New Folder Name Prototype Data Book

LIGO-T900033-00-D

LIGO 40m PROTOTYPE SERVO SYSTEM DATA BOOK

M. E. ZUCKER

5 DECEMBER 1990

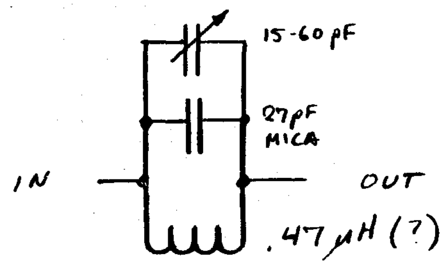
VERSION 1.0

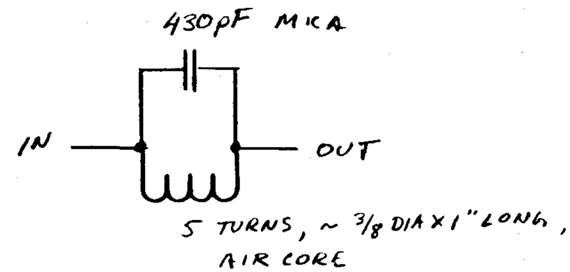
B. LASER LOOP: GENERAL

10/10/90 MEZ

LASER STABILIZATION LOOP

RF REJECTION FILTERS;





12.3 MHz REJECT

-35 dB peak atten

-3dB BW 7MHz - 16MHz

24.6 MHz REJECT

- 17dB peak atten

-3dB BW 23 MHz - 25MHz

TRANSFER FUNCTION OF BOTH IN SERIES
STORED ON HP4195A FLOPPY DISK
DISK LABEL "ZUCKER, START 10/10/90, DISK #1"
FILE NAME "LLNOTCHES1"

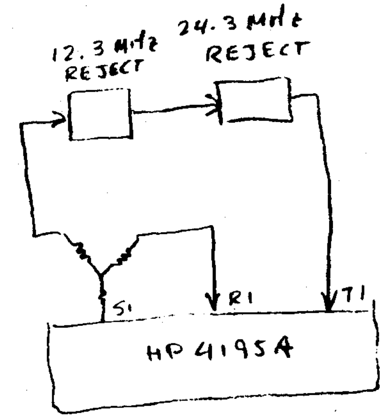
10/10/90 mez

NETWORK

A: REF B: REF 0 MKR 12 302 687.708 Hz
10.00 225.0 T/R -34.1216 dB
[dB][deg] θ 54.4350 deg

DIV DIV START 1 000 000.000 Hz
10.00 45.00 STOP 100 000 000.000 Hz
RBW: 1 KHz ST: 4.33 sec RANGE: R= 10, T= 10dBm

TRANSFER FUNCTION,
LASER SERVO LOOP
RF REJECTION
NOTCH FILTERS

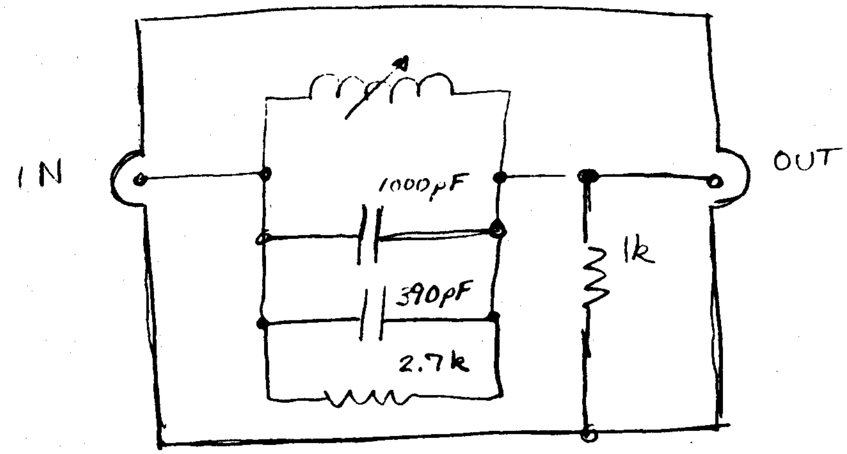


FILE "LLNOTCHES1"
DISK #1, 10/10/90, "ZUCKER"

B3

11/8/90
MEZ

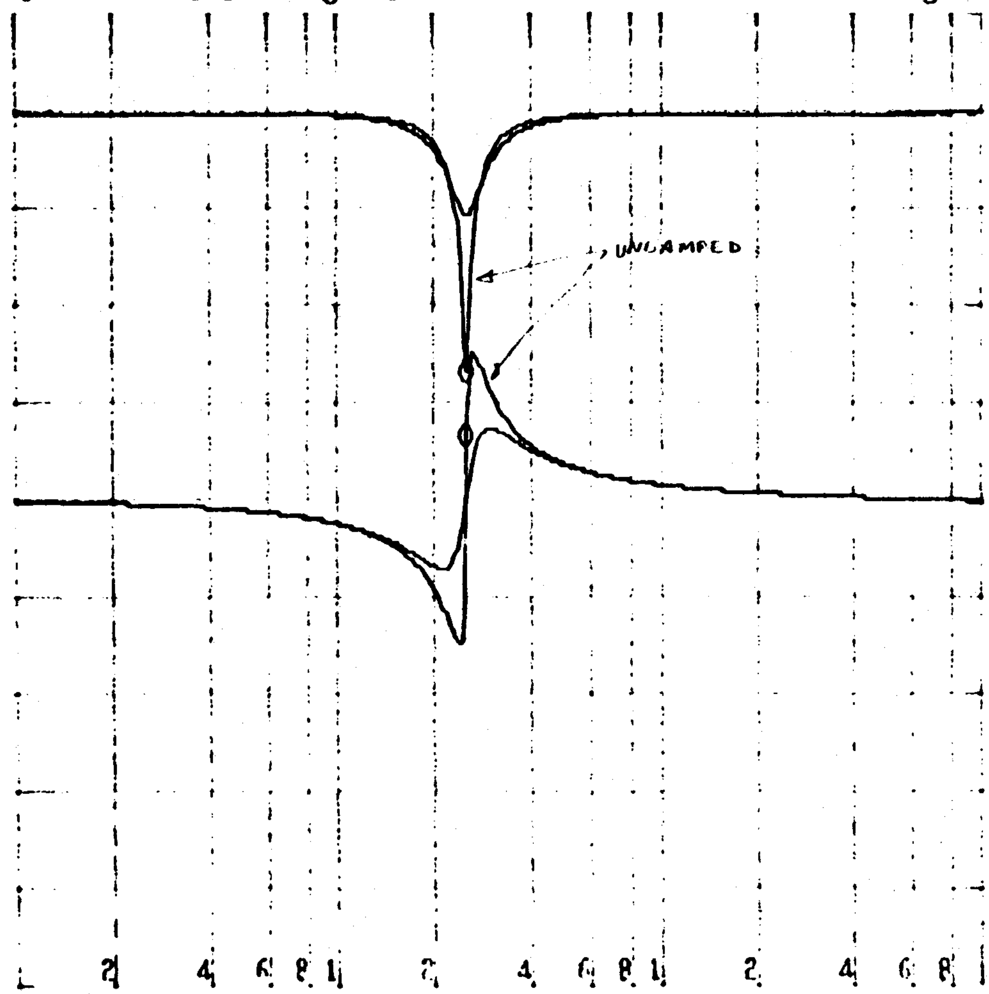
FAST PZT NOTCH FILTER



11/6/9

NETWORK Cor

A: REF B: REF 0 MKR 252 638.771 Hz
10.00 225.0 T/R -27.0474 dB
[dB][deg -] θ 28.8915 deg

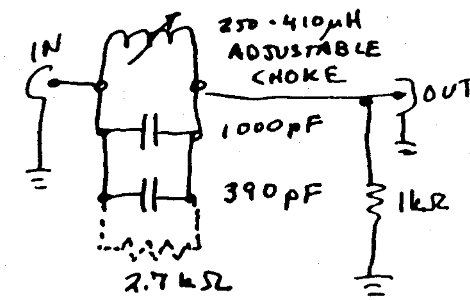


DIV DIV START 10 000.000 Hz
10.00 45.00 STOP 10 000 000.000 Hz
RBW: 300 Hz ST: 13.7 sec RANGE: R= 10, T= 0dBm
REF= 1.00000E+01

