Bob Pease
Lab notes 2005

RAP 2005

National Semiconductor
The Sight & Sound of Information

What's All This Common Mode Rejection Stuff?

(Anyhow....)

/RAP

PART I: HISTORY....

R.A. PEASE...

PART II –

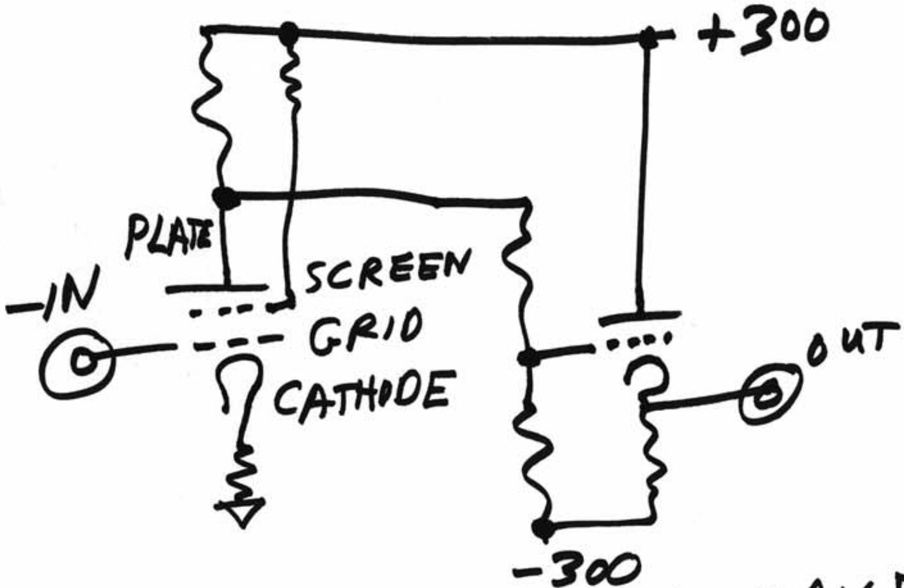
– How to test Op amps for CMRR

PART III

DESIGN FOR RAIL-TO-RAIL CM Range

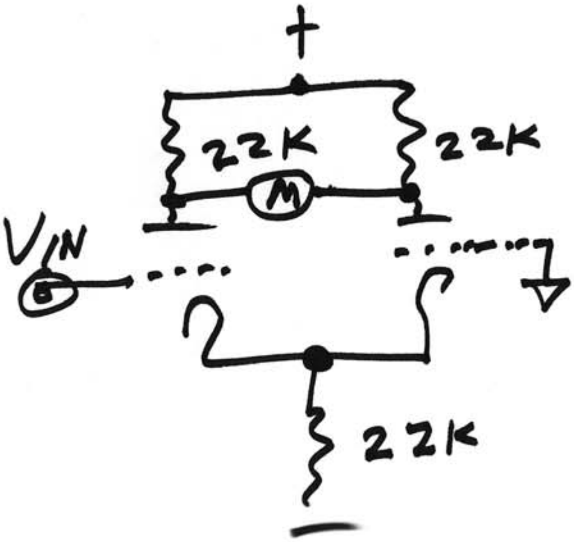
Part IV CIRCUIT DESIGN FOR GOOD CMRR

ONCE UPON A TIME....



- OPAMPS DIDN'T HAVE <u>ANY</u> COMMON-MODE RANGE....

YES, DIFFERENTIAL AMPLIFIERS WERE INVENTED IN THE 1920'S....



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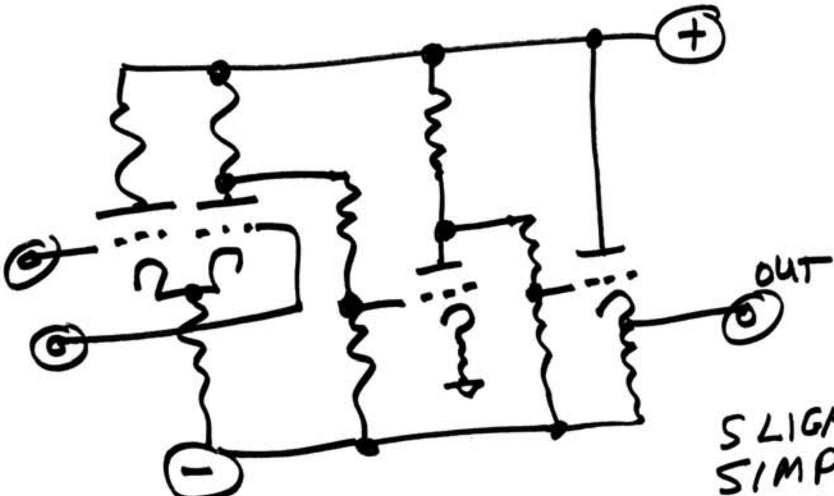
AND THE K2-W CAME ALONG ~ 1952

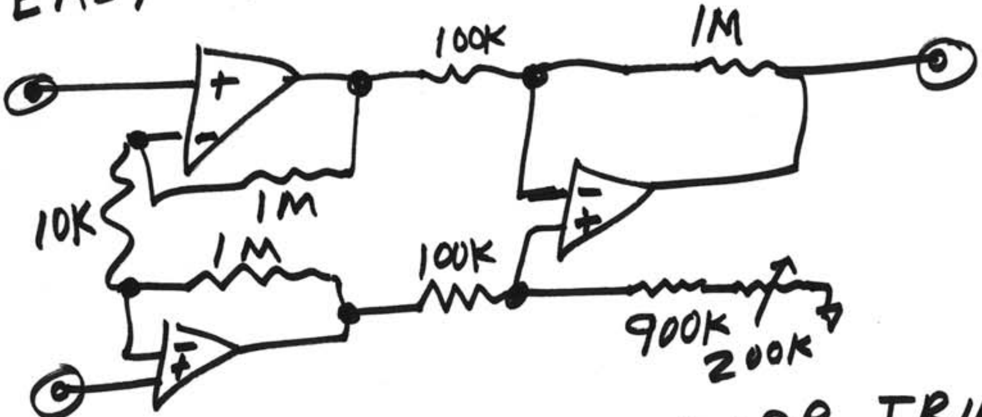


SLIGHTLY SIMPLIFIED ... = 1/2 12AX7

CMRR ≅ 300 for ± 50V

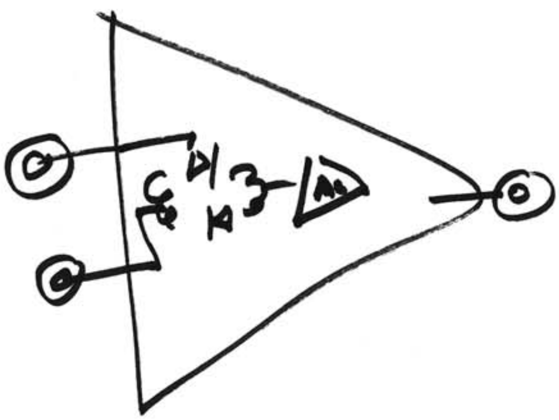
3A

STILL - Differential Amplifier CIRCUITS WERE <u>NOT</u> EASY TO DESIGN WITH TUBES...



(VOS TRIM NOT SHOWN)

THE PHILBRICK P2 USED 8 GERMANIUM TRANSISTORS TO PROVIDE A ±200 VOLT CM RANGE

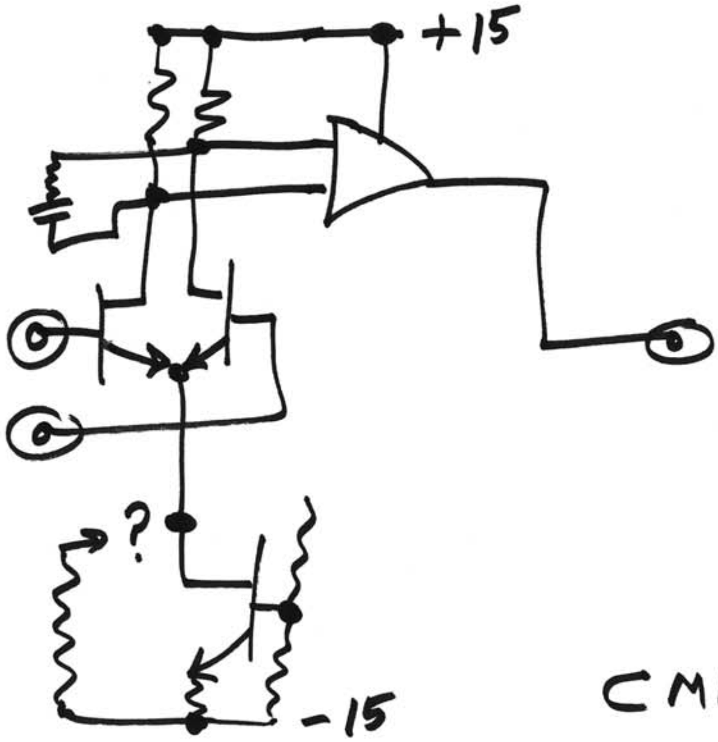


THE CMRR WAS ~ ∞

– IN 1961....

