LBL--32791

DE93 001591

# Ripple Reduction Activities in the MG Room at the Bevatron August 1991 to August 1992

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August 1992

MASTER

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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IMPROVEMENTS OF THE BEVATRON SYSTEM

1. Preface

This job was supervised by C. Celata and is a continuation of R. Salomons and C. Celata's work in the year 1990-1991.

The major task was to improve the spill to a more continuous flow out of particles during the spillout of the particles from the Bevatron Accelerator. The work concentrated on reduction of the ripple and "softening" over the transfer function of the ripple control system. Detailed information and data can be found in the R. Salomons / M. Blasbalg logbook and on the hard disc storage system of the TEK 2630 Fourier Analyzer according to file numbers that are mentioned in the logbook.

2. Magnet Voltage Dividers ( Page 80 in logbook)

Since the cross magnet ac voltages and responses are taken across the dividers which are connected at the magnet corners, these dividers had to be examined very carefully with respect to their temperature and voltage behavior.

According to the MFG company of the resistor, the stability should be in the range of: TCR = -550 PPM/°C

VCR = -25 PPM/VOLT

Both these figures were tested and the resistor behaved within these limited ranges.

The error for cross magnet measurement was calculated according to MFG's stability and accuracy data.

The error (theoretically calculated) was $\approx$ 1%.

$$\frac{\Delta(V2 - V1)}{(V2 - V1)} = 1\%$$

This error is negligible.

3. Magnet Filters (Page 91 in Logbook) - Summarized Data Table

The Table includes the data for the 175, 355, 680, 1080, 1355 Hz filters on the ±1 and ±2 magnets.

L  Filter inductance in mHy (measured)

$L_n$  Filter inductance in mHy calculated according to the mid band filter frequency and measured capacitors which are connected in parallel

C  Total capacitance in µF (measured)

R  Total resistance between filter buss terminals in m ohms (measured)

*f*oFc  Calculated filter band center frequency according to measured actual filters

$f$oFn Calculated required filter band center frequency, according to lowest and highest slip factors

$f$max Maximum expected frequency (Lowest Field)

$f$min Minimum expected frequency (Highest Field)

BWc Filter bandwidth - Calculated

$$BW = \frac{f_o}{Q} \quad Q = \frac{W_oL}{R}$$

BWn Real required BW

<u>NOTE</u>:Slip factors were calculated as follows:

$$K_{max} = \frac{890}{900} \quad K_{min} = \frac{869}{900}$$

TABLE

FILTERS Values of R, C, L, Calcu

| | *175(180)* | *355(360)* | *680(720)* | *1018(1080)* | *1355(1440)* | *60Hz* |
|---|---|---|---|---|---|---|
| | 105 Trns | | | | | |
| L(mHy) | 10.26 | 0.868 | 0.864 | 1.458 | 0.926 | |
| Ln(mHy) | 10.24 | 1.017 | 0.8231 | 1.39 | 0.8873 | 25.13 |
| C(µF) | 81.8 | 206 | 63.6 | 16.74 | 14.75 | 300 |
| R(mΩ) | 140.71 | 16.68 | 48.25 | 53.72 | 48.36 | 345.3 |
| fOFC | 173.728 | 376 | 678.945 | 1018.741 | 1361.817 | |
| | | | | | | |
| fOFN | 173.9 | 347.8 | 695.6 | 1043.4 | 1391.2 | 57.97 |
| | | | | | | |
| fmax | 178 | 356 | 712 | 1068 | 1424 | 59.3 |
| f max c(-3db) | 174.82 | 377.53 | 683.385 | 1021.674 | 1365.976 | |
| f min c(-3db) | 172.637 | 374.47 | 674.505 | 1015.809 | 1357.66 | |
| f min | 169.8 | 339.6 | 679.2 | 1018.8 | 1358.4 | 56.6 |
| BWc | 2.183 | 3.057 | 8.88 | 5.865 | 8.314 | |
| Q | 79.6 | 123 | 76.4 | 173.7 | 163.8 | |
| BWn | 8.2 | 16.4 | 32.8 | 49.2 | 65.6 | |
| fo(m) | 170.5 | 342 | 624.2 | 965.7 | 1290 | |
| ATT@(m) | -34.7 | -52.1 | -36.5 | -18.37 | -24.2 | |
| ATT(m)@fmax | -21.5 | -37.5 | -24.5 | -14.8 | -18.1 | |
| ATT(m)@fmin | -33 | -36.2 | -28 | -16 | 21.1 | |

| | *175(180)* | *355(360)* | *680(720)* | *1018(1080)* | *1355(1660)* | *120Hz* |
|---|---|---|---|---|---|---|
| | 103.3 Trans | | | | | |
| L(mHy) | 10.1 | 0.872 | 0.842 | 1.375 | 0.905 | |
| Ln(mHy) | | | | | | 12.57 |
| C(µF) | 82.8 | 204 | 63 | 16.88 | 14.86 | 150 |
| R(mΩ) | 137 | 15.85 | 48.06 | 51.86 | 44.87 | 172.7 |
| fOFC | 174.038 | 377.352 | 691.025 | 1044.678 | 1372.418 | 115.9 |
| | | | | | | |
| fOFN | 173.9 | 347.8 | 695.6 | 1043.4 | 1391.2 | 115.9 |
| | | | | | | |
| fmax | 178 | 356 | 712 | 1068 | 1424 | 118.7 |
| f max c(-3db) | 175.123 | 378.8 | 695.567 | 1047.68 | 1376.364 | |
| f min c(-3db) | 172.953 | 375.905 | 686.483 | 1041.676 | 1368.472 | |
| f min | 169.8 | 339.6 | 679.2 | 1018.8 | 1358.4 | 113.2 |
| BWc | 2.17 | 2.894 | 9.084 | 6.004 | 7.892 | |
| Q | 80.2 | 130.4 | 76.07 | 174 | 173.9 | |
| BWn | 8.2 | 16.4 | 32.8 | 49.2 | 65.6 | |
| fo(m) | | | | | | |
| ATT@(m) | | | | | | |
| ATT(m)@fma | | | | | | |
| ATT(m)@fmin | | | | | | |

TABLE

FILTERS Values of R, C, L, Calcu

BWn = fmx - fmin; fmax+ Kmaxfon; f min = Kmin·fon; Kmax= $\frac{890}{900}$ ; Kmin = $\frac{849}{900}$

foFn nominal filter center frequency to be: $\frac{\text{fmax= fmin}}{(2)}$

LN calculated nom. filter coil inductance

foFC calculated filter center frequency

fmax maximum possible frequency at the filter band = f nominal·Kmax
fmin minimum possible frequency at the filter band = f nominal·Kmin

BWc = $\frac{fo}{Q}$ 3dB bandwidth of the filter calculated

fminc(-3dB) lower -3dB calculated frequency
fmaxc(-3dB) higher-3db calculated frequency

fFm measured filter center frequency

BWn real necessary BW =fmax-fmin

4. Magnet Transfer Function Measurement Setup and Connection Diagrams
(Page 91 in Logbook)

The setup on DWG 4-1 to 4-4 is designed to measure the cross magnet response in the real system with and without filters. Two amplifiers (var gain $G_v$ 28 ÷ 75) were designed - antiphased, (OP AMP1 CH1, $CH_2$) and two others were designed ($G_V = 28$) which are in phase. (OP AMP2 CH1, $CH_2$) in addition a different amp was added (OP $AMP_3$).

