University of Glasgow

电子科技大学 University of Electronic Science and Technology of China

UESTC 3031: Engineering Project Management & Finance: Design for Manufacturing

Lecture DFM 3: Process Capability

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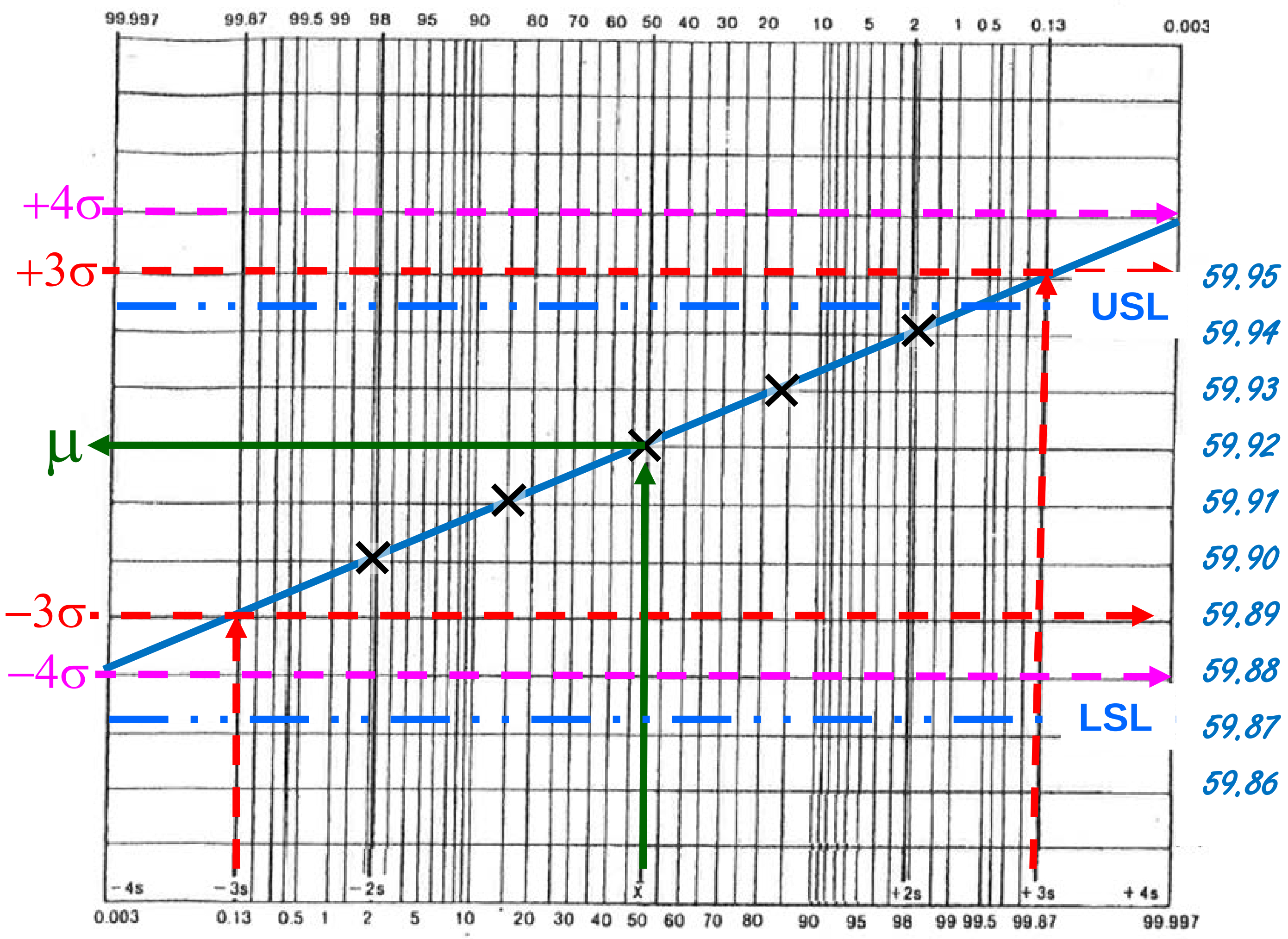
Design for Manufacturing How to use process information…