XF
FP2T NOTCH FILTER

RED, BLUE :
AS BEFORE,
NO DAMPING SHUNT

BLACK, PURPLE :
2.7kΩ DAMPING
SHUNT ACROSS LC

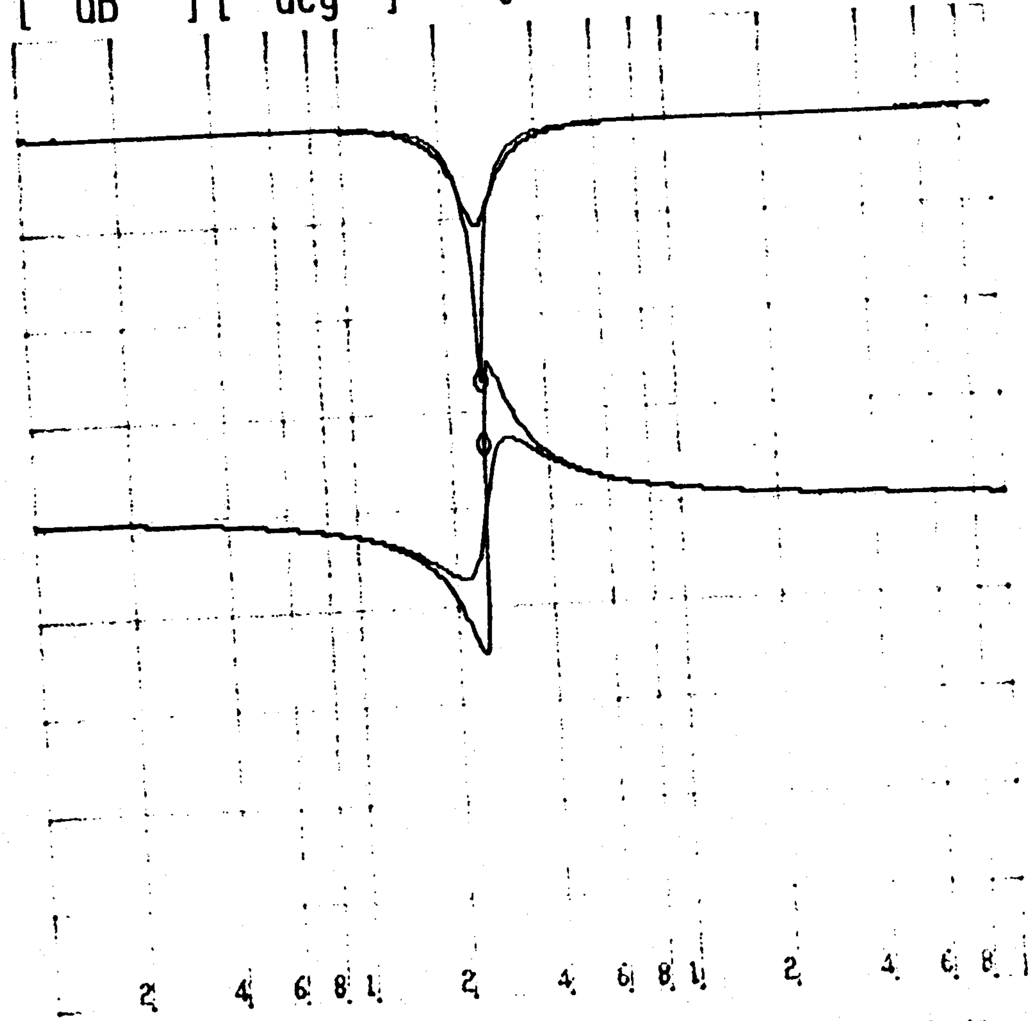


(TEST COND: DRIVEN BY
50Ω SOURCE
OF 4195A & SPLITTER)

B5

11/6/90 mej

NETWORK Cor
A: REF B: REF 0 MKR 252 638.771 Hz
10.00 225.0 T/R -27.0474 dB
[dB][deg] θ 28.8915 deg

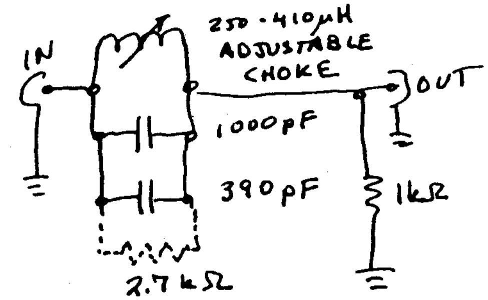


DIV DIV START 10 000.000 Hz
10.00 45.00 STOP 10 000 000.000 Hz
RBW: 300 Hz ST: 13.7 sec RANGE: R= 10, T= 0dBm

XF
FP3T NOTCH FILTER

RED, BLUE :
AS BEFORE,
NO DAMPING SHUNT

BLACK, PURPLE :
2.7kΩ DAMPING
SHUNT ACROSS LC



(TEST COND: DRIVEN BY
50Ω SOURCE
OF 4195A + SPLITTER)

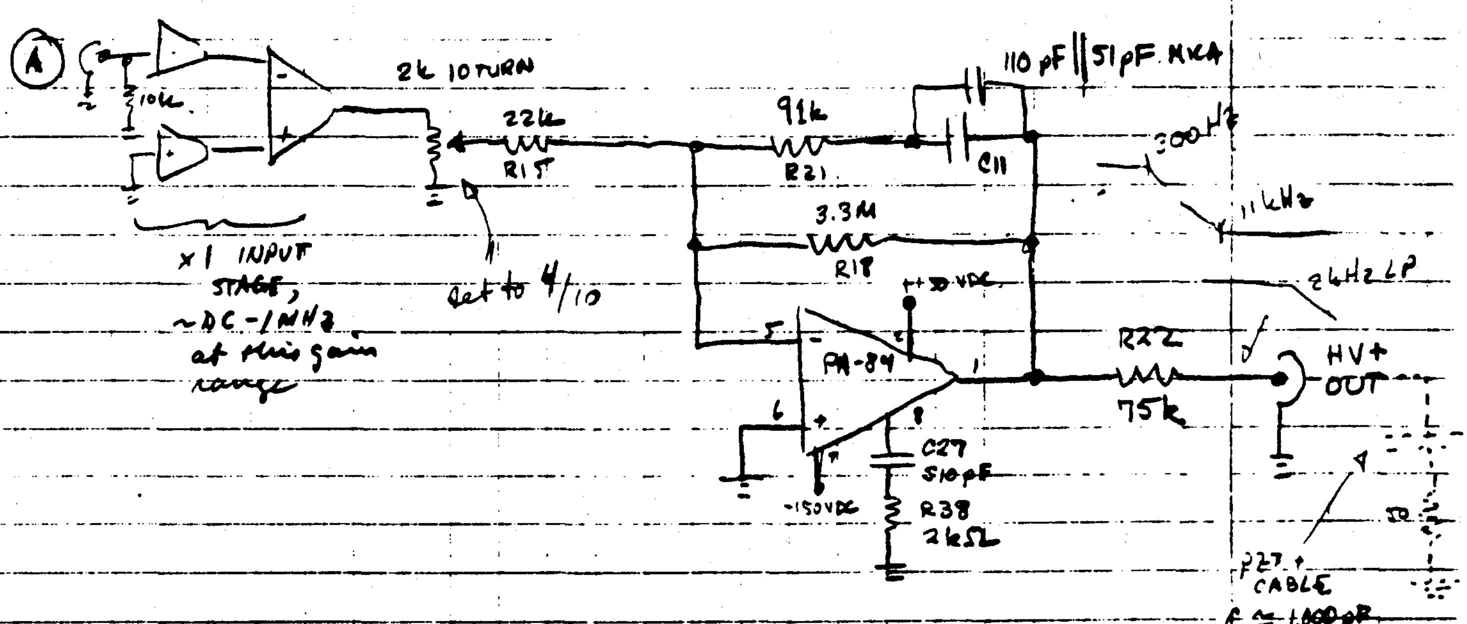
HV # III (PARTIAL SCHEMATIC)

10/25/89

Temporarily setting aside the mystery of the loop gain measurement discrepancy, decided to work on improving laser stabilization loop some more.

JH and BT improved on loop gain by improving the PZT drive amplifier. Previously HV #1 had been used, range x1, vernier + 2/10, ⇒ D.C. Gain = 6 dB effective single pole (due to $Z_{out} = 160\,k\Omega$ / $Z_{PZT} \approx 800\,pF$) @ 1 kHz, extra phase shift at 100 kHz of about 20° due to strays in amplifier circuit (5 pF ∥ 330k ⇒ 100 kHz due to strays across FB loop!)