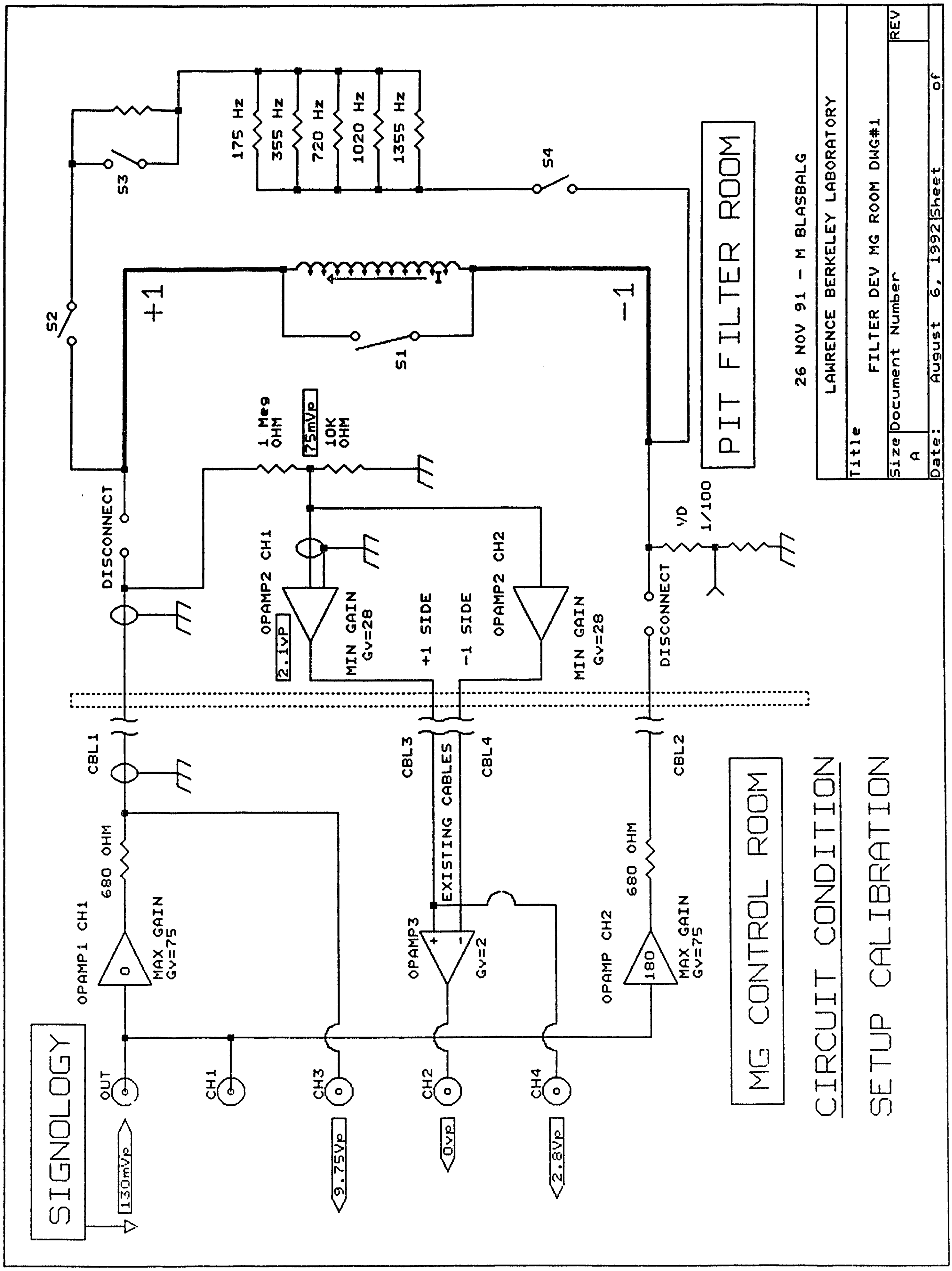
The amps have a minimum response of DC to 2 KHZ. The different setups are as follows:

| | |
|---|---|
| DWG #4-1 | Amplifiers calibration |
| DWG #4-2 | System setup calibration |
| DWG #4-3 | Measuring the filters without magnet |
| DWG #4-4 | Measuring the magnet and the filters. |

S1 shorted is used for system calibration. This measuring system is connected to the Fourier Analyzer TEK-2630 as the following: the sweep signal connected to OP $AMP_1$ $CH_1$, $CH_2$.

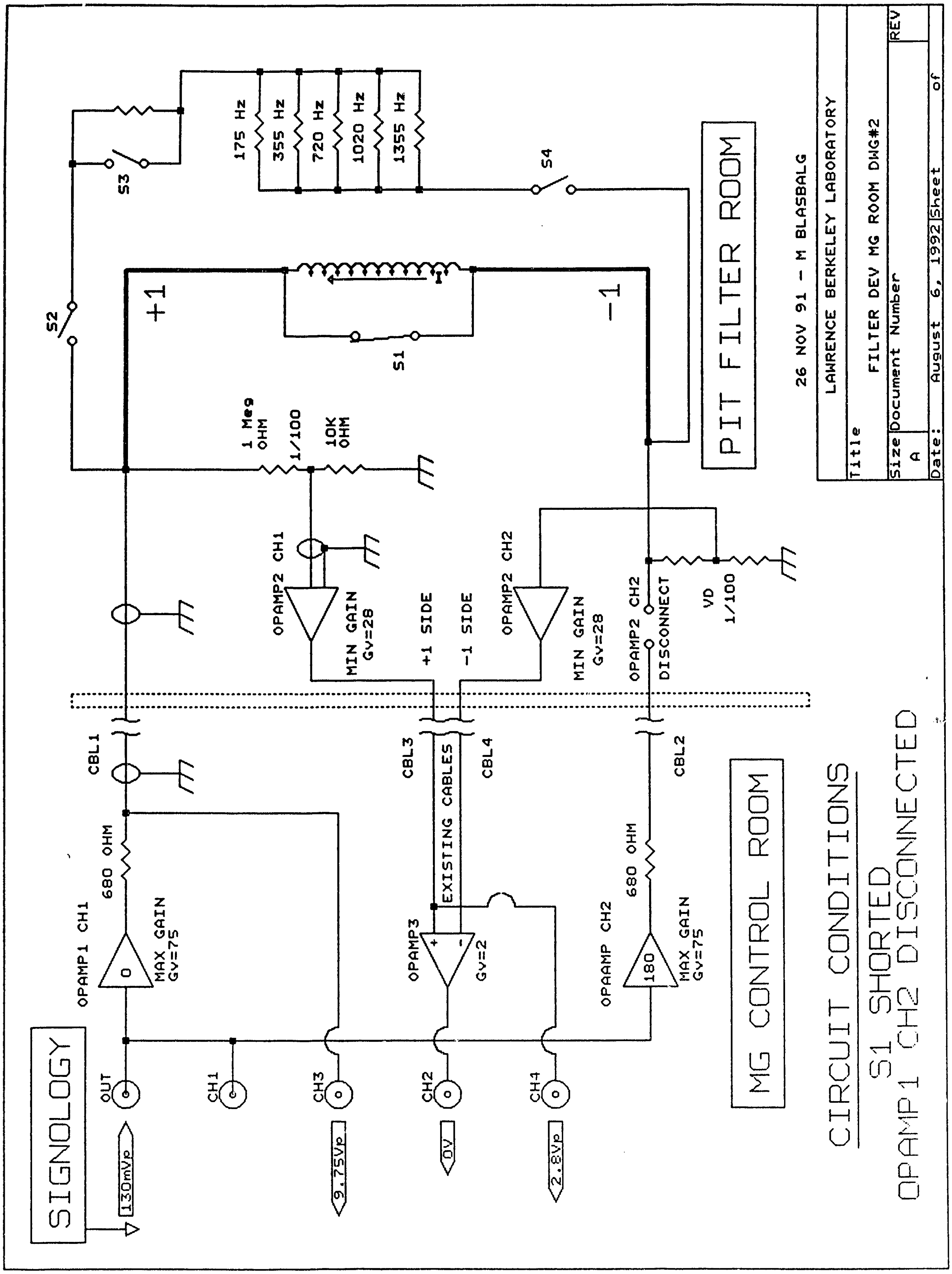
| | |
|---|---|
| CH1 | Monitoring the input sweep signal |
| CH2 | Output of the measuring chain -- response function |
| CH3 | Output of OPAMP1 CH1 |
| CH4 | Output of OPAMP2 CH1 |

On page 109 the calibration response is seen while the magnet is shorted.