BOB

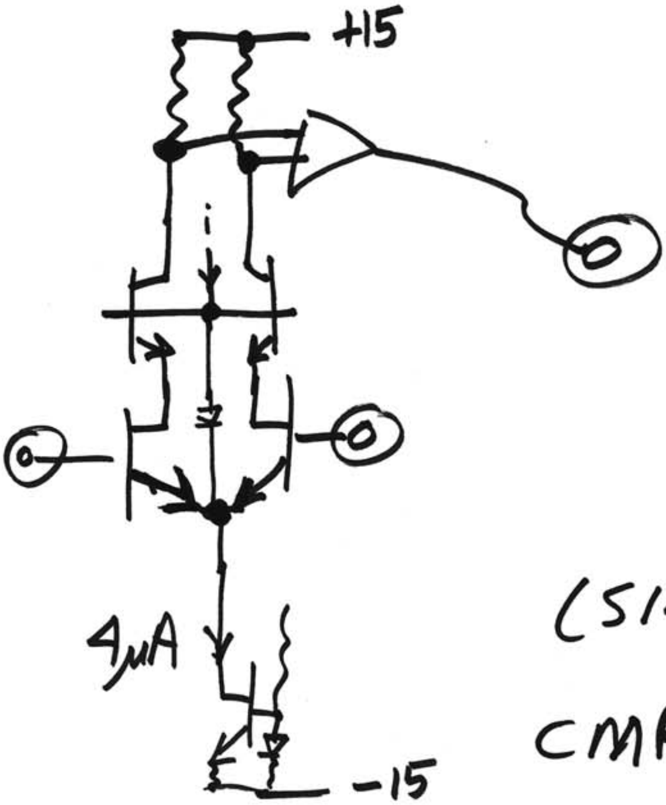
SILICON TRANSISTORS MADE GOOD OP-AMPS POSSIBLE



CMRR > 10,000 WITH GOOD MATCHED NPN's....

4B

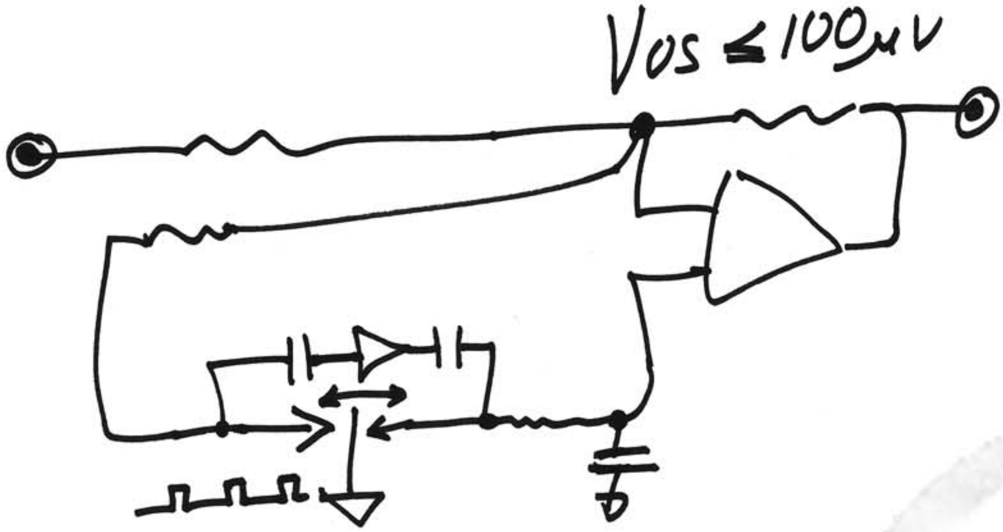
BOB WIDLAR'S LM108 MADE HIGH CMRR FEASIBLE



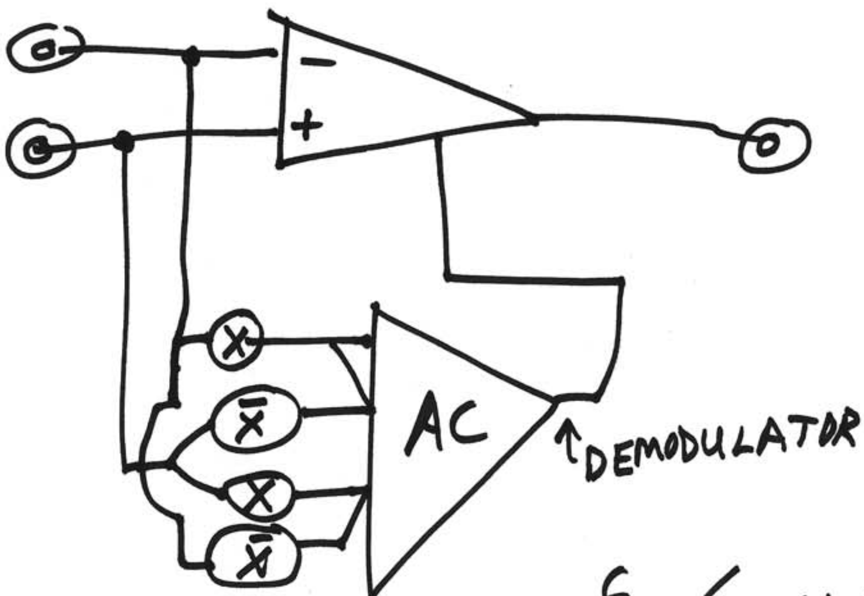
(SIMPLIFIED CIRCUIT)

CMRR = 100,000 TYP.

CHOPPER-STABILIZED AMPLIFIERS USED TO GIVE LOW OFFSET - BUT ONLY AT GROUND



CMOS CHOPPERS MAKE GOOD CMRR FEASIBLE UP TO + 2.7V



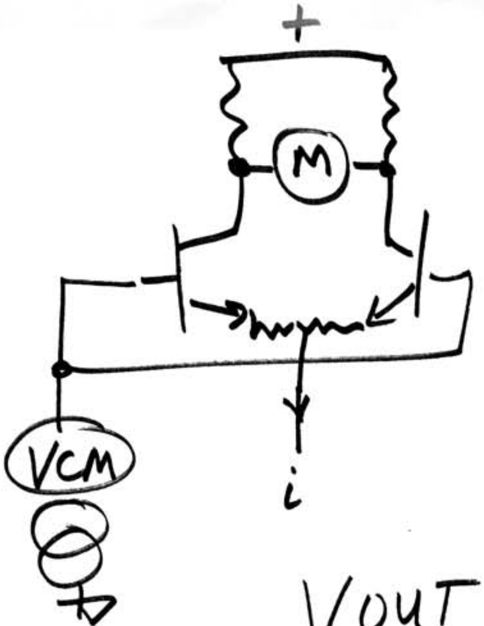
CMRR > 10^6 (3M typical)

WHAT'S ALL THIS COMMON MODE REJECTION STUFF?

(ANYHOW.....?)

PART II: HOW TO MEASURE OP-AMP CMRR....

OK - NOW WE HAVE GOOD OP-AMPS - HOW TO MEASURE?

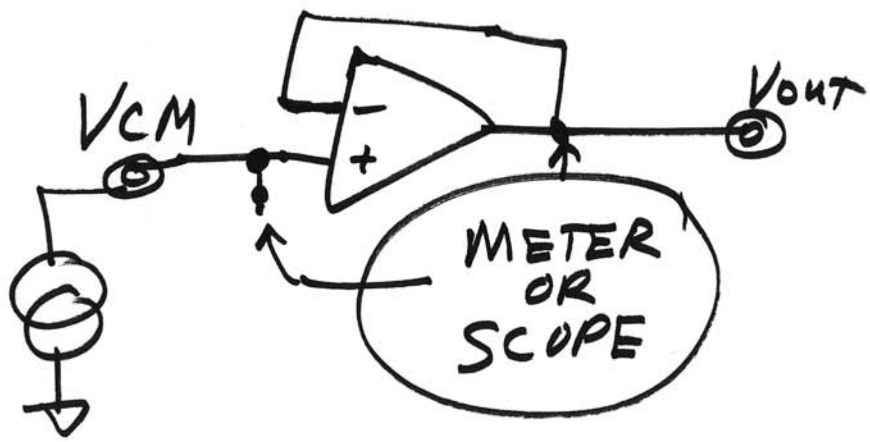


$V_{OUT} = A_V \times V_{CM}/CMRR$

BUT THIS ONLY WORKS FOR LOW GAIN - NOT FOR OPAMPS...

10 21

IS THIS A GOOD WAY TO MEASURE CMRR?



— NO —

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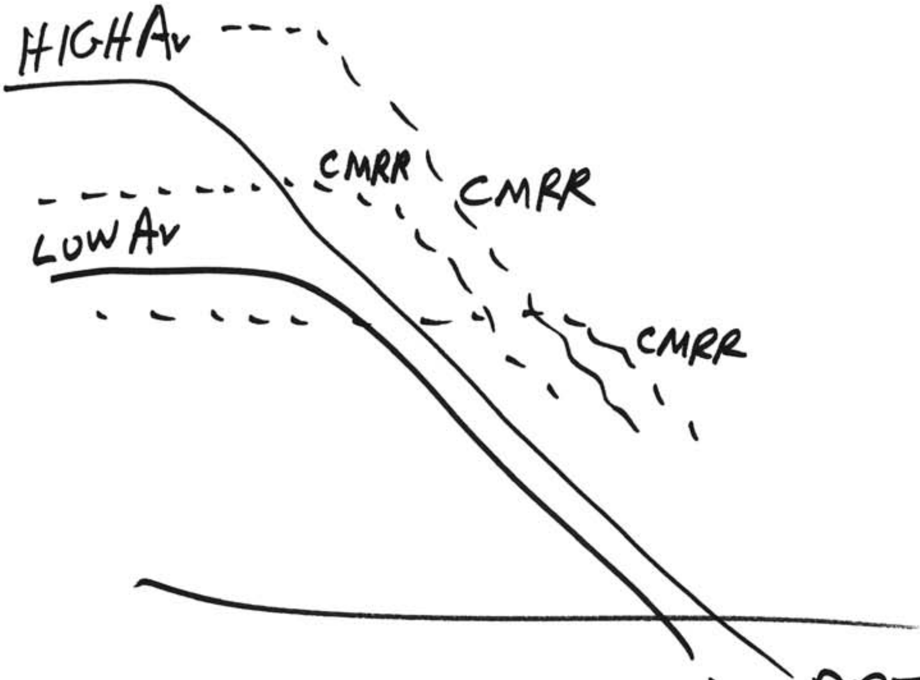
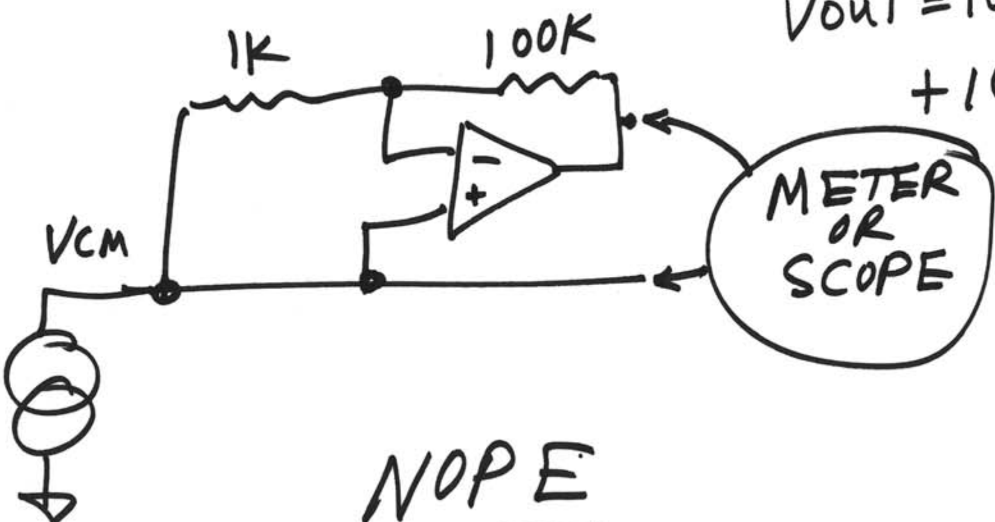


