

When asked to develop a 'New' Broadcast limiter, the consideration is what could be our Competitive Edge?

A line of attack could be using a relatively new light emitting technology, with the venerable LDR  
The LED-LDR, Light Emitting Diode, Light-Determined Resistor  
This combination would be well suited to Solid-State... Op-Amp Control

Either through ignorance, or because I was in a hurry, I build one!

Background:

The key element to any Broadcast Limiter is to 'Compress the Dynamic Range' before doing more aggressive 'limiting', such as clipping

Early Broadcast limiters used Barretters, specially designed electric lamps  
As the level/power increased the lamp would light, increasing resistance...  
Keeping the level somewhat constant  
Works great, but slow!

Variable MU Vacuum tubes have also been used as level Compressors  
The Control curve is non-linear, and requires feedback stabilization  
Also as the level increases the distortion increases, so the acceptable dynamic range is poor

The LDR, Light-Determined Resistor, was extensively used  
First driven by an incandescent lamp, excellent dynamic range, low distortion  
However the control curve is very non-linear  
Other circuits use Neon lamps, better control curve, but more complicated circuitry  
Not well suited for solid state control

NOV 1974?

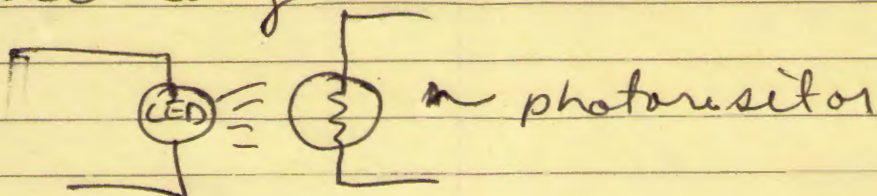
First step, define the problem

①

Problem: build an automatic level set.

using  $v$  controlled resistor

possibility



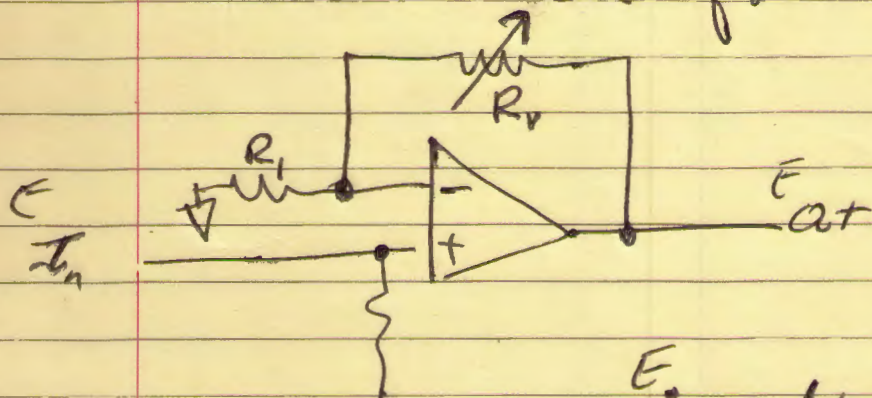
Operating curves of two such devices in Graph 1

also observed resistance change is ~~we~~ slower with lowered light levels. ie current inputs.

Since we need approx 40 db dynamic range let us consider the operating points between  $10k$  and  $1M\Omega$  observing the slope we have

$$R = \alpha I^{1.35}$$

consider the following configuration:

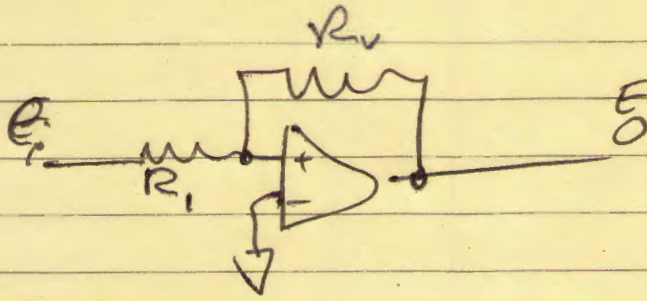


$$\frac{E_{out}}{E_{in}} = 1 + \frac{R_f}{R_i}$$

Notice in this configuration as  $R_f \rightarrow 0$  gain approaches unity -

NICE ?

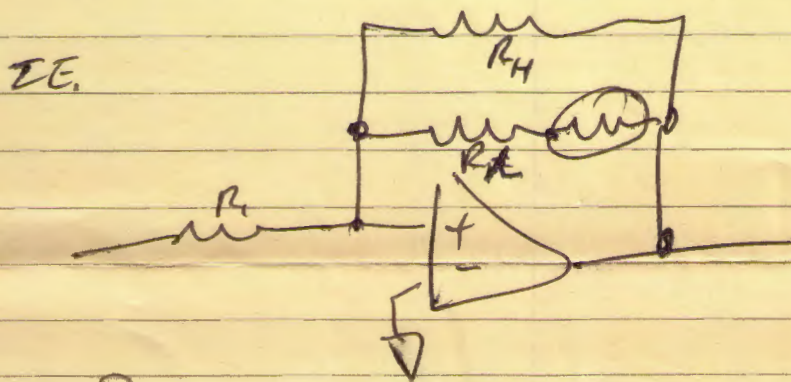
(2)



$$\frac{E_o}{E_i} = -\frac{R_2}{R_1}$$

NOTICE WITH THIS CONFIGURATION, BOTH ENDS ARE OPEN - NOT WHAT WE WANT IF THERE IS TO BE A SIMPLE LIMIT POINT, I.E. NO "GAIN REDUCTION"

COULD BE CLOSED -

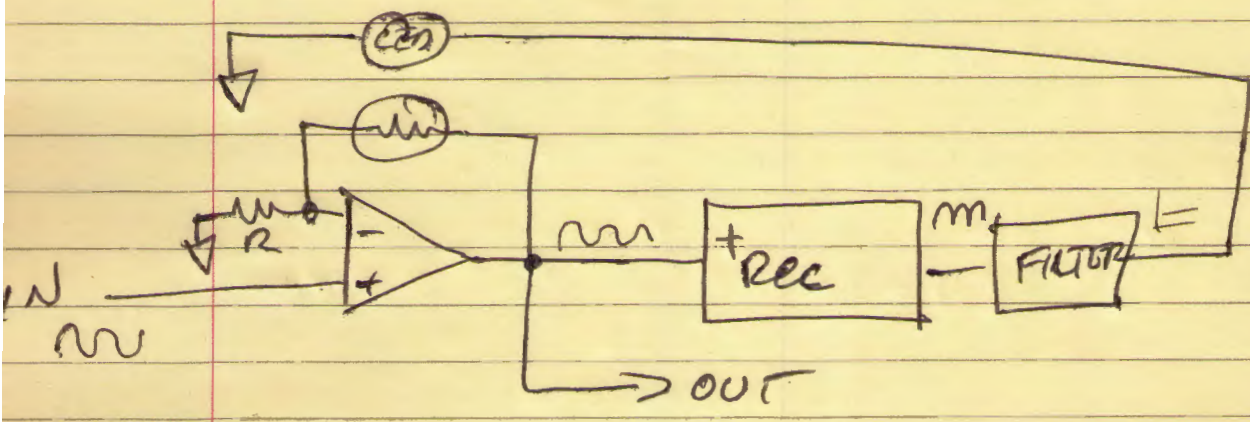


SUCH THAT ~~R\_A~~  $R_H$  limited gain - and  $R_1$  caused ~~gain~~ some fixed gain to be approached.

without the path. let us look more closely at the first approach. Because it starts out with the right function - and a high input impedance!

Since as the level of audio increased it is easier to obtain an increasing AC bias level. . .

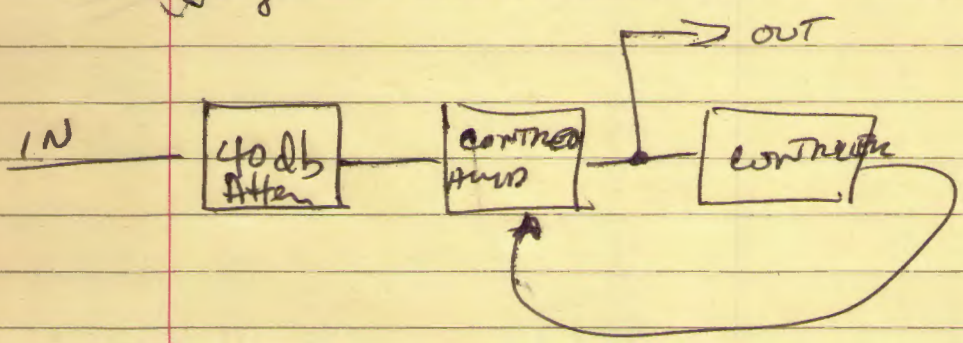
consider this circuit.



Notes -

Since the power supply is approx  $\pm 15$  volts - and we want about 10-20 db of "head room" we must operate below  $\pm 8$  volts,

notice then if we want 40 db of "gain reduction" if  $\pm 3$  volts is chosen - our signal is  $\pm 0.03$  volts.

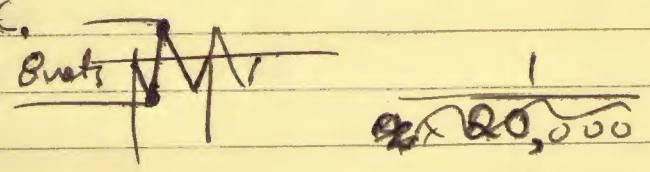


IF WE CHOOSE  $R_1 = 10K$  & we have 40 db gain when  $R_2 = 1meg. \Omega$ . and  $\approx 0$  gain when  $R_2 = 1k\Omega$  or saturation current for op amp.

