Production Testing of Operational Amplifiers

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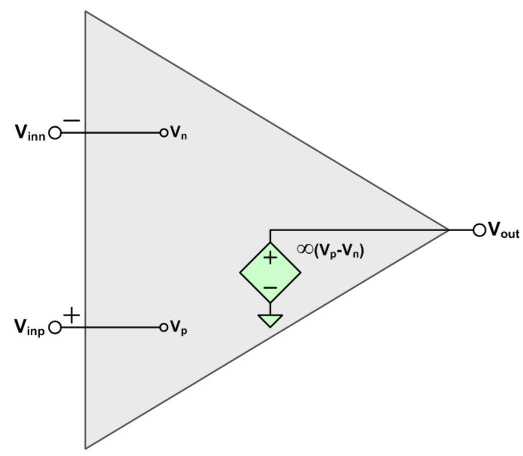
Agenda

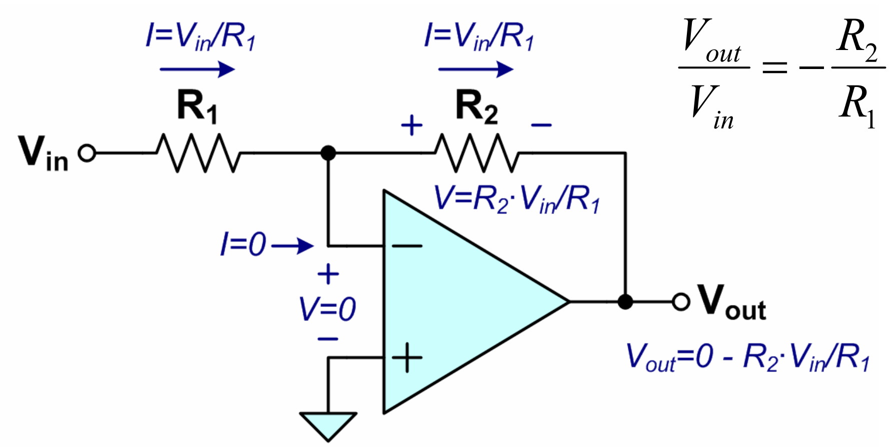
- Opamp Overview
- Production Test Strategy
- The Opamp Servo Loop
- DC Parameter Testing Methods
- Embedded Opamp Servo Loop
- Opamp Testing at TI

Ideal OpAmp Model



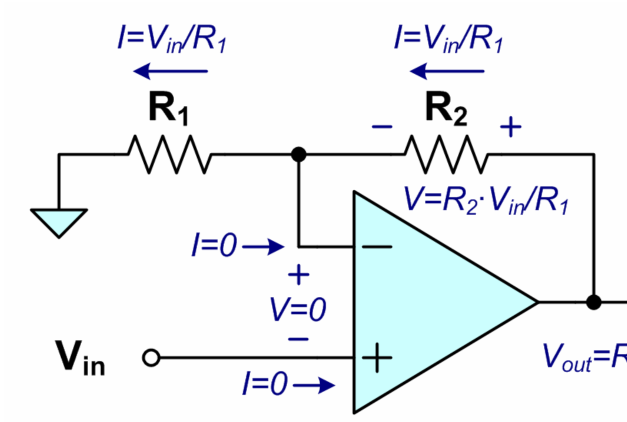
- No current flows into V_{inn} or V_{inp}
- When operated in negative feedback, $V_{inp} - V_{inn} = 0$

Inverting Opamp Configuration



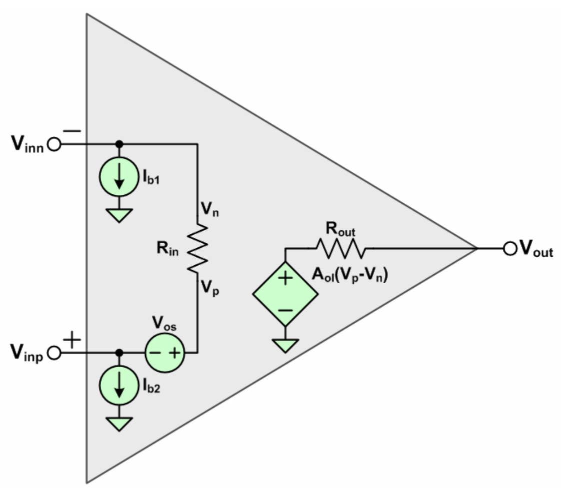
$$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Noninverting Opamp Configuration



