Bob Pease
Lab notes 2005

National Semiconductor
The Sight & Sound of Information

What's All This

- Common
Mode
Rejection
Stuff?

(Anyhow....)

/RAP

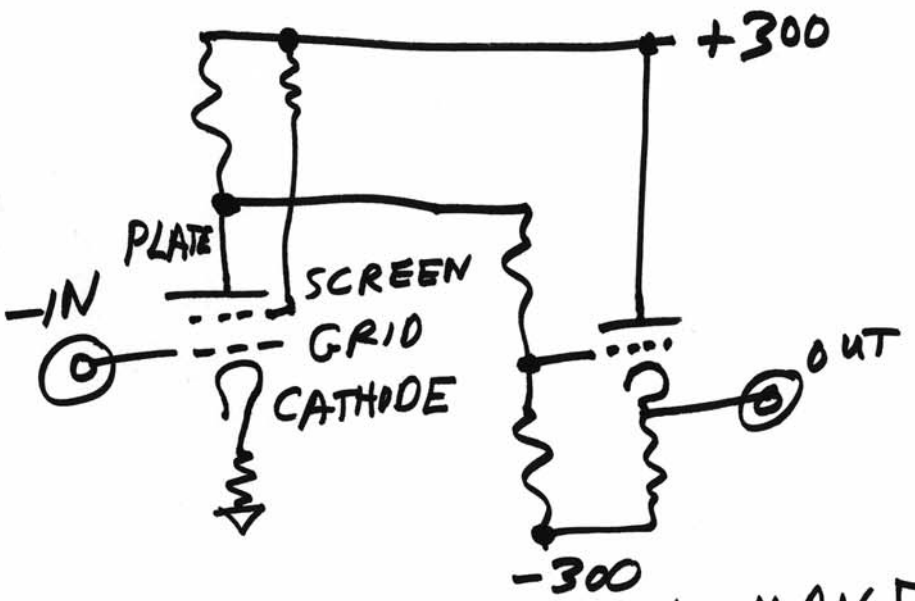
PART I: HISTORY....
R. A. PEASE...

PART II - How to test Op amps for CMRR

PART III DESIGN FOR RAIL-TO-RAIL CM Range

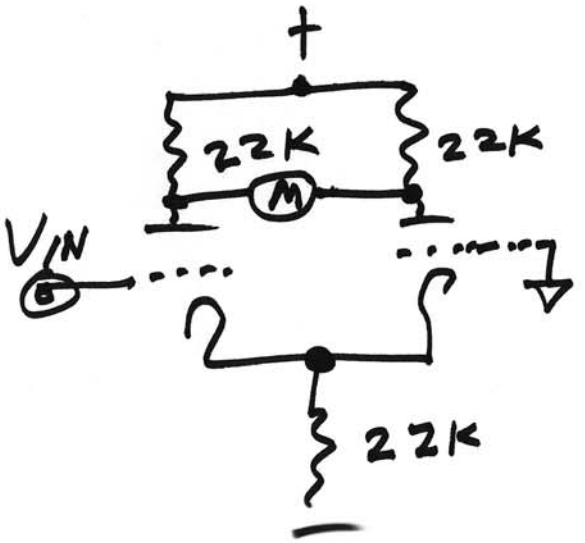
Part IV CIRCUIT DESIGN FOR GOOD CMRR

ONCE UPON A TIME....



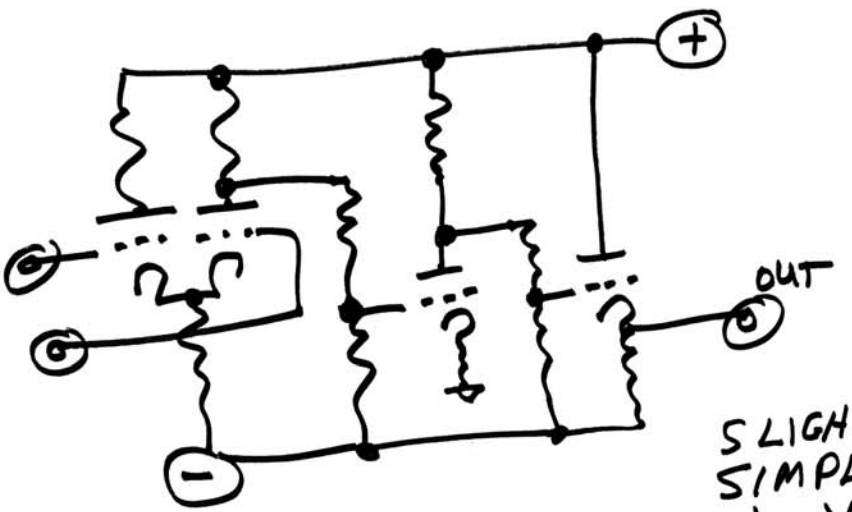
- OPAMPS DIDN'T HAVE ANY COMMON-MODE RANGE....

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



RAP

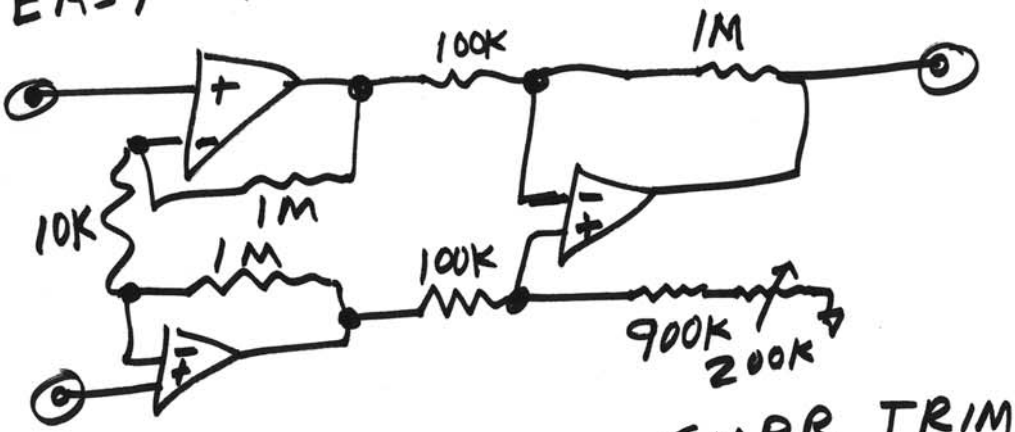
AND THE K2-W CAME ALONG ~ 1952



SLIGHTLY SIMPLIFIED ....
....÷ = ½ 12AX7

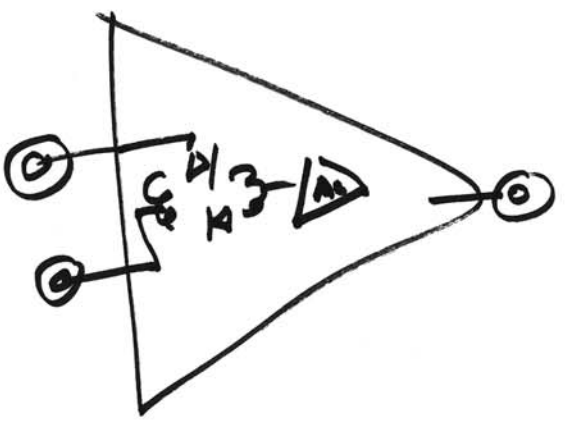
CMRR ≅ 300 for ±50V

STILL - Differential Amplifier CIRCUITS WERE NOT EASY TO DESIGN WITH TUBES...



[Vos TRIM NOT SHOWN]

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

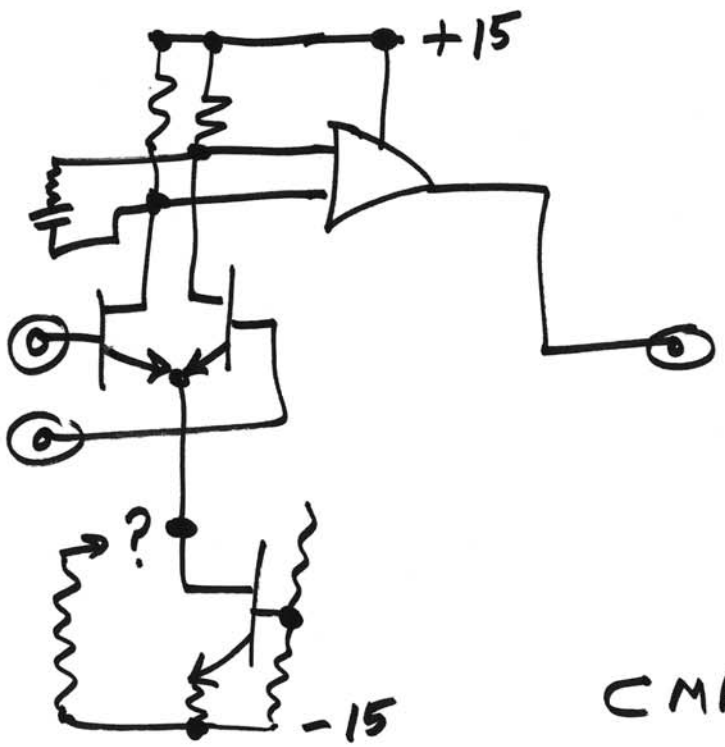


THE CMRR WAS ~ ∞

- IN 1961...