PIT FILTER ROOM
MG CONTROL ROOM
CIRCUIT CONDITION
SETUP CALIBRATION
SIGNOLOGY
26 NOV 91 - M BLASBALG
LAWRENCE BERKELEY LABORATORY
Title
FILTER DEV MG ROOM DWG#1
Size
A
Document Number
REV
Date:
August 6, 1992
Sheet
of
175 Hz
355 Hz
720 Hz
1020 Hz
1355 Hz
S1
S2
S3
S4
+1
-1
1 Meg OHM
10K OHM
75mVp
VD 1/100
DISCONNECT
DISCONNECT
OPAMP2 CH1
MIN GAIN Gv=28
2.1VP
+1 SIDE
-1 SIDE
OPAMP2 CH2
MIN GAIN Gv=28
CBL1
CBL3
EXISTING CABLES
CBL4
CBL2
680 OHM
680 OHM
OPAMP1 CH1
0
MAX GAIN Gv=75
OPAMP3
Gv=2
OPAMP CH2
180
MAX GAIN Gv=75
OUT
CH1
CH3
CH2
CH4
130mVp
9.75Vp
0Vp
2.8Vp

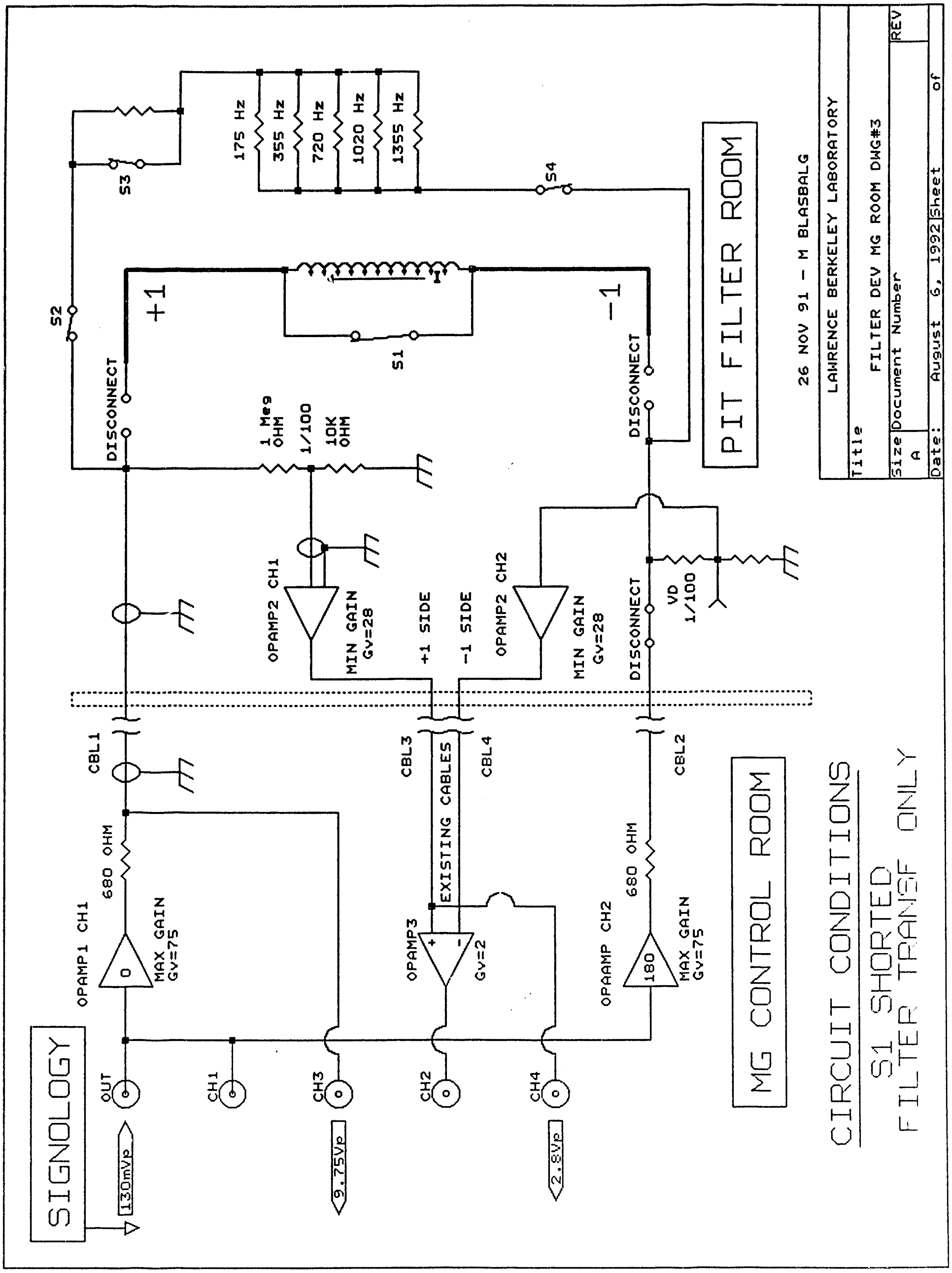
DWG 4-1

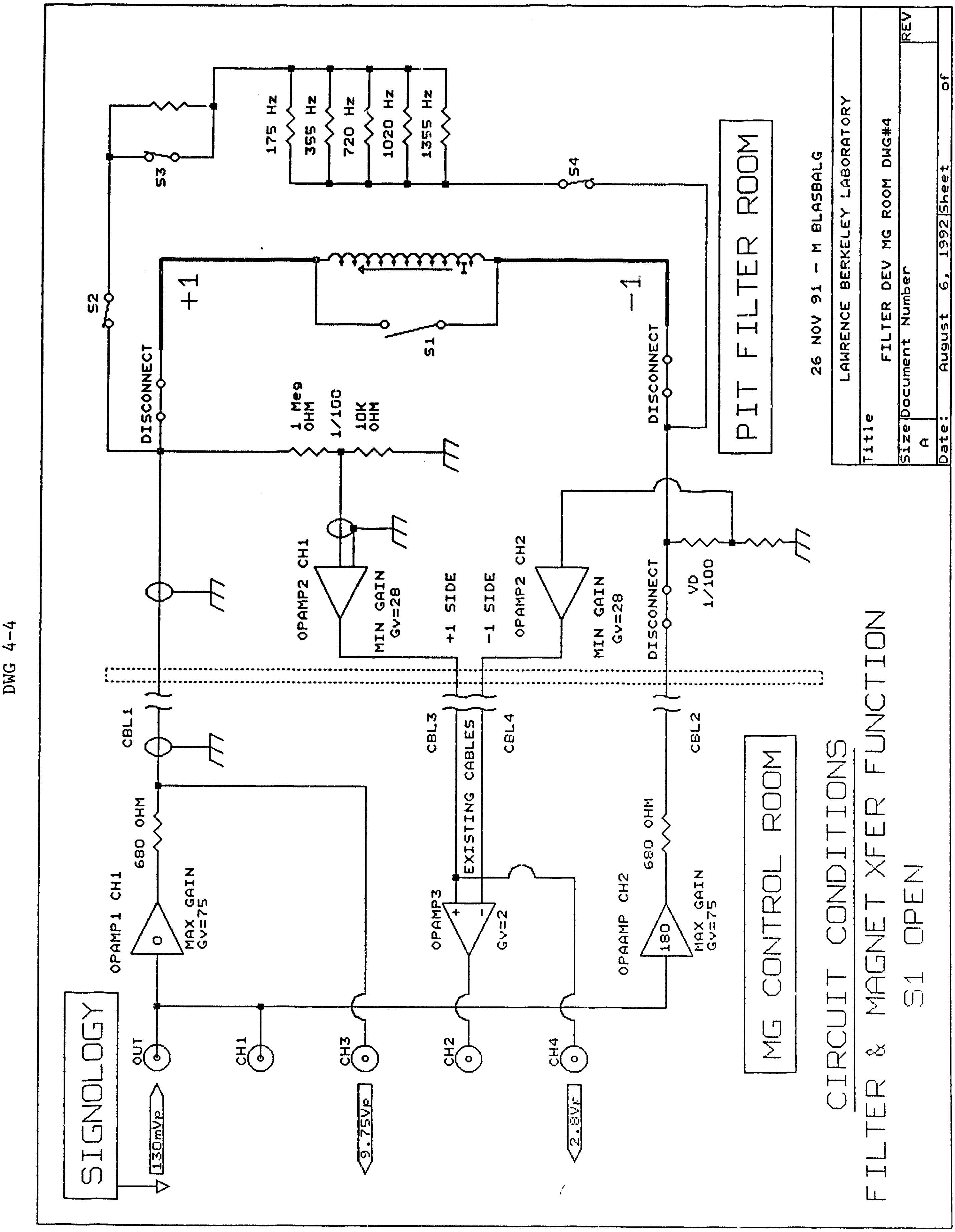
DWG 4-2



175 Hz
355 Hz
720 Hz
1020 Hz
1355 Hz
S1
S2
S3
S4
+1
-1
1 Meg OHM
1/100
10K OHM
OPAMP2 CH1
MIN GAIN Gv=28
+1 SIDE
-1 SIDE
OPAMP2 CH2
MIN GAIN Gv=28
OPAMP2 CH2 DISCONNECT
DISCONNECT
VD 1/100
PIT FILTER ROOM
26 NOV 91 - M BLASBALG
LAWRENCE BERKELEY LABORATORY
Title
FILTER DEV MG ROOM DWG#2
Size A
Document Number
REV
Date: August 6, 1992
Sheet of
CBL1
CBL3
EXISTING CABLES
CBL4
CBL2
680 OHM
OPAMP1 CH1
0
MAX GAIN Gv=75
OPAMP3
Gv=2
OPAAMP CH2
180
MAX GAIN Gv=75
680 OHM
MG CONTROL ROOM
SIGNOLOGY
OUT
CH1
CH3
CH2
CH4
130mVp
9.75Vp
0V
2.8Vp
CIRCUIT CONDITIONS
S1 SHORTED
OPAMP1 CH2 DISCONNECTED

DWG 4-3


PIT FILTER ROOM
MG CONTROL ROOM
SIGNOLOGY
CIRCUIT CONDITIONS
S1 SHORTED
FILTER TRANSF ONLY
26 NOV 91 - M BLASBALG
LAWRENCE BERKELEY LABORATORY
Title
FILTER DEV MG ROOM DWG#3
Size
A
Document Number
REV
Date:
August 6, 1992
Sheet
of
175 Hz
355 Hz
720 Hz
1020 Hz
1355 Hz
S1
S2
S3
S4
+1
-1
DISCONNECT
DISCONNECT
DISCONNECT
1 Meg OHM
1/100
10K OHM
VD 1/100
OPAMP2 CH1
MIN GAIN Gv=28
+1 SIDE
-1 SIDE
OPAMP2 CH2
MIN GAIN Gv=28
CBL1
CBL3
EXISTING CABLES
CBL4
CBL2
680 OHM
680 OHM
OPAMP1 CH1
0
MAX GAIN Gv=75
OPAMP3
Gv=2
OPAAMP CH2
180
MAX GAIN Gv=75
OUT
CH1
CH3
CH2
CH4
130mVp
9.75Vp
2.8Vp


DWG 4-4
SIGNOLOGY
130mVp
OUT
CH1
CH3
9.75Vp
CH2
CH4
2.8Vp
OPAMP1 CH1
0
MAX GAIN
Gv=75
680 OHM
CBL1
OPAMP3
+
-
Gv=2
EXISTING CABLES
CBL3
CBL4
OPAAMP CH2
180
MAX GAIN
Gv=75
680 OHM
CBL2
MG CONTROL ROOM
CIRCUIT CONDITIONS
FILTER & MAGNET XFER FUNCTION
S1 OPEN
OPAMP2 CH1
MIN GAIN
Gv=28
+1 SIDE
-1 SIDE
OPAMP2 CH2
MIN GAIN
Gv=28
DISCONNECT
VD
1/100
DISCONNECT
1 Meg
OHM
1/100
10K
OHM
DISCONNECT
+1
S1
-1
S2
S3
S4
175 Hz
355 Hz
720 Hz
1020 Hz
1355 Hz
PIT FILTER ROOM
26 NOV 91 - M BLASBALG
LAWRENCE BERKELEY LABORATORY
Title
FILTER DEV MG ROOM DWG#4
Size
A
Document Number
REV