$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1} + 1$$

OpAmp DC Model with Imperfections



- V_{inn} – Negative Input
- V_{inp} – Positive Input
- V_{out} – Output
- I_{b1}, I_{b2} – Input Bias Current
- R_{in} – Input Impedance
- R_{out} – Output Impedance
- V_{os} – Input Offset Voltage
- A_{ol} – Open Loop Gain

OpAmp - Typical Specs

OpAmp Characteristics	OPA277 *Low V_{os}*	OPA129 *Low I_B*	OPA627 *V_{os}/I_B/ BW*	THS4031 *Hi BW*
Open Loop Gain (A_{ol})	160db	120db	120db	98db
Input Offset Voltage (V_{os})	5uV	0.5mV	40uV	0.5mV
Input Bias Current (I_B)	2.5nA	30fA	1pA	3uA
Input Offset Current (I_{OS})	2.5nA	30fA	0.5pA	30nA
Gain Bandwidth (BW)	8Mhz	1Mhz	16Mhz	100Mhz
Common Mode Rejection (CMRR)	138db	118db	116db	95db

- **TI currently manufactures more than 1000 different opamp models!**

Production Testing Strategy

Characterization vs. High Volume Production

- It is not cost effective to extensively test all parameters in production
- Generally a shorter test list is sufficient to guarantee performance
- Key data sheet and predictive parametric items should be selected

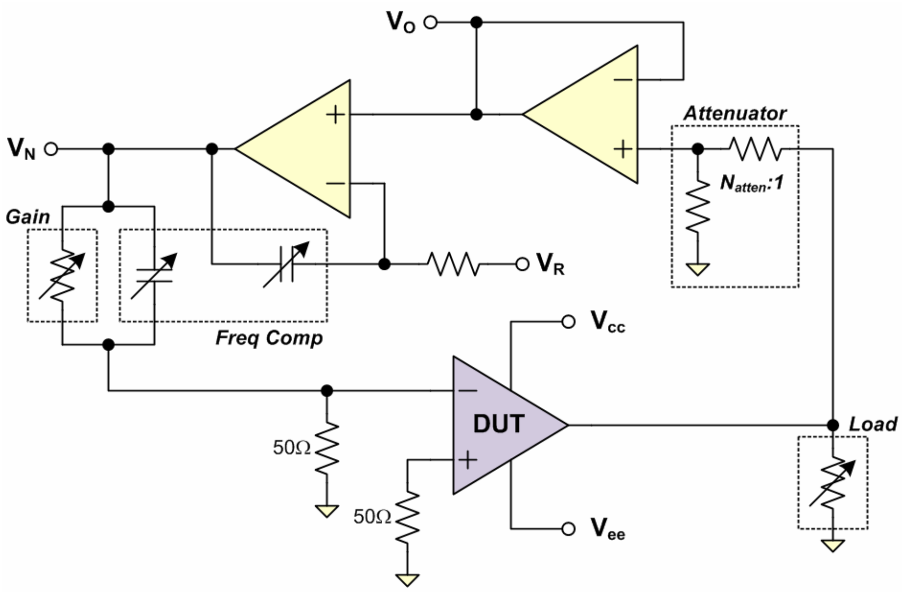
AC vs. DC Testing

- Precision Opamps have a test list dominated by DC parameters
- High speed Opamps may have mostly AC parameters tested
- This presentation focuses on DC testing