IN GENERAL – YOU CAN'T PREDICT
HIGH OR LOW DC GAIN OR CMRR,
HIGH OR LOW AC GAIN OR CMRR.

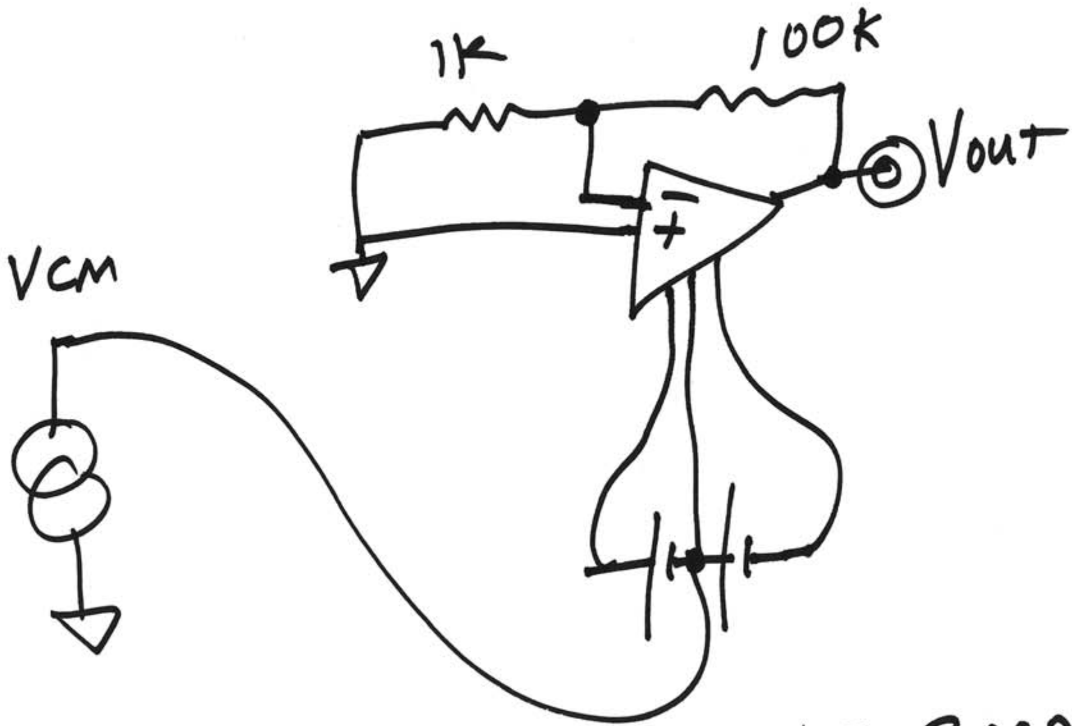
AH - THIS MUST BE A GOOD WAY TO MEASURE CMRR

$$V_{OUT} = 101\,\frac{V_{CM}}{CMRR} + 101\,\frac{V_{OUT}}{A_V}$$



NOPE

THIS HAS TO BE GOOD



UH-UH. NOT GOOD

VOUT = 101 [VCM/CMRR + VOUT/AV]

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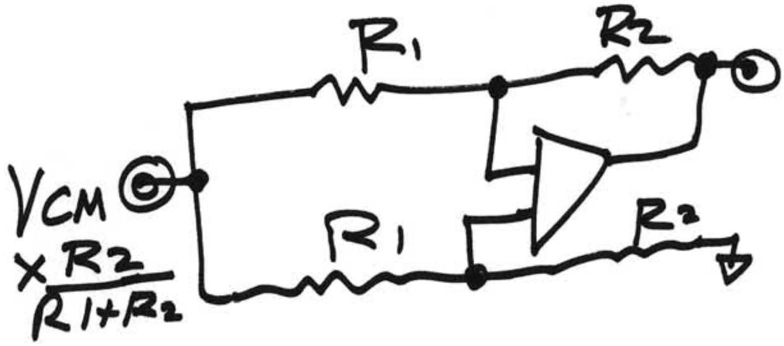
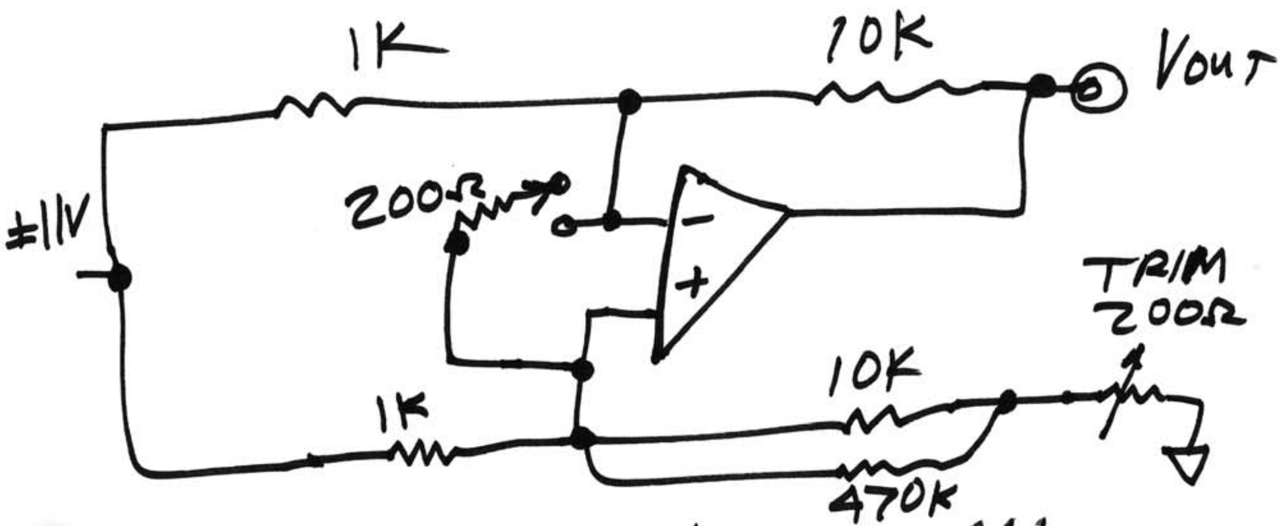
OK, HOW ABOUT **THIS** ?

-ASSUME PERFECT RESISTORS



-THIS IS GOOD- NOW -
WHERE DO WE GET THE
"PERFECT R's" ??

AHA - WE'VE GOT IT!!



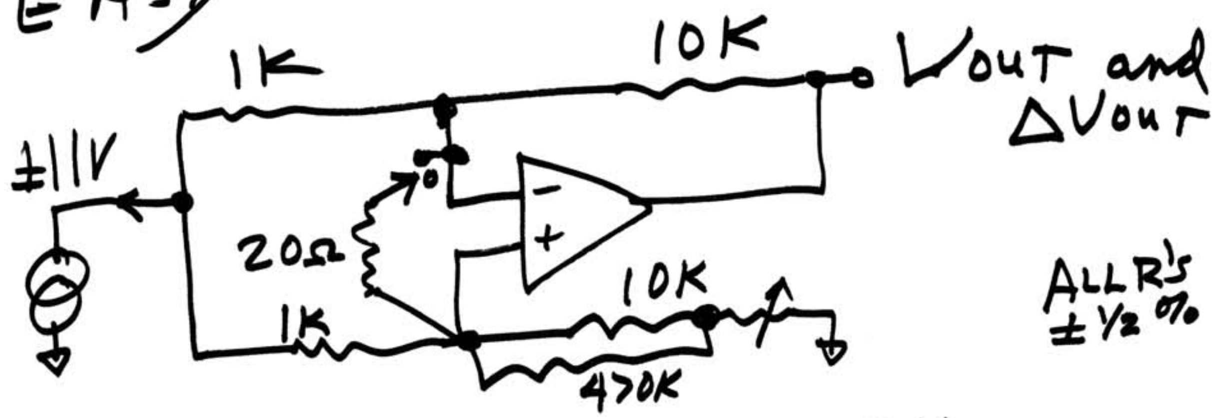
NOISE GAIN = 11 - OR - 111

SO VOUT (p-p) = (VCM/CMRR) x 11 or 111

THUS - VCM/CMRR X100 = Δ VOUT

WHAT IF YOU NEED TO MEASURE CMRR > 110dB?