Date: August 6, 1992
Sheet
of

The programmed scales of the TEK 2630 were used to use and achieve the maximum available dynamic range.

5. Response of Existing Magnet System Including Ripple Reduction Filters
(Page 122 in logbook)

The response of both magnets ±1 and ±2 are given on Page 122 to 125 in the logbook.

On Page 122 a (SPICE) simulation is given as well.

Except for frequency accuracy (shifted center frequency in existing filters due to inaccuracy of components), 3 major problems are seen:

a. A bump of the response function at around 5 Hz

b. An interaction between the filters and magnet. This transient is seen also in the SPICE simulation.

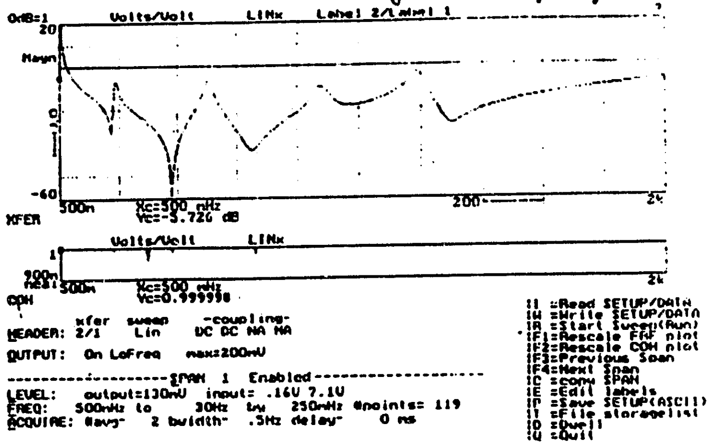
c. We found that this sharpness degradation occurs due to mutual inductance/loading of the coils/filters. After repositioning of the filter coils down in the filter pit, this problem was solved.

6. Magnet Filters -- Mutual Inductance Problem (Page 130 in Logbook)

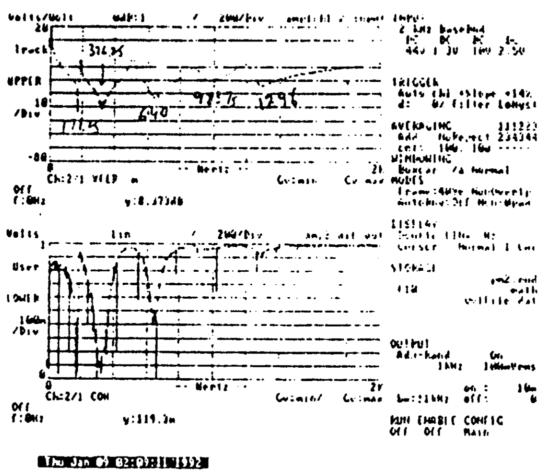
As mentioned in paragraph 4.(a) the response degradation was due to mutual inductance. This was proven by flipping the filter coil over, physically achieving a 180° change in mutual inductance. The result of this experiment is in the Logbook, page 129, 130, original position page.

On page 130 the "flipped over" coil configuration is shown for magnet ±2. Various configurations in which coils are positioned vertically each to another are shown on pages 137 through 139. The response of (the new assembled filter pit) the magnet and filters is shown on page 194 in the Logbook.

f # SET 3 DG4A.PM1 Mike Bennet
8 Jan 1992
±1 Mag original filter coil const.




1070 filter coil in original position
all other coils in original position
f # ORGPM2.RND ±2 magnet
9 January 1992



SPICE SIMULATIONS FOR DAMPED AND UNDAMPED FILTER SYSTEM

## 7. Damping the Magnet Filters (page 137 in Logbook)

### 7.1 Filters and spurious behavior across the magnet.

Since the filters are series resonant circuits (in different frequencies) which are connected in parallel to the big magnet (each half magnet has an induction of 2.5Hy), the response of the half magnet, including filters, will be a multi notch response. In our case, 5 notches in the $175_{Hz}$ $355_{Hz}$ $680_{Hz}$ $1080_{Hz}$ $1355_{Hz}$ frequencies. Spurious frequencies (generator harmonics) are damped in these frequencies according to the notch depth and shape.