- suggest we go out to 5 meg ohms - and use  $R_2 = 50k\Omega$  this give greater tolerance for low  $R_2$ .

Slew rate problems. Notice here we are always working at an operating point above unity gain! Thus we are asking for amplification at all times and a maximum gain of 40 db - 100:1

consider the triangle wave of 20 kHz.



20,000 \* 2 \* 8 volts = 240,000 volts/sec  
at 40 db gain - or .24 volts/microsec  
100 \* .24 = 34 volts/microsec. 10  
Not for 741

### Analysis of configuration #1

although equation for signal output approaches 1:1 - we have that the control device has little leverage at low light levels - this means we cannot directly monitor the C.C.D. current to get a gain reduction monitor.

- Also the circuit requires a very large feedback resistor R, thus causing the operating point to be above light level are very low - so slow response to slow.

Taking advantage of the saturation characteristics of the photo resistor and the output op amp - a negative feedback circuit will also allow a gain reduction asymptote.

this occurring very close to saturation current - of the op amp - thus as the input signal is increased ~~no~~ past saturation no greater  $i_{in}$  current will flow - thus simplifying metering

Since saturation occurs near  $1k\Omega$  - the unity gain point is easily established at any desired level - Notice also that the dynamic range is greatly increased -  $\approx 1k\Omega$  to  $10\text{ meg}\Omega$  or  $10,000:1$  80 db! - actually only 60db for op amps with significant offset voltage without offset compensation - also 80db for an op amp is hopeful - however we gain a great deal of room to work with.

Notice since so much dynamic range exists in this configuration we can ~~very~~ Taylor the response curves by - adjusting the input resistor - as the voltage operating point is adjustable by the feedback loop...

### Configuration 2 -

Gain control is excellent however - attack and decay are not perfect.

If  $C_f$  is made large attack is still fast with considerable overshoot - a property - that is not satisfactory

As might be expected from a closed loop - if stability is wanted at low freq. - problems arise as ~~over~~ overshoot at busts arrive.

Not knowing that packaged units existed, I made the first one

A small brass tube with a  
Red Light Emitting Diode at one end  
Photo Resistor at the other end  
Potted with epoxy filled with Carbon Black for Opacity



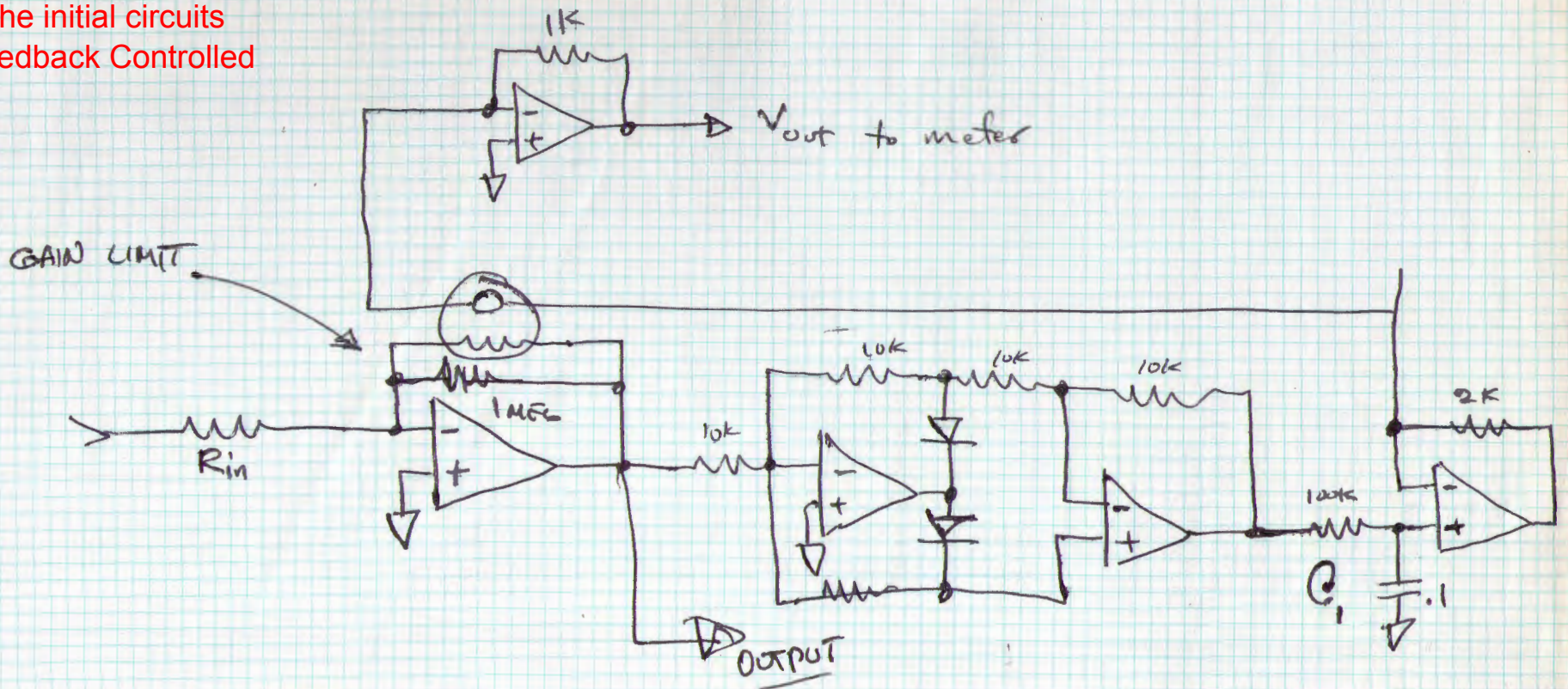
Amazingly it worked!!!

The first page of the Circuit Doodles still has some Epoxy Residue!!!

The rest of the stuff is from early Experiments using the "Bean" in various circuits  
And Graphs of the performance... Must have made sense in 1974, a Jumble now

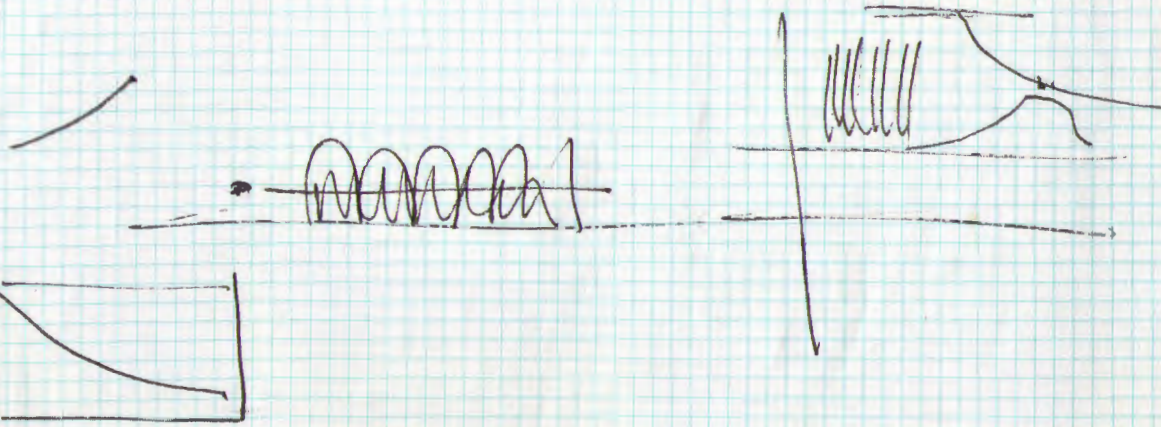
The Concept of using the "Bean" in a shunt circuit came a little later

