Package induced instability in voltage reference microcircuits encapsulated in plastics

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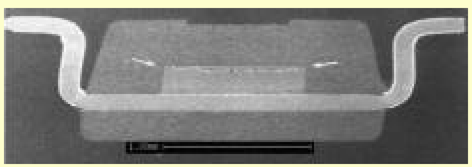
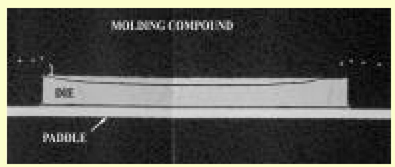
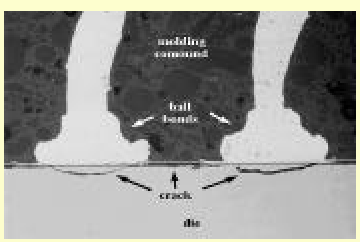
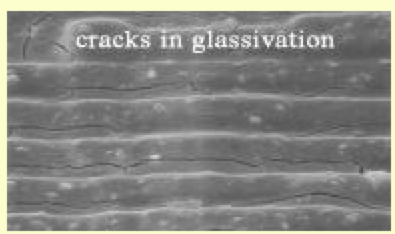
Effect of mechanical stresses on reliability: catastrophic and parametric failures

- **Packaging related mechanical stresses is a characteristic feature of PEMs.**
- **MS are caused by cure shrinkage and CTE mismatch between MC and die assembly materials.**
- **Typical compressive stresses caused by packaging are 50 MPa to 100 MPa.**
- **MS result in mechanical damage and parametric shift.**









Cracking is a result of concentration of internal and external stresses and is typically developed during TC:

- Cratering;
- Wire bond lifting;
- Cracking in passivation;
- Die cracking.

Why mechanical stresses cause changes in characteristics of linear devices?

Parametric variations are due to changes in the electronic band structure of Si, which causes changes in E_g and m.

- Piezo-resistance effect (caused by μ variations):
  - –Si resistors: can reach 2-3% at 100 MPa, has different sighs for n- and p-types, and is larger for p-type;
  - –MOSFETS: affects Idsat, is larger in n-type with longer channels(>1 um).
- Piezo-junction effect – the change in the saturation current of BJT (caused by E_g and μ variations):
  - –results in VBE changes up to 4 mV at 200 MPa, which is especially important for band-gap references;
  - –decreases with increasing temperature and is larger for compressive stress than for tensile stress.

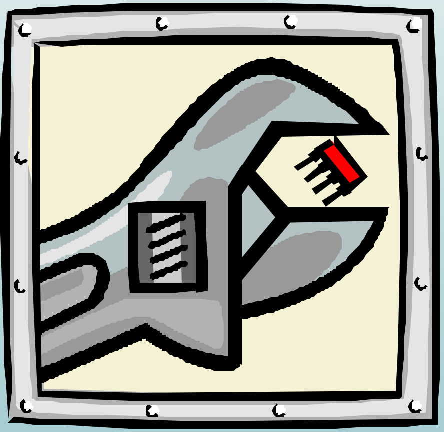
Variations in mechanical stresses caused by changes in environmental conditions might cause instability in precision linear devices.

Purpose and Outline

<u>Purpose:</u> ***to evaluate moisture absorption and desorption expansion and shrinkage of MCs and assess its effect on characteristics of precision voltage reference PEMs.***

<u>Outline:</u>

- Introduction.
- Hygroscopic swelling measurements.
- Swelling characteristics of MCs.
- Environmental effects in Vref PEMs.
- Comparison with external mechanical stresses.
- Conclusions



Moisture induced swelling in MCs and mechanical stresses in PEMs

<u>Coefficient of moisture expansion:</u>

CME = (DL/L)/(Dm/M)

<u>Mechanical stress in PEMs:</u>

$$s \text{ » } \mathbf{A} \text{ ´ } \mathbf{E} \text{ ´ } \mathbf{[(}a_{\mathbf{MC}} \mathbf{-} a_{\mathbf{LF}}\mathbf{)} \text{ ´ } D\mathbf{T + CME} \text{ ´ } D\mathbf{m/M]}$$

At $\alpha_{MC} \approx \alpha_{LF}$ mechanical stresses are due to only variation of moisture content.

At CME = 0.1 to 0.4, $\Delta \alpha$ ~ 10 ppm/^{o}C, and Δm/M ~ 0.5%, moisture-induced stresses are equivalent to thermal stresses at ΔT ~ 50 - 200 ^{o}C.