Since the ripple reduction control system includes somewhere the filters (because our ripple source includes the magnet and filters) it is "healthy" for a control system not to have abrupt phase variations as a function of frequency. Our solution to this problem was to decrease the sharpness of the filter notches which resulted in smoother phase response in the notch regions. An additional advantage of damping the resonance circuits (filters) is that their influence in the frequency domain is broadened around the center/resonance frequency.

The disadvantage ("where we pay") is, that the notches are not deep as in the undamped configuration. SPICE simulations were done for various different damping configurations. Measured and simulation results are on pages 194, 195 in the logbook.

Damped filters were tested in a "hot machine". Spurious magnitudes were measured in the 0 - 2KHZ band on both halves of the magnets.

In low fields the damped configuration caused an increase of spuriouses at the lower band in an amount that was unacceptable.

In medium and high fields an improvement along the whole band was recognized.

The values of the damping resistors in the different damping configurations, including spurious magnitudes in different fields, is given in tables on page 191, 192, in the logbook.

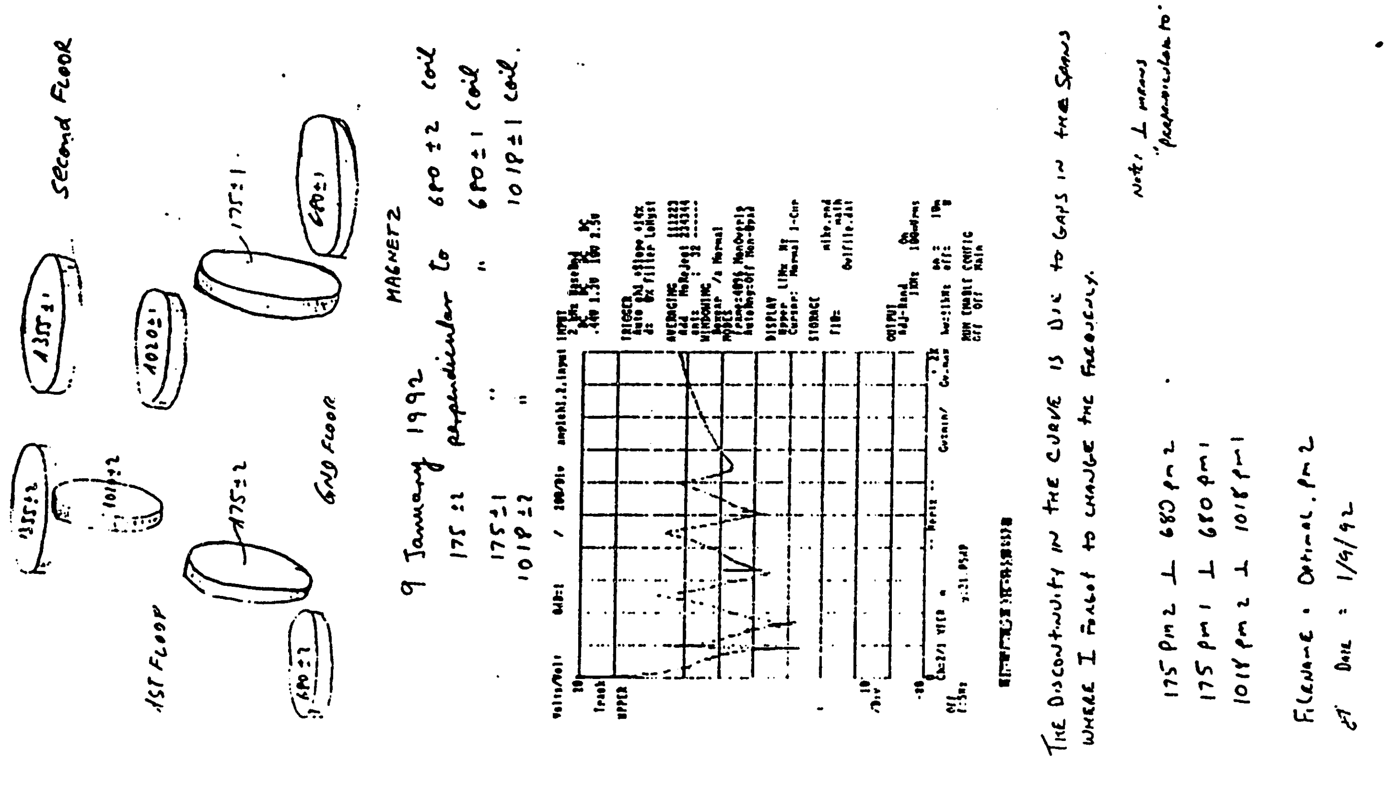
The next step was testing filters in a running "hot" machine while particles spill is extracted.

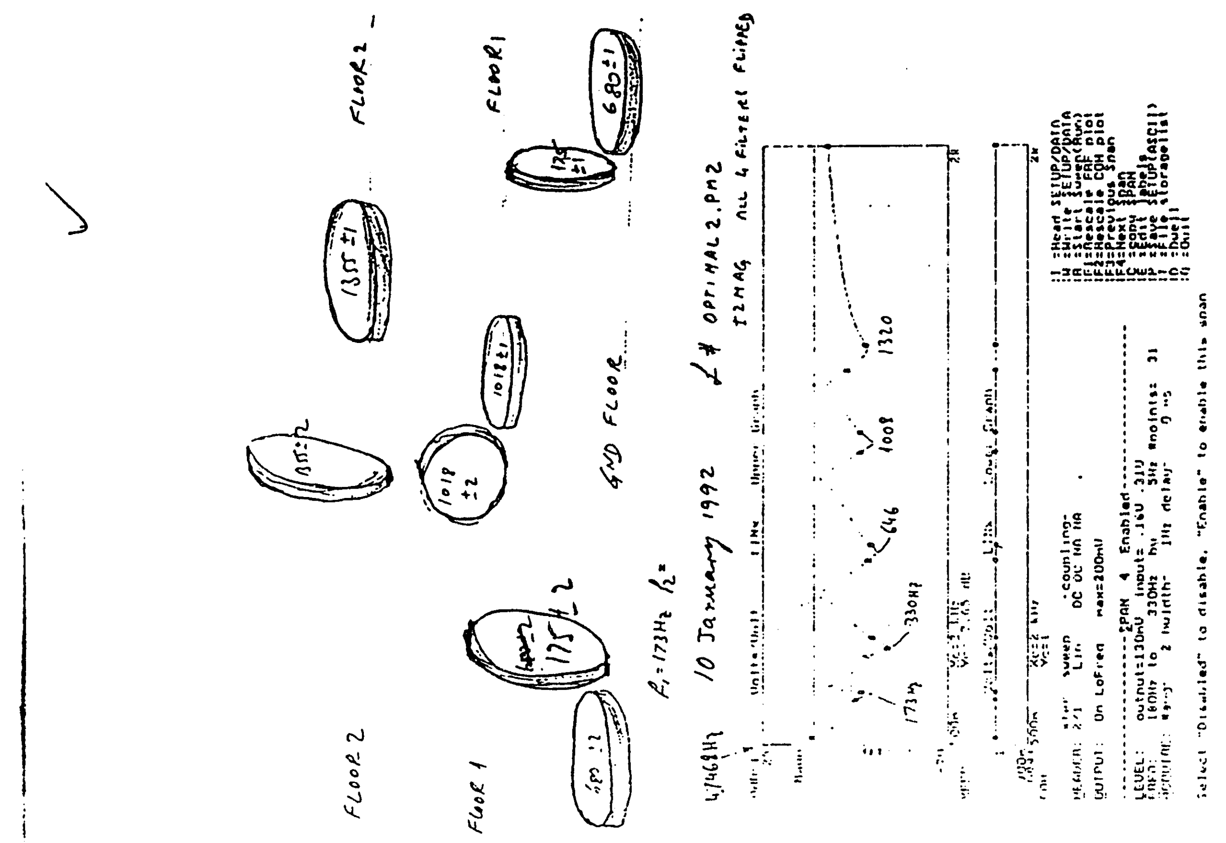
## 7.2 Damped Magnet Filters 1st Configuration -- Spill Histograms.