Notice, the initial circuits were Feedback Controlled

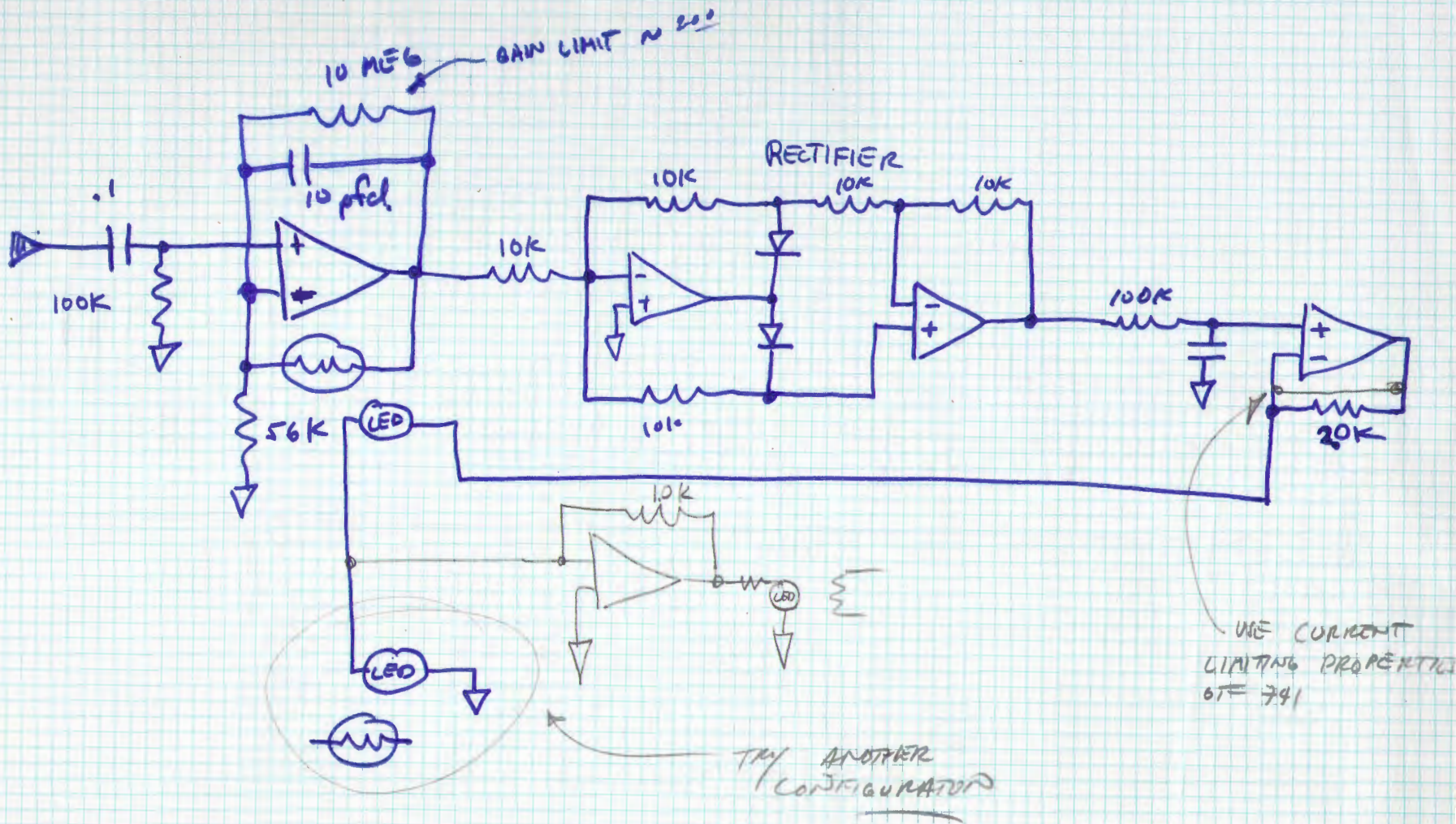


CIRCUIT CONFIGURATION #2

1/2 sec



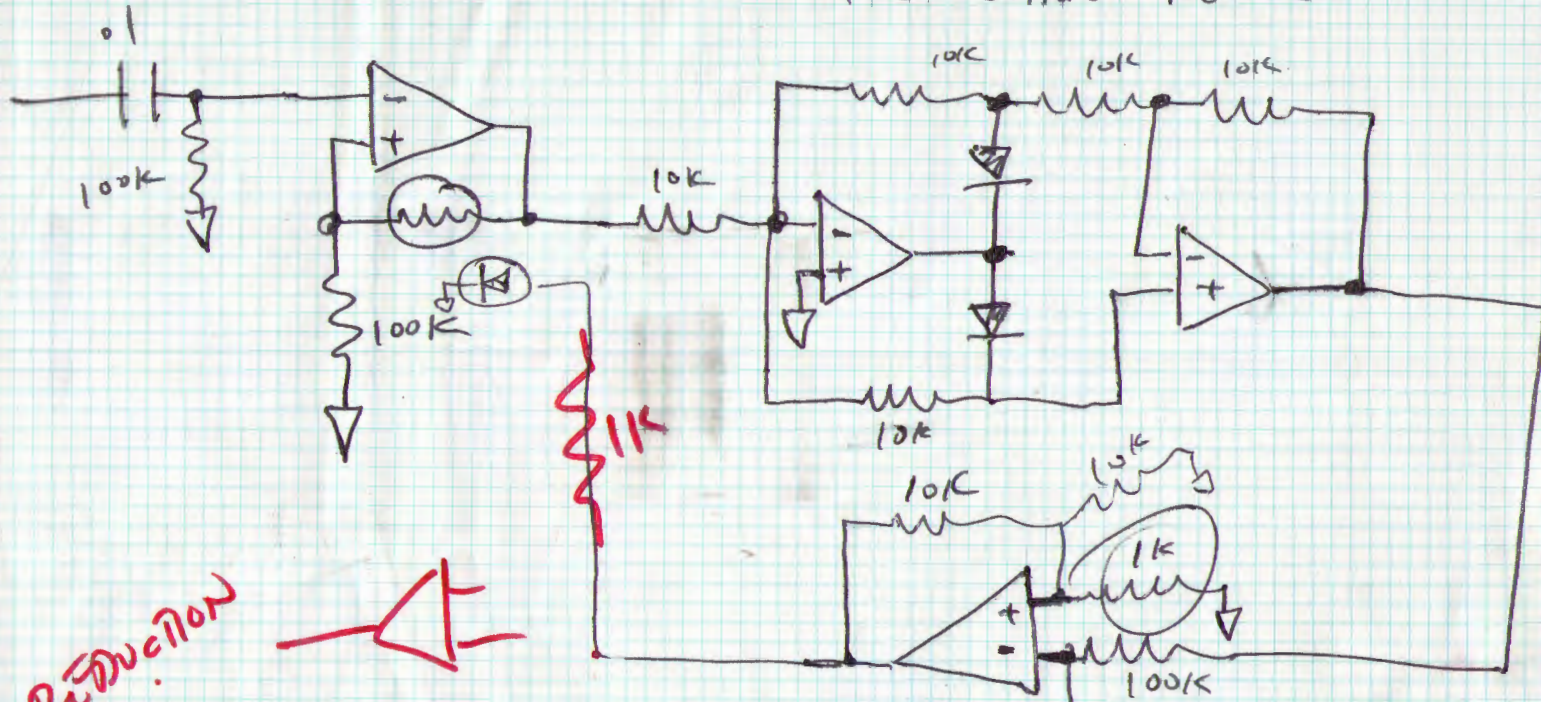
Black Potting Epoxy from the first Gain Control Module, The "Bean"