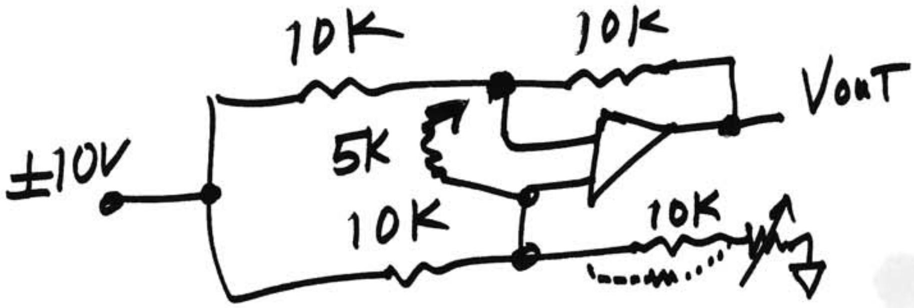
EASY!



NOISE GAIN = 11 or 1011

SO ΔVout = [Vcm/CMRR] X1000

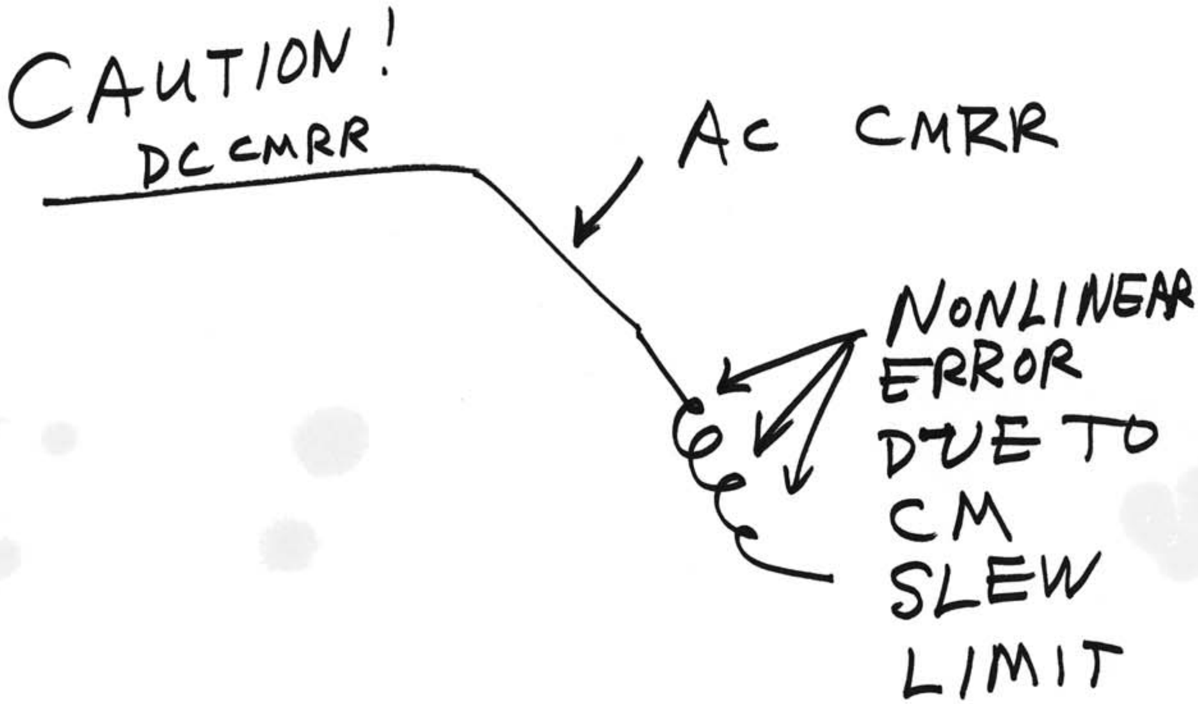
WHAT IF YOU NEED TO MEASURE CMRR FOR 50KHZ?



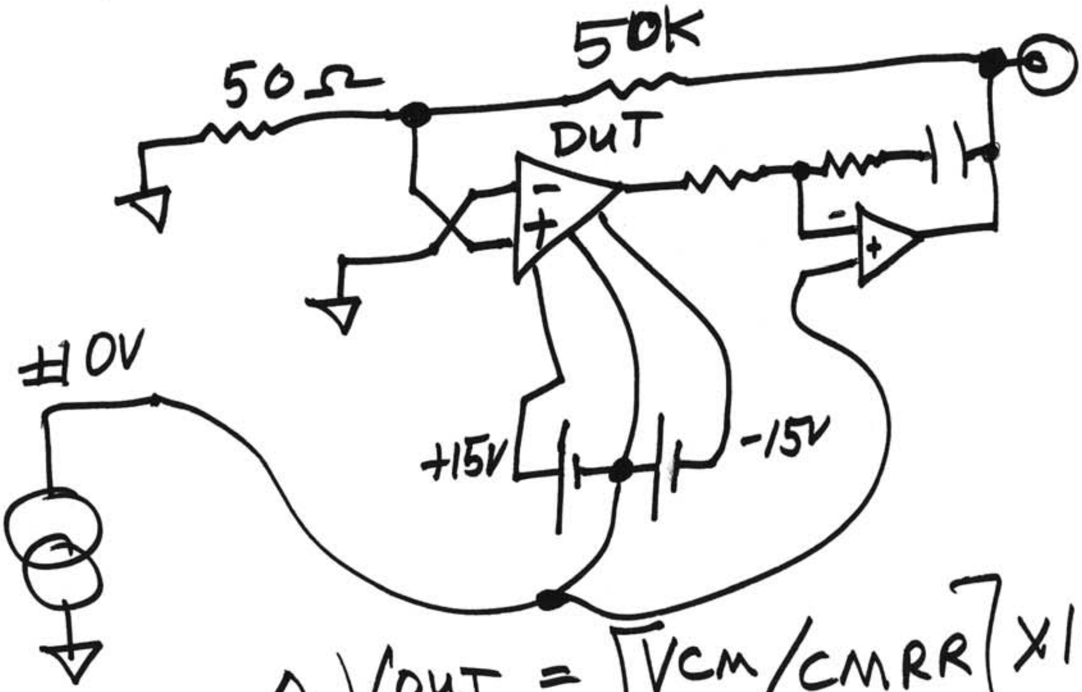
NG = 2 or 6

$4 \times V_{CM}/CMRR = \Delta V_{OUT}$

$BW \cong GBW/10$


CAUTION!
DC CMRR
AC CMRR
NONLINEAR ERROR DUE TO CM SLEW LIMIT

ANOTHER <u>VALID</u> WAY TO MEASURE CMRR:



$$\Delta V_{OUT} = \left[V_{CM} / CMRR \right] \times 1000$$

BUT,
BEWARE, THIS WORKS
<u>ONLY</u> AT DC & VERY
LOW FREQUENCIES.

- AC ERRORS ARE -
- UNSPECIFIED.

/RAP

What's All This

COMMON MODE REJECTION STUFF?

(Anyhow.....)

Part III –
Rail-to-Rail CM Range

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LIST OF TYPICAL OP-AMPS WITHOUT +Vs OR -Vs Rail CM Range

- LM741
- LM725
- LM108
- LM709 — and -
- MANY MANY MORE....

LIST OF OPAMPS WITH CM RANGE TO —VS [GROUND]

- LM 358 - LM 324
- LMV324 - LMV322 - LMV 321
- LMC 660 -(QUAD) LMC 662 (DUAL)
- MANY MORE -
- PLUS - ALL RAIL-TO-RAIL - INPUT CIRCUITS