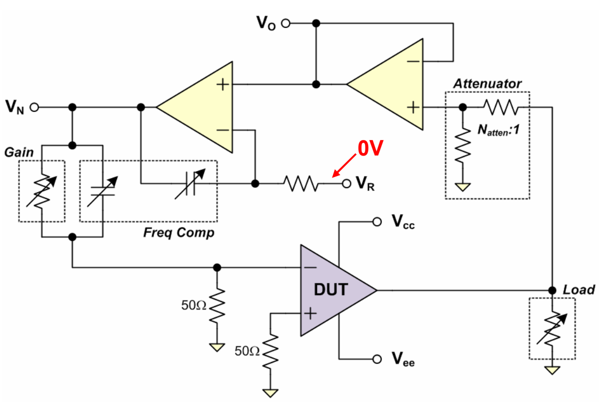
Embedded vs. Standalone Opamps

- Embedded Opamps generally have a more limited test list and often operate with unipolar supplies
- This presentation focuses primarily on standalone Opamps

OpAmp Servo Loop



Input Offset Voltage (V_{os})

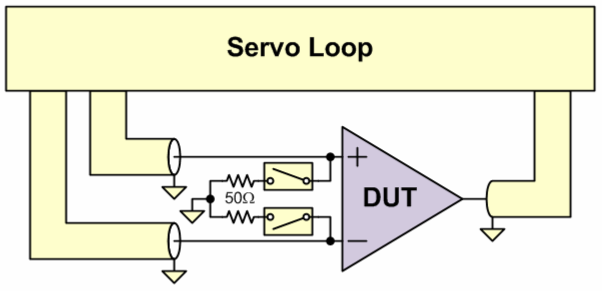


- Set V_{cc} and V_{ee} to desired voltages
- Connect desired Load
- Set Gain and Freq Comp
- Set V_R to 0V
- Measure V_N

$$V_{os} = \frac{V_N}{Gain}$$

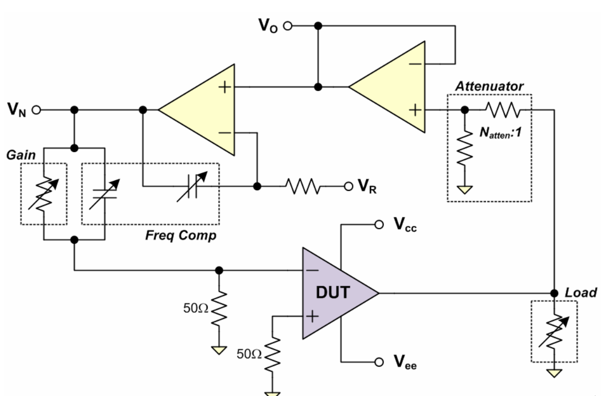
- The Gain should be chosen as large as possible such that worst case V_{os} will not saturate the servo amp (i.e. V_N will be saturated)
- Adjust Frequency Compensation to insure the loop does not oscillate

Achieving Low V_{os} Measurements



- The 50Ω terminations are generally part of the Servo Loop instrument
- Each point of interconnect between the Servo Loop and the DUT adds to the chance of thermal EMF voltage error (i.e. relays, connectors, etc)
- Thermal EMF occurs at dissimilar metal junctions with a thermal gradient
- Locating the termination near the DUT with Low EMF or Latching Relays greatly reduces the potential for V_{os} measurement error due to EMF

Open Loop Gain (A_{ol})

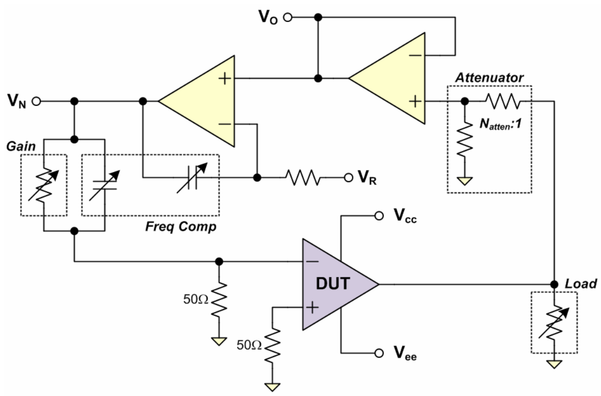


- Set V_{cc} and V_{ee} to desired voltage
- Connect desired Load
- Set Gain and Freq Comp
- Set V_R to V_{R1}
- Measure V_{N1}
- Set V_R to V_{R2}
- Measure V_{N2}

$$A_{ol} = \left| \frac{V_{R2} - V_{R1}}{V_{N2} - V_{N1}} \right| \cdot \frac{Gain}{N_{atten}}$$