BOB

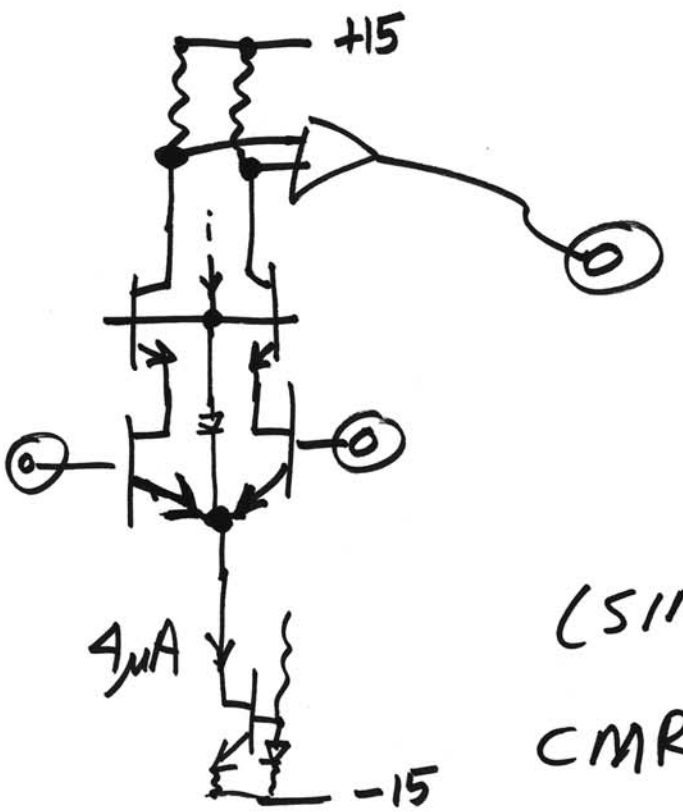
SILICON TRANSISTORS MADE GOOD OP-AMPS POSSIBLE



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

4B

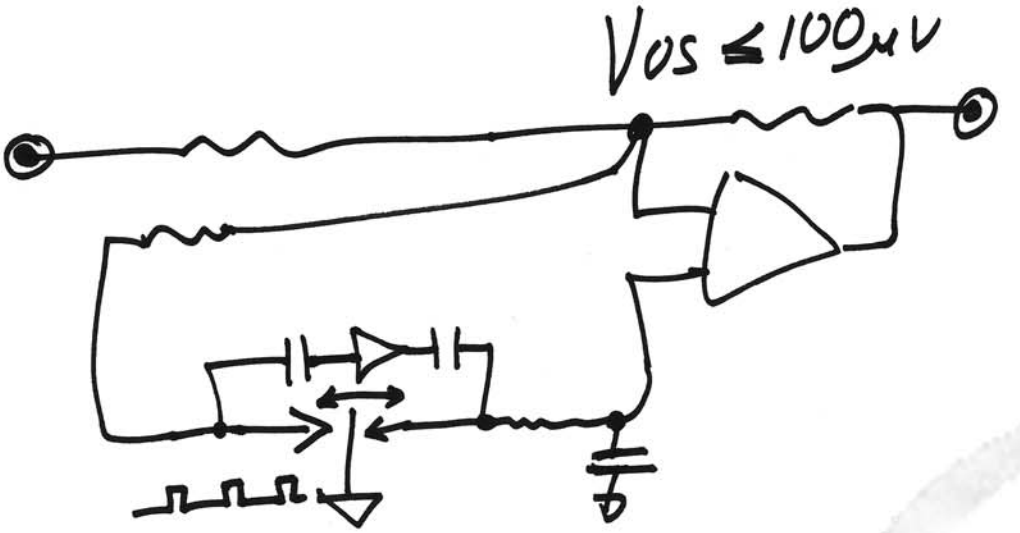
BOB WIDLAR'S LM108
MADE HIGH CMRR
FEASIBLE



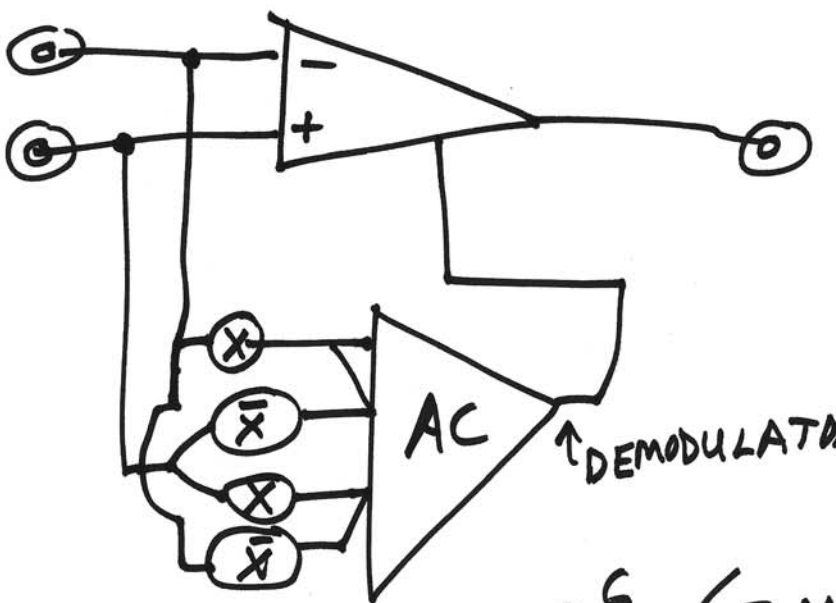
(SIMPLIFIED CIRCUIT)

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



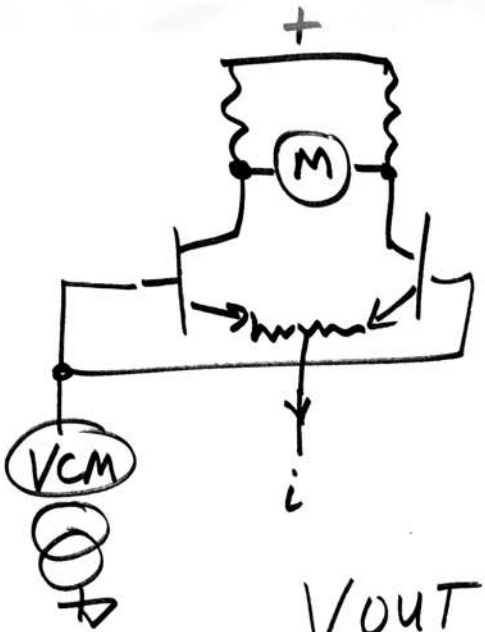
CMRR > 10^6 (3M typical)

WHAT'S ALL THIS COMMON MODE REJECTION STUFF?

(ANYHOW.....?)

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

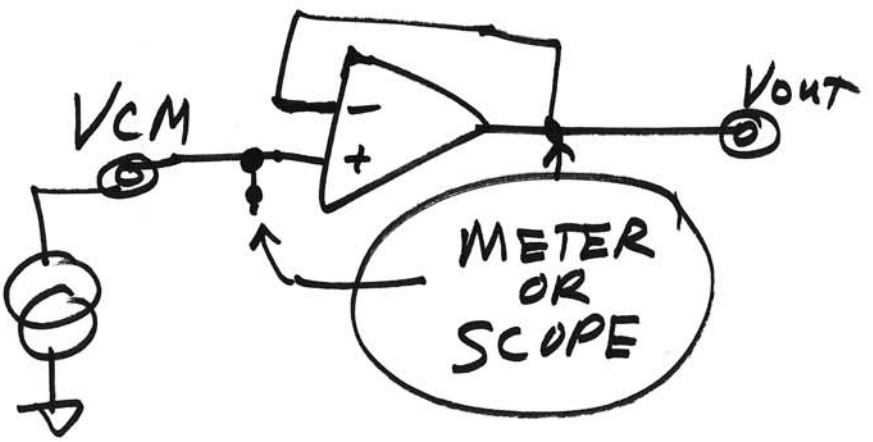
OK - NOW WE HAVE GOOD OP-AMPS - HOW TO MEASURE?



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

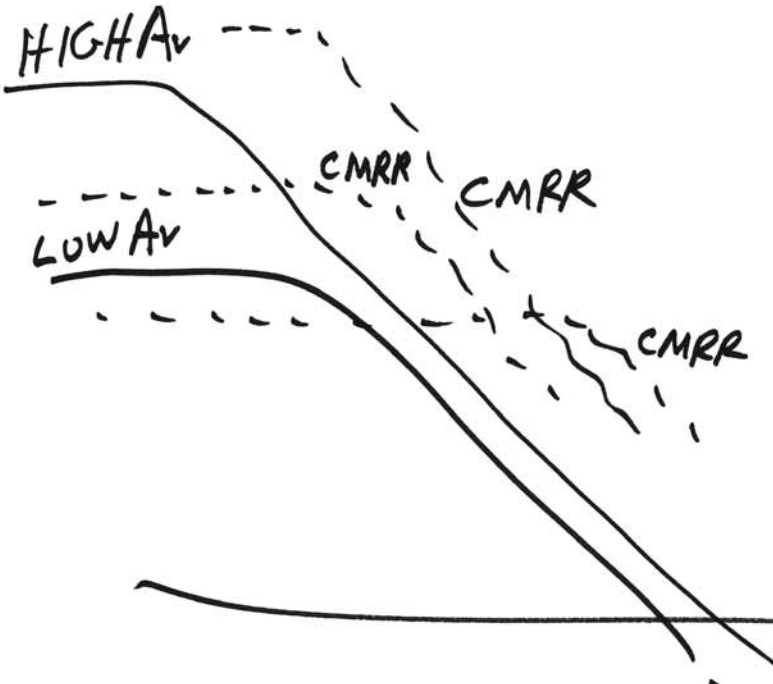
BUT THIS ONLY WORKS FOR LOW GAIN - NOT FOR OPAMPS...

Is THIS A GOOD WAY TO MEASURE CMRR?