On pages 175 to 177 in the logbook are the results of a BevDev with damp'd filters where spill histograms were taken with damped and undamped filters.

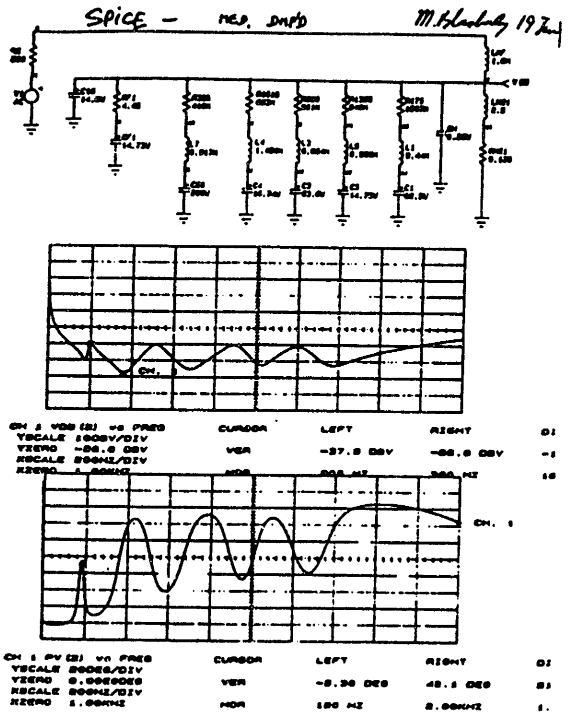
If we compare the original configuration with ripple reduction on to the damped configuration with ripple reduction on, we can notice a clear improvement for the amount of $2 \cdot 10^8$ particles.

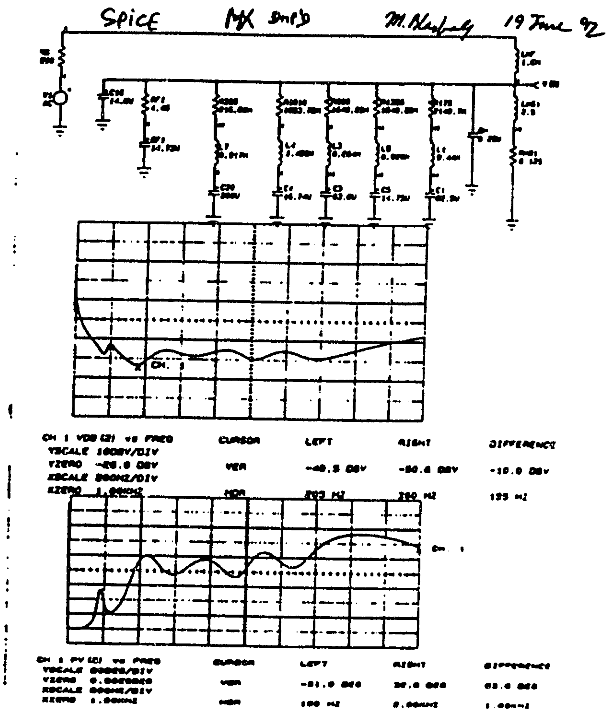
## 7.3 Damped Filters 2nd Set of Configurations

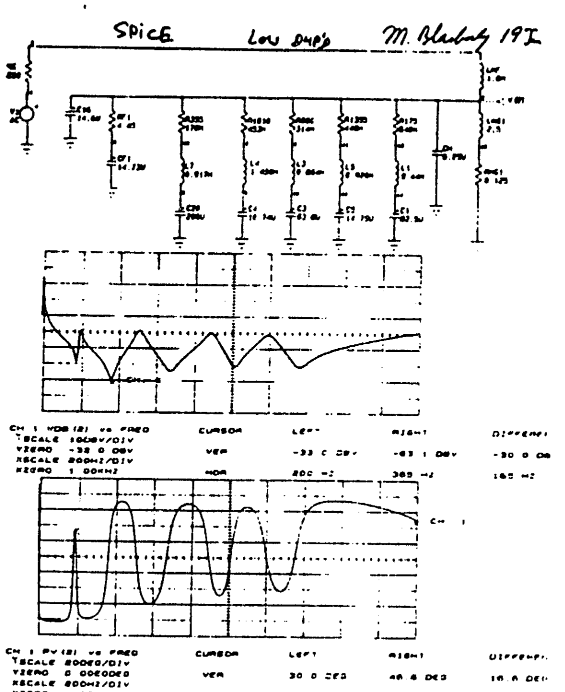


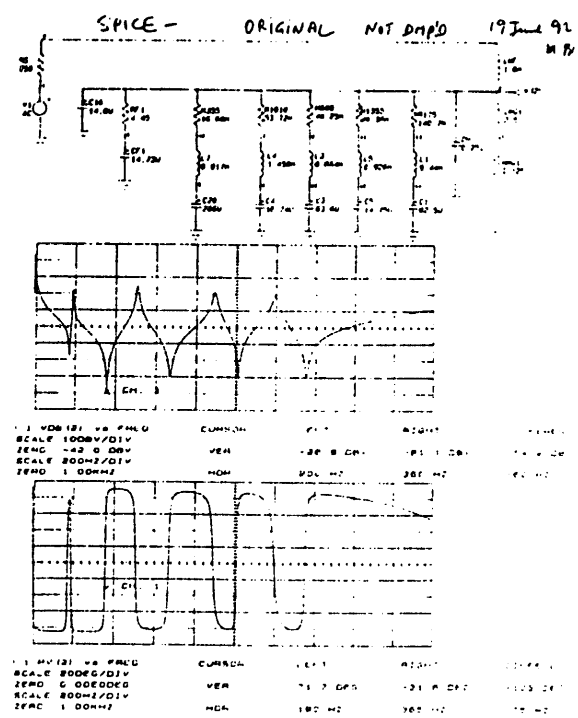




System Measuring Results With Original Filters and With Damped Filters
(Data was taken with TEK 2630)