Hydrostatic weighting technique

Theory of technique

Archimedes of Syracuse

Born: 287 BC in Syracuse, Sicily

$$V = \frac{P - P_{im}}{r_{liquid}}$$

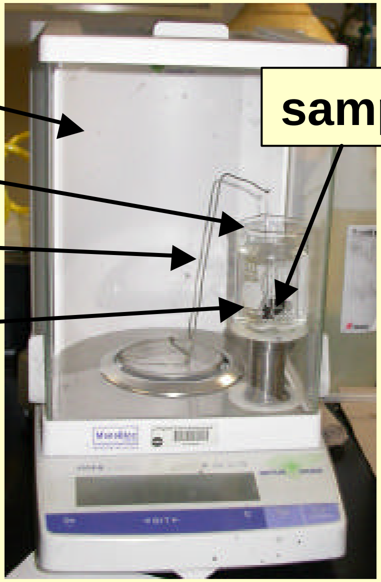
$$CME = \frac{1}{3} \times \frac{V_{moist} - V_{init}}{M_{moist} - M_{init}} \times \frac{M_{init}}{V_{init}}$$

Benefits of hydrostatic weighting technique:

simple, accurate, fast, in-situ.

Necessary equipment:

- Balance ±0.1 mg;
- Beaker;
- Piece of wire;
- **Liquid.**
  (low molecular weight perfluoropolyether fluid, 1.77 g/cc, T_b = 175 ^{o}C)



Swelling test results

Moisture characteristics of different PEMs after 85 ^oC/85% RH/168 hrs

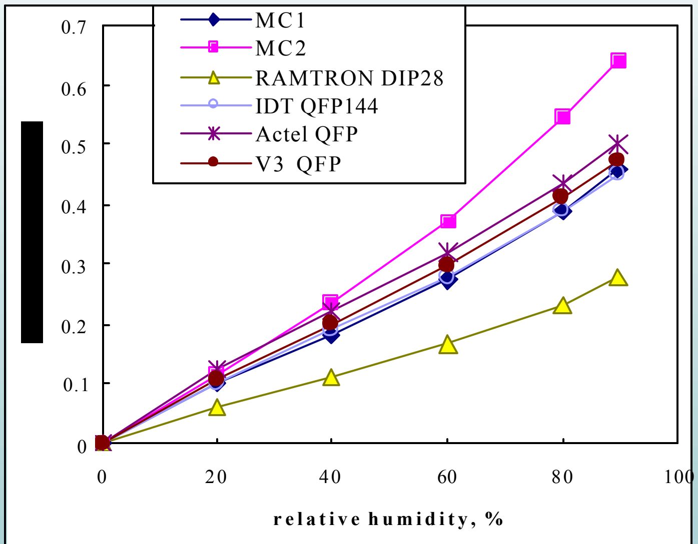
Part	Package	dM, %	dV, %	CME
HA3-5217A-5	DIP-8	0.29 (0.016)	0.25 (0.074)	0.25
HA3-5104-5	DIP-14A	0.31 (0.012)	0.53 (0.106)	0.49
HA3-5330-5	DIP-14B	0.32 (0.002)	0.39 (0.045)	0.36
FM1808	DIP28	0.18 (0.002)	0.20 (0.015)	0.32
49C465PQF	QFP144/IDT	0.33 (0.011)	0.27 (0.034)	0.24
LT1014IS	PLCC32	0.27 (0.013)	0.19 (0.07)	0.18
H7MG00104B	QFP160	0.28 (0.012)	0.09 (0.02)	0.1
A1240A - 1	QFP144/Actl	0.32 (0.011)	0.12 (0.023)	0.11
AD780AR*	SOIC8	0.3		0.24
AD780BR*	SOIC8	0.28		0.22
LT1461*	SOIC8	0.22		0.27

* measurements were performed using TGA/TMA technique

- Accuracy of the CME measurements is ~15% for large packages (V ~2.5 cm^3) and ~30% for smaller packages (V ~0.75 cm^3).
- CME is in the range from 0.1 to 0.49.

Moisture uptake sorption isotherms

Equilibrium moisture uptake at 85 ^{o}C



Sorption follows Henry's law:

$$dM_{\infty} = h \times P = h \times P_s \times f$$

Sorption coefficient:

$\eta = \eta_o \times \exp(\Delta H/kT)$,

ΔH - heat of moisture solution.

Water pressure: $P_s = P_o \times \exp(-Q/kT)$

Q - heat of water vaporization.