Last Lecture: Demonstrated how to characterise a process and use process capability chart

This lecture will apply this knowledge to improve your circuit designs…

1. Summarise the process capability analysis
2. Look at where you can obtain process data from literature
3. Apply data to a real design
4. Use statistical ‘tricks’ to improve the circuit performance.

Capability Chart Summarised



Information from Datasheets

electrical characteristics at V_{DD} = 5 V, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	TLV2721Y MIN	TLV2721Y TYP	TLV2721Y MAX	UNIT
V_{IO}	Input offset voltage	$V_{DD}\pm = \pm1.5$ V, $V_{IC} = 0$, $V_O = 0$, $R_S = 50\ \Omega$		610		µV
I_{IO}	Input offset current			0.5	60	
I_{IB}	Input bias current			1	60	
				−0.3		

1 σ typ figure

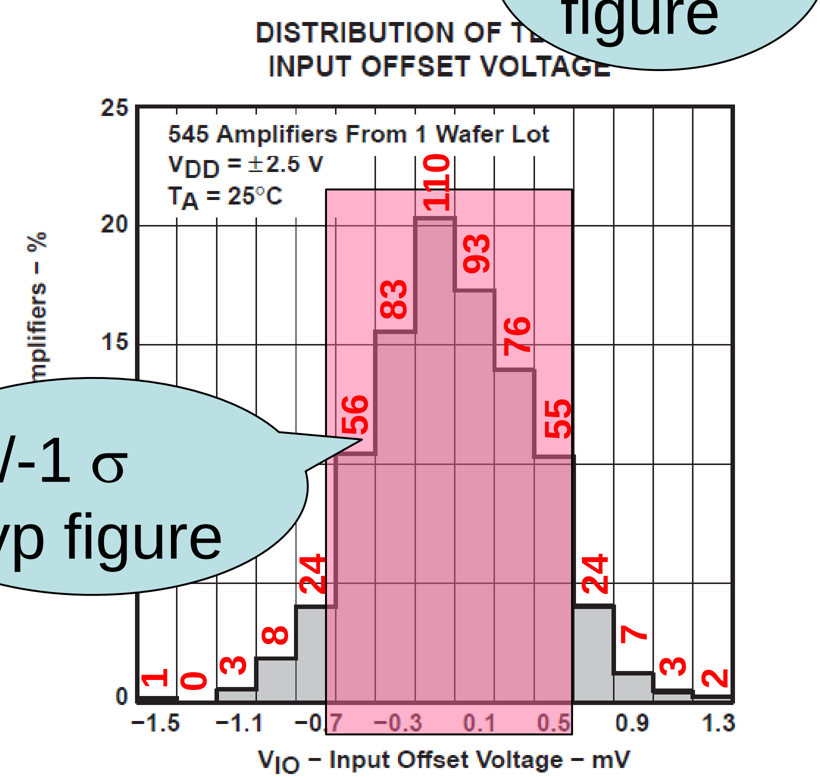
Example: TLV 2721 Op Amp

- You can extract information from datasheets AND perform capability analysis

Be careful…

- **Worst case (Min/Max) limits STILL apply**
- But you can statistically get improved performance