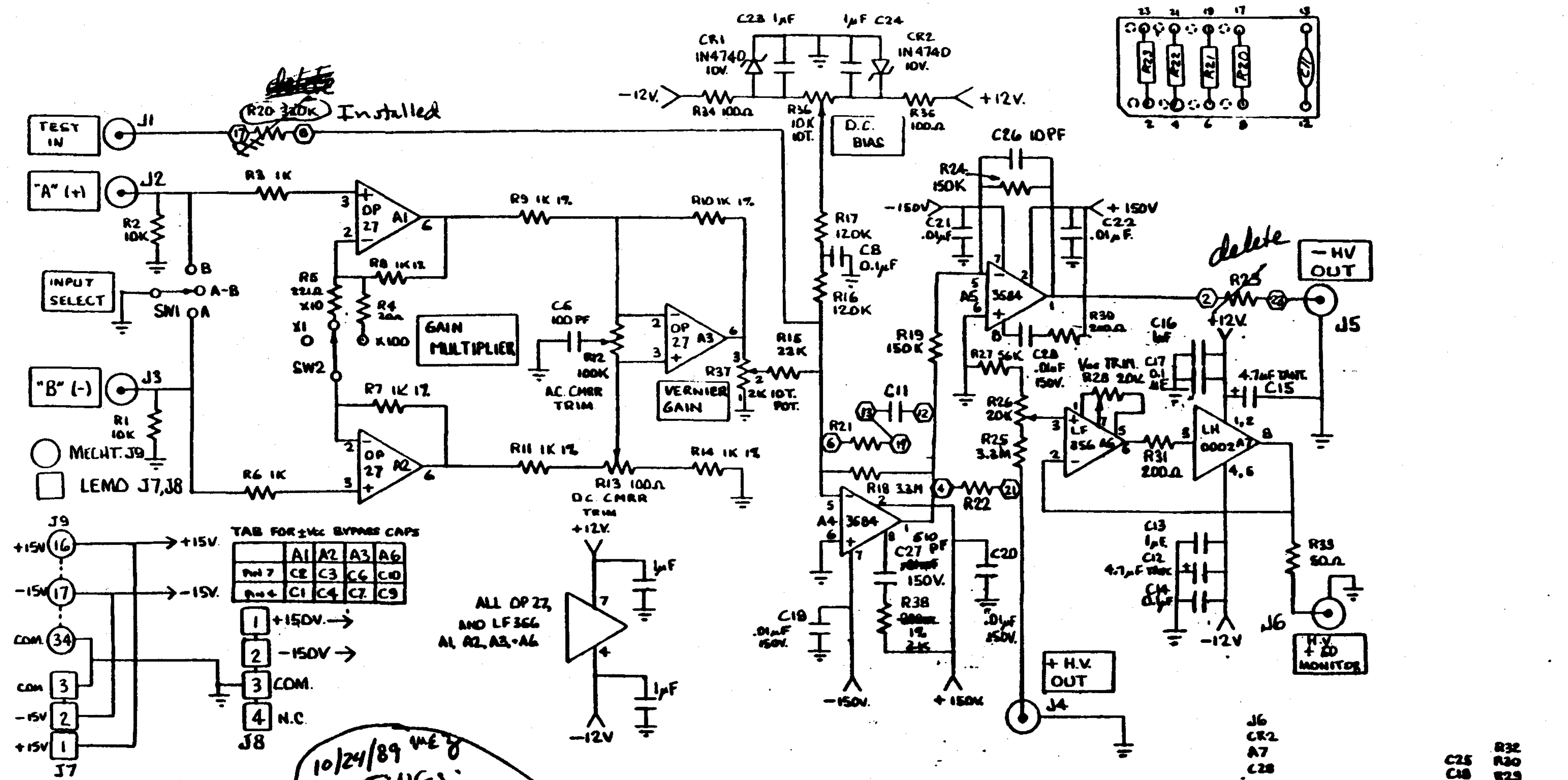
Installed improved circuit (abbreviated diagram below, complete diagram + xfer-function to follow)



HV # III
AS CONFIGURED 10/24/89 FOR SUCCESSFUL LOCKING IN LASER STABILIZATION SERVO LOOP

NB ÷50 mon. still drives line driver + "Vector" HV amp exactly as before.

HV # III INSTALLED 10/24/89 TO DRIVE FAST PZT MIRROR IN LASER LOOP



10/24/89 me
SETTINGS;
INPUT → "A"
MULTIPLIER → x1
VERNIER → 4.0/10

NOTES 1. ⌐J¬ INDICATES JUMPER TO SHORT
2. J7, J8, and J9 ARE ALL MOUNTED ~~ON BACK PANEL~~

SMARTWRK FILE C:\SMARTWRK HVAMP.PCB
DRAWN FROM E. LINDELEF OF 9-1-87 PROHVAMP.PL
ADDED COMP CARRIED PIN NO's TO DWG

REPLACES 87-0901-1

LAST: J6, CR2, A7, C28, R39

NO'S SKIPPED: C25, C18, R32, R30, R29

CALIFORNIA INSTITUTE OF TECHNOLOGY GRAVITATIONAL PHYSICS		
HV AMPLIFIER ± 150V.		
DRAWN BY B.TINKER	DATE 3-4-88	DRAWING NO.
CHECKED BY	SCALE	
APPROVED BY	W.O.	

88-0304-1

R20 = 330K
C11 = ~~5~~ pF → 150 pF 10/24/89 me
R21 = 91K
R22 = 75K
~~R20~~ } not used
R23 }

MODIFIED 10-2~~0~~-89 B.T.

	WAS	IS
C27	.01μF	510pF
R38	200Ω	2K 1%

MOD. 1 S/N. 3

BB

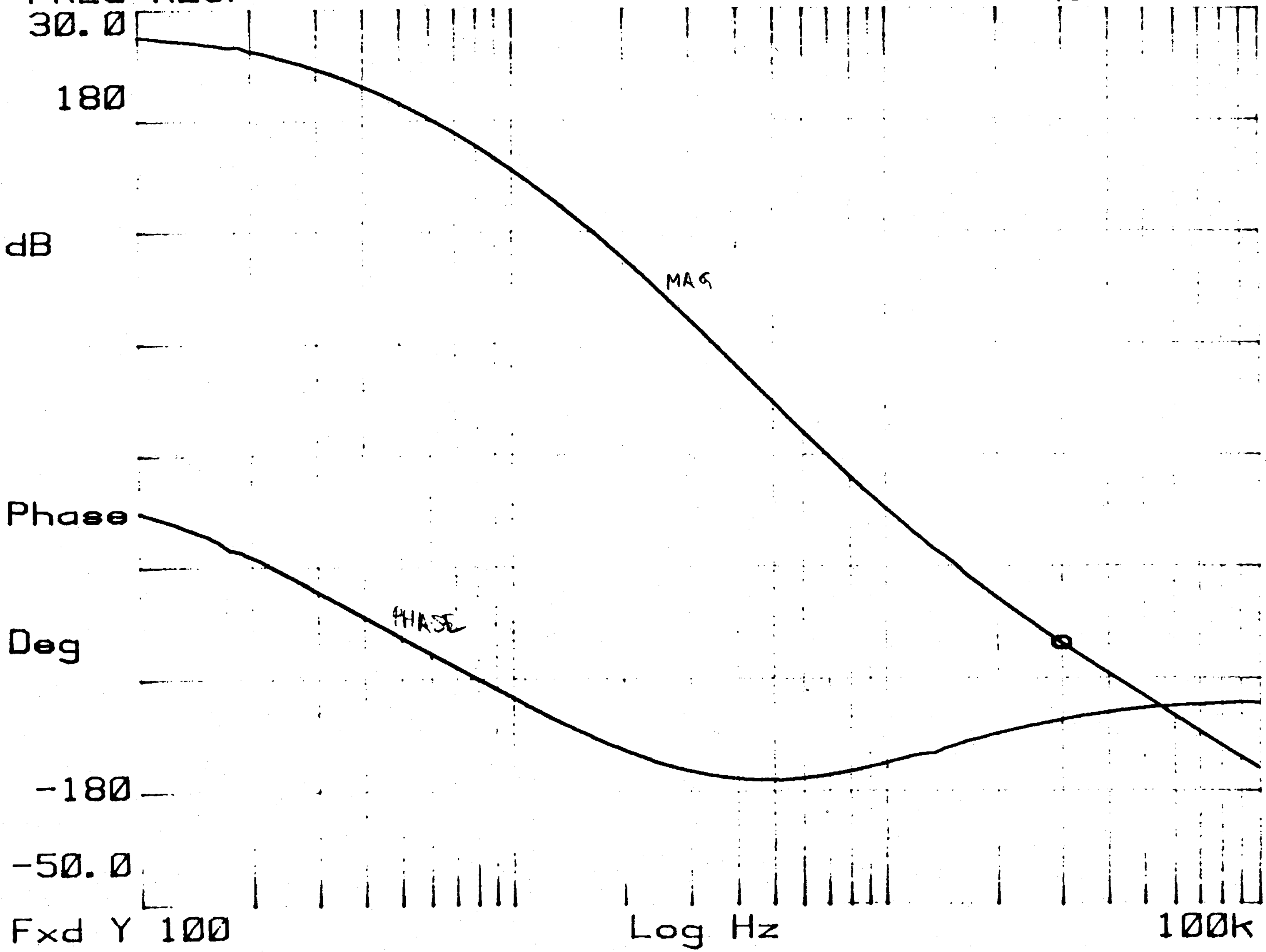
X=29.854kHz
Ya: 6.758 dB

FREQ RESP

(3) 10/24/89 15:41

Modified Freq. Response
of HV #III
Increased C_{FB} to 150pF in PA-84 Ckt.