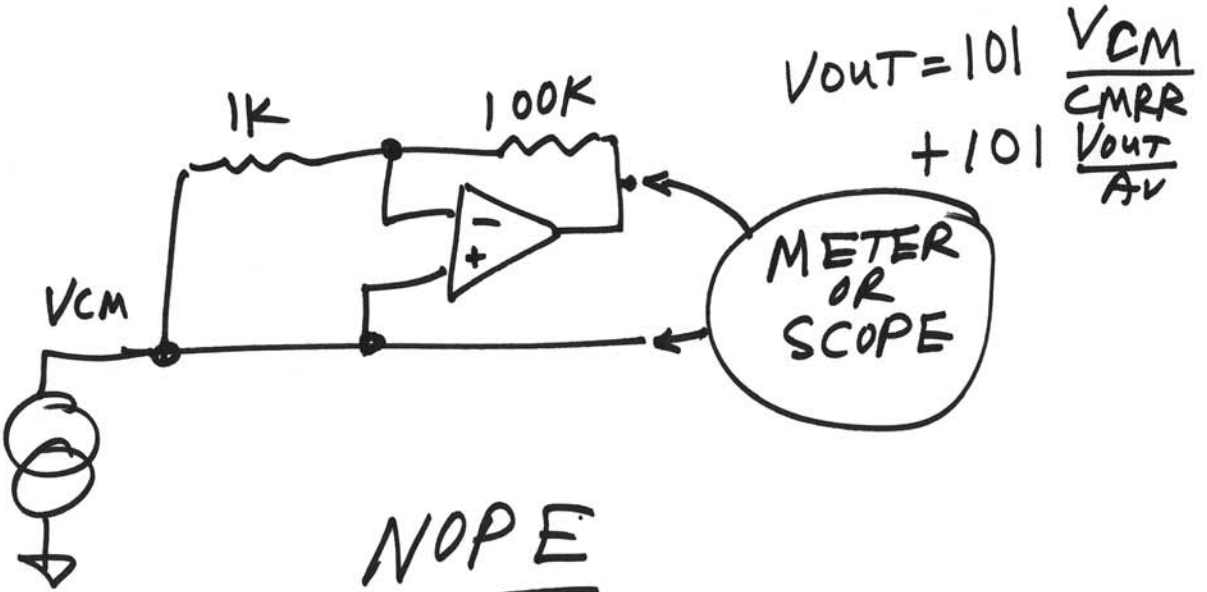
– NO –

RAP



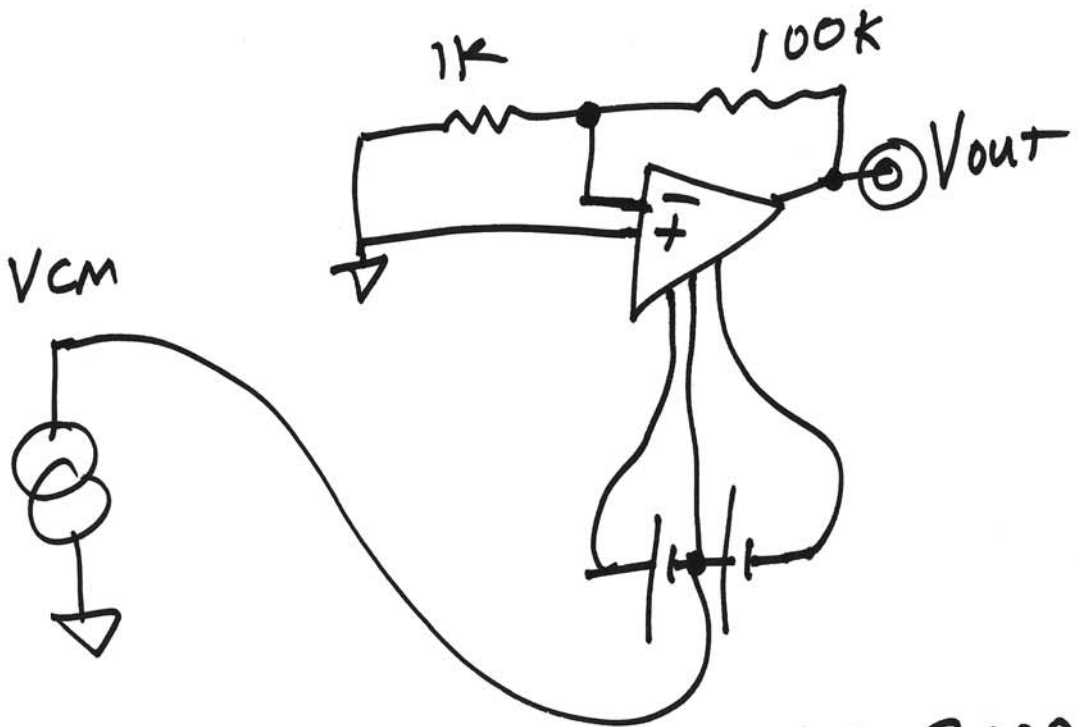
IN GENERAL - YOU CAN'T PREDICT
HIGH OR LOW DC GAIN OR CMRR,
HIGH OR LOW AC GAIN OR CMRR.

AH - THIS MUST BE A GOOD WAY TO MEASURE CMRR



NOPE

THIS HAS TO BE GOOD



UH - UH. NOT GOOD

$V_{OUT} = 101\,[V_{CM}/CMRR + V_{OUT}/A_V]$

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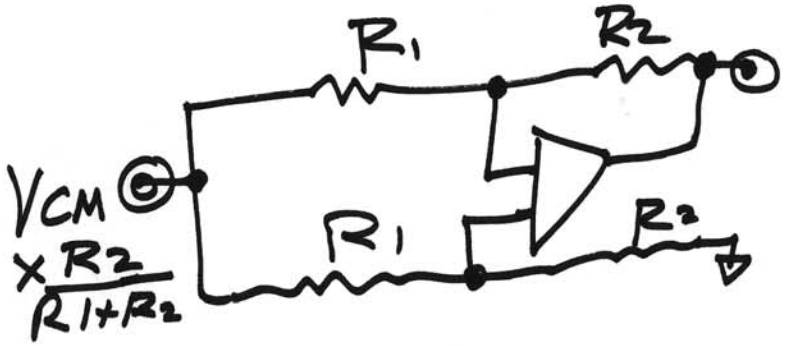
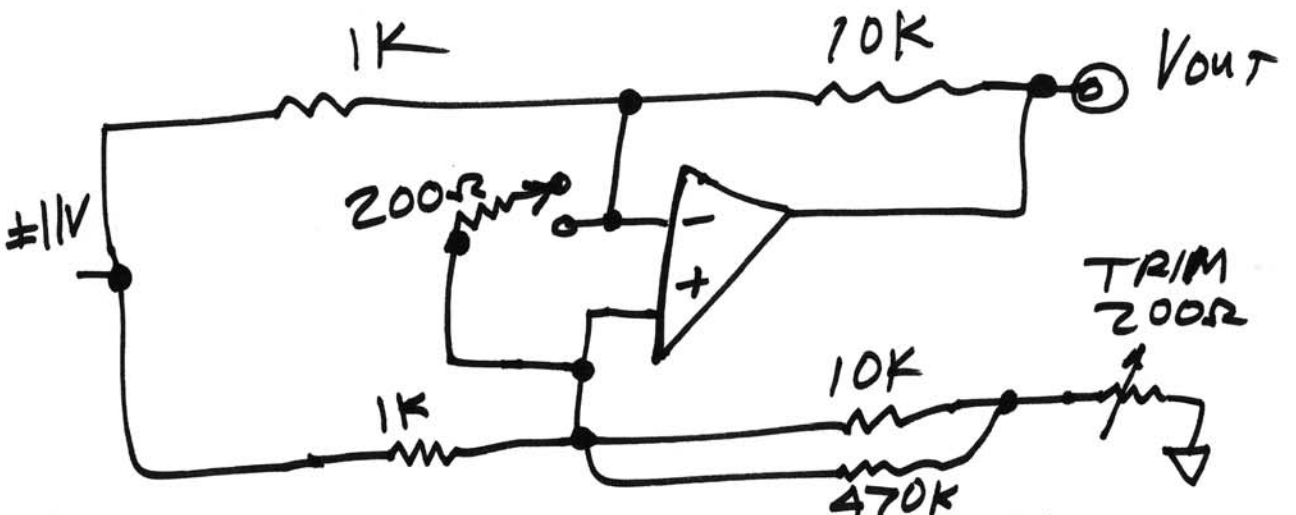
OK, HOW ABOUT THIS?

- ASSUME PERFECT RESISTORS



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

AHA - WE'VE GOT IT!!



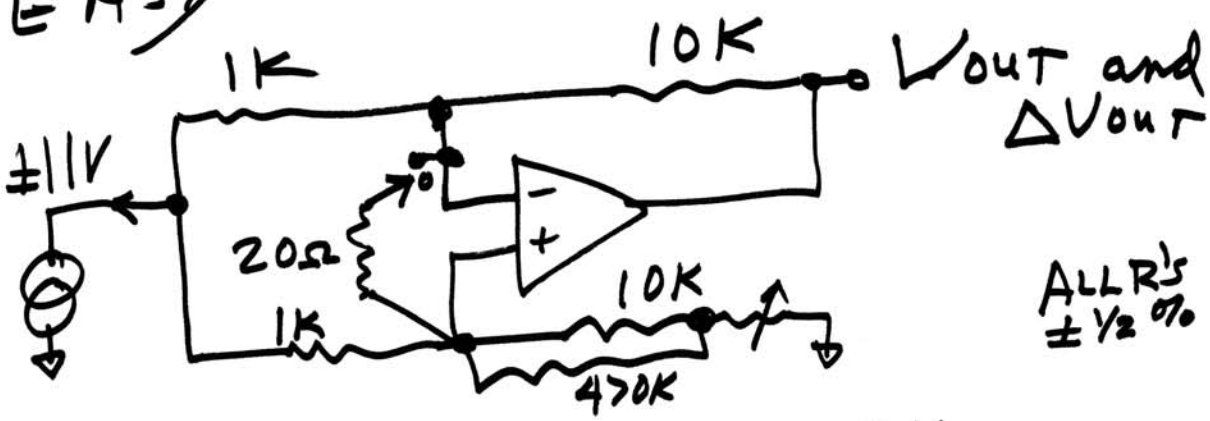
NOISE GAIN = 11 - OR - 111

SO $V_{OUT\,(p\text{-}p)} = (V_{CM}/CMRR) \times 11$ or 111

THUS - $V_{CM}/CMRR \times 100 = \Delta V_{OUT}$

WHAT IF YOU NEED TO MEASURE CMRR > 110dB?