- As in the V_{os} setup, it is critical to choose Gain and V_R levels such that V_N does not become saturated
- Aol is often reported in uV/V or dB units

Common Mode Rejection Ratio (CMRR)

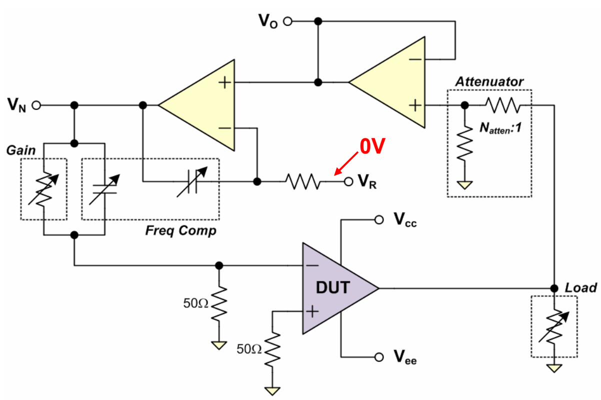


- Set V_{cc} and V_{ee} to desired voltage + V_{cmrpos}
- Connect desired Load
- Set Gain and Freq Comp
- Set V_R to V_{cmrpos} / N_{atten}
- Measure V_{N1}
- Set Vcc and Vss to desired voltage - V_{cmrneg}
- Set V_R to V_{cmrneg} / N_{atten}
- Measure V_{N2}

$$CMRR = \left| \frac{V_{cmrpos} - V_{cmrneg}}{V_{N2} - V_{N1}} \right| \cdot Gain$$

- This method actually moves the power supplies and output and leaves the common mode at 0V. The net effect is the same, however.
- CMRR is often reported in uV/V or dB units

Power Supply Rejection Ratio (PSRR)

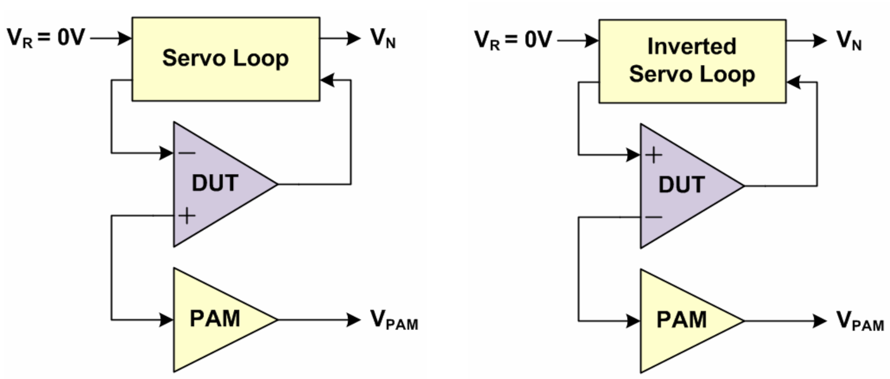


- Set V_{cc} and V_{ee} to minimum voltages
- Connect desired Load
- Set Gain and Freq Comp
- Set V_R to 0V
- Measure V_{N1}
- Set V_{cc} and V_{ee} to maximum voltages
- Measure V_{N2}

$$PSRR = \left| \frac{|\Delta V_{cc}| + |\Delta V_{ee}|}{V_{N1} - V_{N2}} \right| \cdot Gain$$