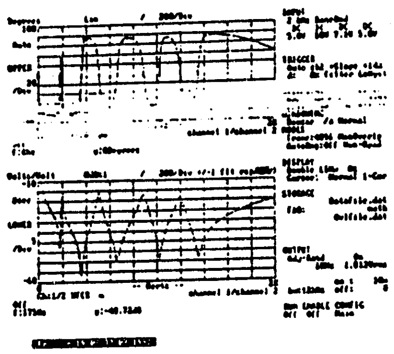




SPICE SIMULATIONS FOR DAMPED AND UNDAMPED FILTER SYSTEM

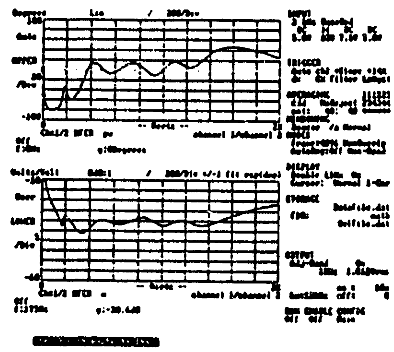
±1 MAG
NO DAMPING
M. Bennett

REASSEMBLED FILTER PIT
ORIGINAL FILTERS



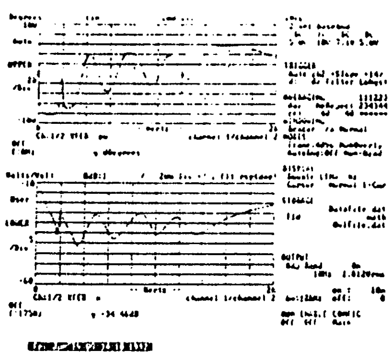
±1
MAX DAMPING
M. Bennett

REASSEMBLED FILTER PIT
MAX DMP'D



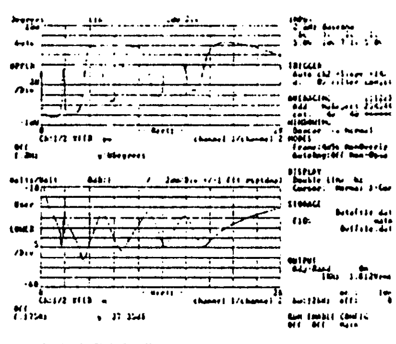
±1 MAG
MED DAMPING
M. Bennett

REASSEMBLED FILTER PIT
MEDIUM DAMP'D



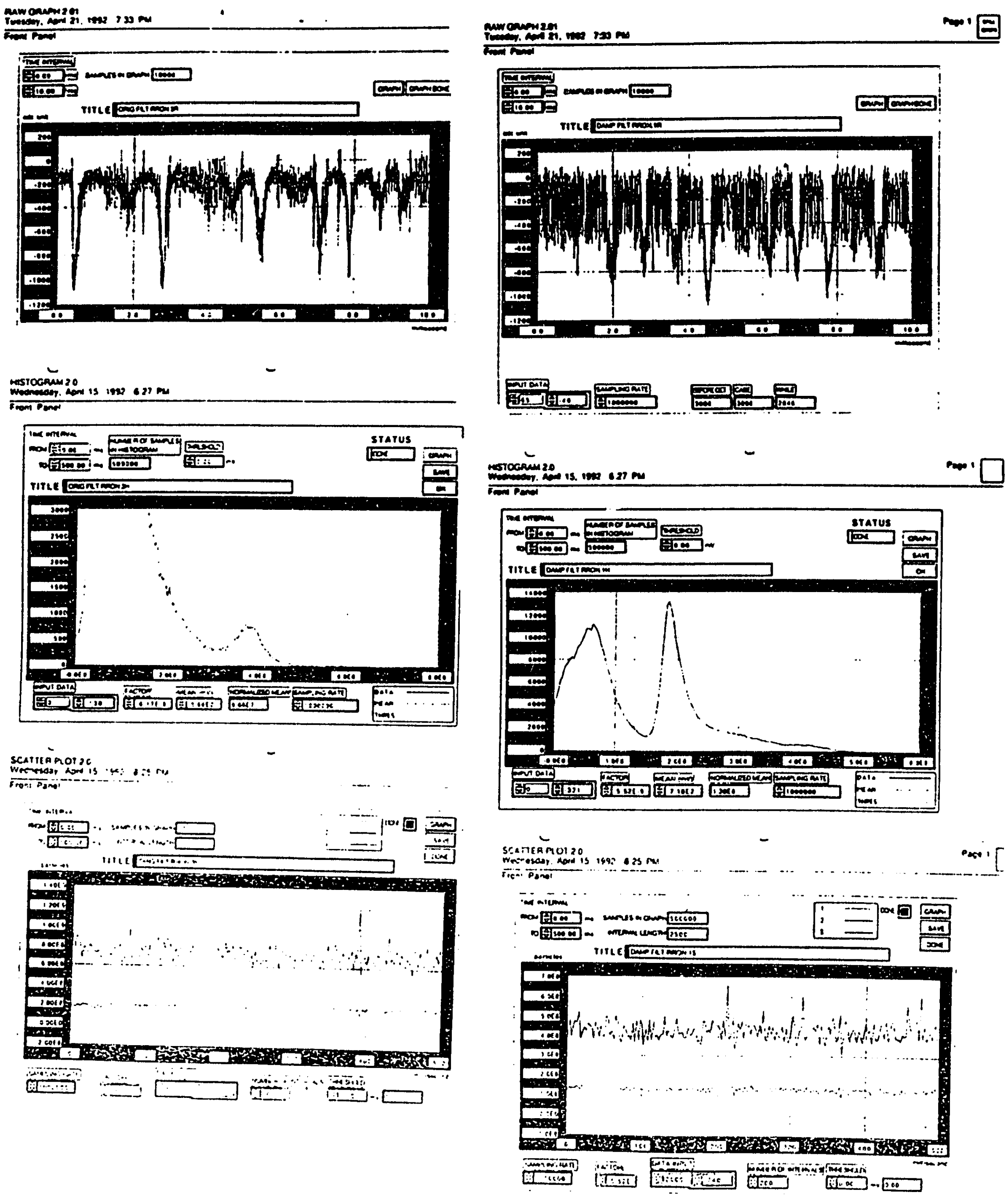
±1 MAG (COLD)
MIN DAMPING
M. Bennett

REASSEMBLED FILTERPIT
MINIMUM DAMP'D

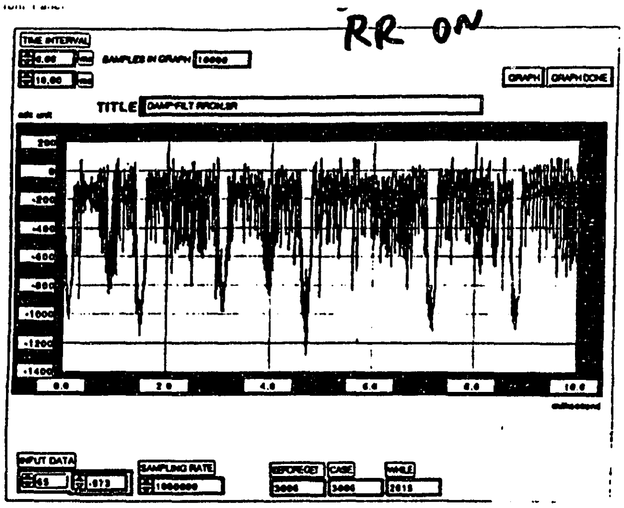


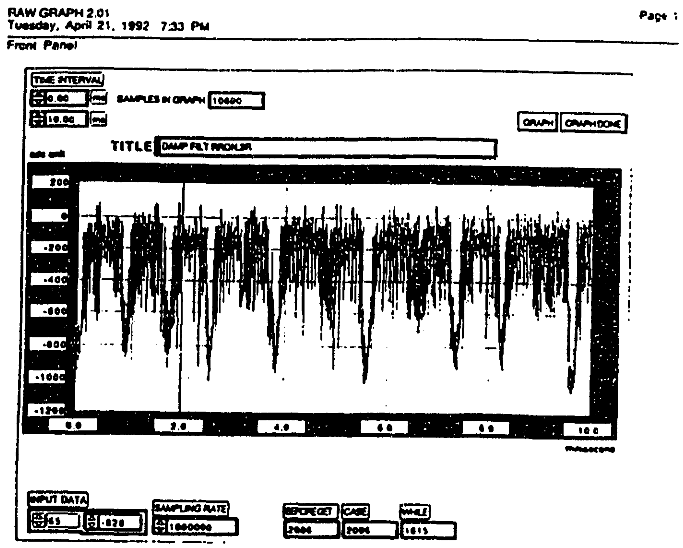
SYSTEM MEASURING RESULTS WITH ORIGINAL FILTERS AND WITH DAMPED FILTERS. DATA WAS TAKEN WITH TEK 2630

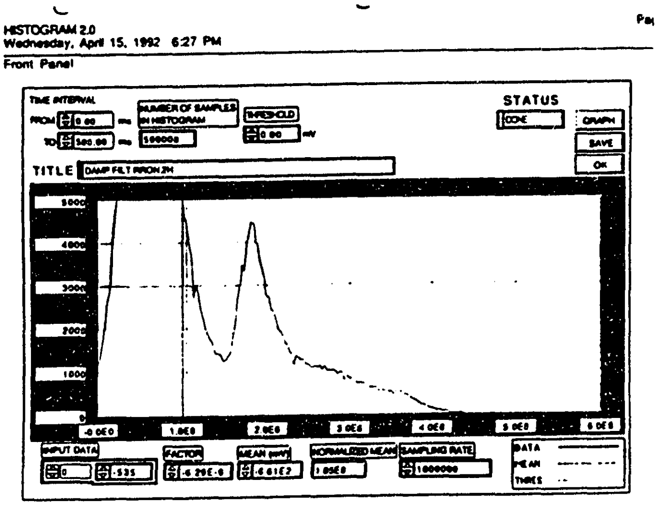
Another set of 3 damped filters configurations was prepared and SPICE simulated. The new damping resistor values were defined according to the experience with the first set of configurations. Refer to pages 194 to 198 in logbook. This set of configurations was not tested still in a hot machine and while spilling particles (histograms).