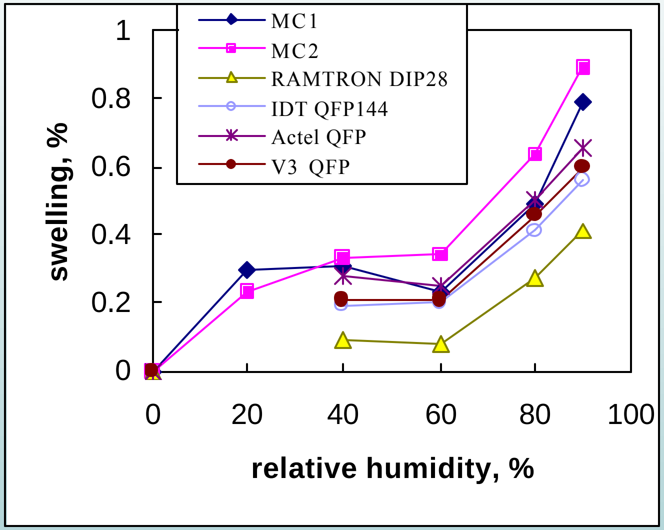
$$dM_{\infty} = h_o \times P_o \times f \times \exp\left(\frac{\Delta H}{kT} - \frac{Q}{kT}\right)$$

For MC: $\Delta H \approx Q = 0.42$ eV

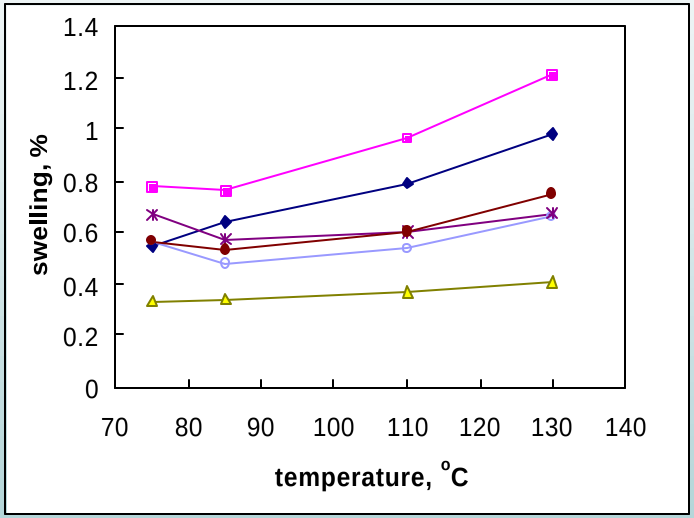
Moisture uptake linearly increases with RH and depend only slightly on temperature

Moisture swelling variation with temperature and humidity

Equilibrium moisture volume swelling isotherm at 85 ^oC

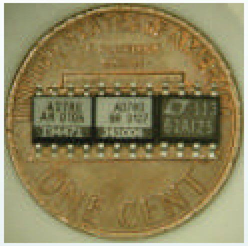
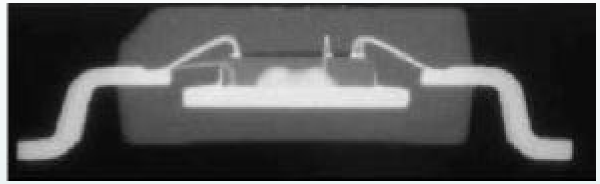
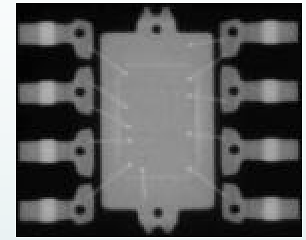


Equilibrium moisture volume swelling at 85% RH



- Swelling isotherms had a sigmoidal shape => CME is not a constant (it also depends on baking conditions).
- Swelling efficiency is higher at low and high humidity.
- At 85%RH and 75 ^oC < T < 130 ^oC moisture pressure increases >100 times, however swelling variations are <50%.

Precision bandgap 2.5 V Vref PEMs

Average characteristics of materials and standard deviations (in brackets)

Part (DC)	LF CTE, ppm/^{o}C	MC TG, ^{o}C	MC CTE1, ppm/^{o}C	MC CTE2, ppm/^{o}C
AD780AR (0106)	17.5 (Cu)	171 (4.4)	15.1 (2.3)	89 (12)
AD780BR (0127)	17.5 (Cu)	173 (5)	16.4 (1)	77 (25)
LT1461AI (0113)	4.3 (alloy 42)	138 (3)	9.8 (0.5)	65 (4.4)

