What's All This
- Common
  Mode
  Rejection
  Stuff?
(Anyhow...)
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...
AND THE K2-W CAME ALONG ~ 1952

CMRR ≈ 300 FOR ±50V
STILL - Differential Amplifier circuits were NOT easy to design with tubes...

CMRR TRIM

[VOS trim not shown]
The Philbrick P2 used 8 germanium transistors to provide a ±200 volt CM range.

The CMRR was \( \approx \infty \) – in 1961….
SILICON TRANSISTORS GOOD OP-AMPS POSSIBLE

<CMRR > 10,000 WITH GOOD MATCHED NPN'S....
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

$V_{os} \leq 100 \mu V$
CMOS CHOPPERS MAKE GOOD CMRR FEASIBLE UP TO +2.7V

CMRR > 10^6 (3M typical)
WHAT'S ALL THIS COMMON MODE REJECTION STUFF?

(A NYHOW.....?)

PART II: HOW TO MEASURE OP-AMP CMRR....
OK - Now we have good op-amps - how to measure?

\[ V_{\text{OUT}} = A \cdot V_{\text{CM}} / \text{CMRR} \]

But this only works for low gain - not for op-amps...
Is THIS A GOOD WAY TO MEASURE CMRR?

- NO -
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

\[ V_{\text{OUT}} = 101 \left( \frac{V_{\text{CM}}}{\text{CMRR}} \right) + 101 \left( \frac{V_{\text{OUT}}}{A_{\text{V}}} \right) \]

NOPE
THIS HAS TO BE GOOD

VCM

1K

100K

\[ V_{out} = 10 \left( \frac{V_{CM}}{CMRR} + \frac{V_{out}}{A_v} \right) \]

RNP 2005
OK, HOW ABOUT THIS?
- ASSUME PERFECT RESISTORS

 THIS IS GOOD- NOW-
 WHERE DO WE GET THE "PERFECT R's" ??
AHA - WE'VE GOT IT!!

\[
\text{Noise Gain} = 1 \text{ or } 111
\]

So \( V_{\text{out}} (p-p) = \left( \frac{V_{\text{CM}}}{\text{CMRR}} \right) \times 11 \text{ or } 111 \)

Thus \( V_{\text{CM}} / \text{CMRR} \times 100 = \Delta V_{\text{out}} \)
What if you need to measure CMRR > 110 dB?

Easy!

\[ \text{Noise Gain} = 1 \text{ or } 10 \text{ or } 100 \]

So \[ \Delta V_{\text{out}} = \left[ \frac{V_{\text{CM}}}{\text{CMRR}} \right] \times 1000 \]
WHAT IF YOU NEED TO MEASURE CMRR FOR 50KHz?

\[ N_G = 2 \text{ or } 6 \]

\[ 4 \times \frac{V_{cm}}{CMRR} = AV_{out} \]

\[ BW \leq GBw/40 \]
CAUTION!
DC CMRR

Ac CMRR

Nonlinear error due to CM Slew Limit
ANOTHER VALID WAY TO MEASURE CMRR:

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

RDP
List of typical op-amps without rail CM range
+V or -V
- LM 741
- LM 725
- LM 108
- LM 709 — 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, LF 444
- LF351, LF 353

AND OF COURSE - ALL RAIL-TO-RAIL INPUT AMPLIFIERS
HOW TO MAKE A RAIL-TO-RAIL INPUT AMP

① Pump it up (+5V)
MAKE A R-R INPUT USING 2 INPUTS

(\(I_1 + I_2 \leq \text{CONSTANT}\))
How to make R-R Vcm amplifiers using MOS-FETs (U.S. Pat. ...)

Advantages:
- Very linear
- Low noise
- High Zin
HOW TO MAKE HIGH CM RANGE...

USE TRANSFORMERS...

- T1, 15 MHz
- ±(600) mV

ADVANTAGES - VCM > 100 V
- ZIN > 100 MO
- LOWNOISE - 1 mV for 100 Hz
Later we'll explain why you may (or may not) need rail-to-rail C.M. range.

More later. Rap
WHAT'S ALL THIS CMRR STUFF,?
(Anyhow?)
(PART III)

RAP 2005
Differential Amplifiers

or Instrumentation Amplifiers
OK - WHAT IS AN "INSTRUMENTATION AMPLIFIER" ?

RAP
$\text{Gain} = K$

$Z_{\text{IN}} = \text{HIGH}$
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 - 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? (abit better)
0.01% MATCH?....
Do you want to trim your CMRR without a pot?

Refer to LB-46...
EXAMPLE...

Beware of:
- $V_{os}$
- $CMRR$
OK — what is the Zin?

1K?

1M?
IMPROVED!!

PER THE LM102 Datasheet....
REALLY GOOD CIRCUIT!!!
\[-G = \frac{(R_2 + R_2/R_1) + 1}{R_4/R_3}\]

- CMRR is improved
  by \(nR_4/R_3\)
- BW is improved
OTHER TRIM GAMES....
CAUTION ABOUT C.M. SLEW RATE.....
Simpler is better

\[ G = \frac{R_2}{R_1} + 1 \]

(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
±200 Volts of CM RANGE featuring P2/P2A
DOUBLE INPUTS

LMH 6645, -46 -47 (55MHz)
LM 6152, 6154
LM 7301
LM 6134, LM 6132 (75MHz)
LM 6142, 44 (TINY)
LM 8261, -62 (Low Power)
LM V931, -32, -34 (Cap Load)
LM 1.8V Supply
SMOOTH & SLOW PING
LMC 6482, -84
LMV 710, -711, -712
LMC 6462, -64
LMC 8101
LMC 6494

DUAL/QUAD
LOW PWR.
M POWER
SINGLE
QUAD
WHAT'S ALL THIS STUFF, ?
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.

**Americas**
Email: new.feedback@nsc.com
Phone: 1-800-272-9959

**Europe**
Fax: +49 (0) 180-530 85 86
Email: europesupport@nsc.com
Phone: Deutsch +49 (0) 69 9508 6208
English +44 (0) 870 24 0 2171
Français +33 (0) 1 41 91 87 90

**Asia Pacific**
Email: ap.support@nsc.com

**Japan**
Fax: 81-3-5639-7507
Email: jpn.feedback@nsc.com
Phone: 81-3-5639-7560

**The Bob Pease Show**
All-analog talk show hosted by Bob Pease and streamed 24/7 from the National website.
www.national.com/bobpeaseshow

**Analog University®**
Expand your knowledge and understanding of analog with our free online educational training tool.
analogU.national.com