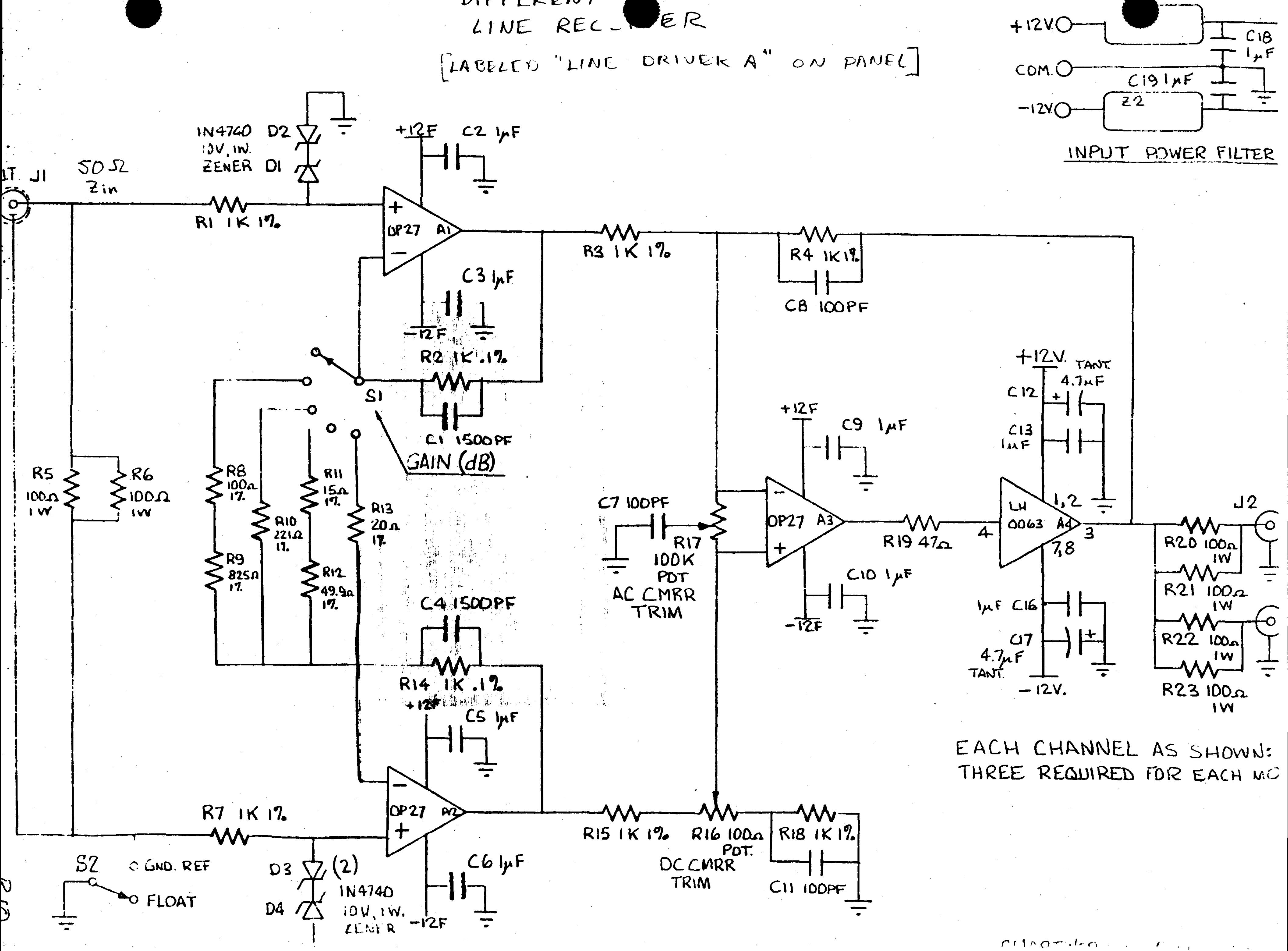
FREQ RESP



89

DIFFERENT[redacted]
LINE REC[redacted]ER

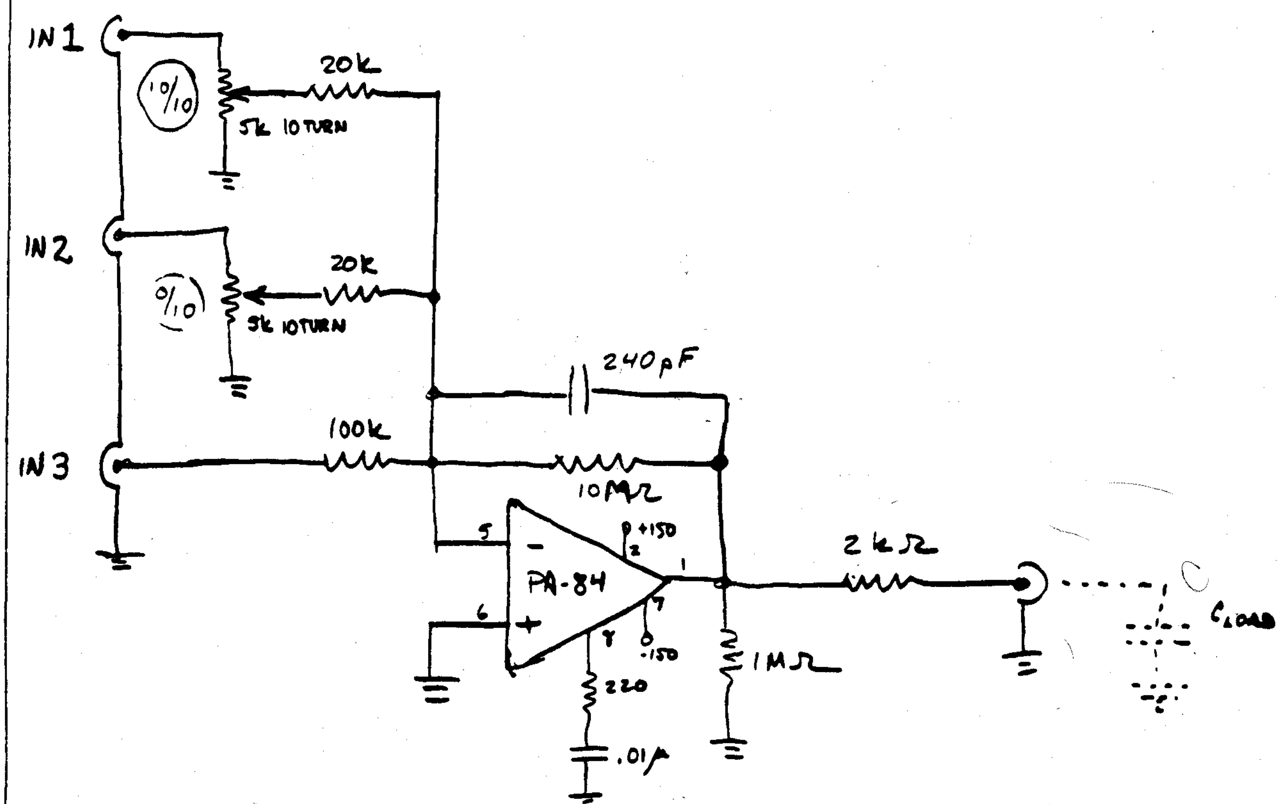
[LABELED "LINE DRIVER A" ON PANEL]