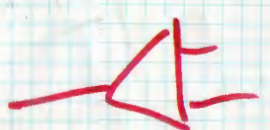
CONFIGURATION #1

# USE OF PHOTO ~~DIODE~~ RESISTOR LED

Full WAVE RECTIFIER

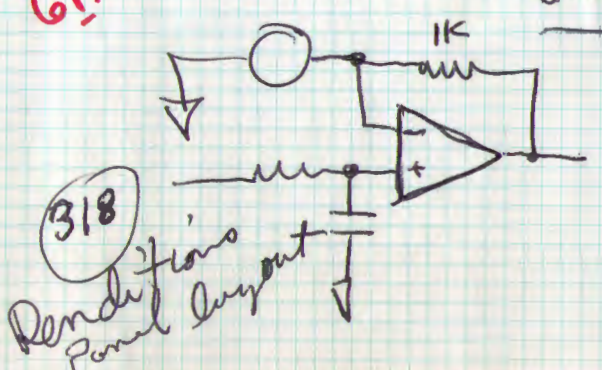


**GAIN REDUCTION**



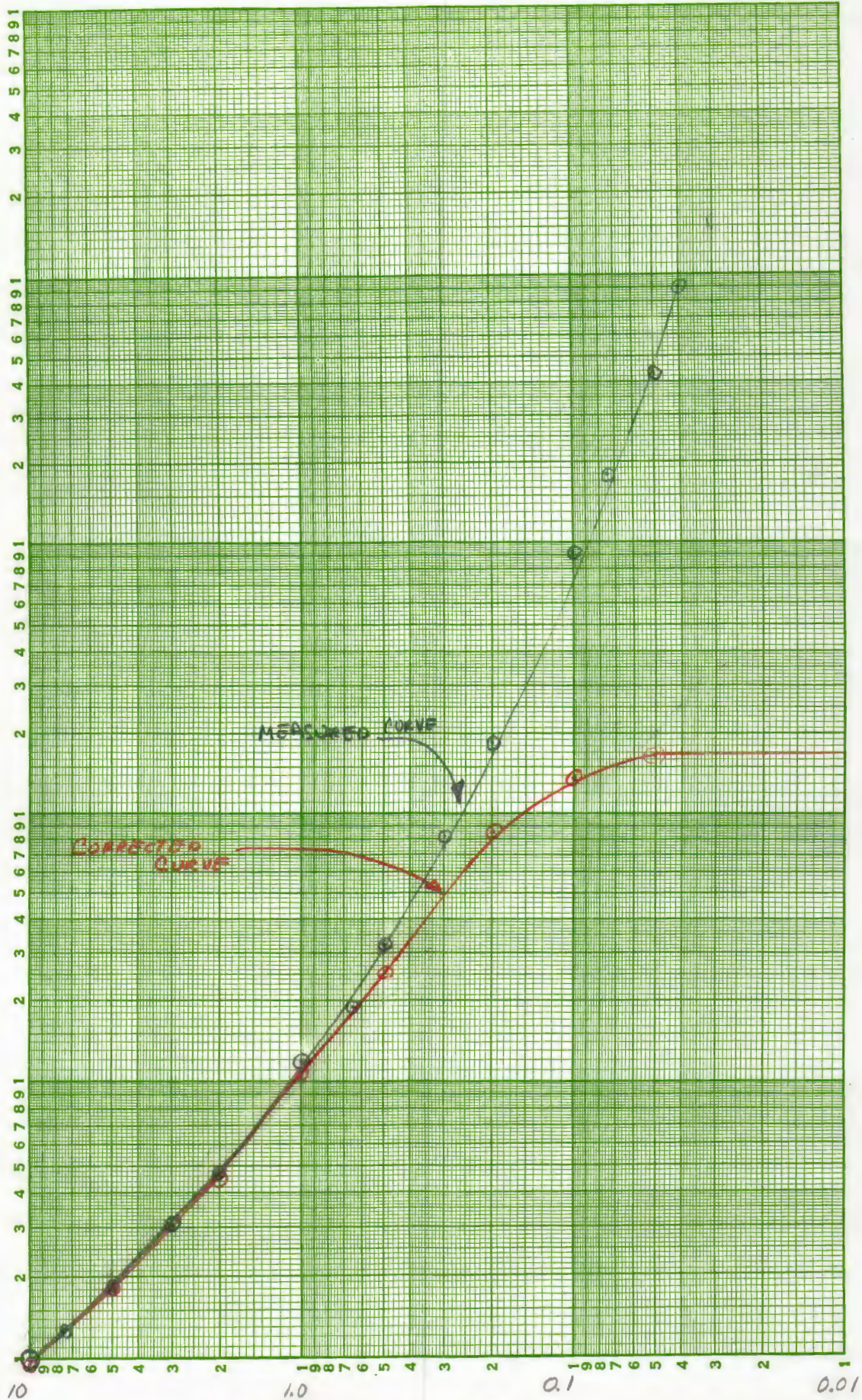
UNOPTIMIZED

300 milli sec .001  
 - Delay :  
 9 cps @ 1000 cps



Kilohms

100,000  
10,000  
1,000  
100  
10  
1.0

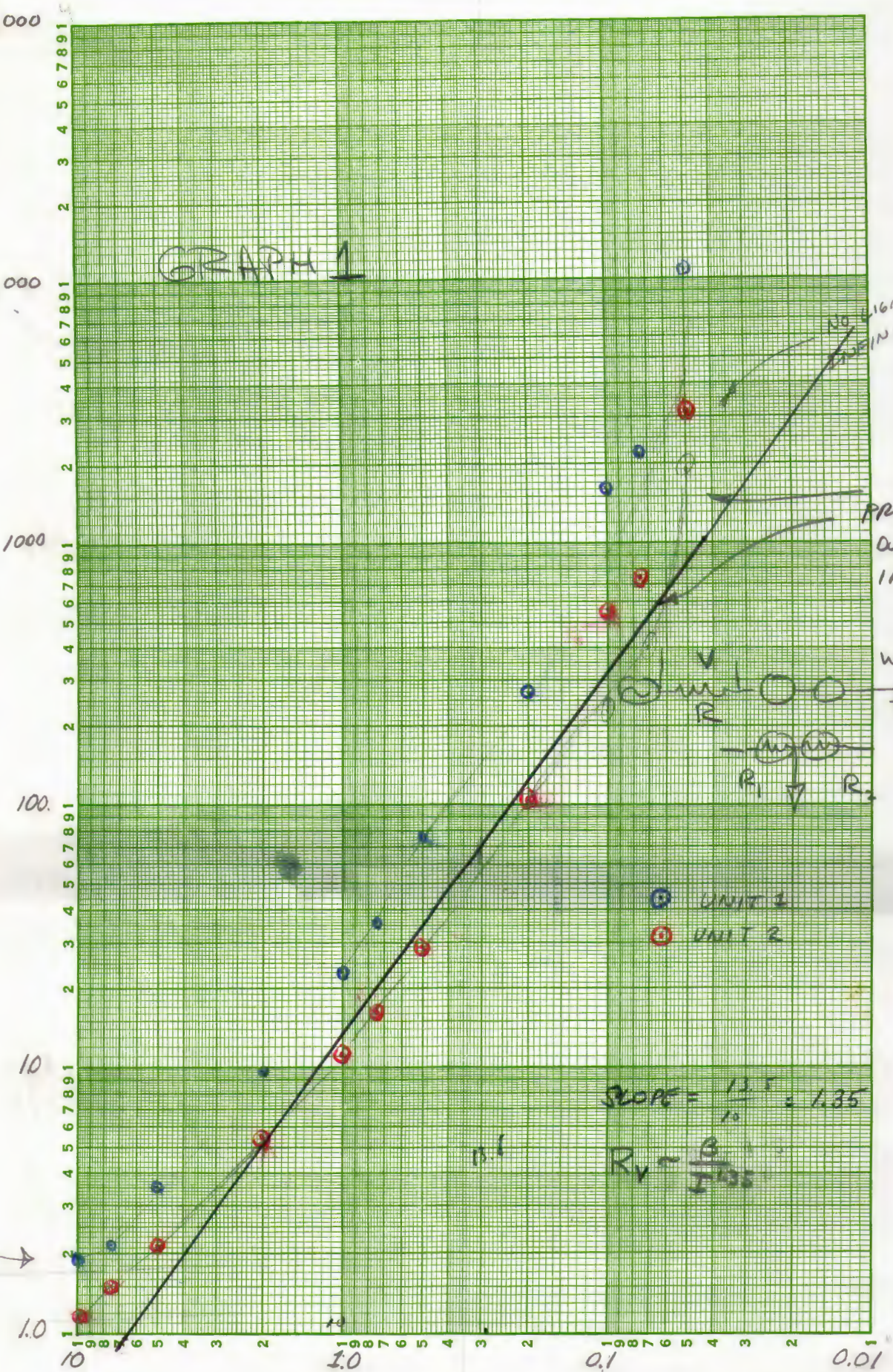


Input current milliamperes

Output Resistance Kilohms

Lower Asymptote

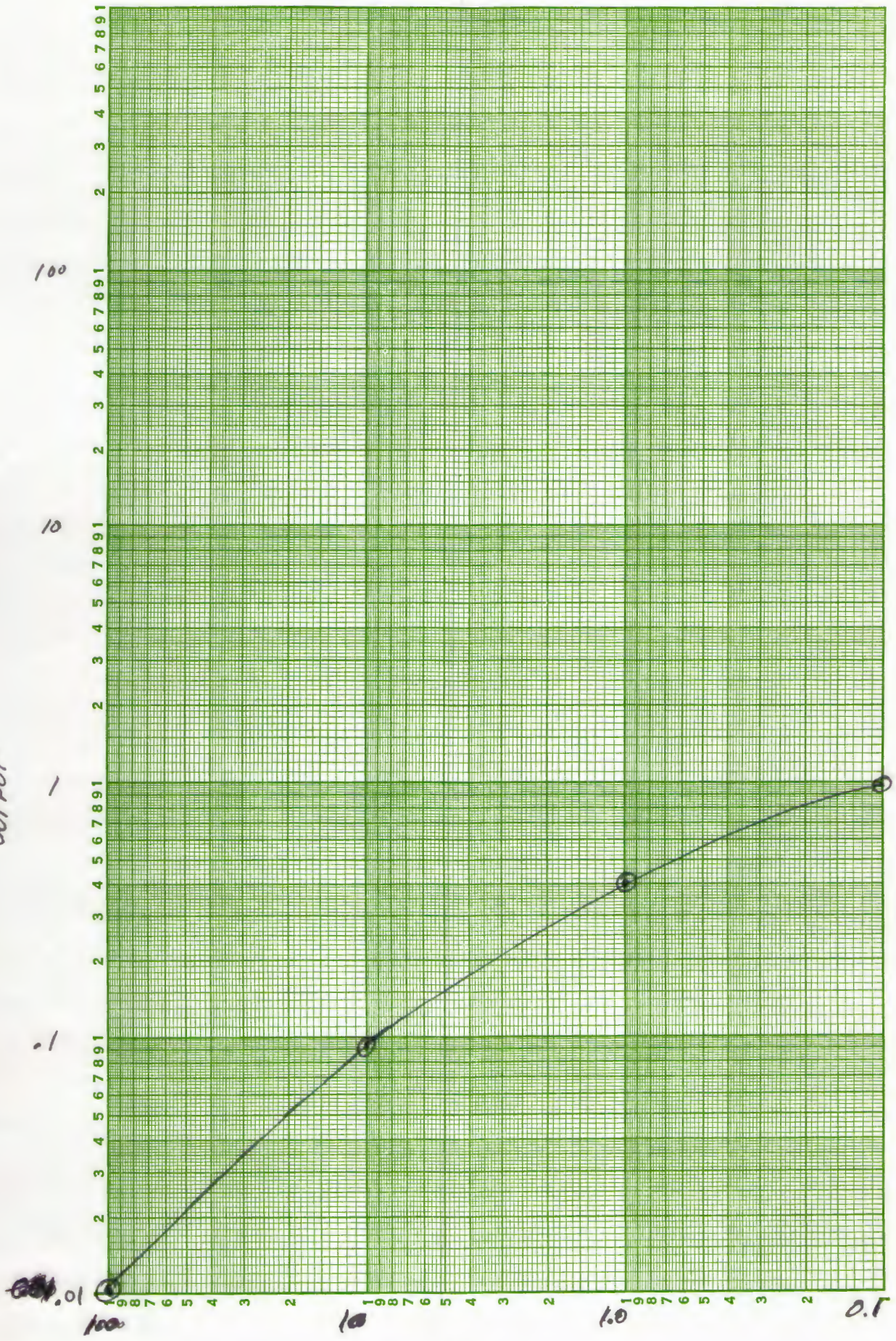
GRAPH 1



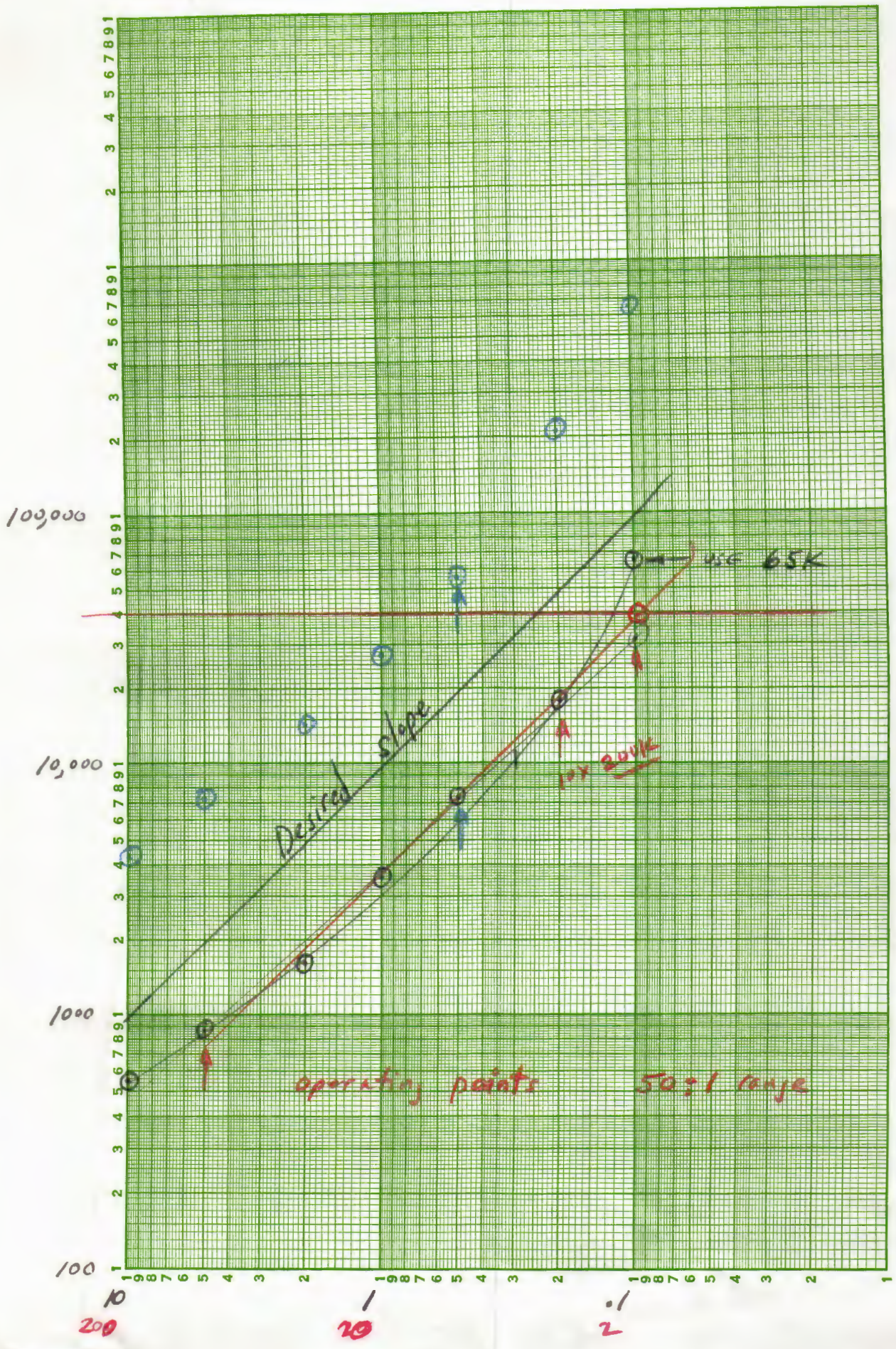
Input current milliamps

$$\frac{V_{out}}{V_{in}}$$

OUTPUT



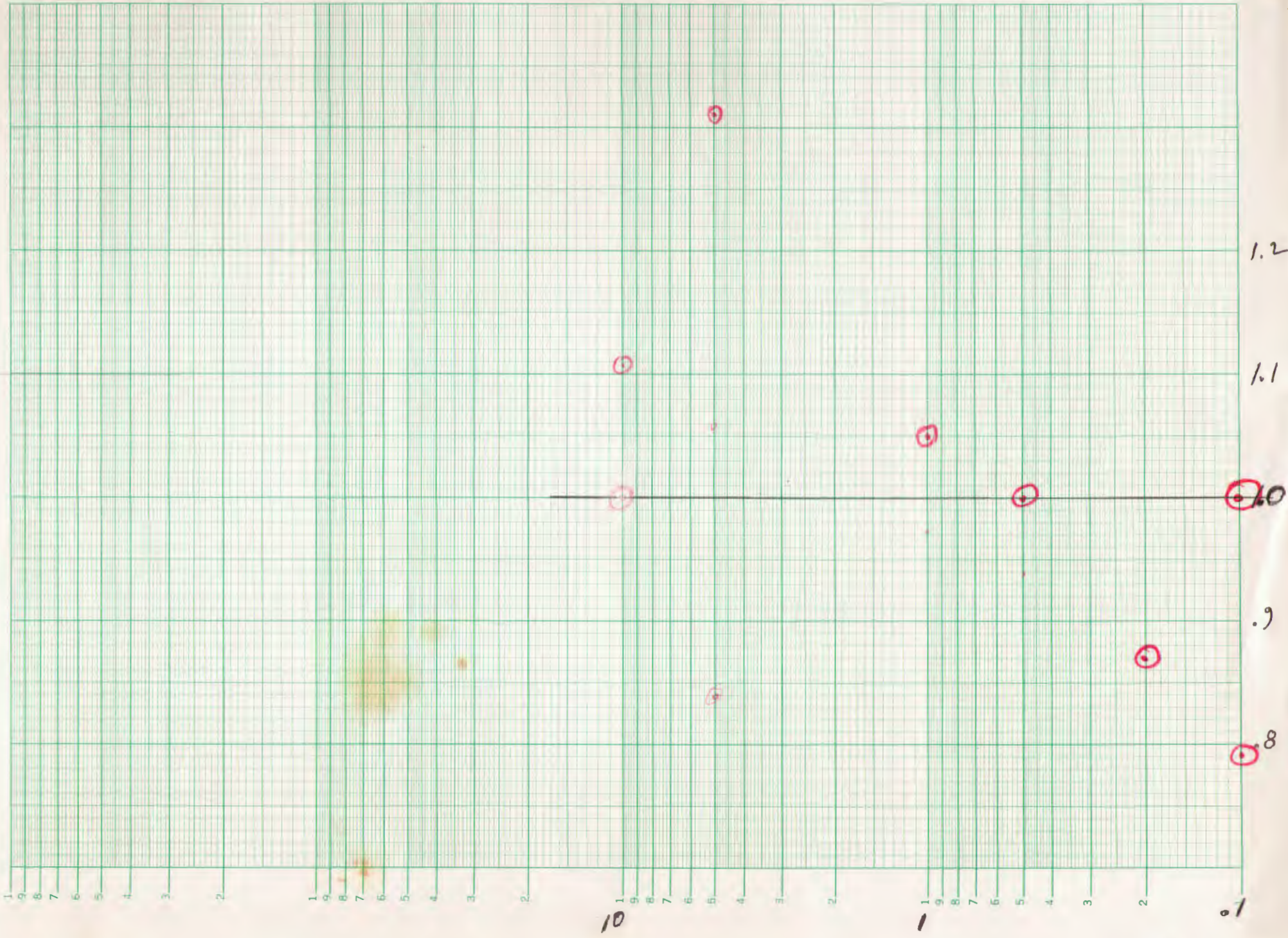
$$R_s/R_v$$



Semi-Logarithmic  
4 Cycles x 10 to the inch

R 2470-SL-4

VERNON  
Ruler LINE  
MADE IN U.S.A.



"RMS" Feed Forward ("Open Loop") Gain Control