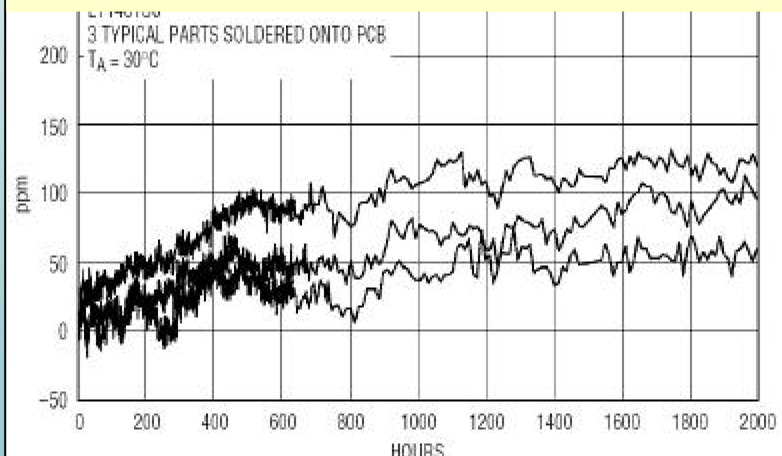
What level of the output stability is necessary?

Data sheet information:

Long-term stability:

- AD780 ± 20 ppm/1khr;
- LT1461 ± 60 ppm/1khr.

By default, humidity is assumed to be constant



System resolution requirements:

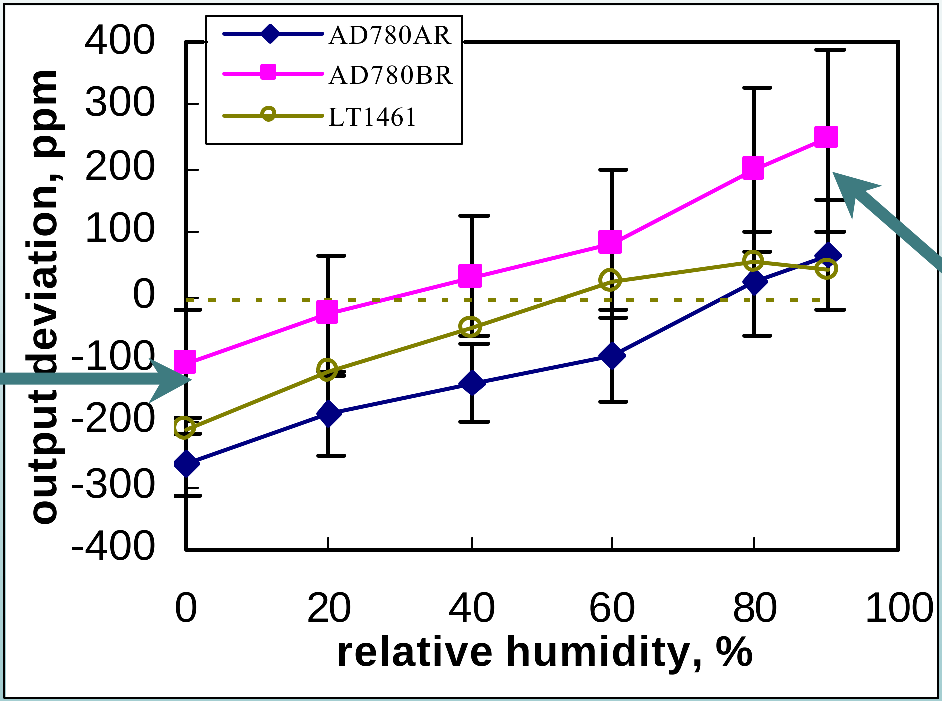
Resolu-tion, bit	1LSB, ppm	dVout, mV
8	3906	9766
10	977	2441
12	244	610
14	61	153
16	15	38

Voltage references are the biggest source of error in AD/DA systems

Output voltage moisture sorption isotherm

Effect of humidity on Vout deviation measured at RT during storing at 85 °C for 168 hrs.

A negative shift of ~150 to 300 ppm can be expected in vacuum due to moisture outdiffusion