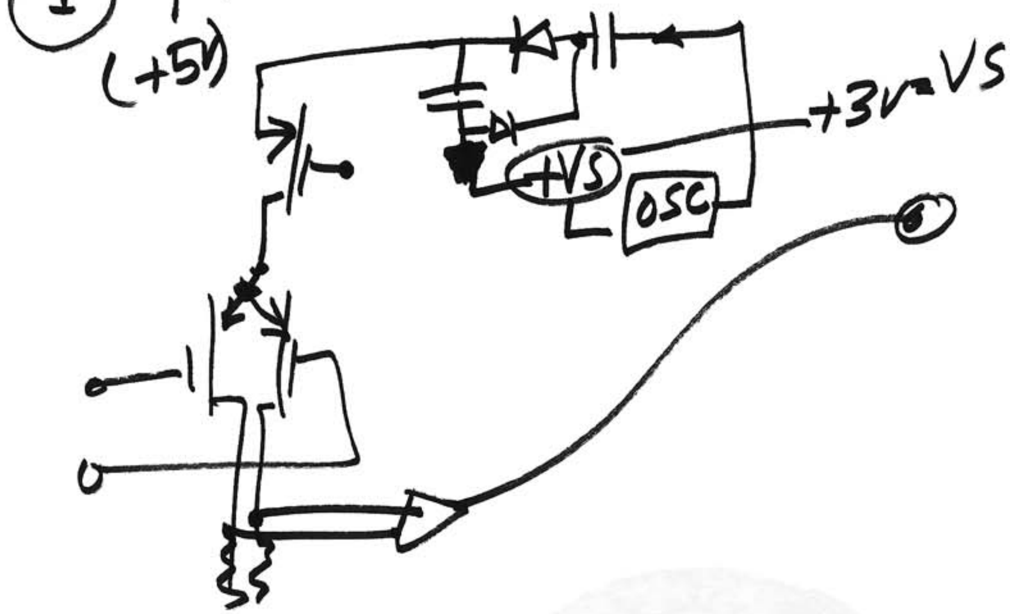
LIST OF OP AMPS
WITH CM RANGE TO +VS –

- LM101A – LM301A
- LF156 – 356
- LF411 – LF412 (DUAL)
- LF347, LF444
- LF351, LF353

— AND – OF COURSE –
ALL RAIL-TO-RAIL INPUT AMPLIFIERS

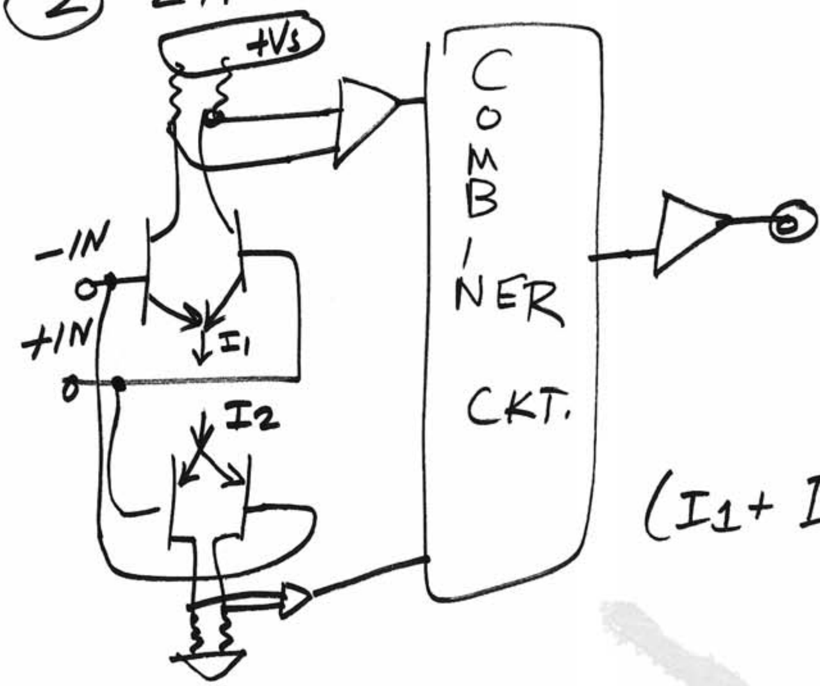
HOW TO MAKE - A - RAIL-TO-RAIL INPUT AMPL

(1) Pump it up -



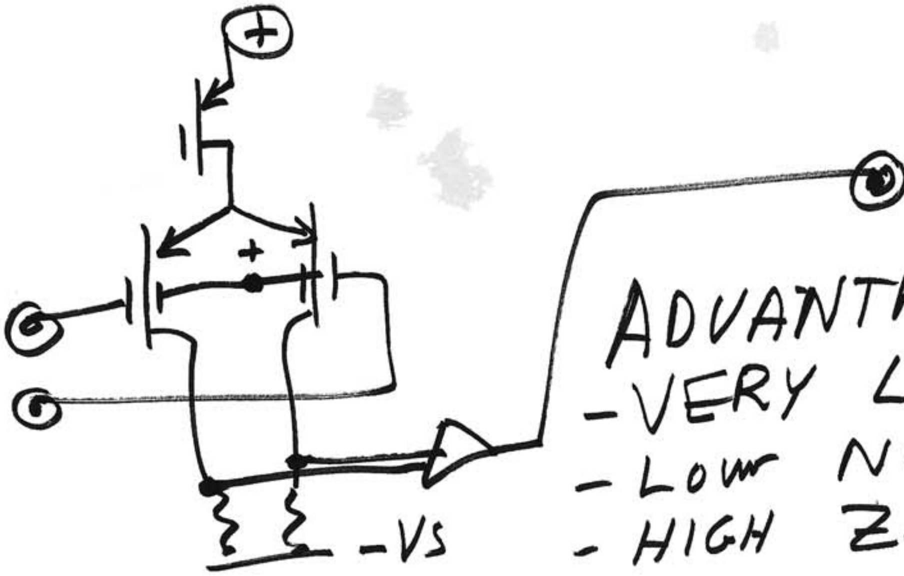
MAKE A R-R INPUT USING

② 2 INPUTS



($I_1 + I_2 \cong$ CONSTANT)

HOW TO MAKE R-R V_{cm} AMPLIFIERS USING SWOOPING MOS-FETS (U.S. PAT. ...

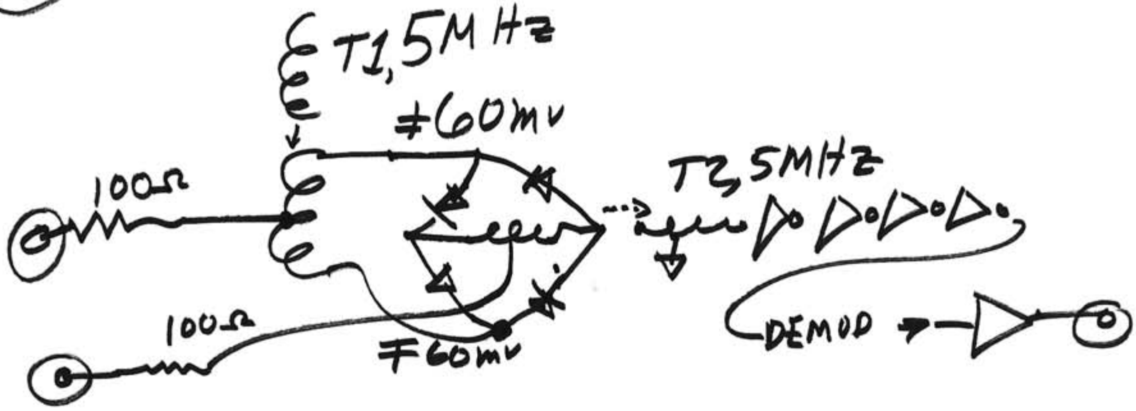


ADVANTAGES -

- VERY LINEAR
- LOW NOISE
- HIGH ZIN

HOW TO MAKE HIGH CMRange...

4 USE TRANSFORMERS...



ADVANTAGES - VCM >100V
- ZIN >100MΩ
- LoNOISE - 1μV for 100Hz

LATER WE'LL
EXPLAIN WHY
YOU MAY (OR MAY NOT)
NEED RAIL-TO-RAIL
C.M. RANGE

RAP

/more later. RAP

WHAT'S ALL THIS CMRR STUFF, ? (Anyhow?)

(PART IIII)

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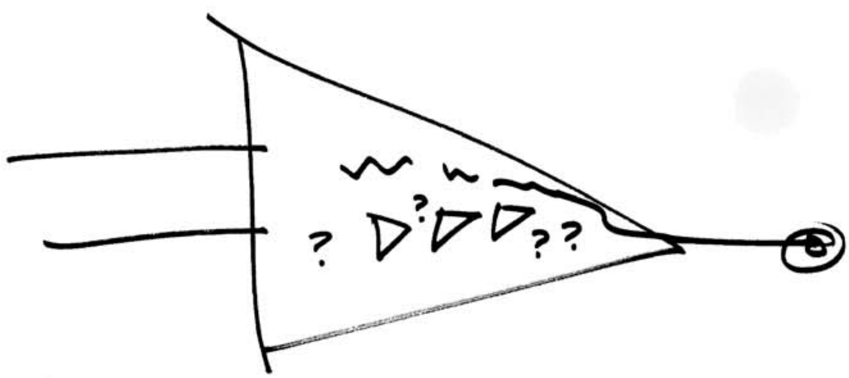
Differential Amplifiers

(OR) Instrumentation Amplifiers.



OK - WHAT IS
AN "INSTRUMENTATION
Amplifier"?

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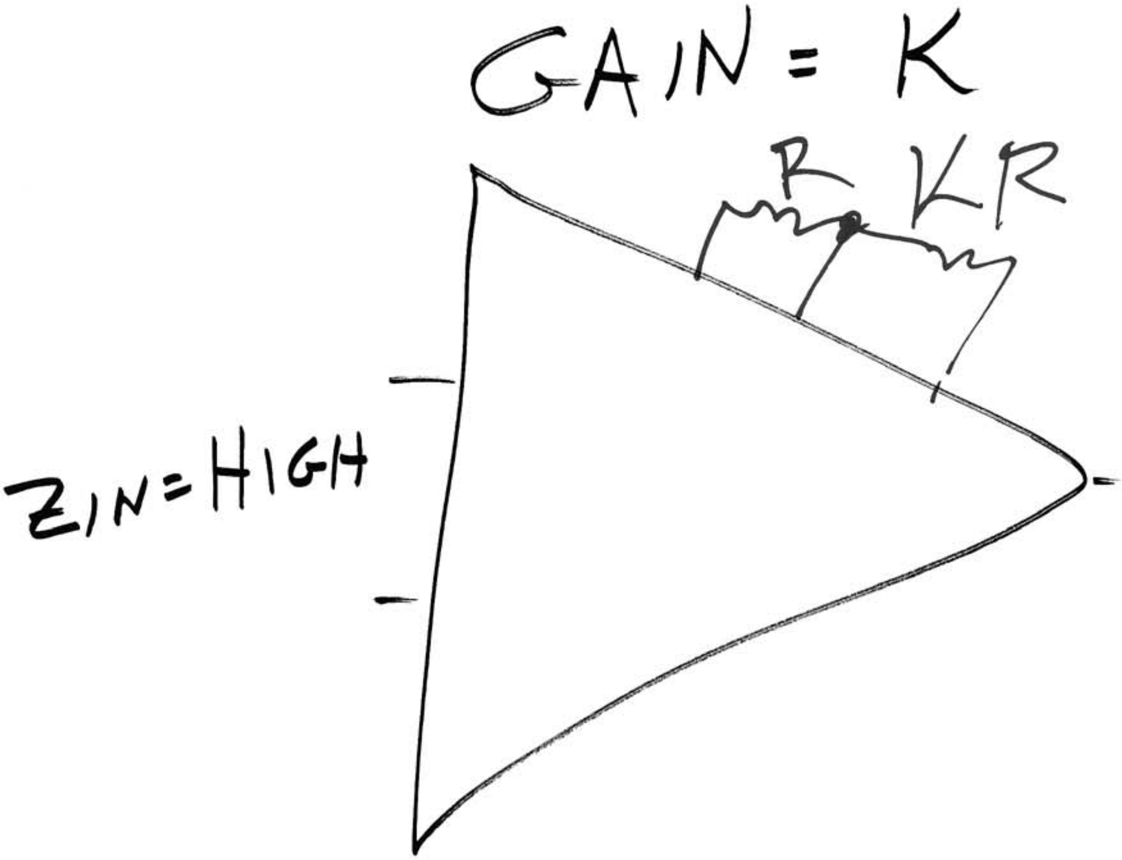
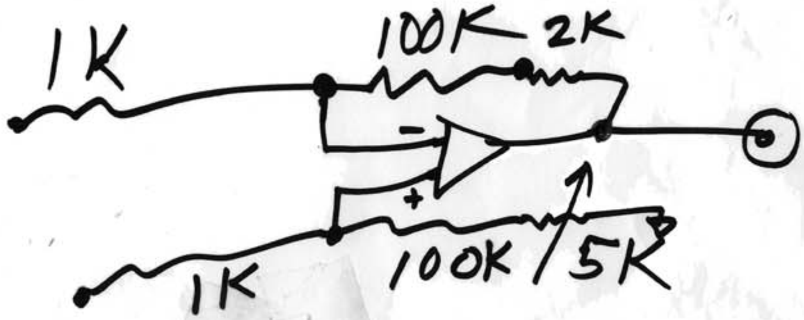