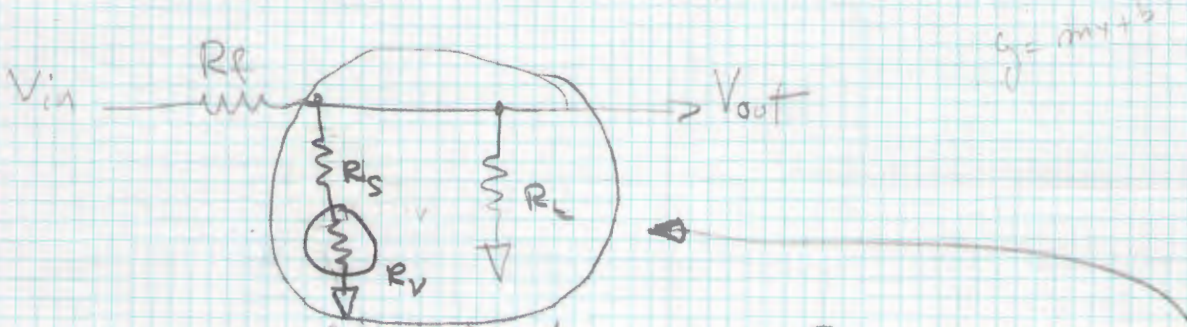
After plotting the LED-LDR response was determined to be nearly linear  
Allowing for a much improved Feed-Forward Control

Early use of Shunt Gain Control

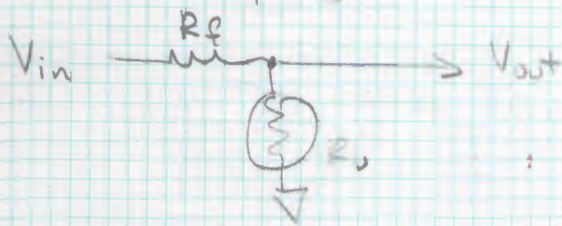
Notice the use of two LED-LDR's  
One for Audio Control, the Other for metering (Gain Reduction)

# Analysis of shunt control for open loop ①

Using shunt regulation



in simplified terms  $R_V \text{ may } =$



$$V_{out} = V_{in} \frac{R_V}{R_f + R_V}$$

$$\frac{V_{in}}{V_{out}} = \frac{R_f + R_V}{R_V} = \frac{R_f}{R_V} + 1$$

Notice as  $R_V \rightarrow \infty$   $\frac{V_{in}}{V_{out}} \rightarrow 1$

The problem for open loop control

We may assume the current to the LED is proportional to the amplitude of the incoming signal i.e.