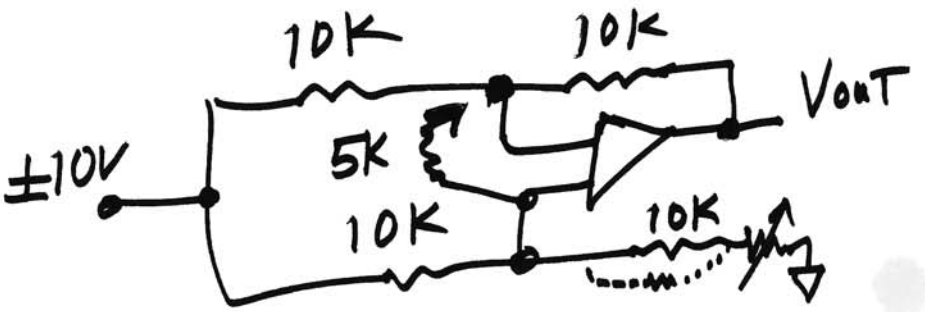
EASY!



NOISE GAIN = 11 or 1011

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

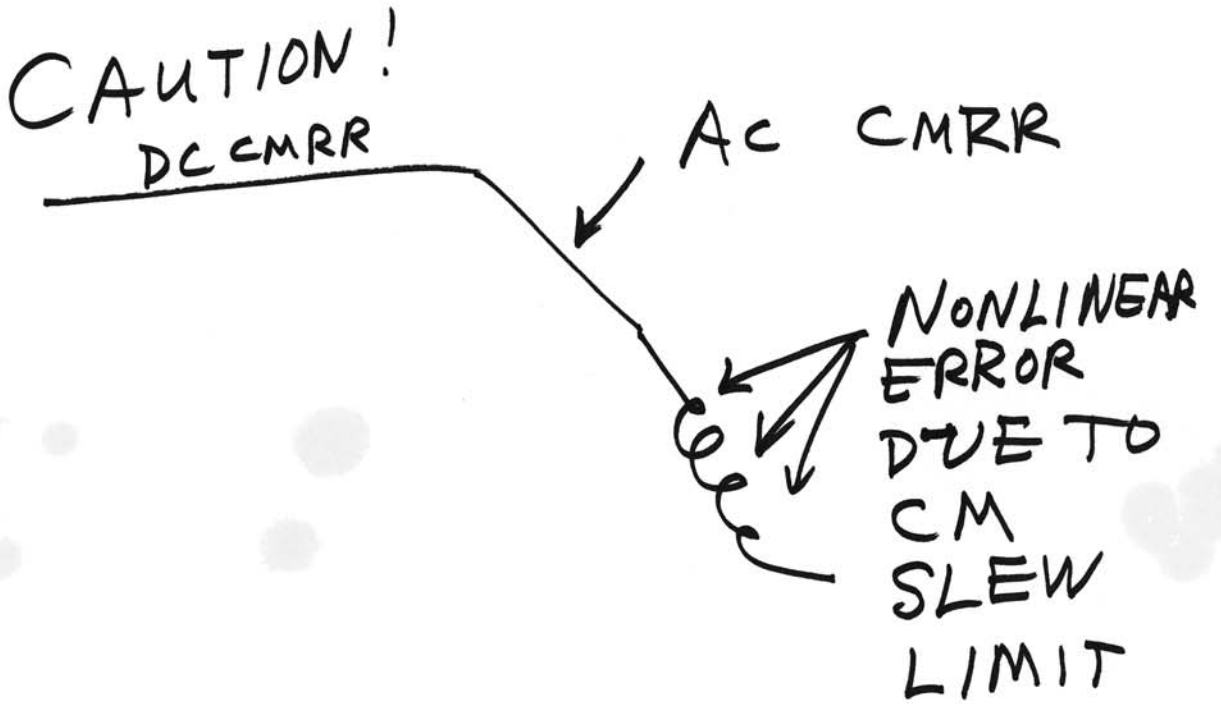
WHAT IF YOU NEED TO MEASURE CMRR FOR 50KHZ?



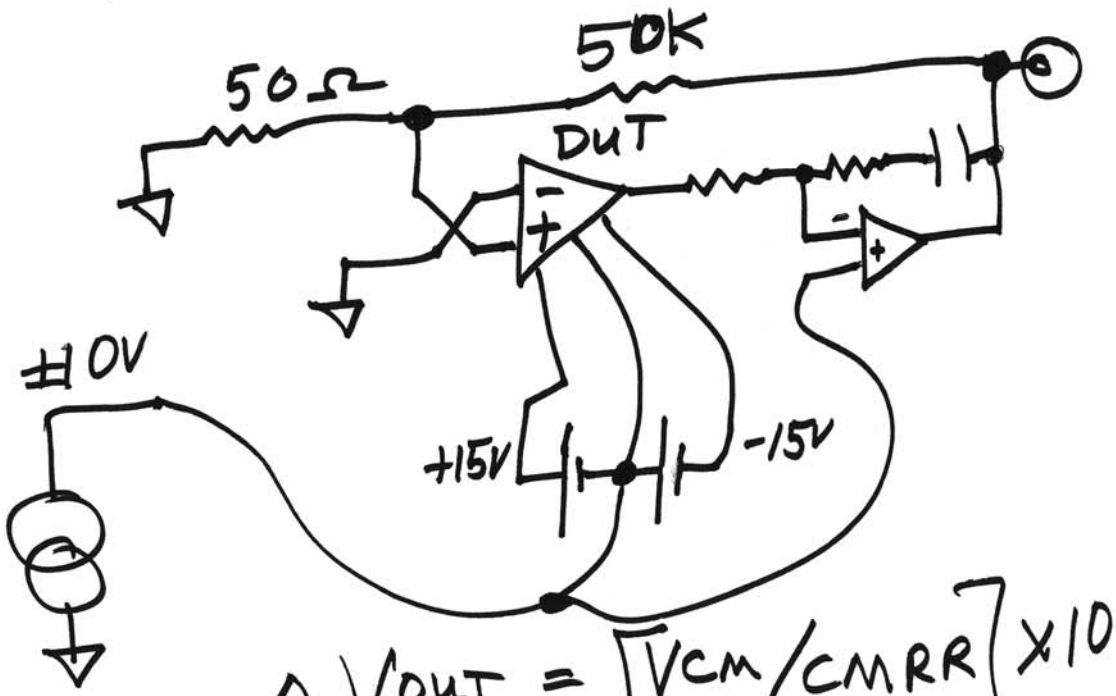
NG = 2 or 6

4 x VCM/CMRR = ΔVOUT

BW ≅ GBW/10


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

ANOTHER VALID WAY TO MEASURE CMRR:



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

BUT,
BEWARE, THIS WORKS
ONLY 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

RAP

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) LMC662(DUAL
- MANY MORE -
- PLUS - ALL RAIL-TO-RAIL - INPUT CIRCUITS