GAIN = K
R
KR
ZIN=HIGH

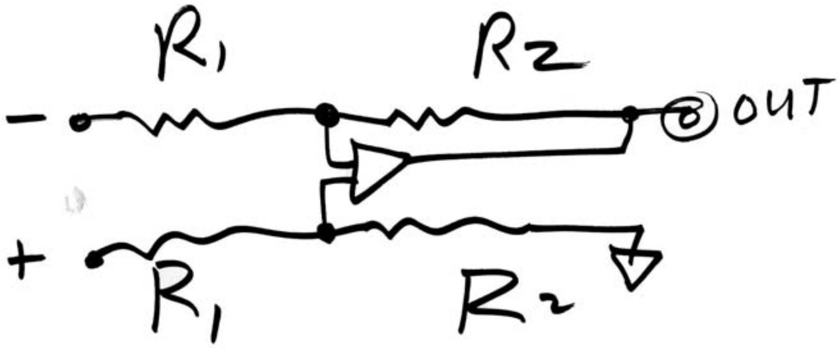
NOTE, THE OLD
μA725 data-sheet
SAID IT WAS "AN
INSTRUMENTATION
AMPLIFIER"

It wasn't....
It isn't....

NOTE –
(almost) ALL
Instrumentation Amplifiers
need R TRIMS....

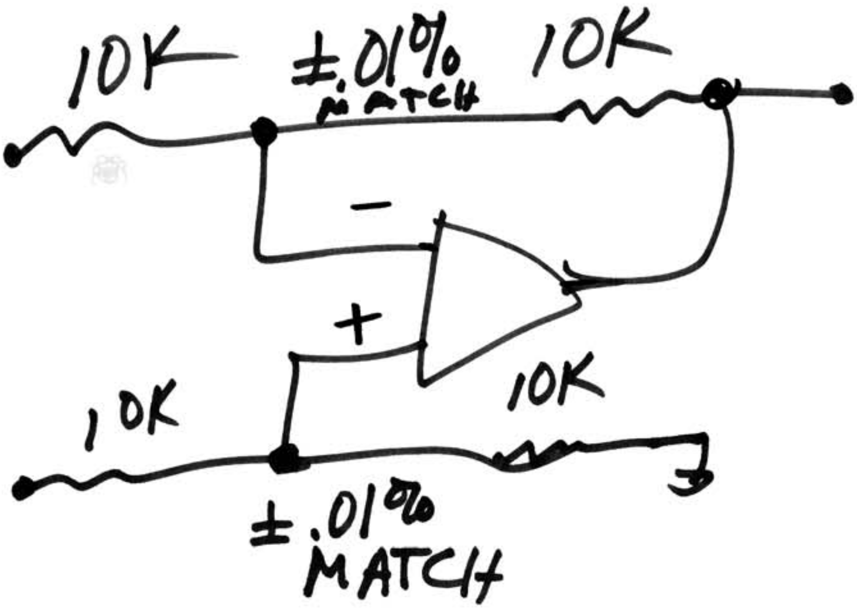


You'll need a TRIM POT.
for CMRR



- GOOD Differential Amplifier
- Needs TRIMS

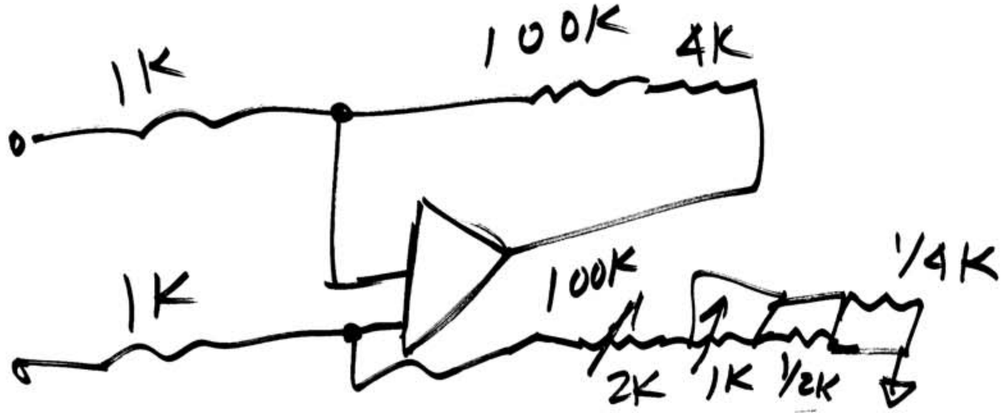
BUT - ZIN ISN'T HIGH.....



YOU WANT
THIN-FILM
NETWORKS WITH
0.01% MATCHING....

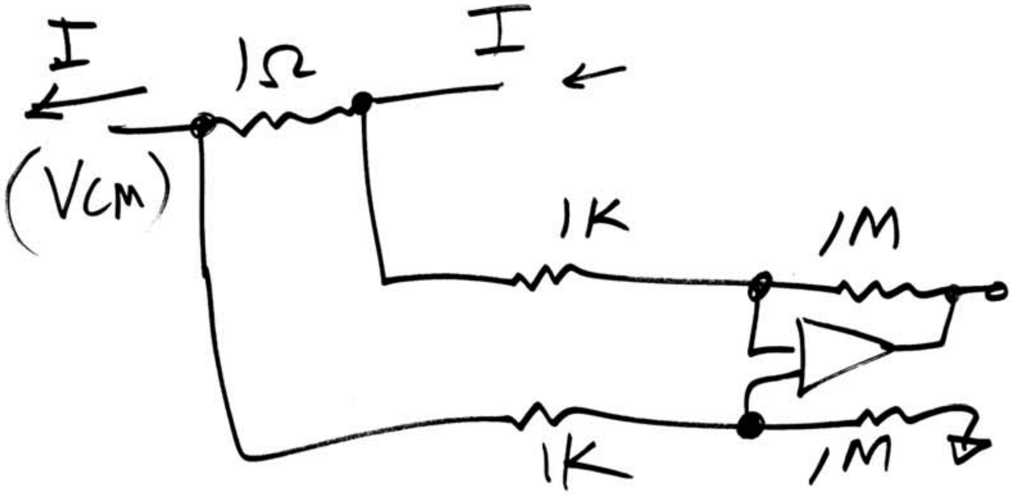
NOT JUST FOR
CORRECTING
(CANCELLING OUT)
the Op-amp's CMRR
BUT R-RATIO
1% Resistors? Ha!
0.1% Resistors? (A BIT BETTER.)
0.01% MATCH? .....

DO YOU WANT TO TRIM YOUR CMRR WITHOUTA POT?

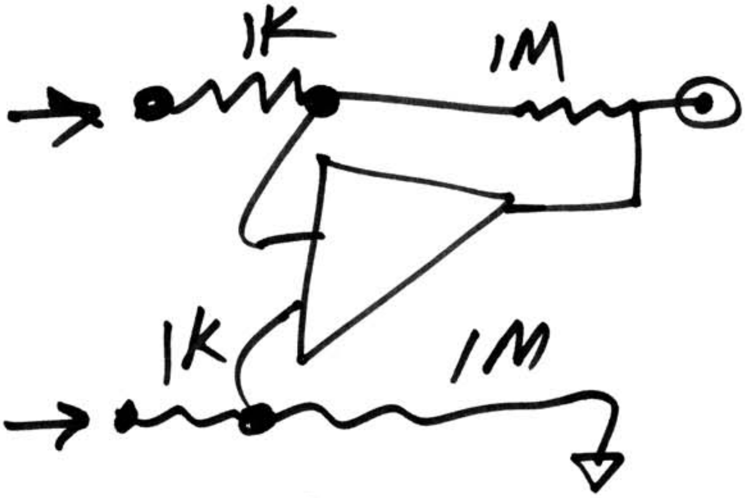


Refer to LB-46...

EXAMPLE ...