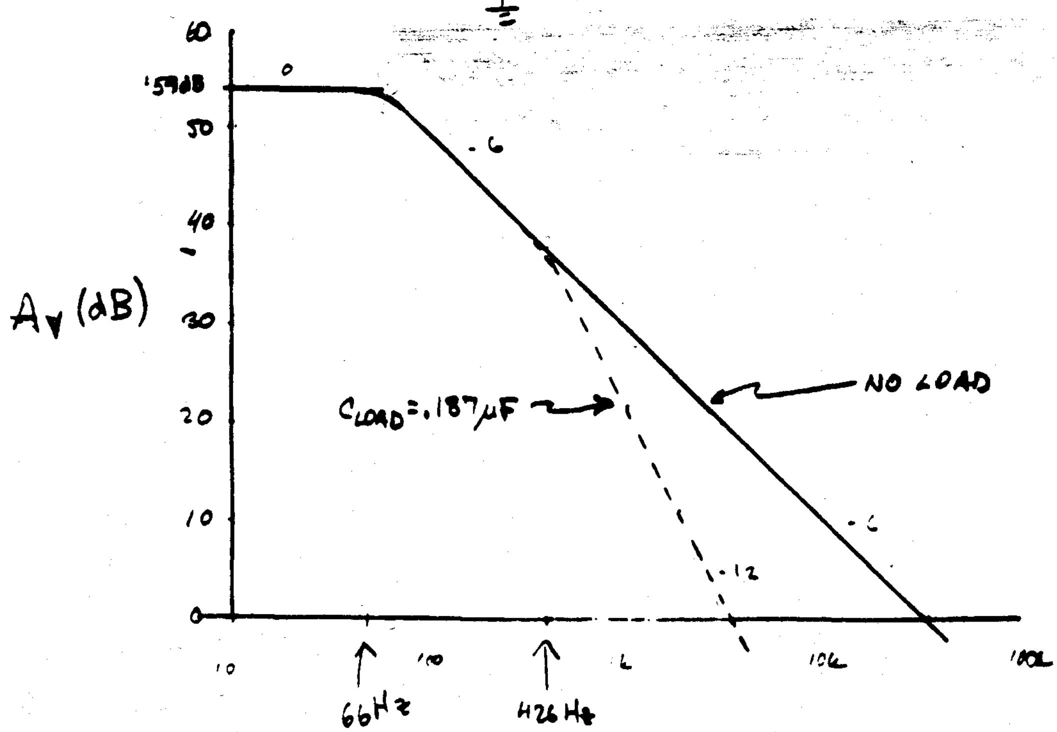


EACH CHANNEL AS SHOWN:
THREE REQUIRED FOR EACH MC

11/15/88 MEZ

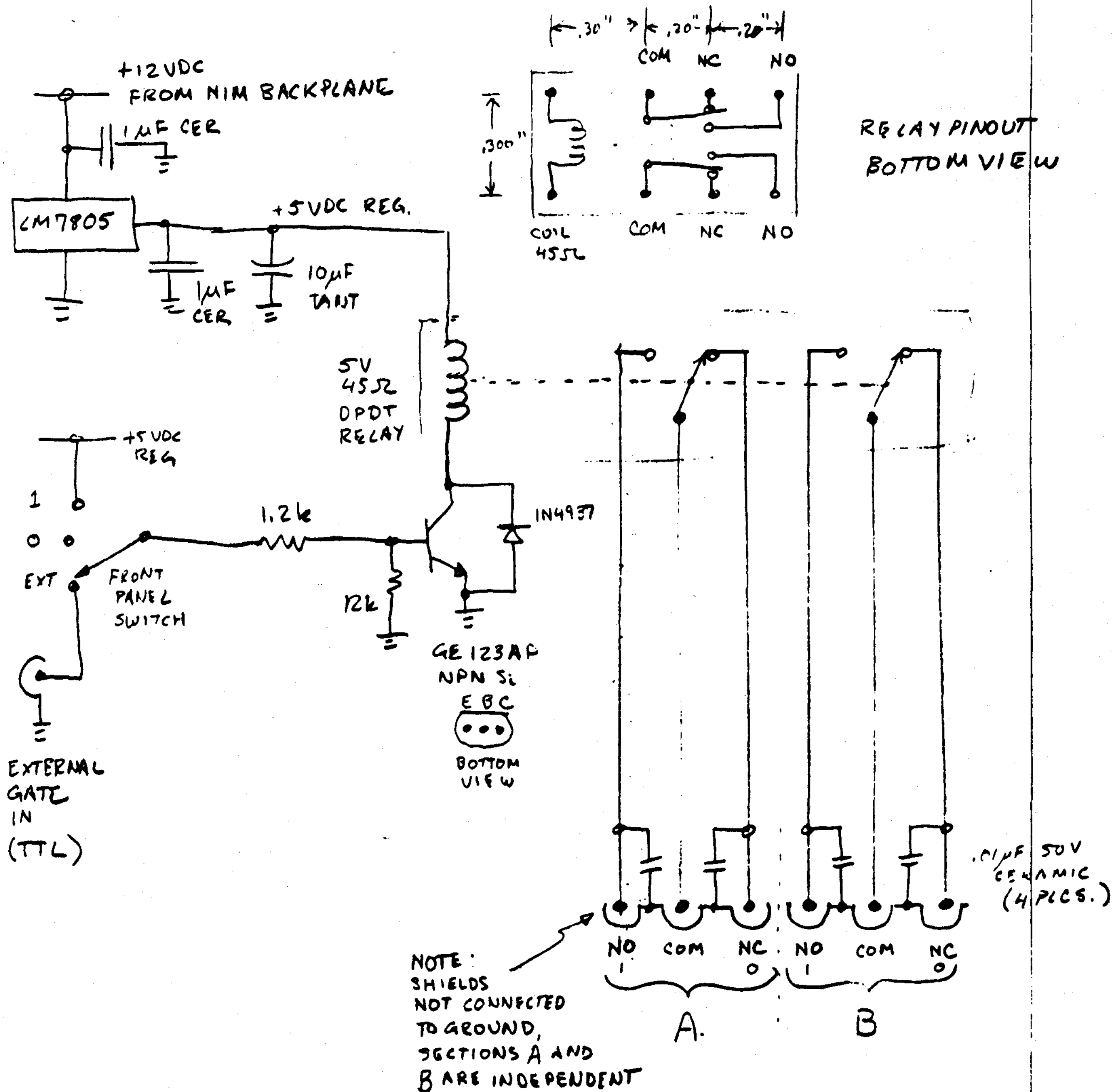
MODE CLEANER SERVO LOOP "VICTOR H.V. AMP"



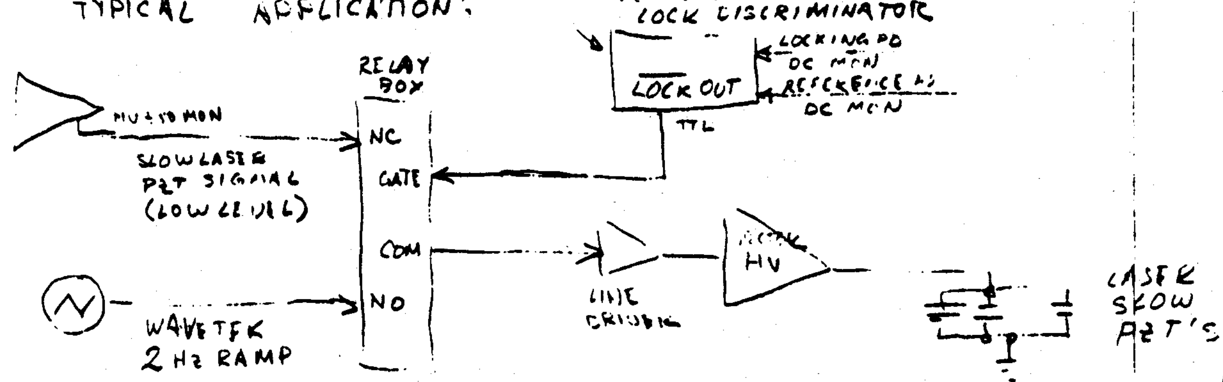


10/31/81 MEG

DPDT RELAY FOR AUTOMATIC LASER RE-LOCK



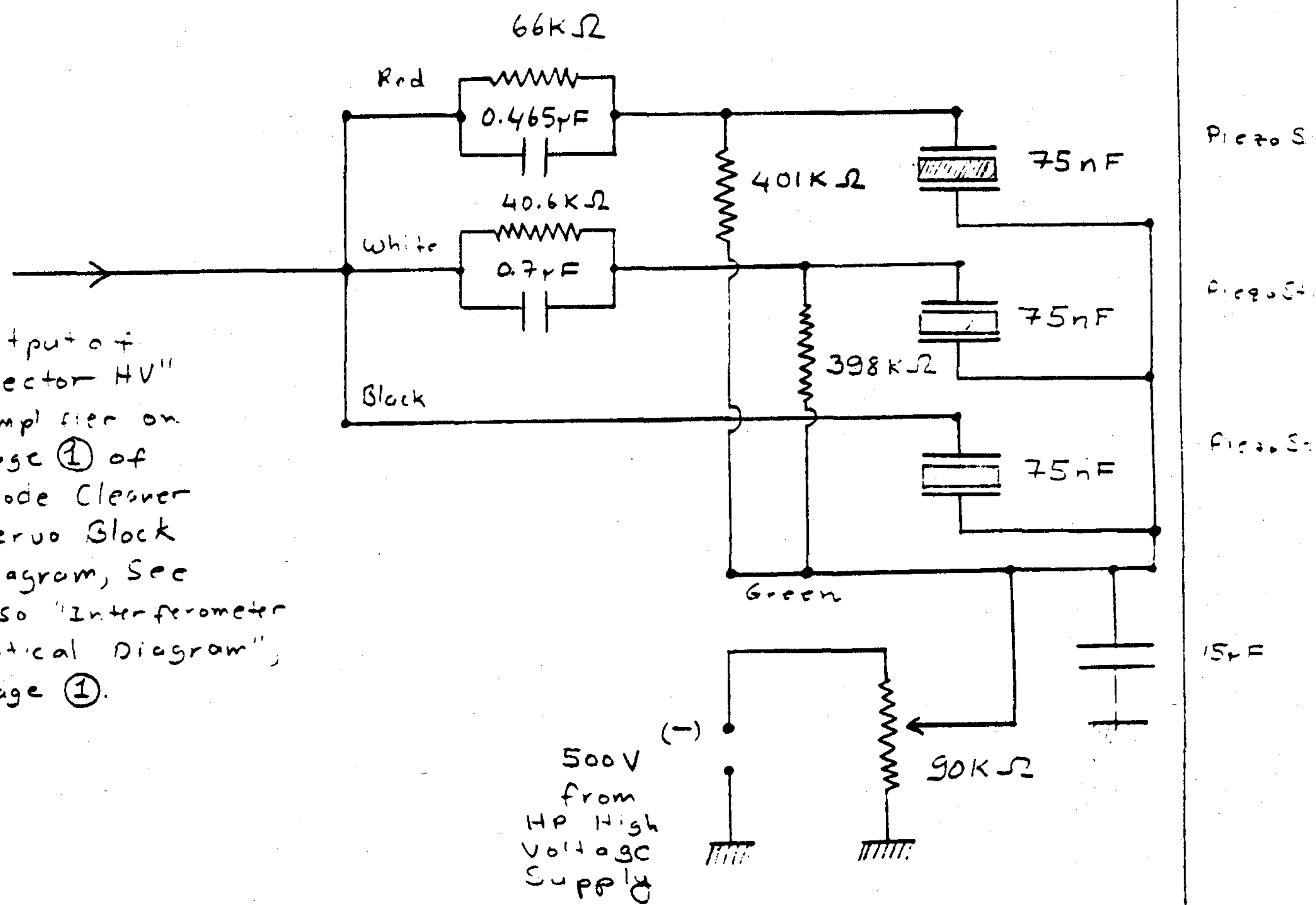
"TYPICAL" APPLICATION:



B12

3 Piezo Stack Balancing Network

(For the Laser "BARNEY")



Output of "Vector HV" Amplifier on page ① of Mode Cleaner Servo Block Diagram, See also "Interferometer Optical Diagram", page ①.