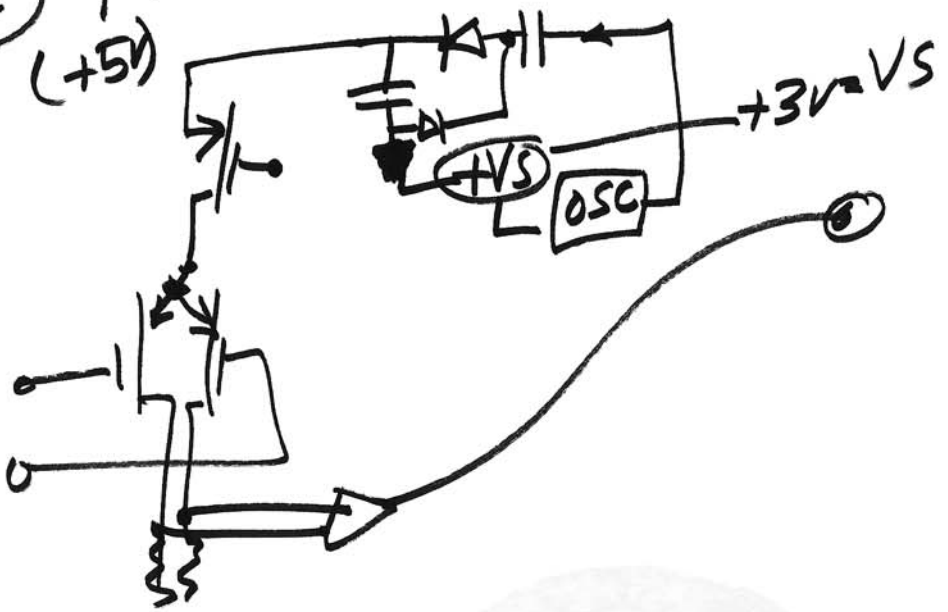
LIST OF OP AMPS
WITH CM RANGE TO +VS −

- LM101A - LM301A
- LF156 - 356
- LF411 - LF412 (DUAL)
- LF347, LF 444
- LF351, LF 353

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

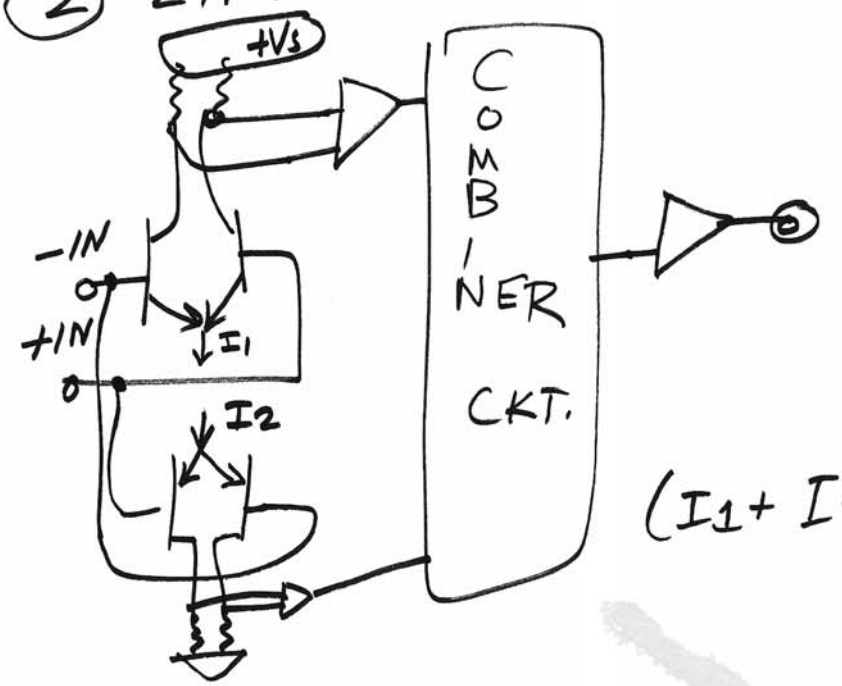
HOW TO MAKE A RAIL-TO-RAIL INPUT AMPL

(1) Pump it up -



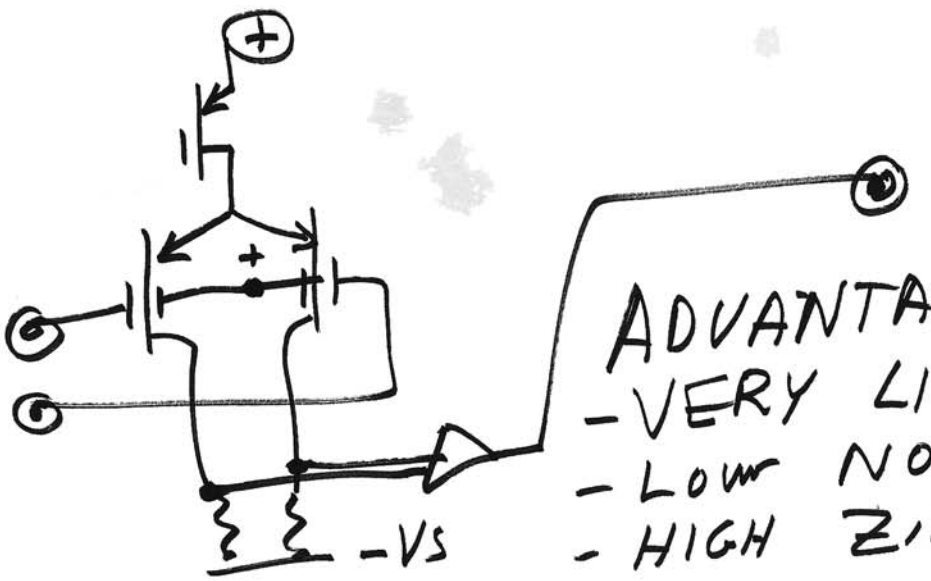
MAKE A R-R INPUT USING

(2) 2 INPUTS



$(I_1 + I_2 \cong \text{CONSTANT})$

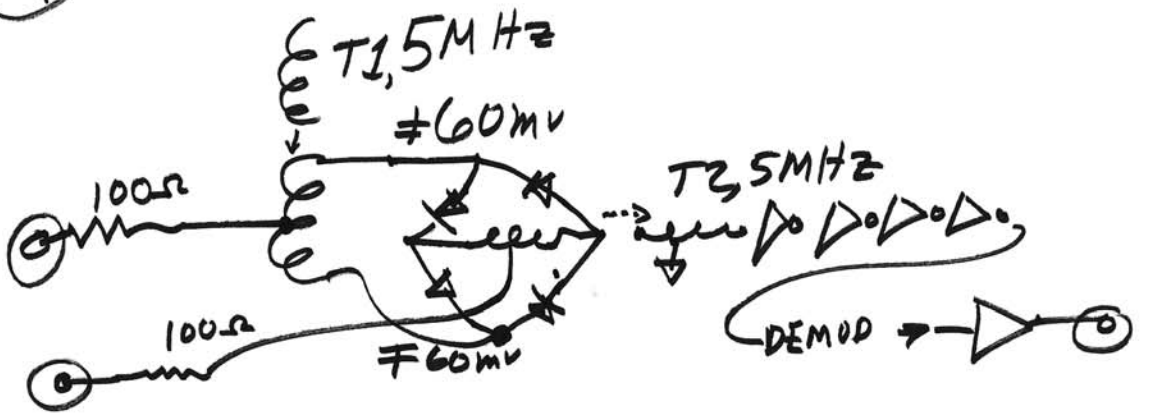
HOW TO MAKE R-R V_{CM} AMPLIFIERS USING SWOOPING MOS-FETS (U.S. PAT. ...



ADVANTAGES -
- VERY LINEAR
- LOW NOISE
- HIGH Z_{IN}

HOW TO MAKE HIGH CM Range...

(4) USE TRANSFORMERS...



ADVANTAGES - $V_{CM} > 100V$
- $Z_{IN} > 100M\Omega$
- Lo Noise - $1\mu V$ 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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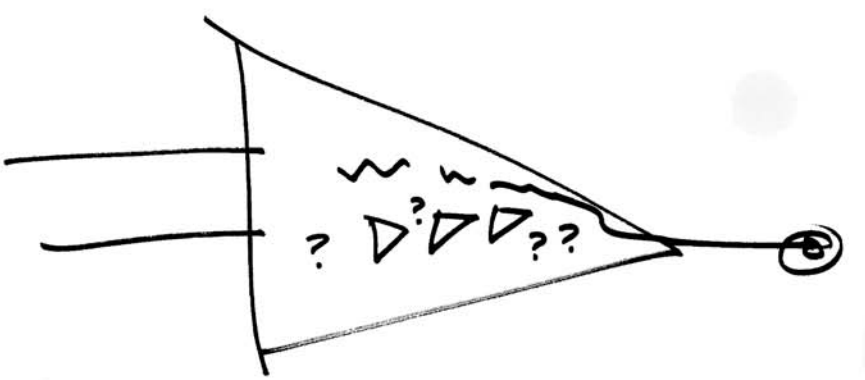
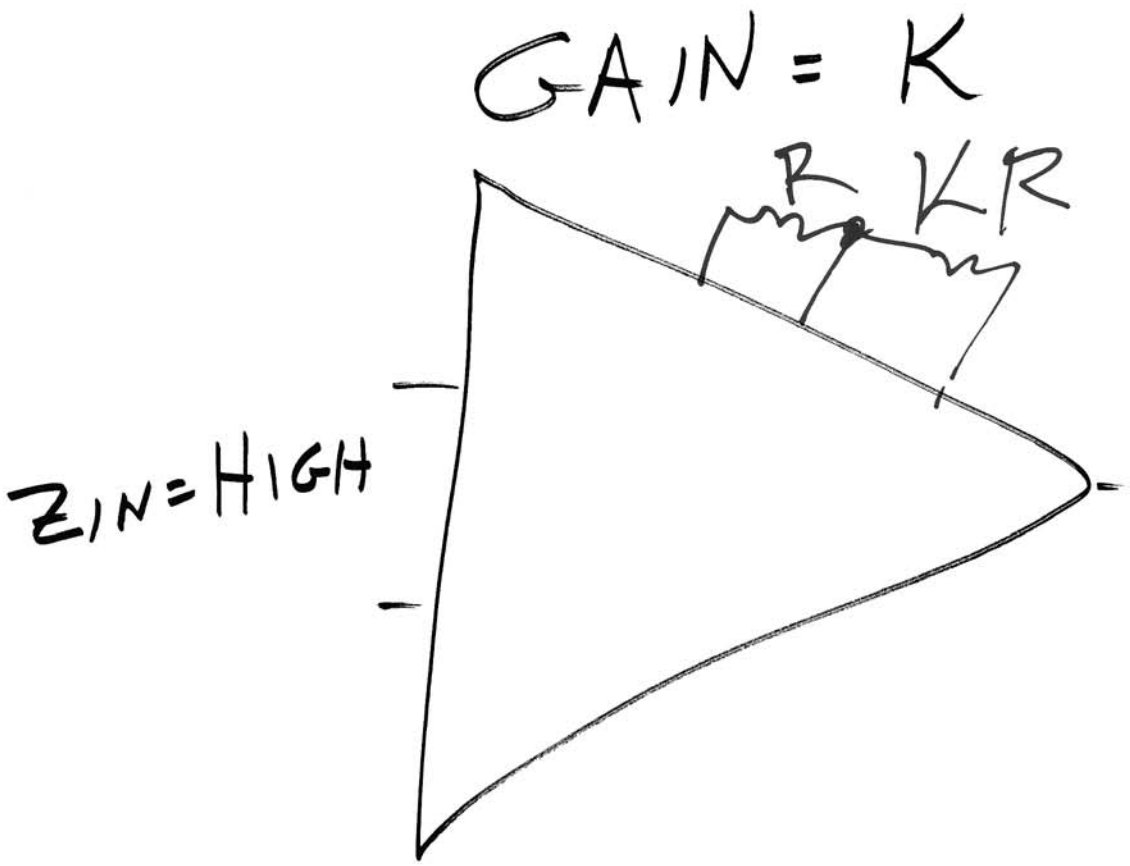
Differential Amplifiers

(OR) Instrumentation Amplifiers.



OK - WHAT IS
AN "INSTRUMENTATION
Amplifier"?