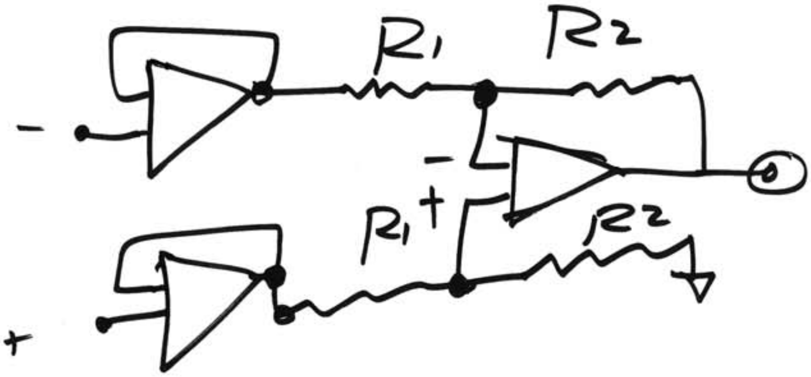


Beware of -
- Vos -
- CMRR ....



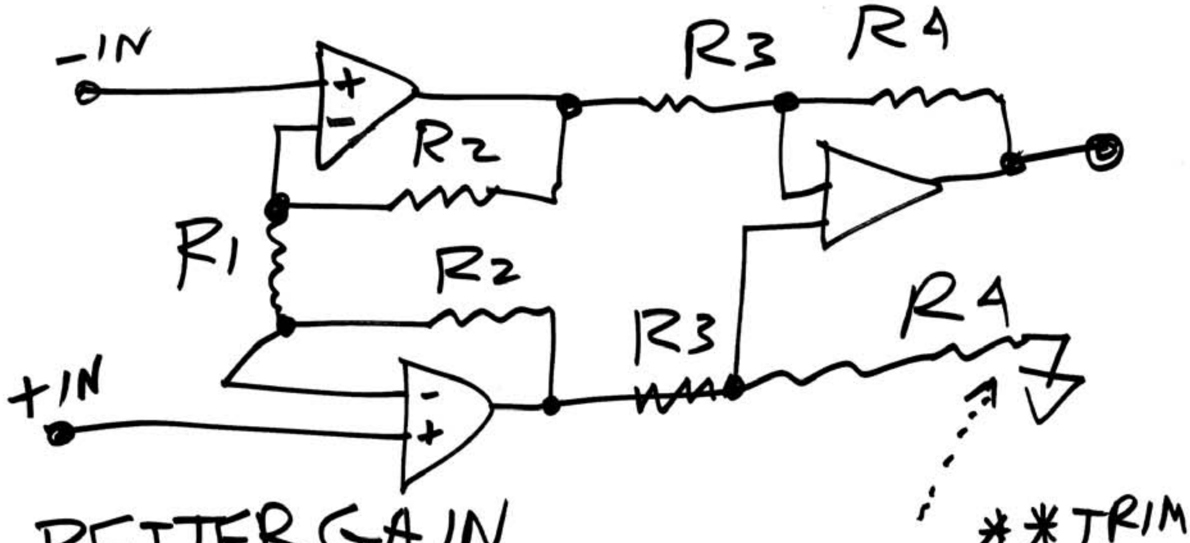
OK —
what is the ZIN?
1K?
1M?

IMPROVED!!



PER THE LM102 Datasheet....

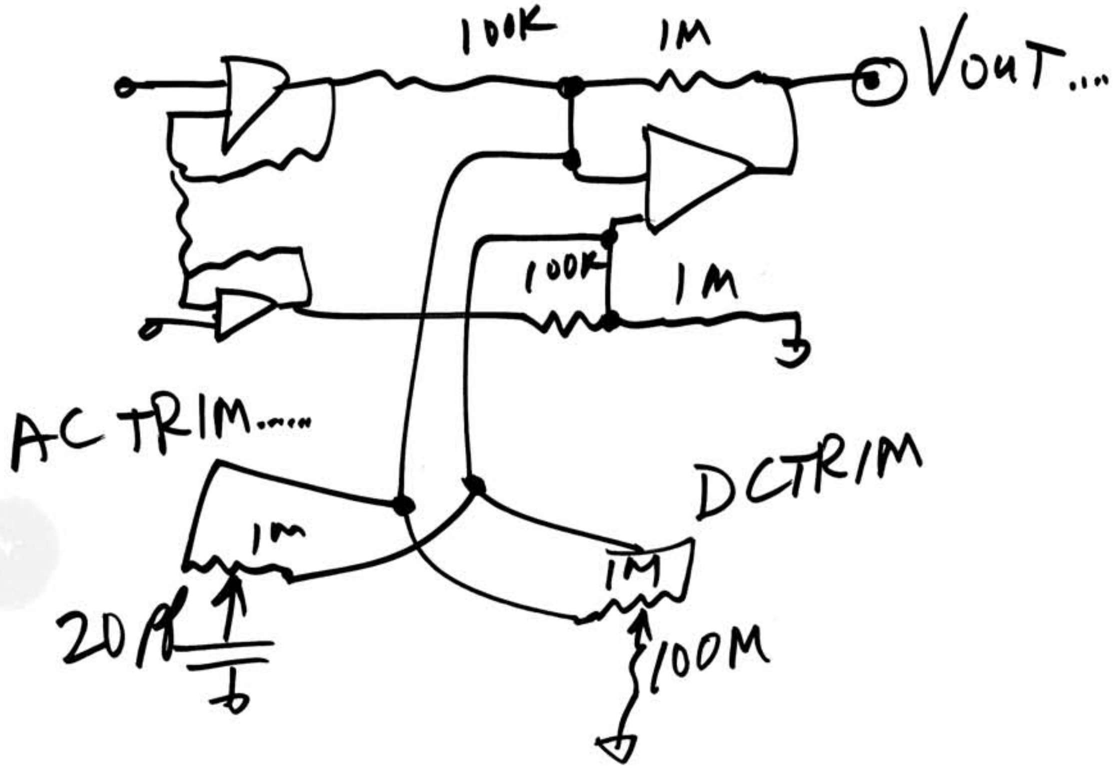
REALLY GOOD CIRCUIT !!!



- BETTER GAIN
- BETTER BW.
- BETTER CMRR.....

- $G = (R_2 + R_2 / R_1) + 1 \times (R_4 / R_3)$
- CMRR is improved by $\sim R_4/R_3$
- BW is improved

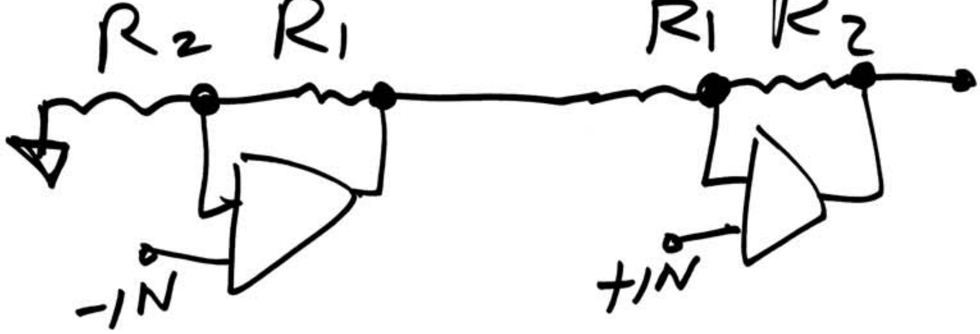
OTHER TRIM GAMES....



CAUTION ABOUT

C.M. SLEW RATE....

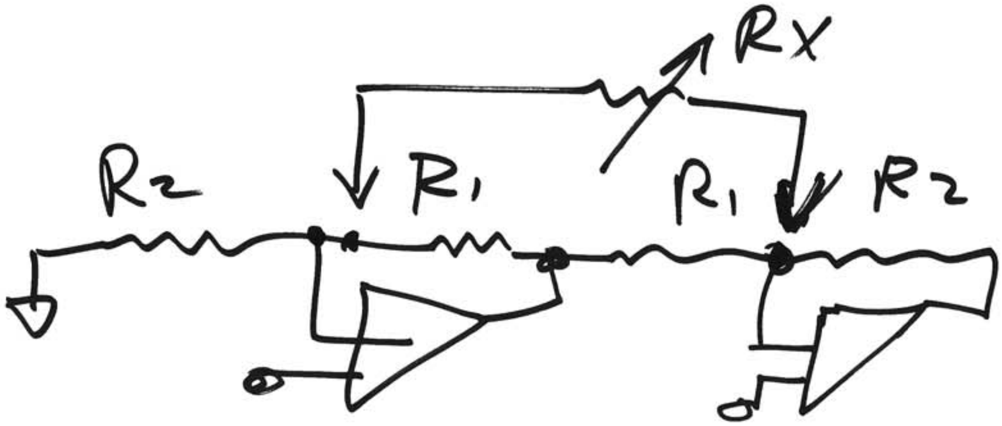
SIMPLER IS BETTER



$$G = \frac{R2}{R1} + 1 \quad !$$

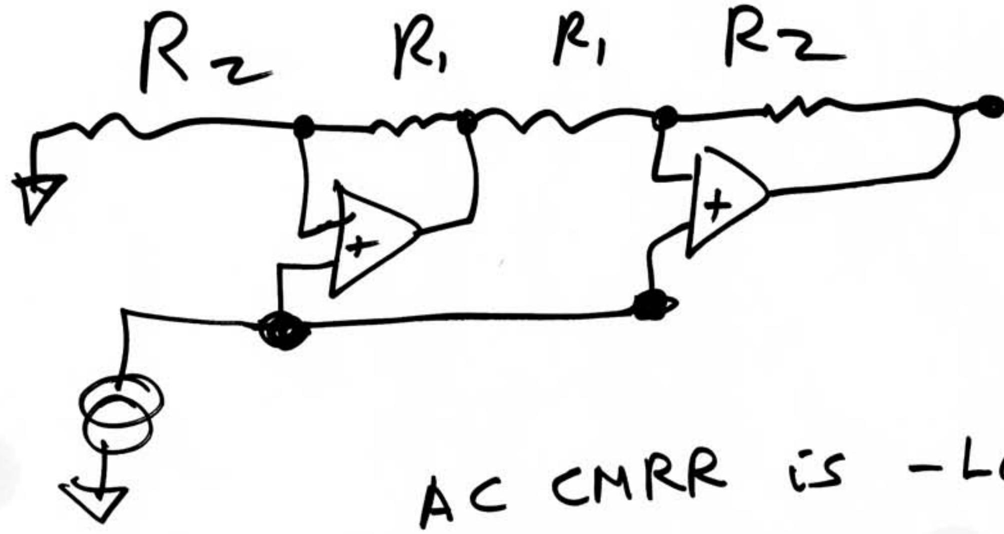
(Well, Maybe NOT....)