'Also on page ① of "mode cleaner servo Block Diagram".

Page ① of ①
July 25, '89 YG

C. LASER LOOP: SENSORS AND ACTUATORS

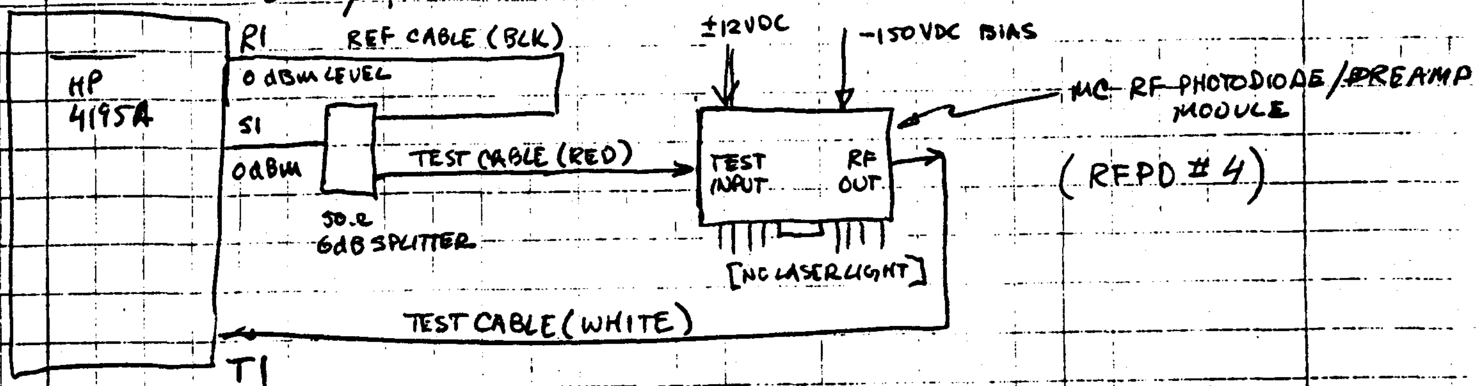
SENSITIVITY OF RF DETECTION SYSTEM + "OPTICAL GAIN"

8/4/89 M.E. Zucker 18:20

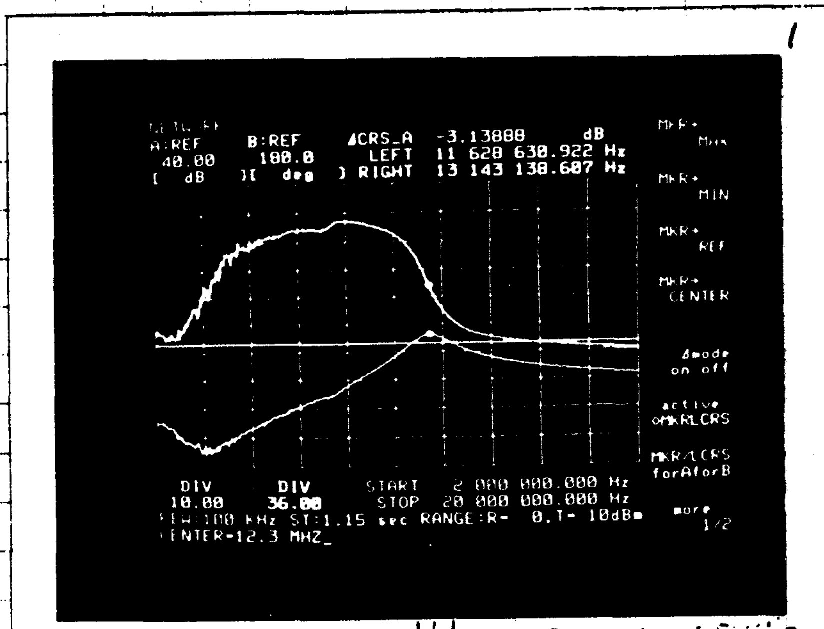
Recording measurements of optical and electronic transfer functions of various key elements of the estalater-pockels cell laser stabilization loop. (A.K.A. "Mode Cleaner Servo")

① Measured response of mode cleaner RF photodiode / preamp module at RF frequency using HP 4195A network analyzer

Setup:



8/9/89 10:15



UPPER TRACE: $ARG(T_1/R_1)$, DEG

LOWER TRACE: $|T_1/R_1|$, dB

← 3dB WIDTH ≅ 1.5 MHz

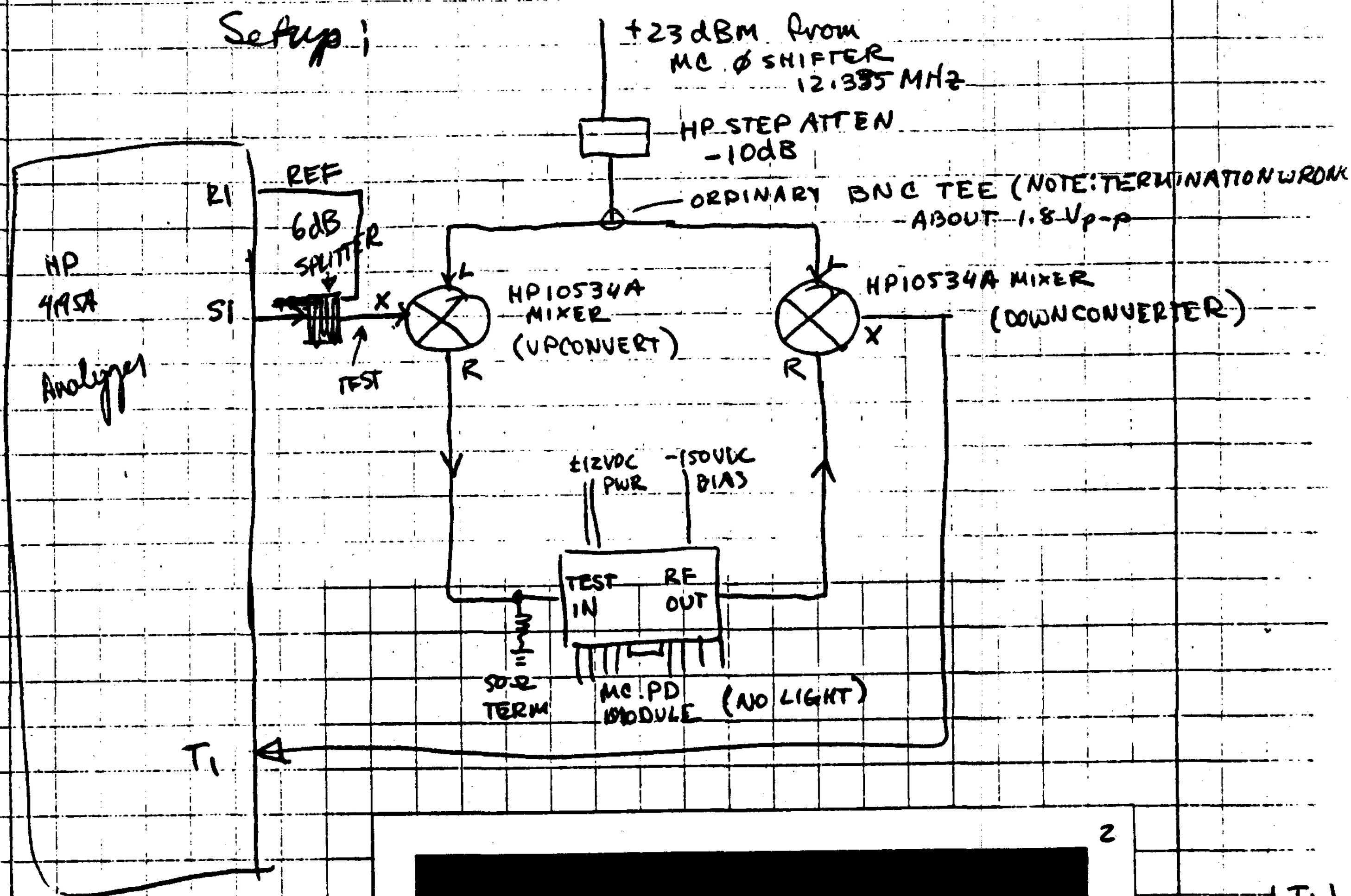
LINEAR FREQUENCY SCALE, 2 MHz → 20 MHz

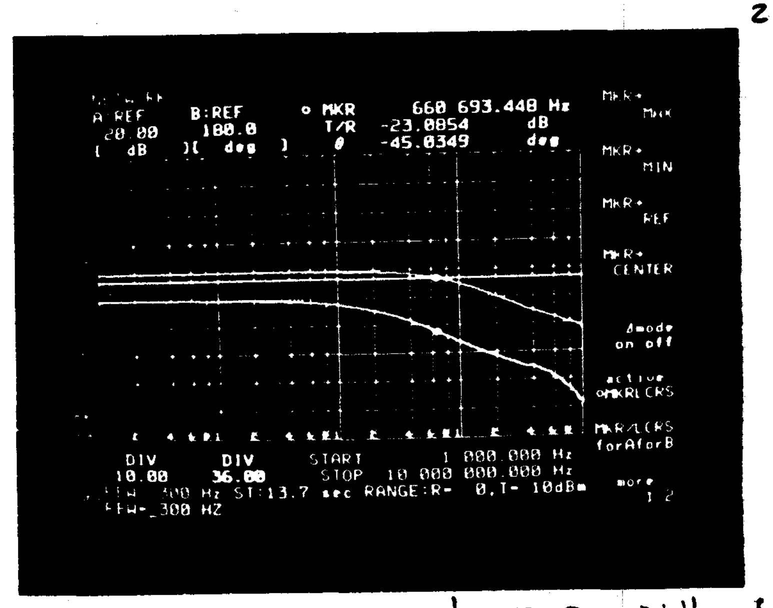
NOTE THAT PHASE IS + 40° AT CENTER FREQUENC

8/4/89 Cont'd. MEZ

② Measured "equivalent baseband response" of RF photodiode unit by upconverting the network analyzer's sweep to 12.33 MHz (amplitude modulation, suppressed carrier, just like an optical phase error producer).