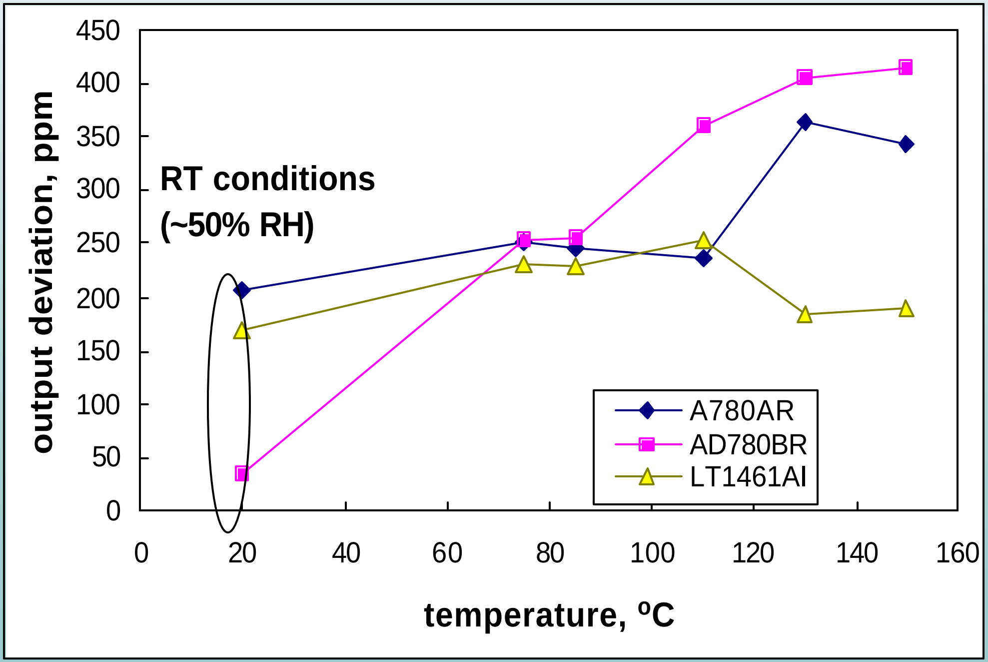
A positive shift up to 350 ppm can be expected in high humidity conditions

Voltage output varies virtually linearly with relative humidity

Unbiased HAST results

Test conditions: soaking for 168 hr at 85% RH at each temperature

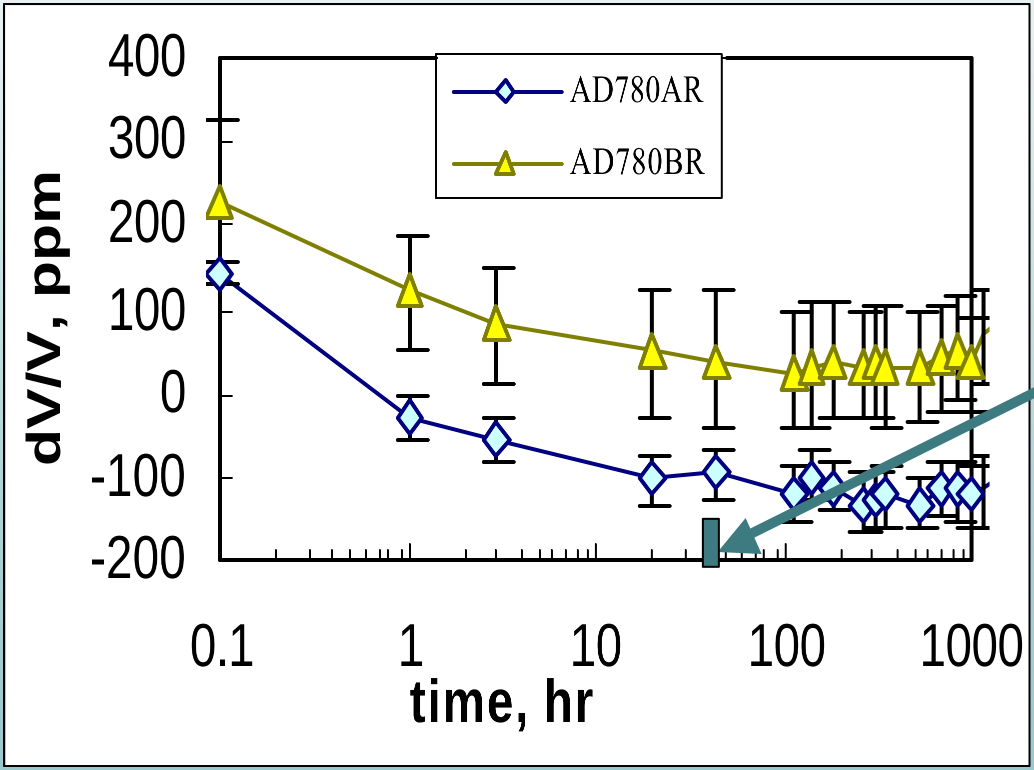
Output deviation with the temperature of HAST testing



- Moisture sorption at RT causes output variation comparable to HAST.
- Temperature increase at 85% RH from 85 ºC to 150 ºC results in relatively small increase of dVout (from ~250 ppm to ~ 400 ppm) due to relatively small variations in Δm and swelling.