GOOD NEWS!

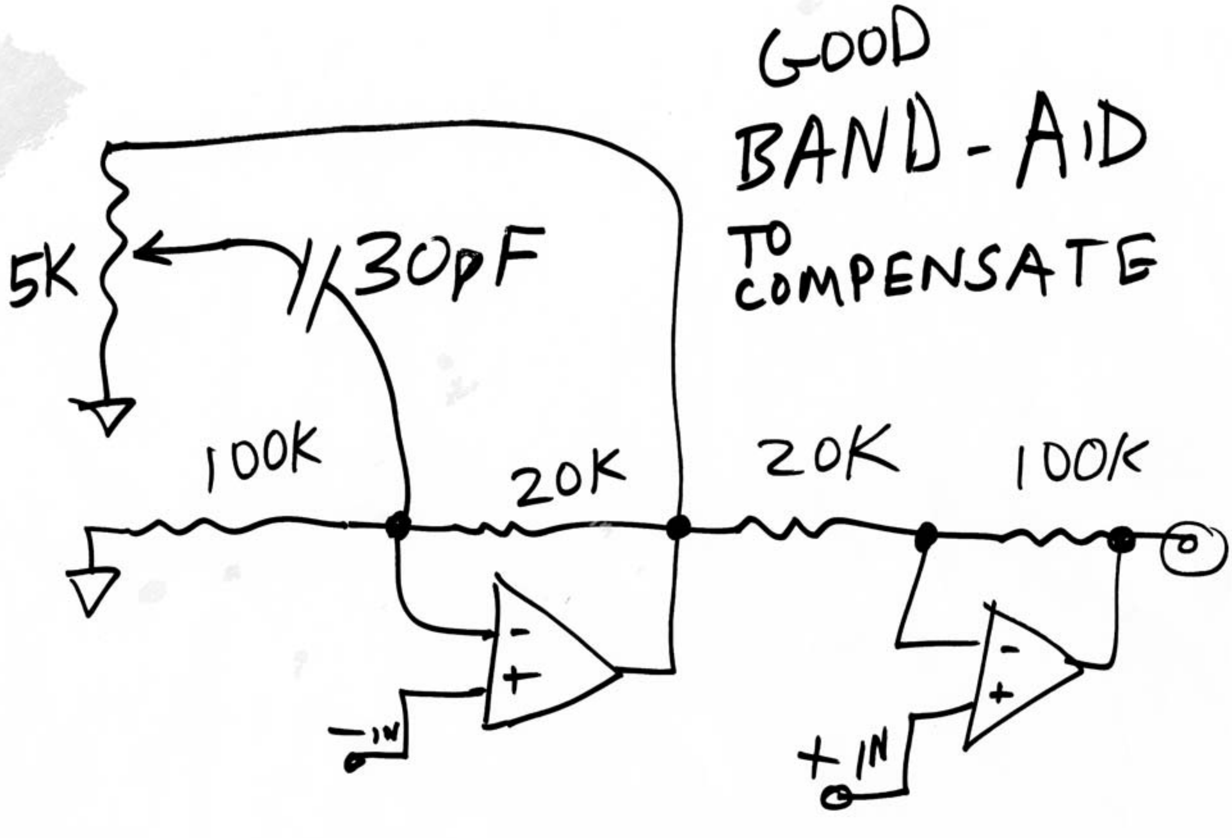


$$G = \left(\frac{R2}{R1} + 1\right) + \left[\frac{2R2}{RX}\right]$$

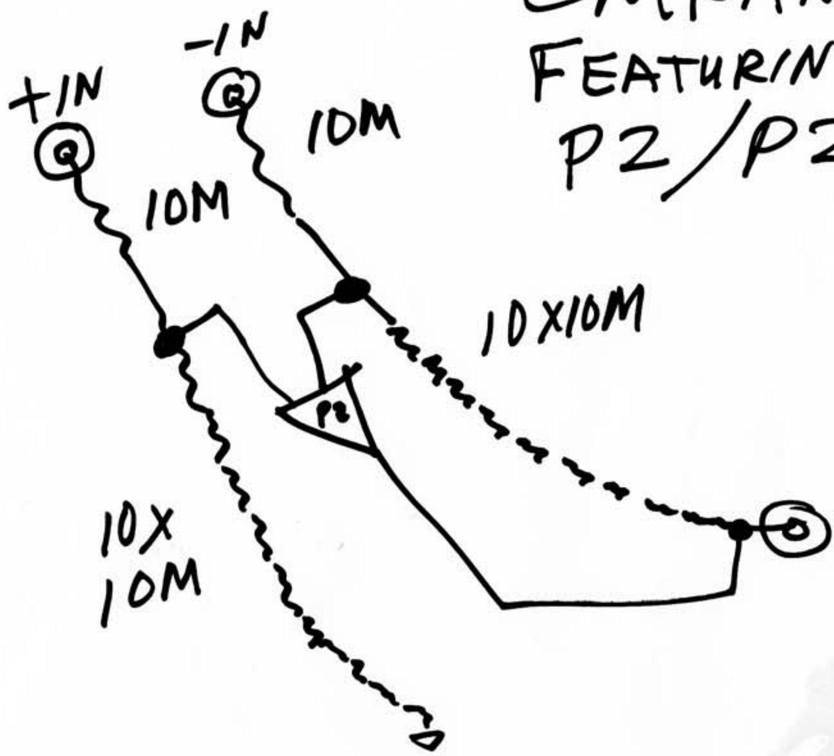
NOT SO GOOD NEWS...



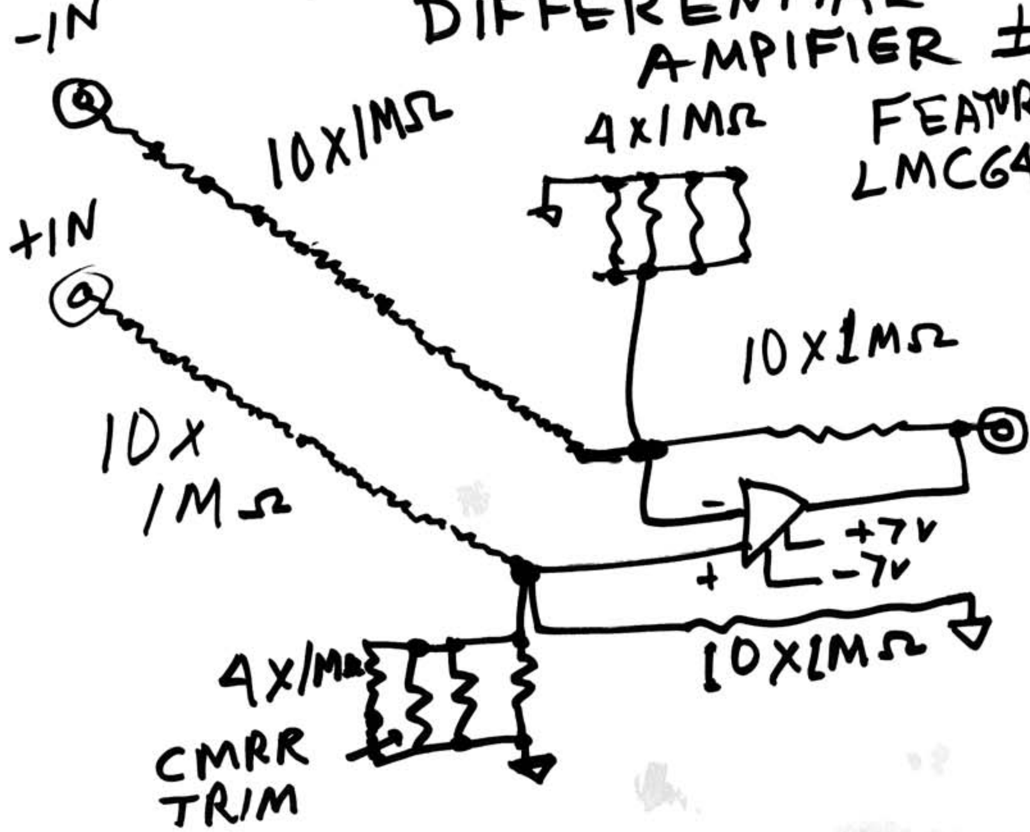
AC CMRR is -LOUSY....


GOOD
BAND-AID
TO
COMPENSATE
5K
30pF
100K
20K
20K
100K
-IN
+IN

±200 Volts of CMRANGE Featuring P2/P2A



HIGH CM-RANGE DIFFERENTIAL AMPIFIER ±200V FEATURING LMC6484



DOUBLE INPUTS

LMH6645, -46 -47 -(55MHz)

LM6152, 6154 (75MHz)

LM7301 (TINY)

LM6134, LM6132 (LOW Power)

LM6142, 44 " "

LM8261, -62 -(∞ Cap Load)

LMV931, -32, -34 (1.8V Supply)

SMOOTH & SWOOPING

LMC6482, -84

LMV710, -711, -712

LMC6462, -64

LMC8101

LMC6494

DUAL/QUAD

LOW PWR.

μPOWER

SINGLE

QUAD

WHAT'S ALL THIS STUFF, ?

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The Bob Pease Show

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