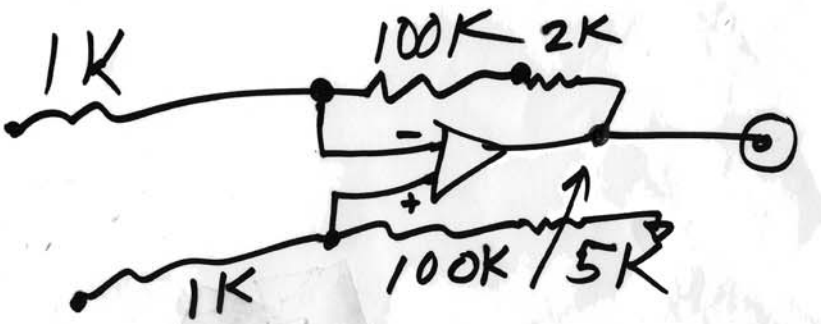
RAP


GAIN = K
R
KR
ZIN = HIGH

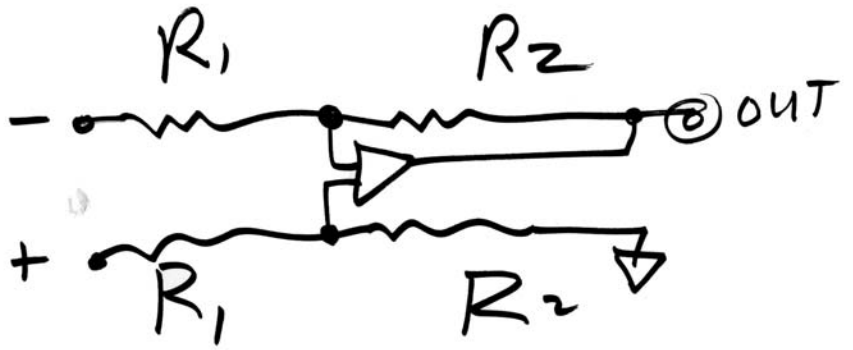
NOTE, THE OLD
MA725 data-sheet
SAID IT WAS "AN
INSTRUMENTATION
AMPLIFIER"

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

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

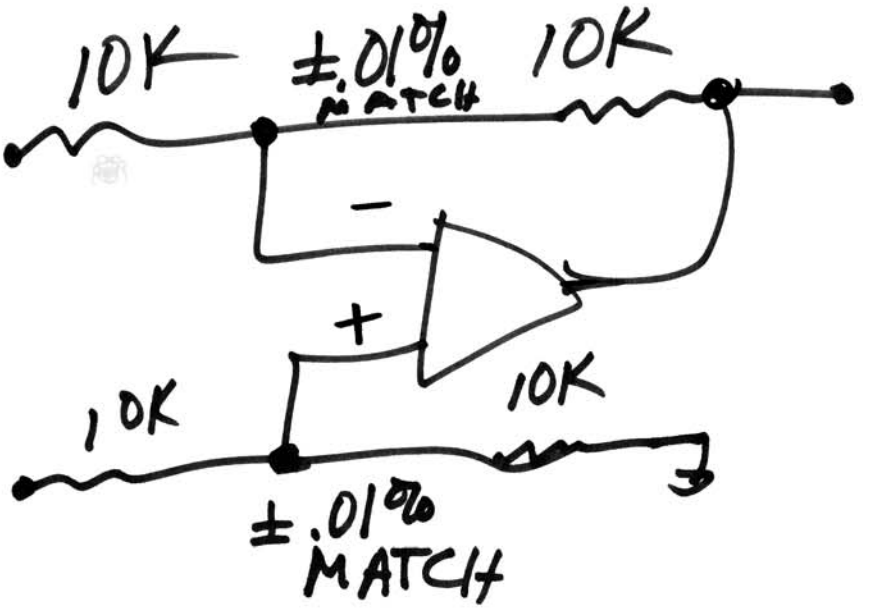


You'll need a TRIM POT. for CMRR



- GOOD Differential Amplifier
- Needs TRIMS

BUT - Z_{IN} ISN'T HIGH.....

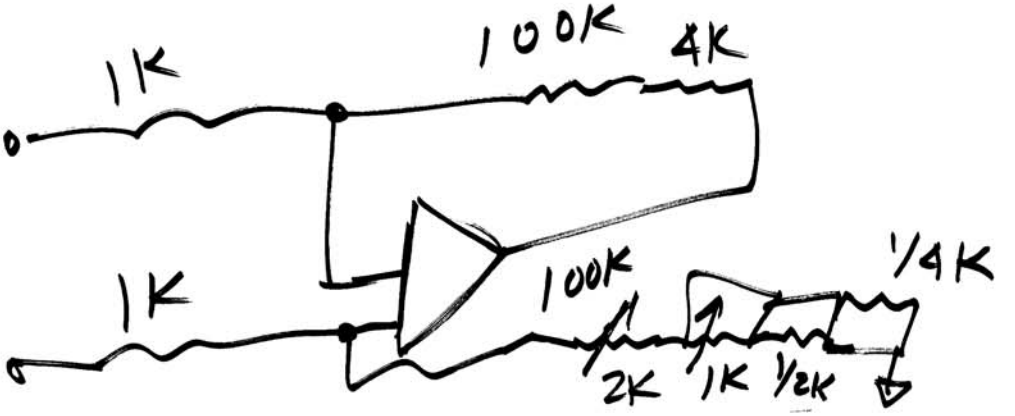


YOU WANT
THIN-FILM
NETWORKS WITH
0.01% MATCHING....

NOT JUST FOR
CORRECTING
(CANCELLING OUT)
the OP-amp's CMRR

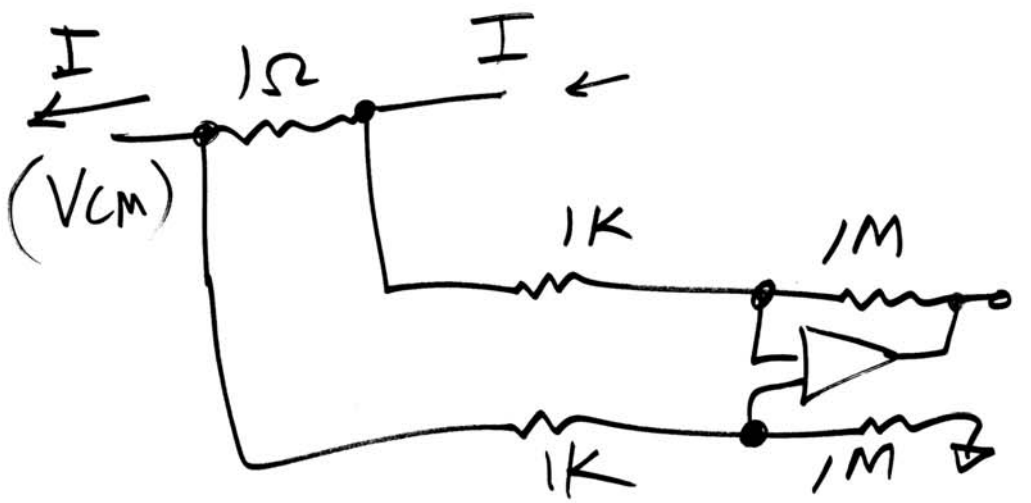
BUT R-RATIO
1% Resistors? Ha!
0.1% Resistors? (A BIT BETTER.)
0.01% MATCH? ....

DO YOU WANT TO TRIM YOUR CMRR WITHOUT A POT?

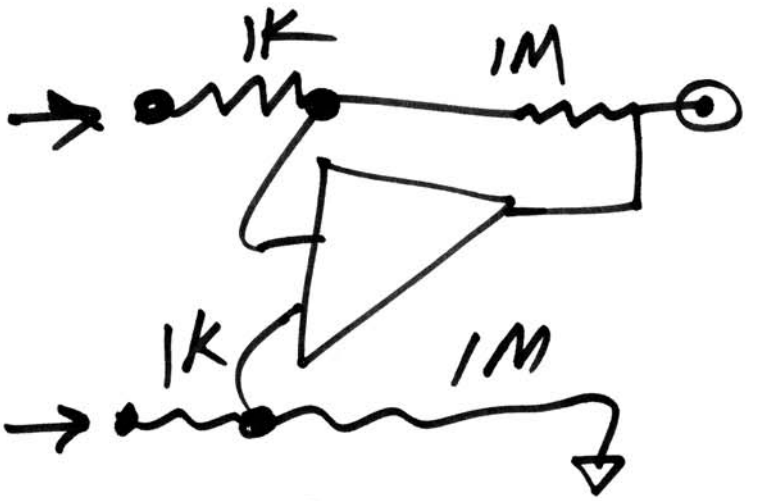


Refer to LB-46...

EXAMPLE ...

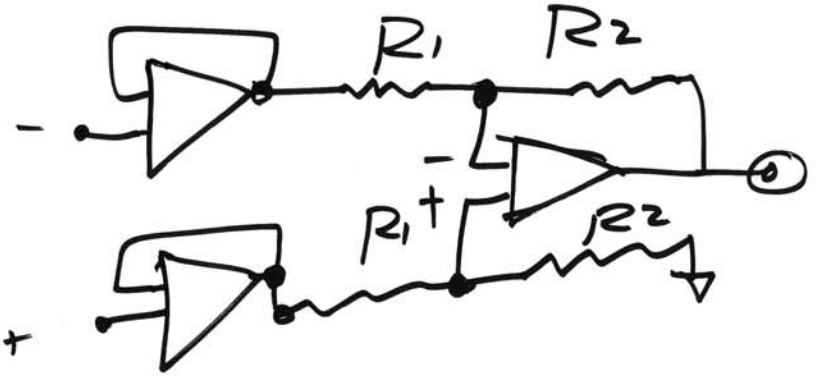


Beware of -
- Vos -
- CMRR ....