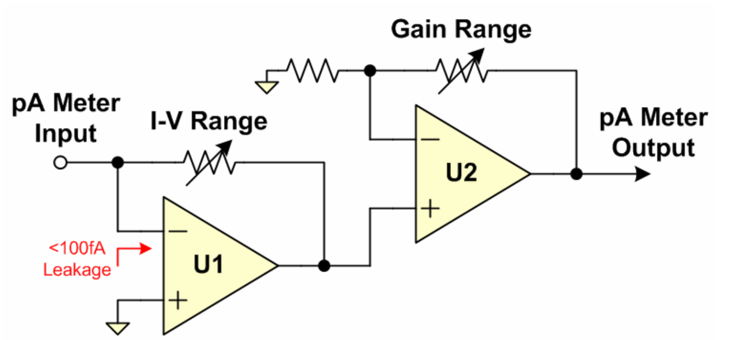
- This test can be combined with the V_{os} test if the given supply values and load are acceptable
- PSRR is often reported in uV/V or dB units

Input Bias Current (I_B) – Picoamp Meter



- When I_B > ~250pA, the Picoamp Meter (PAM) is effective and efficient
- The Servo Loop must support Inverted operation to measure I_B on V_{INN}
- The PAM is usually collocated with the Servo Loop

Input Bias Current (I_B) – Picoamp Meter…



- U1 forms an I-to-V converter and should be a low I_B opamp (OPA129)
- U2 forms a gain stage for ranging of the I-to-V output
- The V_{INP} terminal of U1 sets the Input Common Mode Voltage
- Open Socket Measurements should be made to negate stray leakage and the compounded offsets of U1 and U2

Picoamp Meter Limitations

Cleanliness

- Since the PAM is usually collocated with the Servo Loop, the path can be quite long. To keep stray leakage low, the entire path must be clean.
- Contamination can include: flux, finger oils, absorbed moisture, etc

Dielectric Absorption

- Interconnect dielectrics suffer from “soakage” effects where charge becomes trapped and is slowly dissipated
- This can cause mysterious readings and excessive settling time

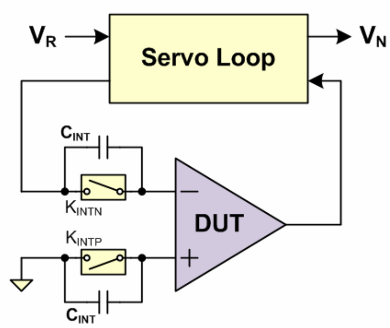
Piezoelectric Charging

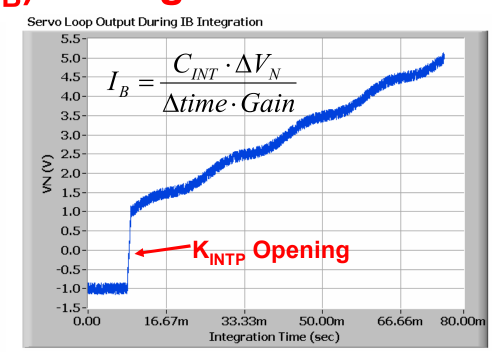
- Most coaxial cabling is susceptible to stray charging during flexure due to the piezoelectric effects of the braid rubbing against the dielectric

I-to-V Input Leakage, Offset Stability, Etc…

- U1 will ultimately limit the low end of measurement capability even in a perfect environment

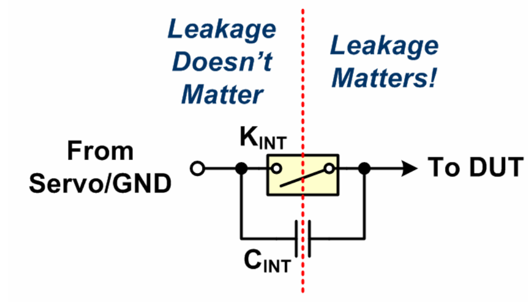
Input Bias Current (I_B) – Integration Method