Setup:





TOP: $\left|\frac{T_1}{R_1}\right|$

BELOW: ARG(

-3dB @ 660 kHz

↑ EFFECTIVE POLE DUE TO PHOTODIODE BANDPASS

8/8/89 Analysis of "Optical transfer function" measurements;

(MEZ) Transfer function on page 004 must be corrected for
ⓐ mis-termination of mixer
ⓑ delay in long cable used to excite PC
ⓒ the bandpass transfer function of the photodiode.
ⓓ the propagation delay in the light path and in the RF cable from the photodiode to the mixer.

The results of this analysis (which is attached to subsequent pages for future reference) are summarized as follows;

With; photodiode now in use on MC (700 kHz "pole" due to bandpass)
950 mV out of lock, 400 mVDC in lock (contrast = 58%)
modulation index ≃ 0.4 $\left(\frac{P_{SIDEBAND}}{P_{CARRIER}} \simeq 0.04\right)$

we get;
$$\frac{\delta V(\text{mixer output, } 50\Omega \text{ term})}{\delta V(\text{ONE GSÄNGER PM-25 POCKELS CELL})} \simeq 5\times10^{-3}\frac{V}{V} \times \left(\frac{1}{1+\frac{jf}{700\,kHz}}\right)$$

Also, from the pockels cell terminals to the mixer output there is a frequency-dependent phase shift which is consistent with a propagation delay of (40 ± 10) nsec; the optical path between pockels cell → cavity → photodiode is about 6.5 m (⇒ 22 nsec), and the cable linking the PD w/ the mixer is 2.3 m (⇒ 11 nsec at 0.7c) for a calculated delay of 33 nsec. There are probably also delays associated with the diode proper, the internal buffer, or the pockels cell itself, but these should not contribute more than 5 nsec total in my estimation.

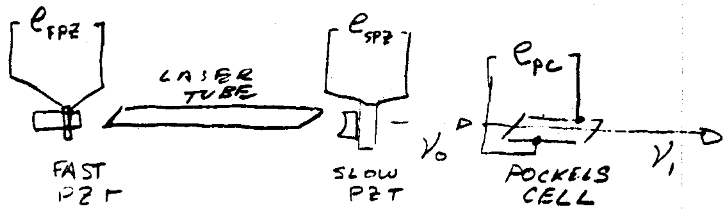
LASER PHASE & FREQUENCY ADJUSTMENT ACTUATORS

MEZ 10/17/90

ν = laser frequency $\simeq 5.8 \times 10^{14}$ Hz or so

ϕ = laser phase

f = audio or video fluctuation frequency



1. Pockels cell;

$$\dot{\phi}_0 = 2\pi\nu_0, \quad \phi_1 = 2\pi\nu_0 t + \frac{2\pi n_{pc} l_{pc}}{\lambda}$$

where l_{pc} = length of Pockels cell, and
n_{pc} = refractive index of cell;

$n_{pc} = n_0 + \alpha e_{pc}$

where α = electrooptic coefficient of cell crystal (V^{-1})

so $\nu_1 = \dot{\phi}_1/2\pi = \nu_0 + \frac{\alpha l}{\lambda}\dot{e}_{pc}$

Example: Gsänger PM-25 cell, at $\lambda = 514.5$ nm,
has $\alpha l = 0.26$ nm/V*, so for a sinusoidal e_{pc} at frequency f,

$e_{pc} = V_0 \cos(2\pi f t)$, we get an output frequency

$$\nu_1(t) = \nu_0 - \frac{2\pi\alpha l f}{\lambda} e_0 \sin(2\pi f t)$$

$$= \nu_0 - 3.2 \times 10^{-3}\left(\frac{e_0}{1V}\right)\left(\frac{f}{1 Hz}\right)\sin(2\pi f t) \text{ Hz}$$

*corresponding to 1 kV/order at this λ.

10/17/90 MEZ

2. Fast PZT mirror;

as long as the laser oscillates in a single longitudinal mode labeled k

$$\nu^k = k\frac{c}{2d}$$

where k is a (large) integer and d is the spacing of the laser cavity (assume $n_{laser} = 1$). The piezo expands or contracts in proportion to e_{FPZ}, so

$d = d_0 + \beta e_{FPZ}$ and

$$\nu^k = \frac{kc}{2(d_0+\beta e_{FPZ})} \simeq \frac{kc}{2d_0}\left(1 - \frac{\beta e_{FPZ}}{d_0}\right)$$

$$\equiv \nu_0^k\left(1 - \frac{\beta e_{FPZ}}{d_0}\right) \text{ for } \beta e_{FPZ} \ll d_0$$

Example; the laser Earnoy has

$d_0 \simeq 2.3$ m and its fast PZT has

$$\beta \simeq \frac{1 \text{ order}}{550 V} \simeq 4.7 \times 10^{-10} \frac{m}{V} \text{ so}$$

$$\frac{\nu^k - \nu_0^k}{e_{FPZ}} \simeq \frac{\beta \nu_0^k}{d_0} = 120 \frac{kHz}{V}$$

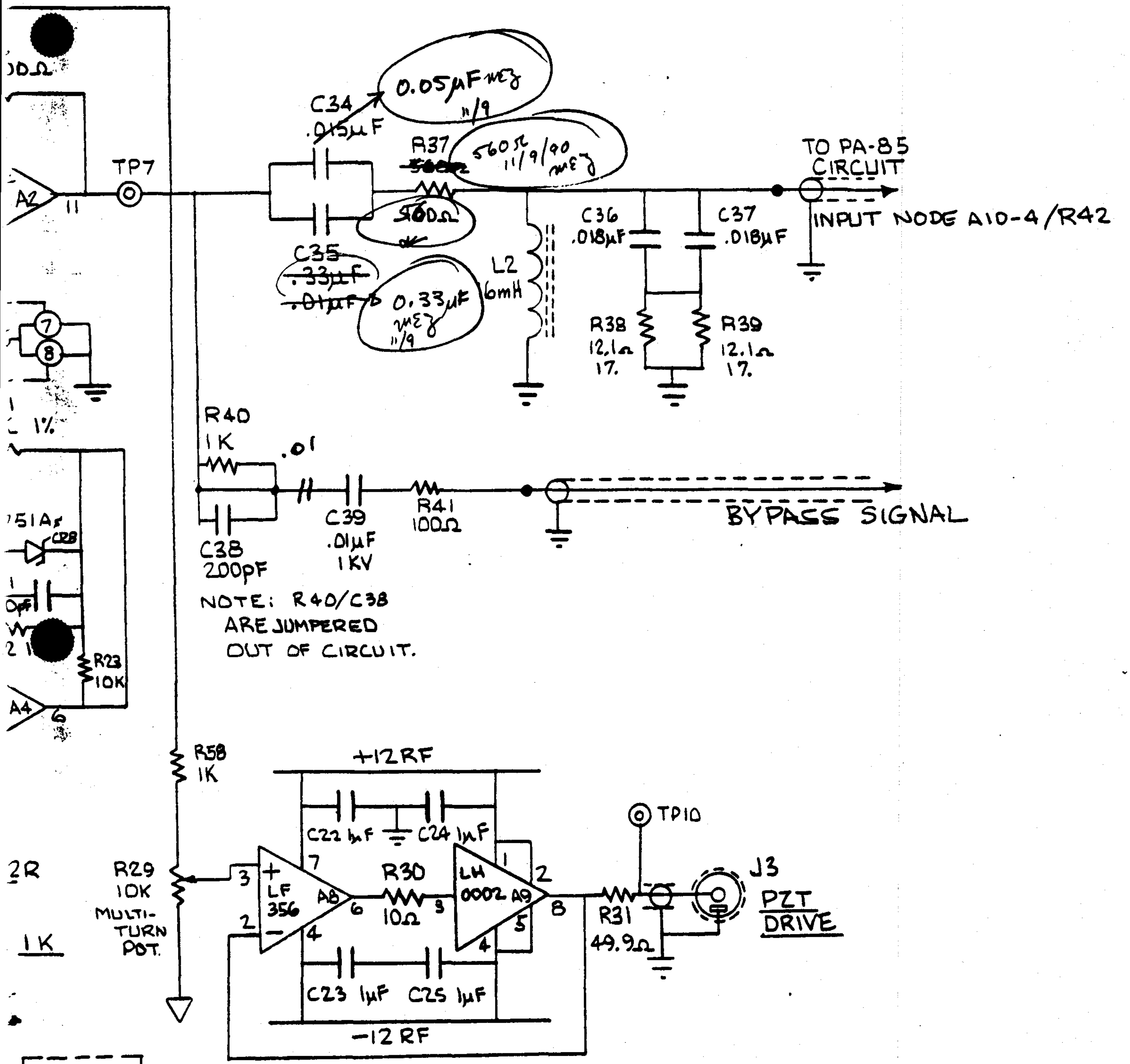
3. Slow PZT mirror; same as fast PZT, different β.