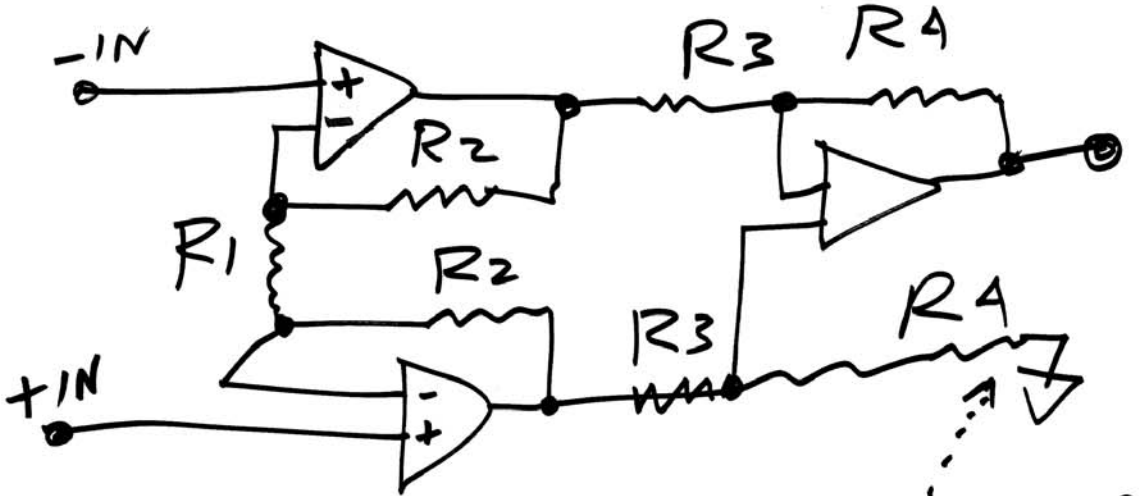
OK —
what is the ZIN?
1K?
1M?

IMPROVED!!



PER THE LM102 Data sheet....

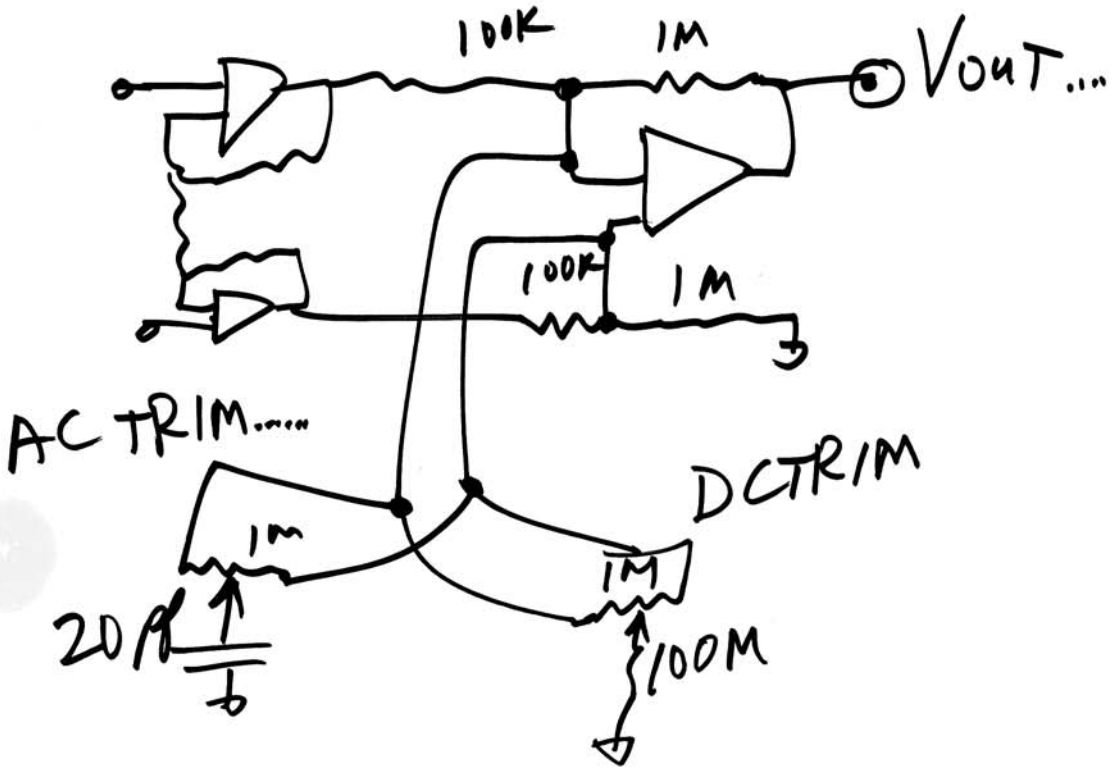
REALLY GOOD CIRCUIT !!!



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

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

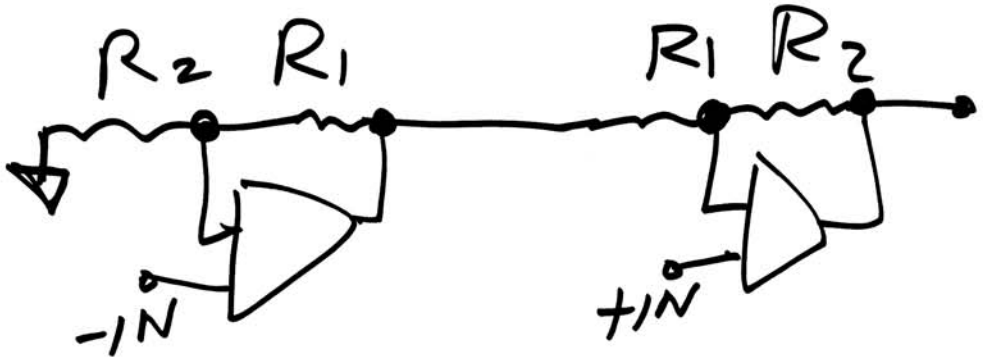
OTHER TRIM GAMES....



CAUTION ABOUT

C.M. SLEW RATE.....

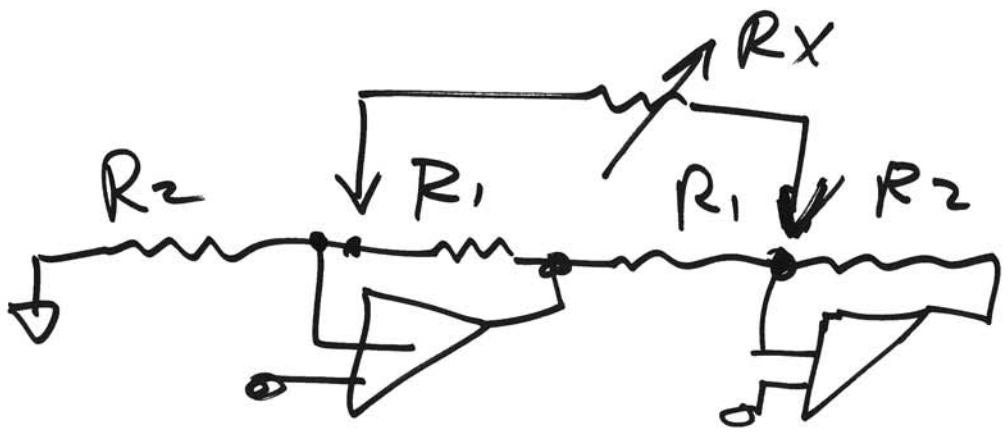
SIMPLER IS BETTER



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

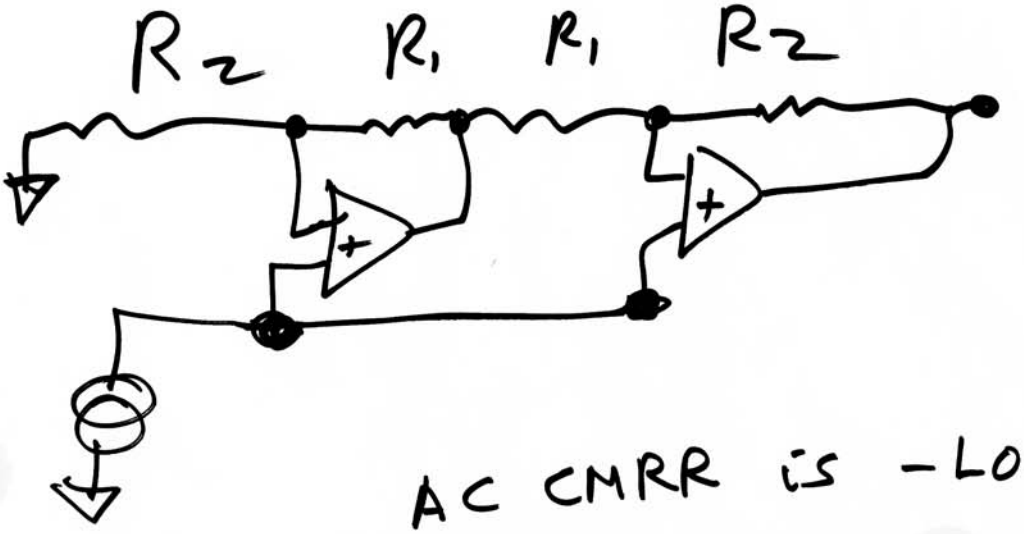
(Well, Maybe NOT....)

GOOD NEWS!