- K_{INTP} and K_{INTN} are closed for normal operation (i.e. V_{os}, A_{ol}, etc)
- Opening one of the relays allows bias current to integrate into C_{INT}
- Charge Injection during switching will cause a jump in V_N (coaxially shielded relays should be used to keep this manageable)
- Integration times set to a multiple of 16.6ms will reject 60Hz noise
- A typical choice for C_{INT} is a 1000pF WIMA Film

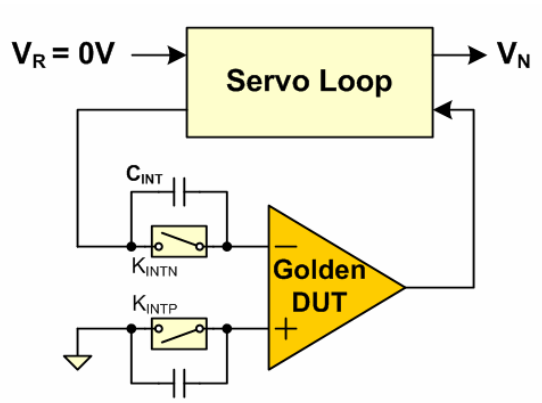
Integration Method…



Leakage only matters on the DUT side of C_{INT}/K_{INT}

- **Cleaning** – We must now only clean around the DUT
- **Dielectric Absorption** – Only PCB Dielectric around DUT + C_{INT}
- **Piezoelectric Charging** – Effectively a non issue
- **Environmental Noise** – We can now easily integrate out 60Hz Noise
- **Opamp Limitations** – No Opamp needed, no issue

Integration Method – Open Socket Cal…



Open Socket Calibration requires an Opamp to close the loop

- "Golden" data logged unit with known I_B

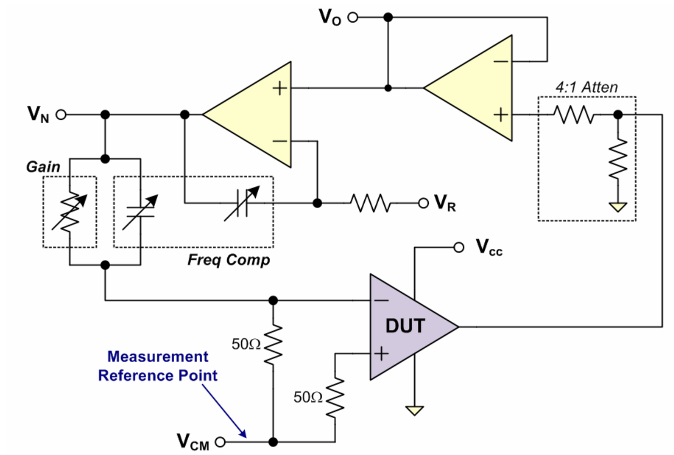
Relating to Small Bias Currents…

- 1 Coulomb (C) of Charge = 6.24E18 Electrons
- 1 Ampere (A) = 1 C/sec
- 1 femto Ampere (fA) = 1E-15 A
- 1 fA = 1E-15*6.24E18 = 6240 Electrons/sec
- 1 60Hz Line Cycle = 16.6 msec
- 1 fA over 1 Line Cycle = 6240*0.0166 = ~104 Electrons
- **Small Bias Current measurement is about counting Electrons!**

Tips for Measuring sub 10pA I_B

- DIB should be immaculate between C_{INT}/K_{INT} and Socket
- Baking the DIB can help drive out excess absorbed moisture
- Some types of sockets can have higher background leakage and dielectric absorption
- Some types of low I_B Opamps can trap charge in their input stages if not handled carefully resulting in erratic I_B measurements
- Use an ionizer
- Keep stray unionized air flow away
- Integrate over multiple line cycles
- Data logged "Golden" unit for offset cal