Kinetics of the output deviation due to moisture release

Variation of Vout with time of storing at 85 °C after soaking at 85 °C/85% RH



At package thickness 2h = 1.5 mm; moisture diffusion coefficient,

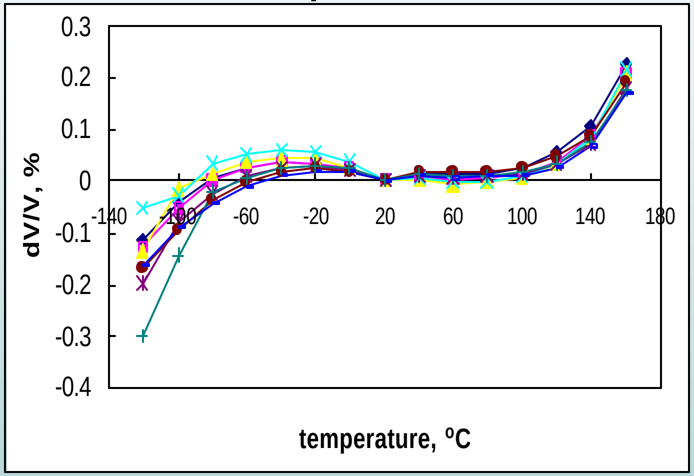
$D_{85} = 4\times10^{-8}\ cm^2/s$

$\Rightarrow \tau_{85} = h^2/D \approx 39$ hr

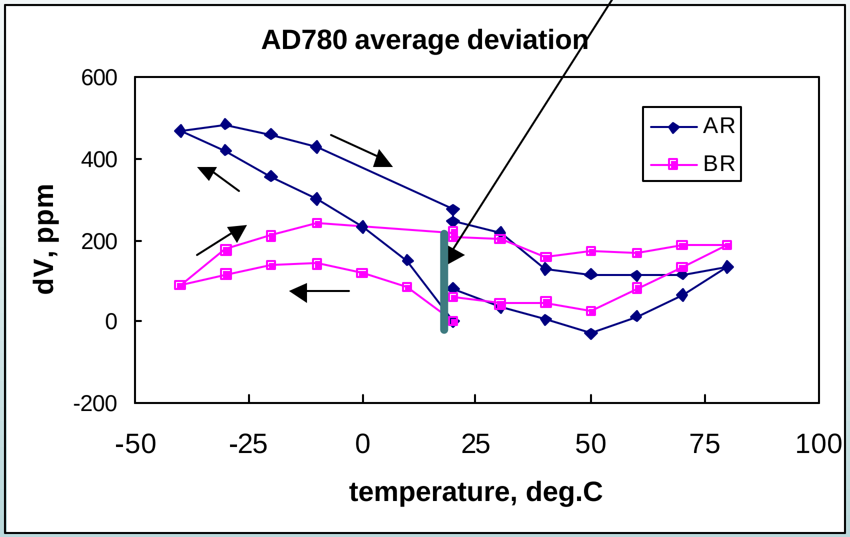
Output relaxation is due to moisture release and can be described by a simple diffusion model.

Effect of temperature

Output voltage deviation with temperature



Low temperature hysteresis

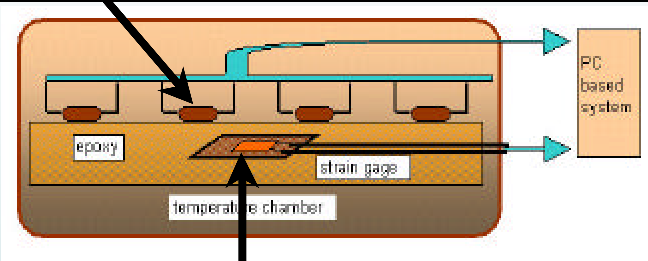


Typically, manufacturers do not specify temperature hysteresis

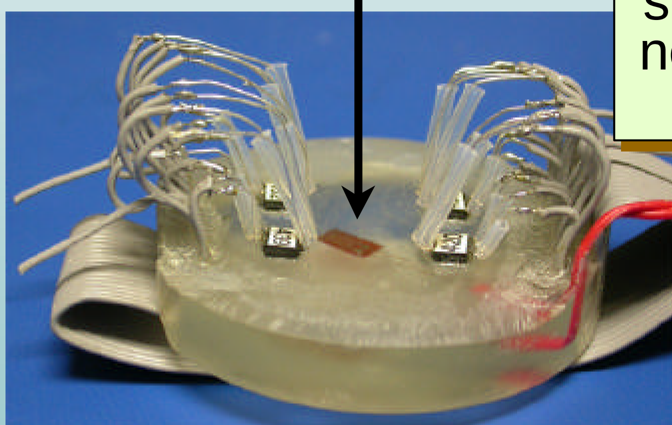
- LT hysteresis is much larger than HT
- Temperature hysteresis is due to creep of MC.
- Temperature variations are partially caused by mechanical stresses.