$$I_{LED} = K V_{in} \quad \text{where } K \text{ is amplifier gain}$$

We have from empirical measurements

$$R_V \sim \frac{\rho}{I^{1.35}} = \beta I^{-1.35} \quad \beta \text{ attenuator unit proportional constant}$$

$$\therefore R_V \sim \beta (K V_{in})^{-1.35} = \frac{\beta}{K^{1.35}} V_{in}^{-1.35}$$

Notice for constant output we must have

$$V_{out} = \frac{V_{in} (B V_{in}^{-1.35} K^{-1.35})}{R_f + \beta V_{in}^{-1.35} K^{-1.35}}$$

= Constant

let equal 1 for simplicity

$$1 = \frac{\beta V_{in}^{.35} K^{-1.35}}{R_f + \beta V_{in}^{-1.35} K^{-1.35}}$$

$$R_f + \beta V_{in}^{-1.35} K^{-1.35}$$

$$1 = \frac{R_f + \beta V_{in}^{-1.35} K^{-1.35}}{\beta V_{in}^{.35} K^{-1.35}}$$

$$1 = \frac{R_f}{\beta V_{in}^{.35} K^{-1.35}} + V_{in}^{-1.70}$$

$$1 = \frac{R_f}{\beta} V_{in}^{-.35} K^{1.35} + V_{in}^{-1.70}$$

Since this equals 1 for all values of  $V_{in}$  - we choose  $V_{in}$  at two values say 1 and 10

$$1 = \frac{R_f}{\beta} K^{1.35} + 1 \quad \text{and} \quad 1 = \frac{R_f}{\beta} K^{1.35}$$

- No way - therefore we must do a Min Norm approx. to the function.

USE GRAPHICAL METHODS.

Notice at ~10 ma we want maximum gain reduction - say 30 db.

let our operating point be ~.650 volts RMS or ~2 volts p-p - and our circuit gain 40db

therefore drive stage must give 10 ma when a signal of 2 volts p-p is present.

DATA FROM GRAPH

Current in	resistance out	$R_T$	$V_{in}/V_{out}$	$V_{out}$
100	1K	995K	103:1	.97
50	1.8K	1.79K	62:1	.805
20	4.8K	4.6K	23:1	.870
10	12K	10.8K	11:1	.910
5	32K	25.6K	5.2:1	.960
2	180K	86K	2.25:1	.890
1	800K	138K	1.78:1	.560

OPERATING POINT

Now CHOOSE THE 20 db point here the signal must be reduced by a factor of 10.

$$\frac{10}{1} = \frac{V_{in}}{V_{out}} = \frac{R_f}{R_v} + 1 \quad R_f = 108K \quad \text{①}$$

at 10ma

$$\frac{100}{1} = \frac{V_{in}}{V_{out}} = \frac{108K}{R_v} + 1$$

estimated value of  $R_v$  -

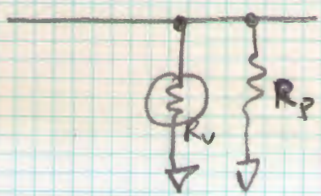
$$R_v = 1.07K$$

very close to actual value.

at 30db or approx.

$$\frac{3}{1} = \frac{P_{in}}{P_{out}} = \frac{108K}{R_v} + 1$$

But it equals ~ 80K

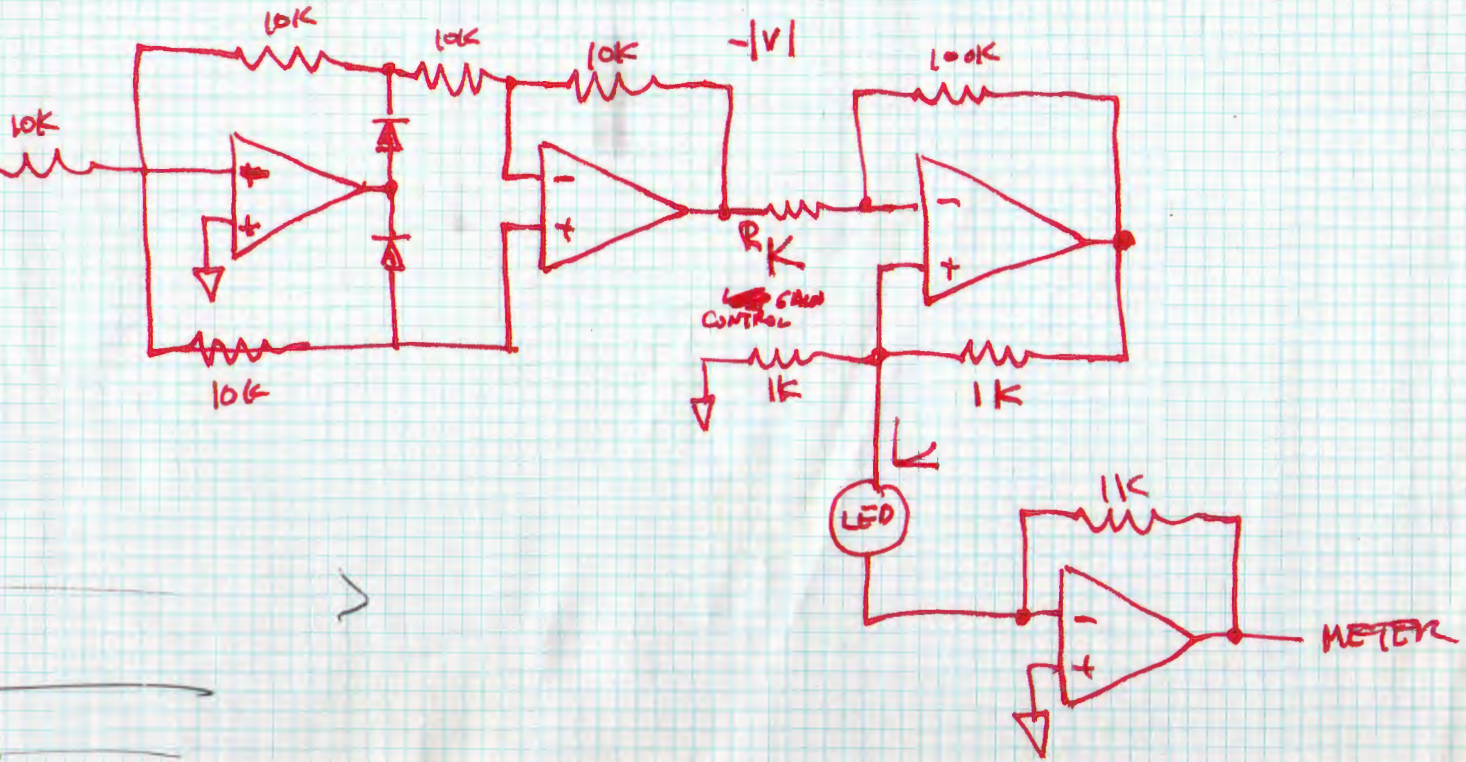
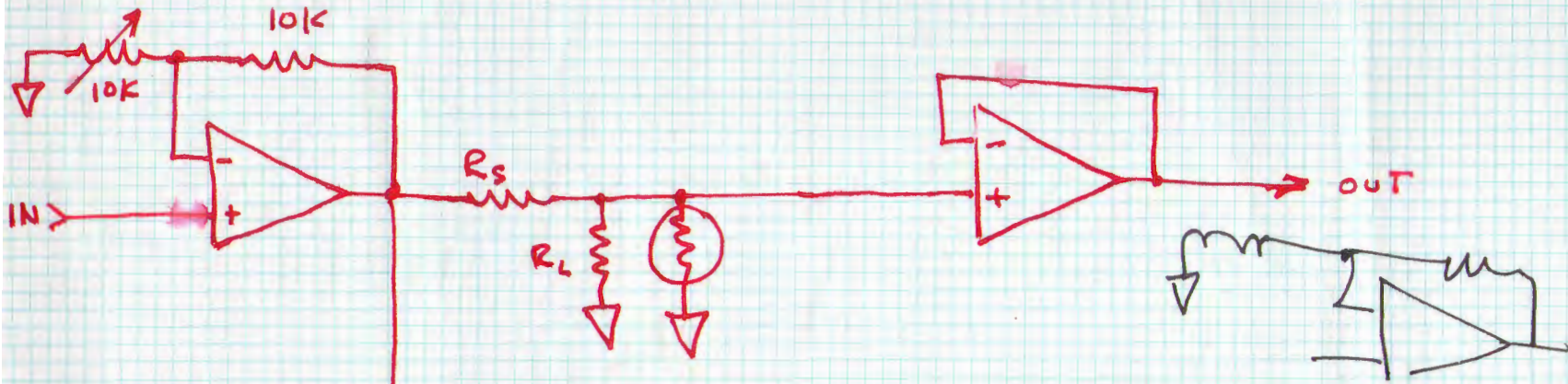