Embedded Opamps

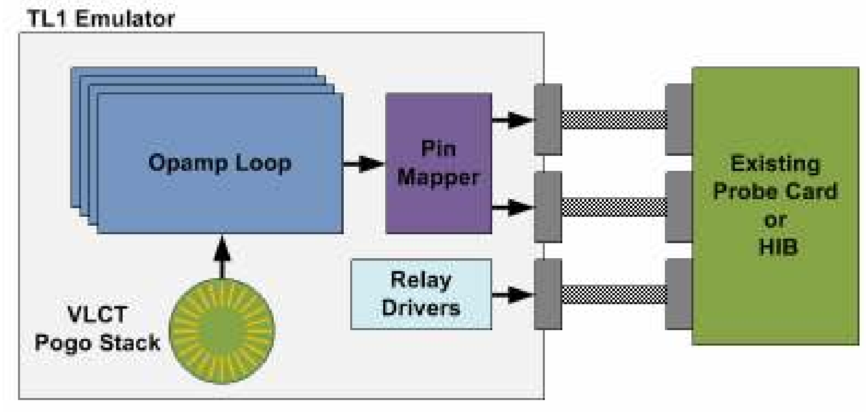


- Embedded Opamps generally do not have bipolar power supplies
- A V_{CM} is required to insure a legal common mode input voltage
- All measurements should be with respect to V_{CM}

TL1 – TI Legacy Opamp Tester

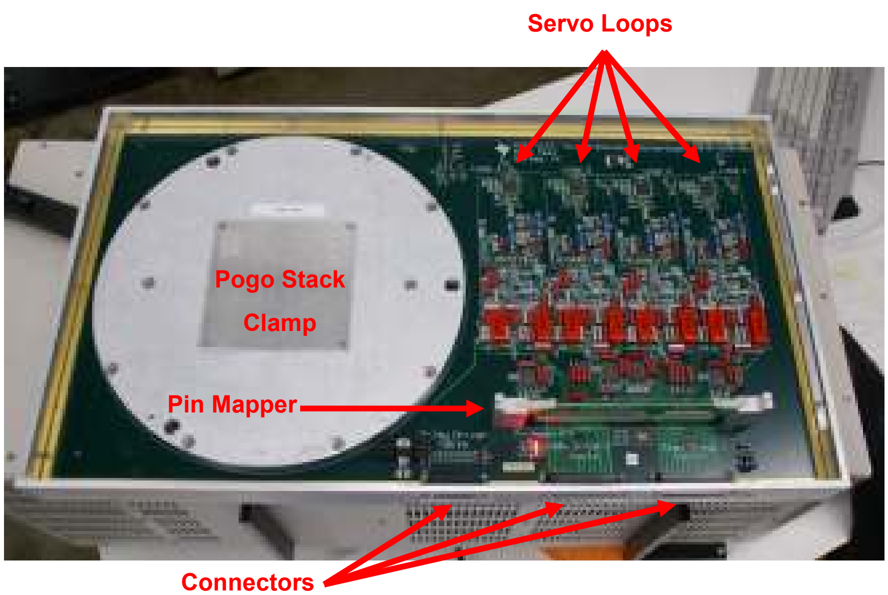
- Early 1980s era internally developed Opamp Tester

Retiring the TL1 – Emulation

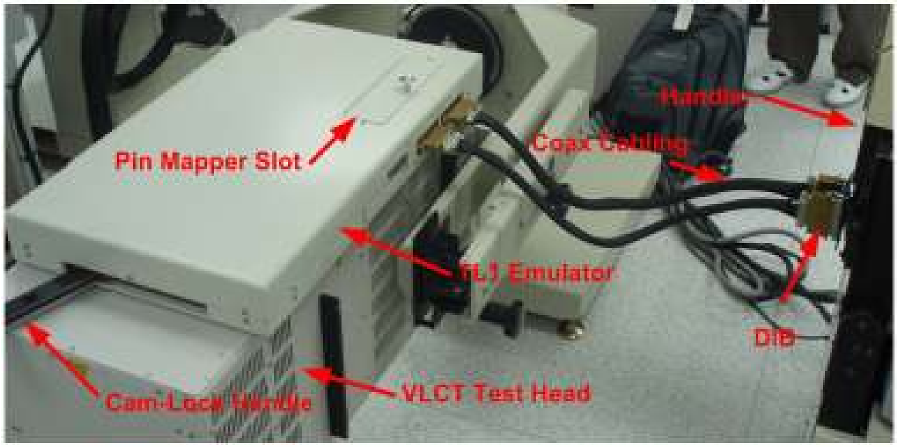


- “Add On” developed for our internal low cost tester to emulate the TL1
- Existing Probe Cards and HIBs were reused
- Rapid program migration tools were developed to speed conversions