Example; for Earnoy, $d_0 \simeq 2.3$ m,

$$\beta \simeq \frac{1 \text{ order}}{70 V} \Rightarrow$$

$$\frac{\nu^k - \nu_0^k}{e_{SPZ}} \simeq 930 \text{ kHz/V}.$$

D. LASER LOOP: PROTOTYPE #1



LASER LOOP AMPLIFIER VER. 1 PROTOTYPE I VER. 1

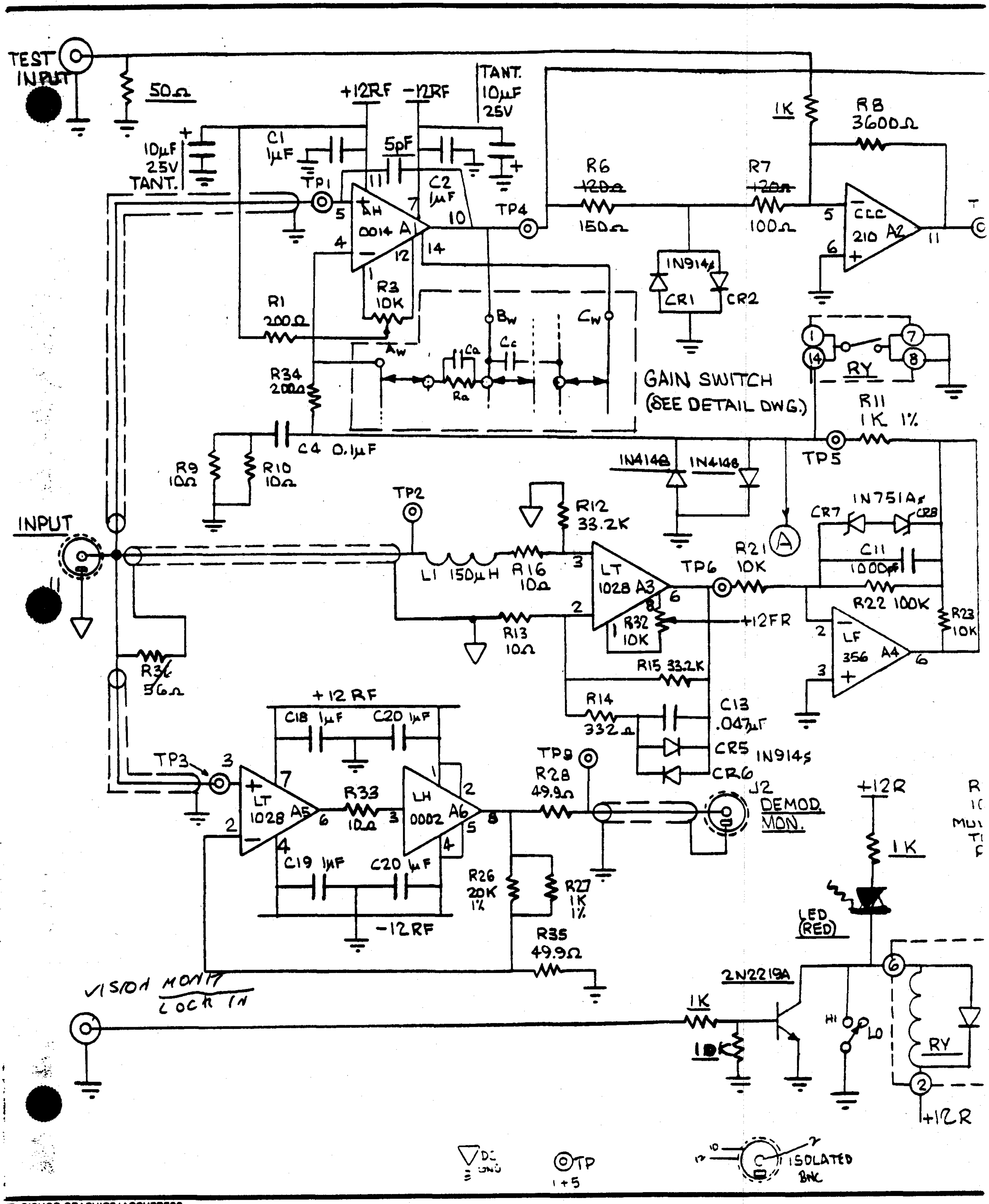
ADDED = COMPONENTS

REBUILD 11-8-90
B.T.
J.C.

Diagram Revised 11/9/90 MEZ

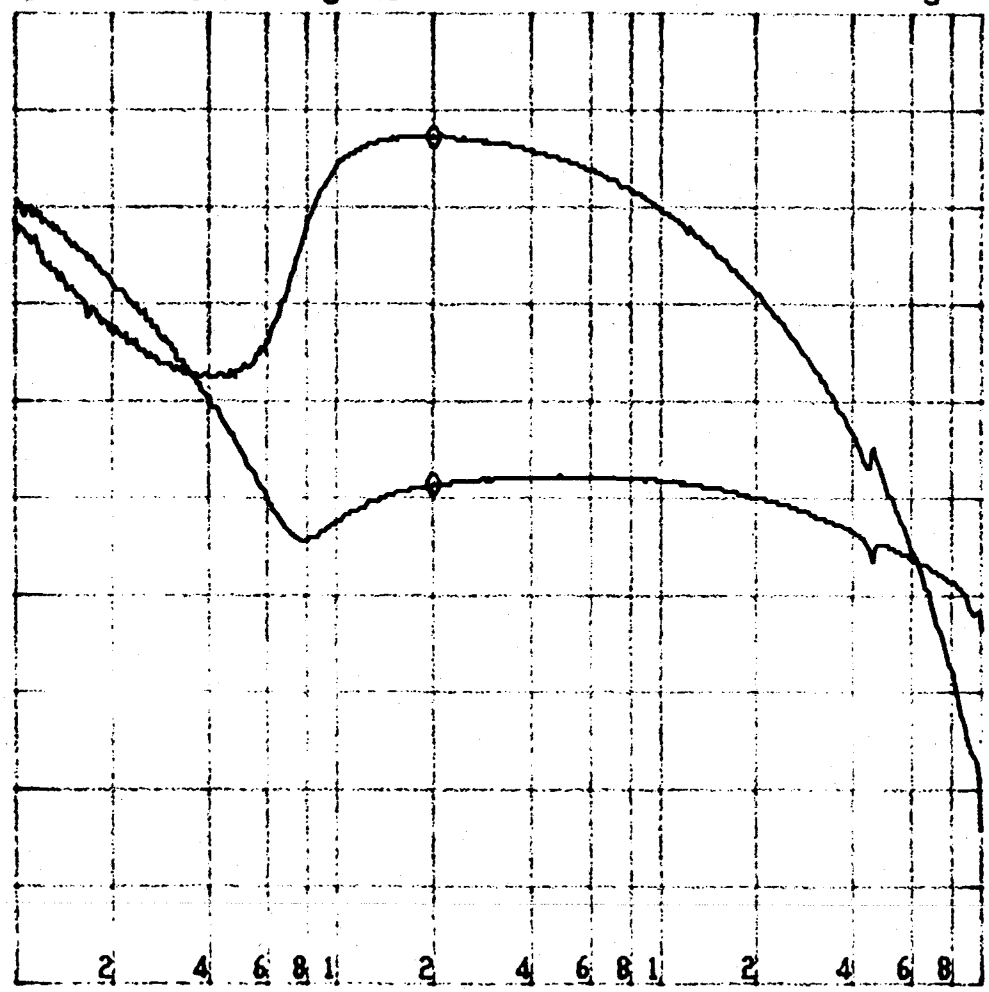
CALIFORNIA INSTITUTE OF TECHNOLOGY GRAVITATIONAL PHYSICS		
LASER LOOP AMPLIFIER - SECTION 1		
DRAWN BY B.T.	DATE 10-9-89	DRAWING NO.
CHECKED BY	SCALE	
APPROVED BY	W.O.	

D1



BISHOP GRAPHICS/ACCUPRESS REORDER NO. A38381

NETWORK Cor
A: REF B: REF o MKR 198 380.966 Hz
90.00 225.0 T/R 41.3117 dB
[dB] [deg] θ 167.567 deg



DIV DIV START 10 000.000 Hz
10.00 45.00 STOP 10 000 000.000 Hz
RBW: 100 Hz ST: 40.2 sec RANGE: R= 10, T= 0dBm
ATT1= 10 DB

11/14/ MSJ 14:57

XF, LaserLoop Proto #1
Demod → A1
PC OUTPUT, END OF CABLE
GAIN "1" (MIN.)

D3