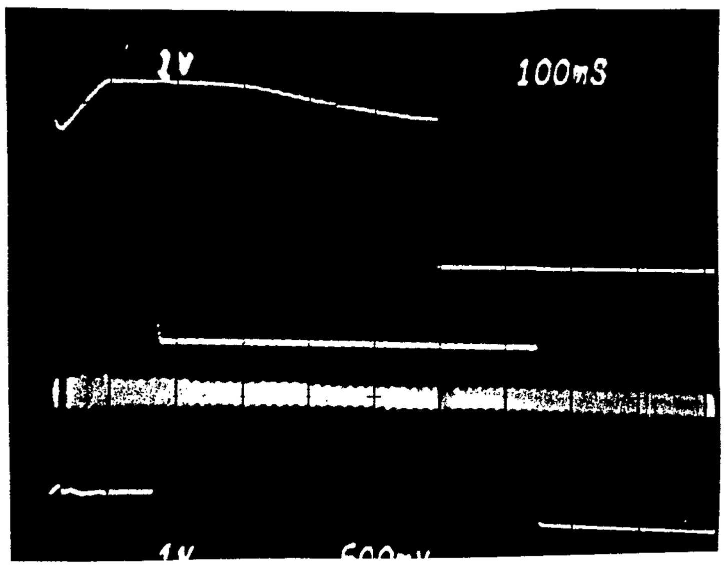


Photo 8

$Q_H = 8.533$

$\cos 17X = 0$

$\sin 17X = 0$

L20

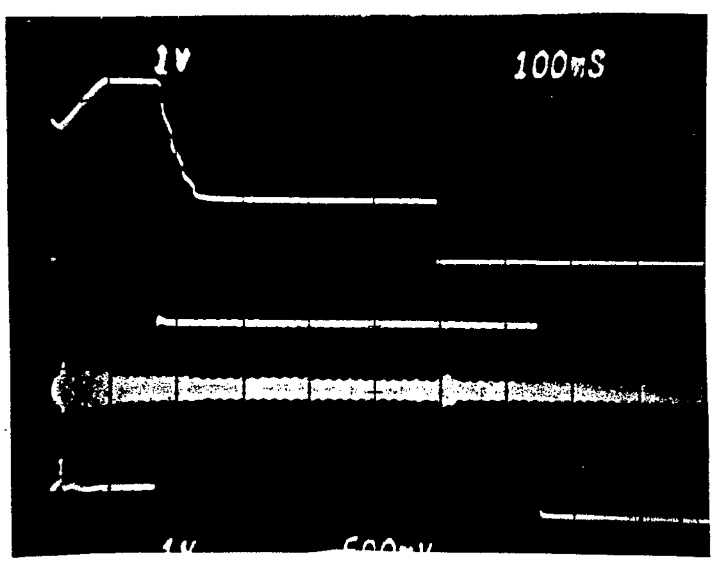


Photo 9

$Q_H = 8.519$

$\cos 17X = 0$

$\sin 17X = 0$

L20

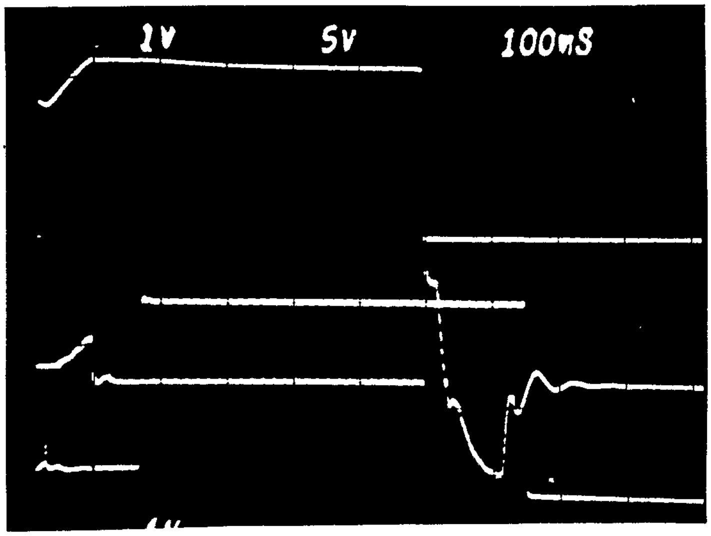


Photo 10

$Q_H = 8.519$

COS17X = -500

SIN 17X = -100

L20

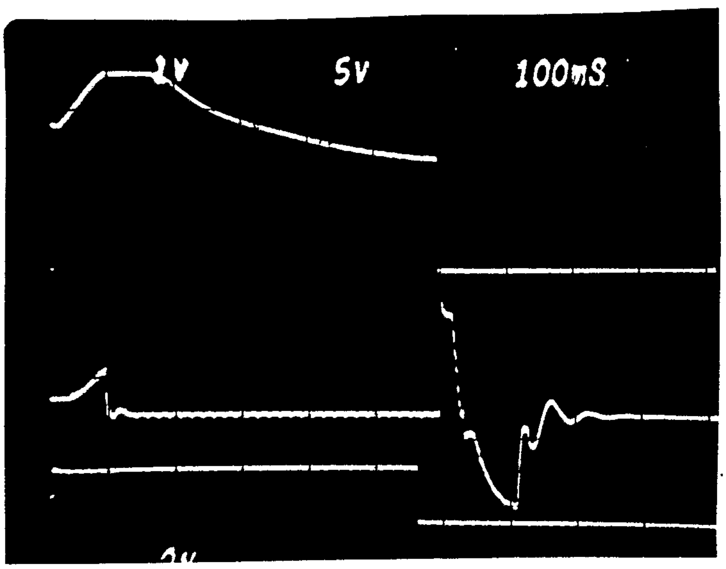


Photo 11

$Q_H = 8.504$

COS17X = -419

SIN 17X = -107

TABLE I

Photo	Horizontal Nu-Quad (NUQH)	Measured Tune (Q_H)	QN17 Correction Cos 17X	QN17 Correction Sin 17X	SBW Calculated From Eq. (2)
7	1100	8.548	0	0	0
8	1200	8.533	0	0	0
9	1300	8.519	0	0	0
10	1300	8.519	-500	-100	0.007
11	1400	8.504*	-419	-107	0.006

*Extrapolated from the first 3 values in the table.