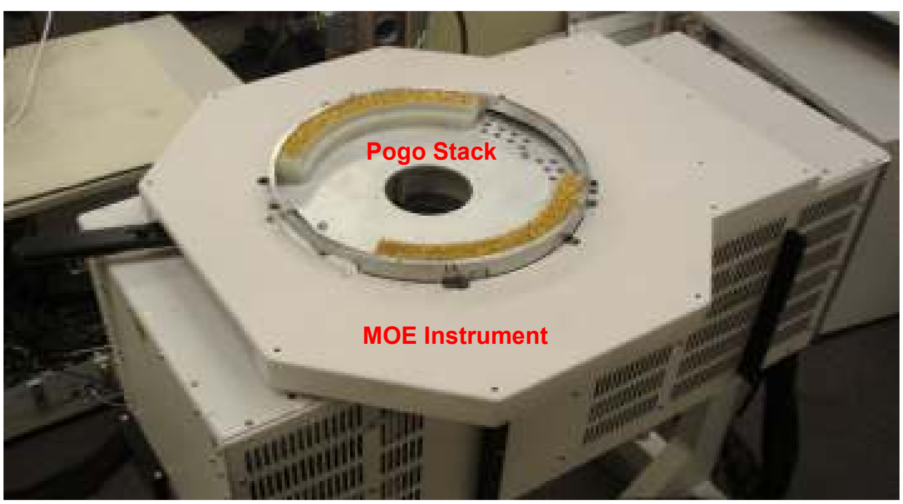
TL1 Emulator - Insides



TL1 Emulator – Connected to Handler

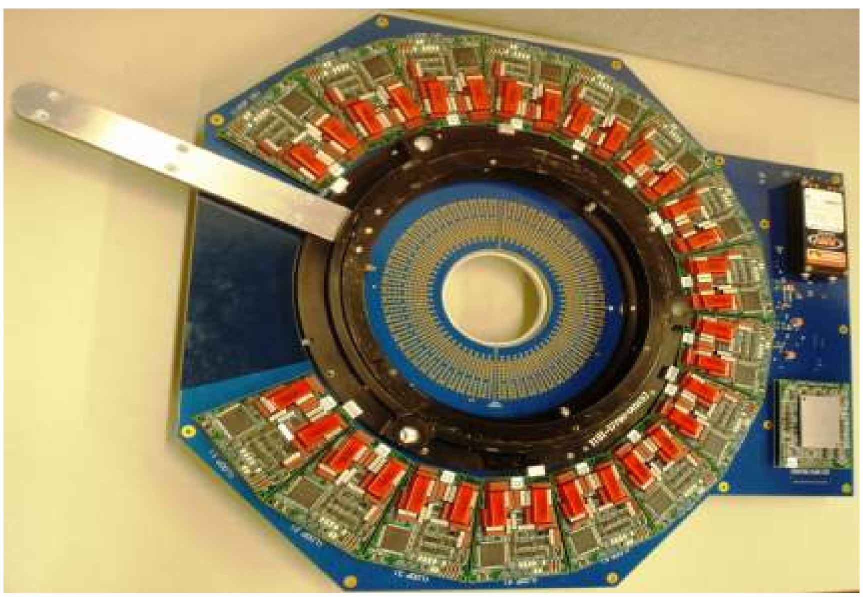


Increasing Throughput – Multisite Opamp Emulator (MOE)



MOE with Quad site SOIC DIB

MOE – Loop Modules



Contact Information…

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