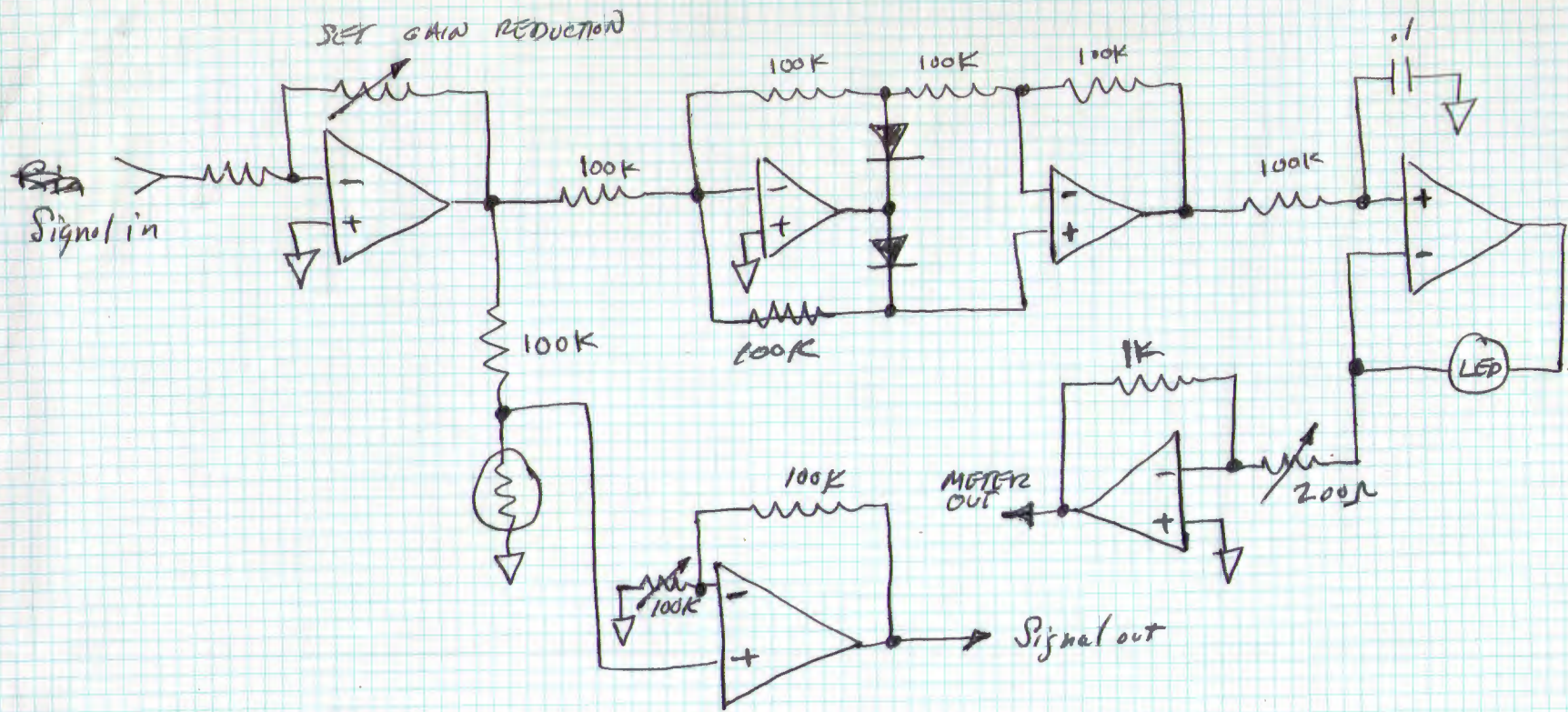
Therefore  $54K = R_T = \frac{R_v \times R_p}{R_v + R_p} = \frac{80K \times R_p}{80K + R_p}$