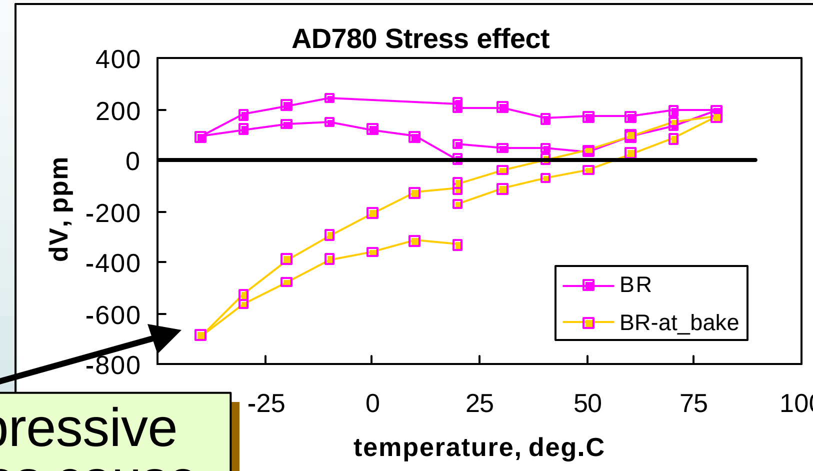
Effect of external mechanical stresses

Parts attached to epoxy block

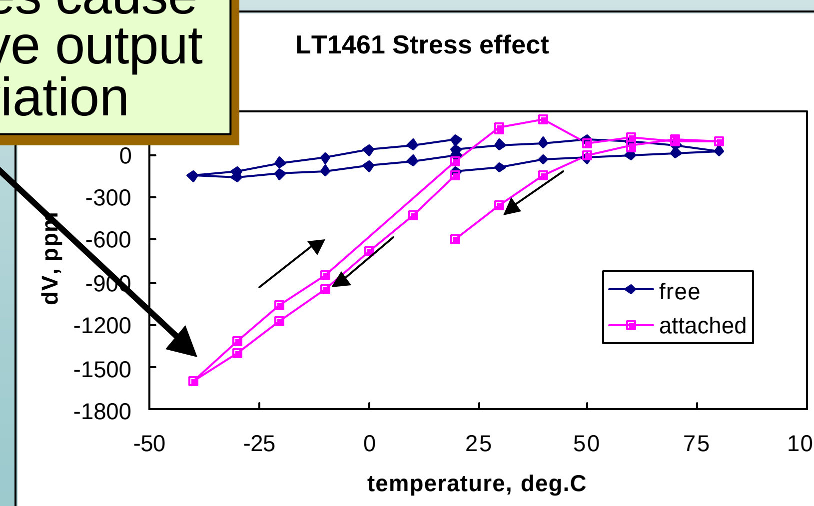


Strain gage



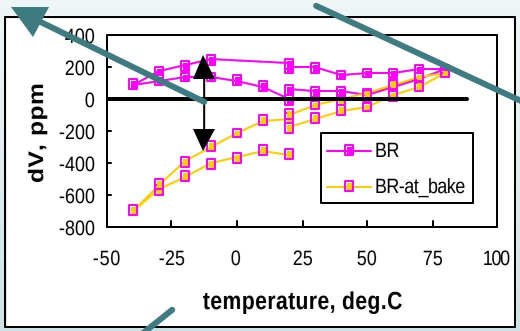


Compressive stresses cause negative output deviation

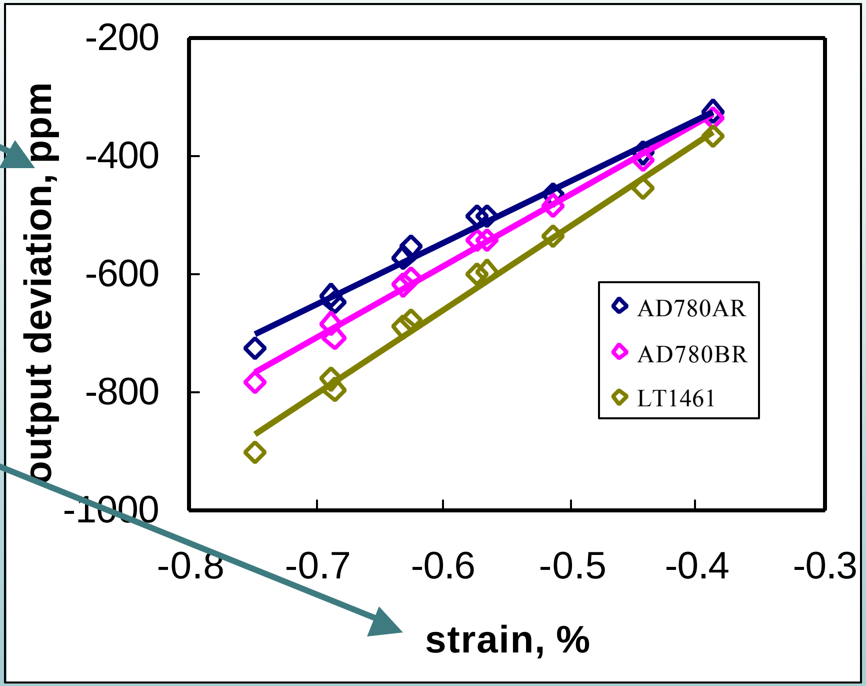


Effect of mechanical stresses

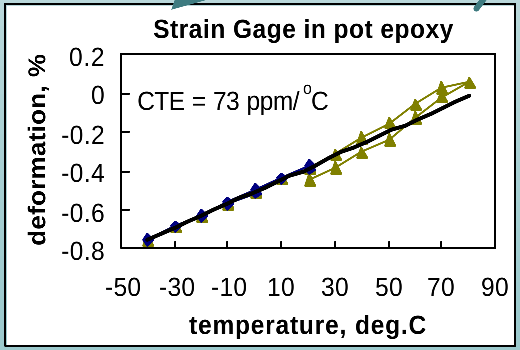
Output deviation due to mechanical stress



Variation of Vout caused by external compressive stresses

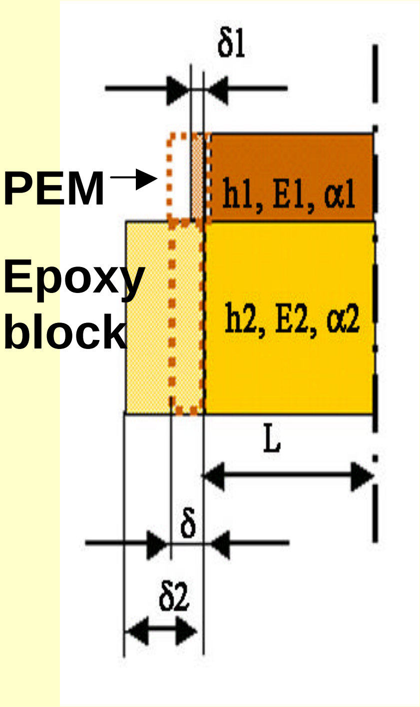


Temperature ⟺ strain



- The output varies linearly with strain.
- Measured GF = $(dV_o/V_o)/(dL/L)$ = 0.1 to 0.14

Estimations of the gage factor



Deformation of the package is less than of the epoxy block

$$\frac{d}{d_2} = \frac{\frac{a_1}{a_2} \times \frac{h_1}{h_2} \times \frac{E_1}{E_2} + 1}{\frac{h_1}{h_2} \times \frac{E_1}{E_2} + 1}$$

At $\alpha_1/\alpha_2 \approx 0.14$ to 0.37; $h_1/h_2 \approx 0.17$; $E_1/E_2 \approx 5$ to 20, package deformation is 1.5 to 3 times less than of the epoxy block.

=> GF = 0.16 to 0.43

Comparison of calculated and experimental Vout deviations

Calculation of package deformation based on Dm and CME

Part	Δm, %		CME	package deformation, %
	vacuum	85% RH		
AD780	-0.17	0.13	0.22	0.066
LT1461	-0.12	0.1	0.27	0.0594

Calculation of the output deviation

Part	package deformation, %	Calculated GF	Calculated dVout, ppm	Experimental dVout, ppm
AD780	0.066	0.16 - 0.26	104 - 168	270 - 350
LT1461	0.059	0.23 - 0.43	138 - 251	170 - 300

Considering simplifications and possible measurement errors, the calculated moisture-induced output deviation is in reasonable agreement with the experimental data

Conclusion

- CME can be measured using a simple hydrostatic weighting technique with accuracy of 15 to 30 %.
- Moisture-induced environmental stresses result in parametric shifts of Vref PEMs, which might cause failures in systems with resolution of >12 bits.
- Kinetics of dV_{out} in humid/dry conditions can be estimated based on diffusion characteristics of MCs.
- External compressive stresses result in negative shift of Vout. The estimated gage factor is in the range from 0.16 to 0.43.
- Estimations of Vout deviations based on moisture uptake, CME, and GF are in reasonable agreement with experimental data.