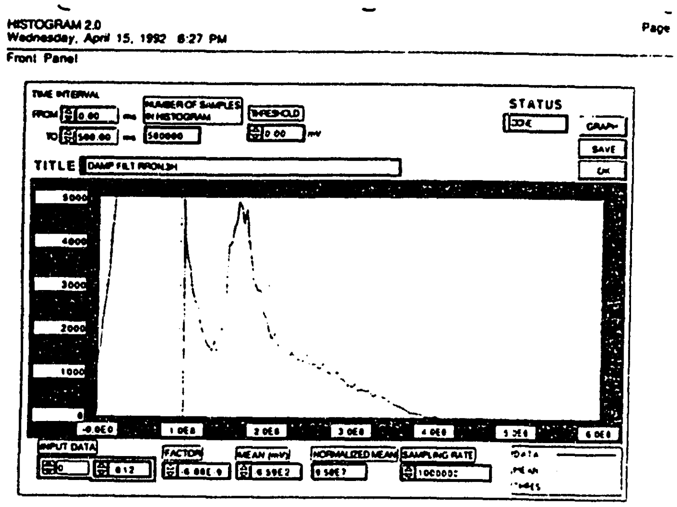


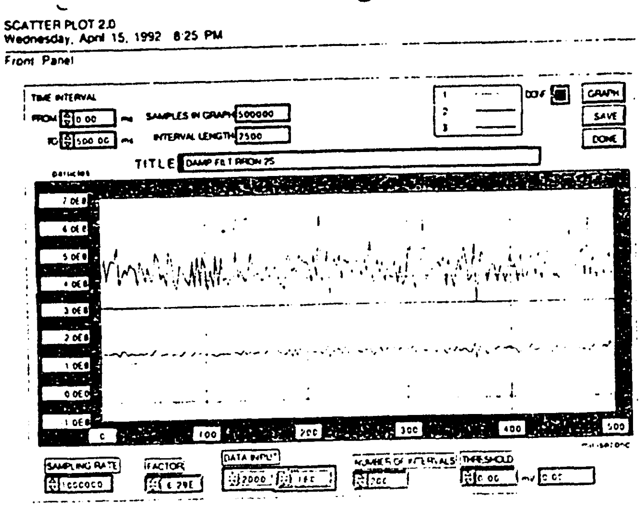

SPILL HISTOGRAMS IN AN ORIGINAL AND DAMPED SYSTEM

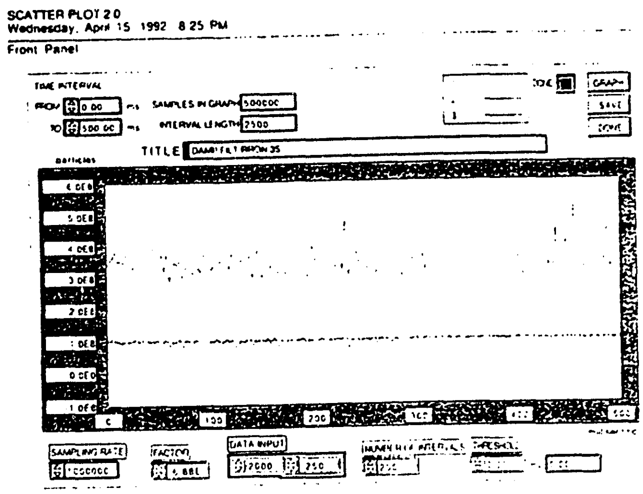


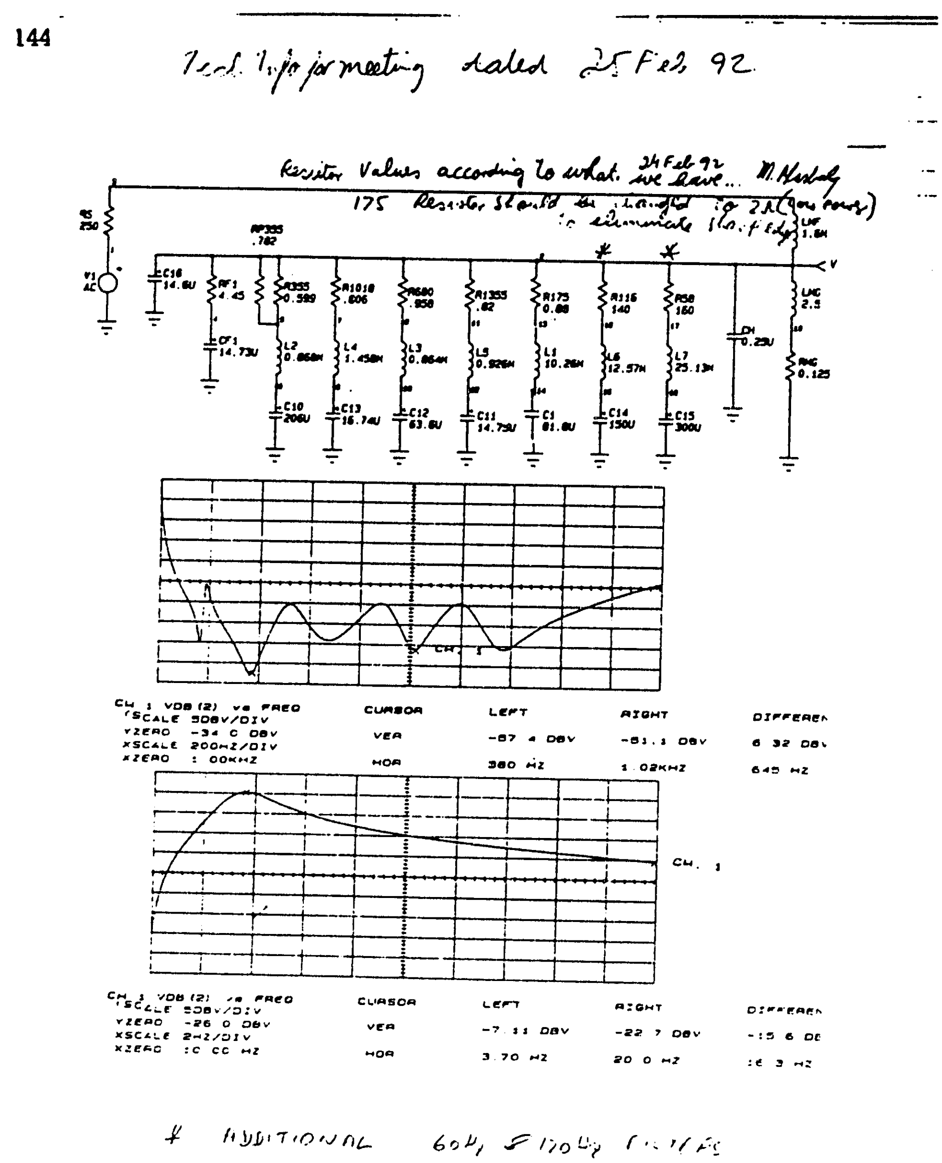




SPILL HISTOGRAMS IN A DAMPED FILTER SYSTEM

# 8. Conclusions and Recommendations for the Future

## 8.1 5Hz Problem

One of the major problems is the 5Hz ripple. This ripple can be reduced perhaps by adding 60 and 120Hz ripple damping filters. These filters, according to spice simulations will damped the 5Hz bump by approximately 7dB (refer to page 144 in the logbook).



## 8.2 175 Sharp Transient Response

This problem can be "treated" by damping the filters. Suggested is to find the filter where value changes of serial damping resistors are the most essential without "paying too much" in attenuation of the spuriouses (motor generator harmonics magnitude).

## 8.3 Mutual Induction

Since a new construction in the pit took place, the mutual inductance is reduced to minimum. Spurious measurements should be taken in the 0 - 2Khz band and comparing these results to the old filter pit configuration (before May 92).

A spill histogram should also be taken comparing to undamped spill histograms in the past.

## 8.4 Damping Filter

Suggested is to take data of spills (histograms) for the new damping filters set configuration. (ref. #7.3)

## 8.5 Ripple Reduction System

Suggested is to analyze by simulation the RR system in the 0 to 10KHz frequency band, concentrating at the 5Hz region. This, in the original configuration and the damped configuration.

# END

DATE
FILMED
11/12/92