$$R_p = 166K$$

operating point such that

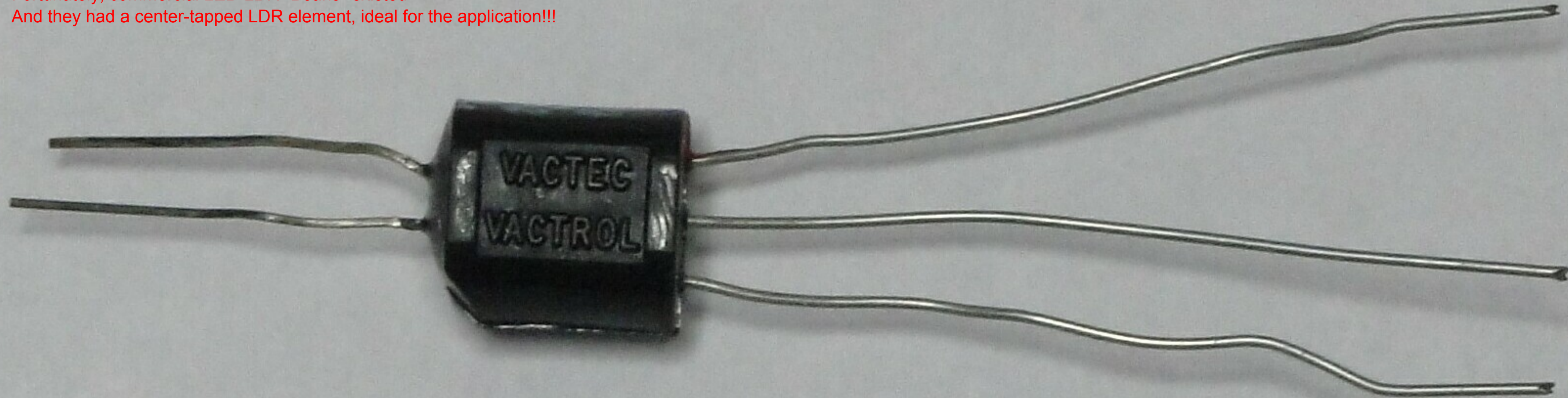
0 db in ic 2voltage p-p for .3 ma

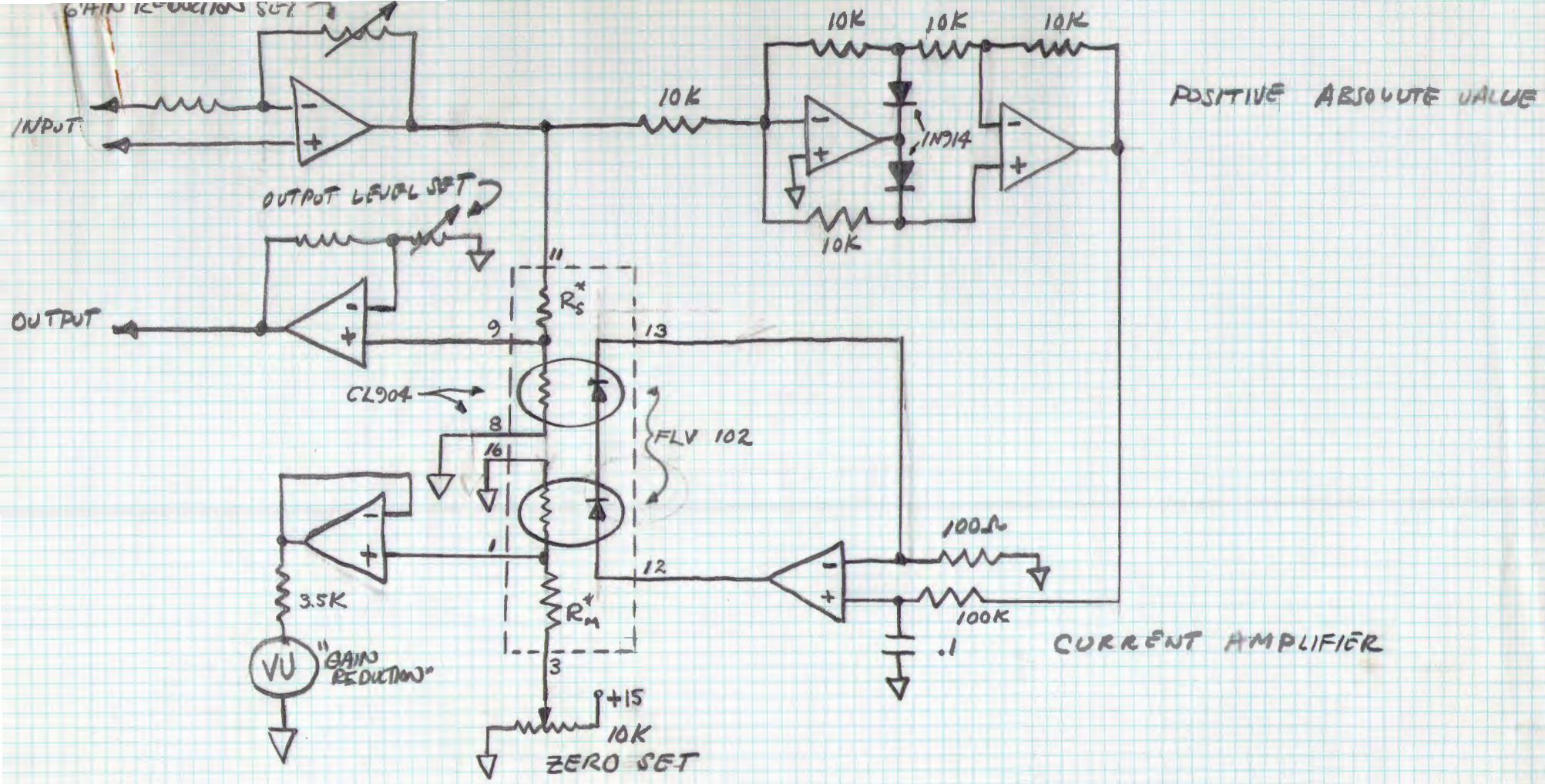




Configuration

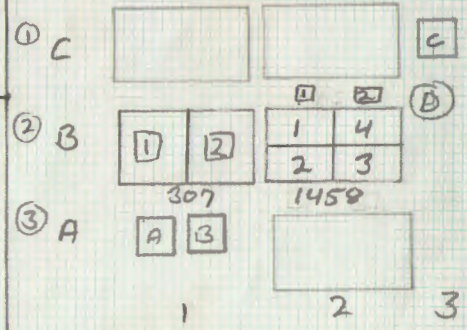
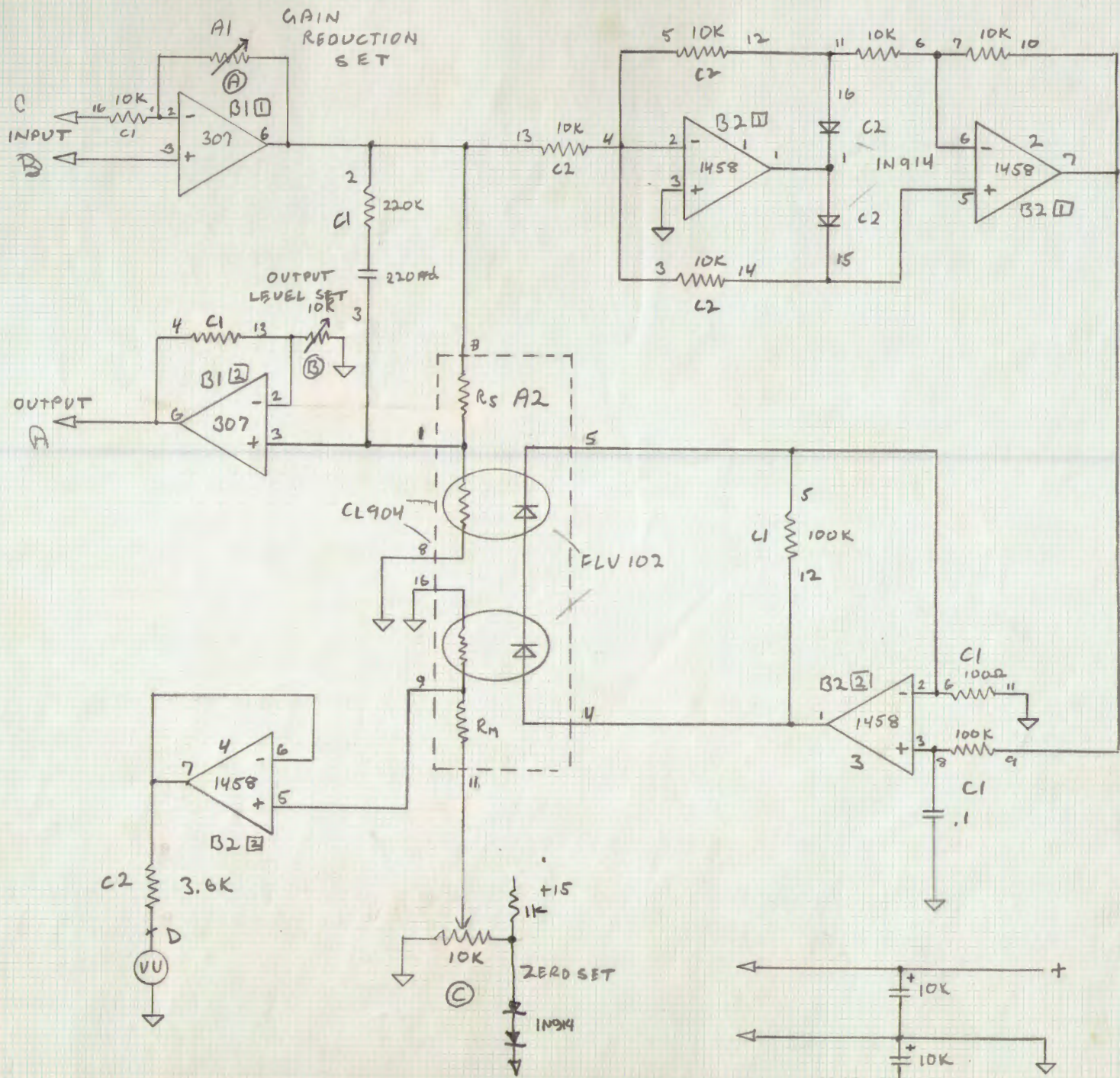
Fortunately, commercial LED-LDR "Beans" existed  
And they had a center-tapped LDR element, ideal for the application!!!



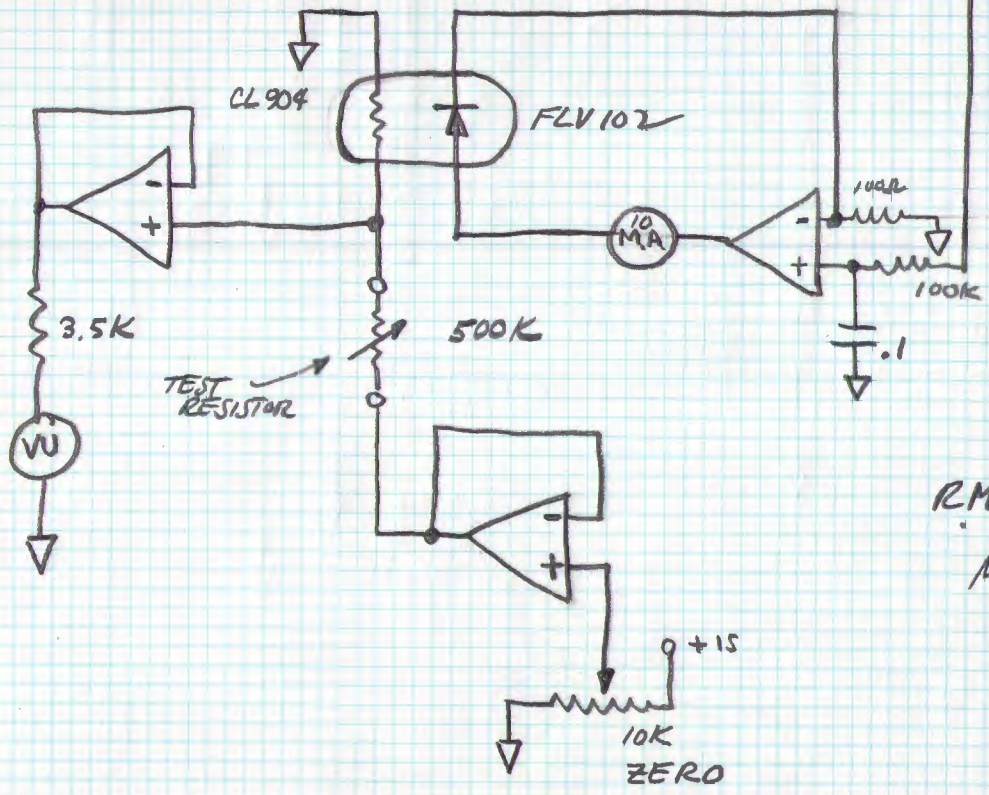
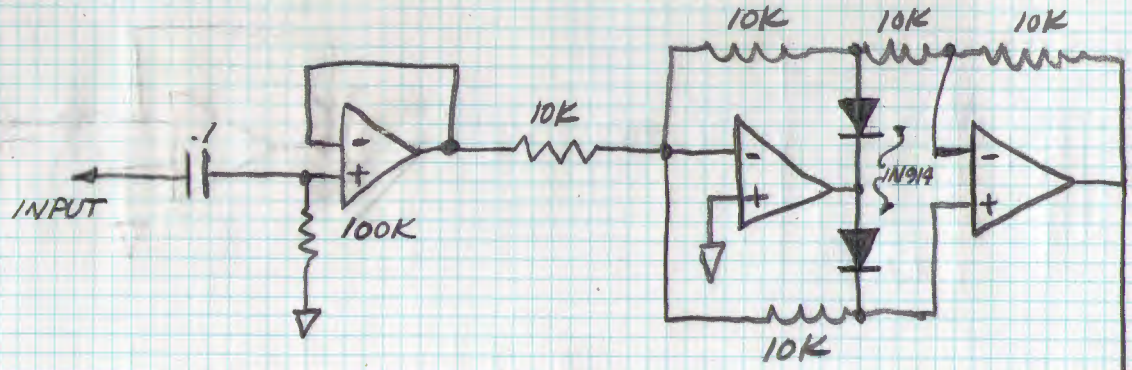


$R_s, R_m$  selected for proper tracking

RMS. LIMITER  
12/16/74 R.A.G.



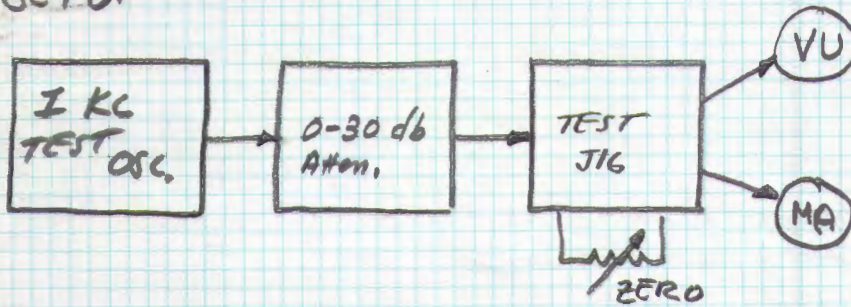
RMS LIMITER  
12-16-74 RA GRAY



RMS LIMITER  
 MODULE CALIBRATION J16  
 12/17/74 RAG

# CALIBRATION PROCEDURES

## SETUP



## TO CALIBRATE FOR $R_s$

1. SET TEST RESISTOR TO MIDRANGE  $\approx 250K$
2. SET ATTENUATOR TO 0 DB
3. ADJUST OSC. OUTPUT TO METER READING OF 10MA
4. SET ATTENUATOR TO -20 DB
5. ZERO METER
6. SET ATTENUATOR TO -10 DB
7. IF METER READ  $-10$  DB GO TO STEP 10
8. ADJUST TEST POT 

{	LESS RESISTANCE IF METER READ LESS THAN -10 DB
	MORE RESISTANCE IF METER READ MORE THAN -10 DB
9. GO TO STEP 4
10. MEASURE TEST RESISTOR - THIS IS PROPER  $R_s$  FOR UNIT.

## TO CALIBRATE FOR $R_M$

REPLACE STEP 4 WITH:

4. SET ATTEN. TO -30 DB

REPLACE STEP 6 WITH:

6. SET ATTENUATOR TO -20 DB