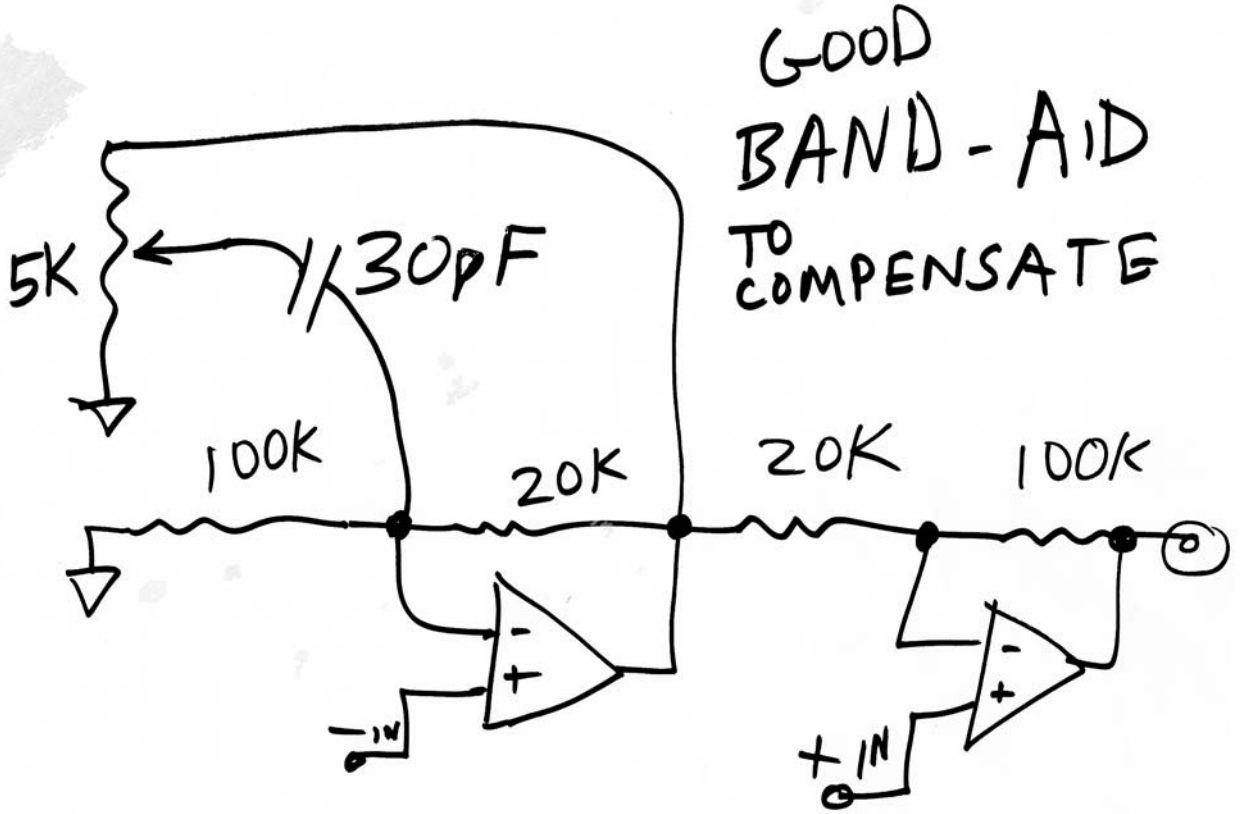


$$G = \left(\frac{R_2}{R_1} + 1\right) + \left[\frac{2R_2}{R_X}\right]$$

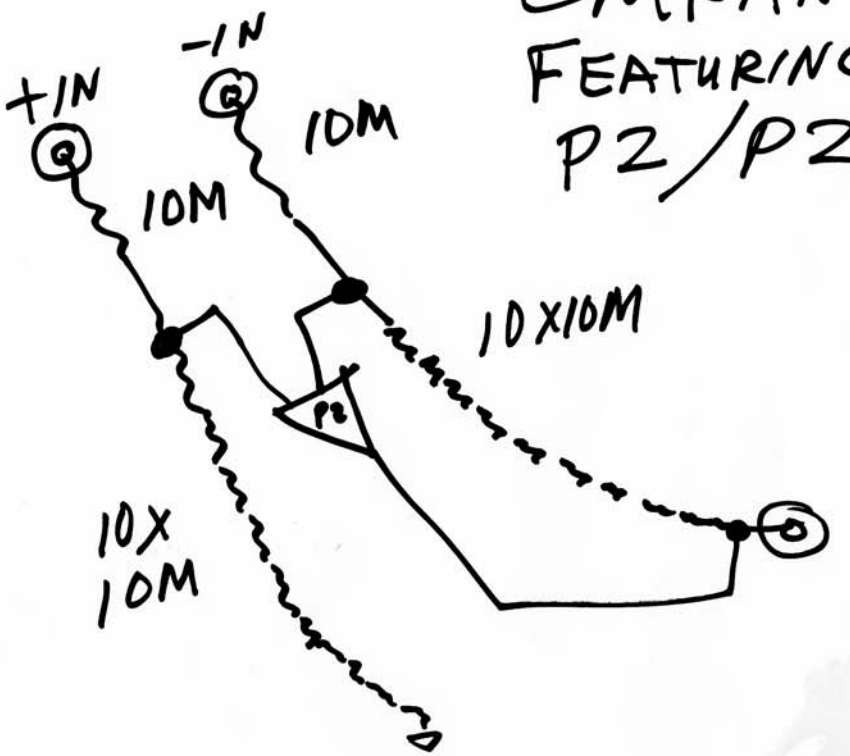
NOT SO GOOD NEWS...

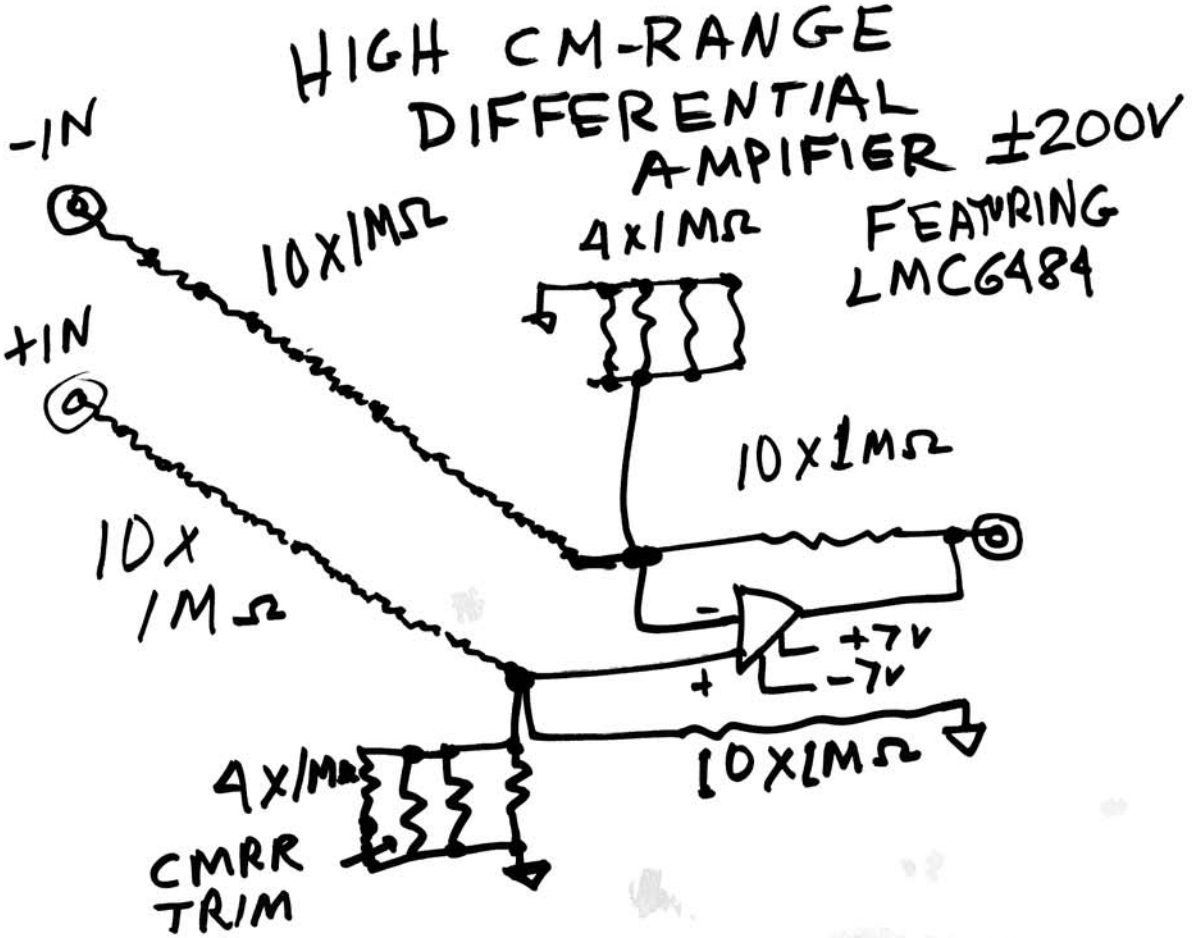


AC CMRR is -LOUSY....


GOOD
BAND-AID
TO
COMPENSATE
5K
130pF
100K
20K
20K
100K
-IN
+IN

±200 Volts of CM Range Featuring P2/P2A




HIGH CM-RANGE
DIFFERENTIAL
AMPIFIER ±200V
FEATURING
LMC6484
-IN
+IN
10X1MΩ
4X1MΩ
10X1MΩ
10X
1MΩ
+7V
-7V
4X1MΩ
CMRR
TRIM
10X1MΩ

DOUBLE INPUTS

LMH6645, -46 -47 -(55MHz)
LM6152, 6154 (75MHz)
LM7301 (TINY)
LM6134, LM6132 (Low Power)
LM6142, 44 " "
LM8261, -62 -(∞ Cap Load)
LM V931, -32, -34 (1.8V Supply)

SMOOTH & SWOOPING

LMC 6482, -84
LMV 710, -711, -712
LMC6462, -64
LMC 8101
LMC 6494

DUAL/QUAD
LOW PWR.
μ POWER
SINGLE
QUAD

WHAT'S ALL THIS STUFF,?

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National Semiconductor provides a comprehensive set of support services. Product information, including sales literature and technical assistance is available through National's Customer Support Centers.

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