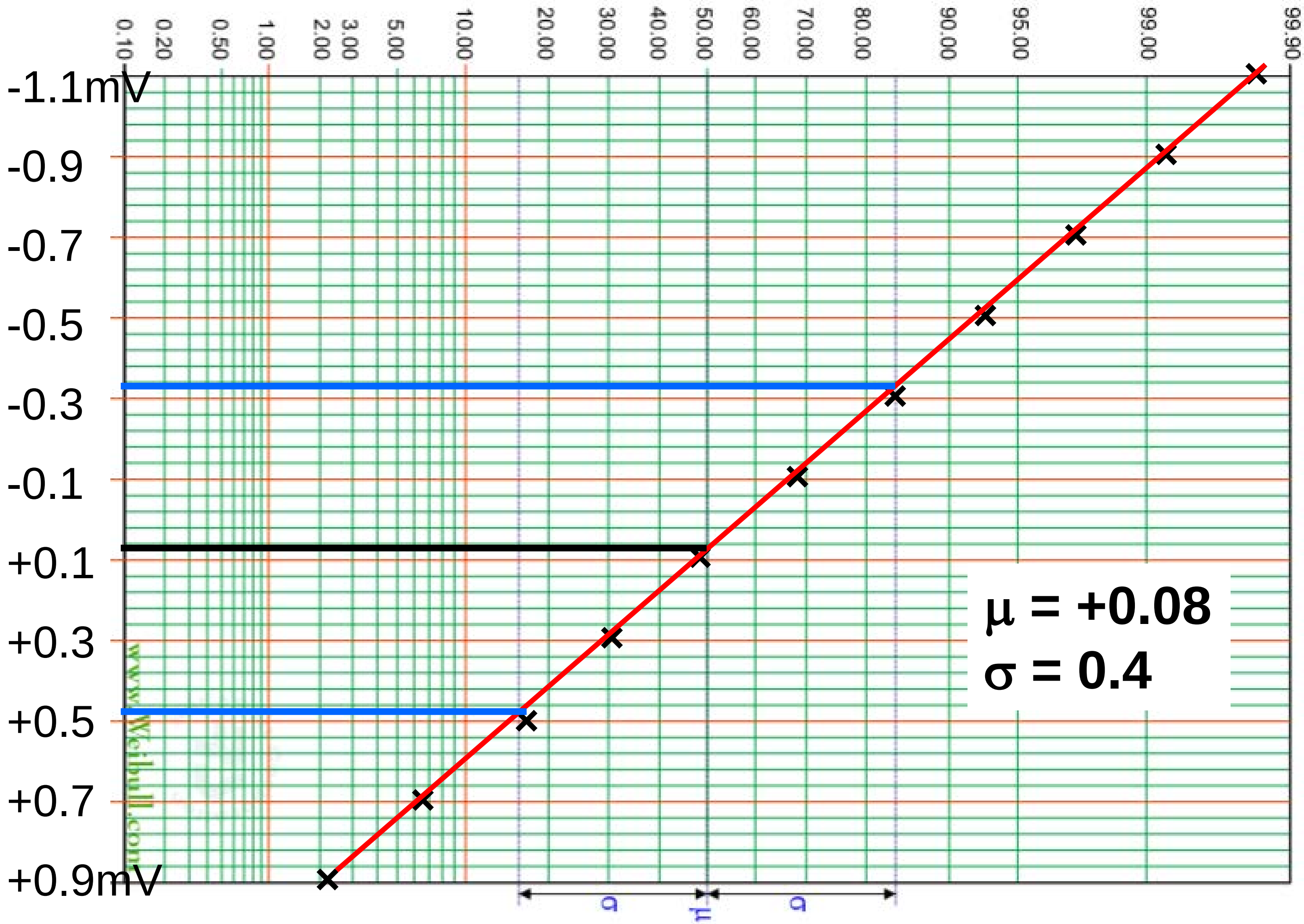
(See SLOA 059 in Reading list)



+/-1 σ typ figure

Figure 2

Plot results to determine Mean(μ) and SD(σ)



Statistics Revision

Addition or subtraction

If $Q = a + b + c$

Then $\sigma_Q = \sqrt{(\sigma_a^2 + \sigma_b^2 + \sigma_c^2)}$

Use absolute numbers (ohms, V etc)

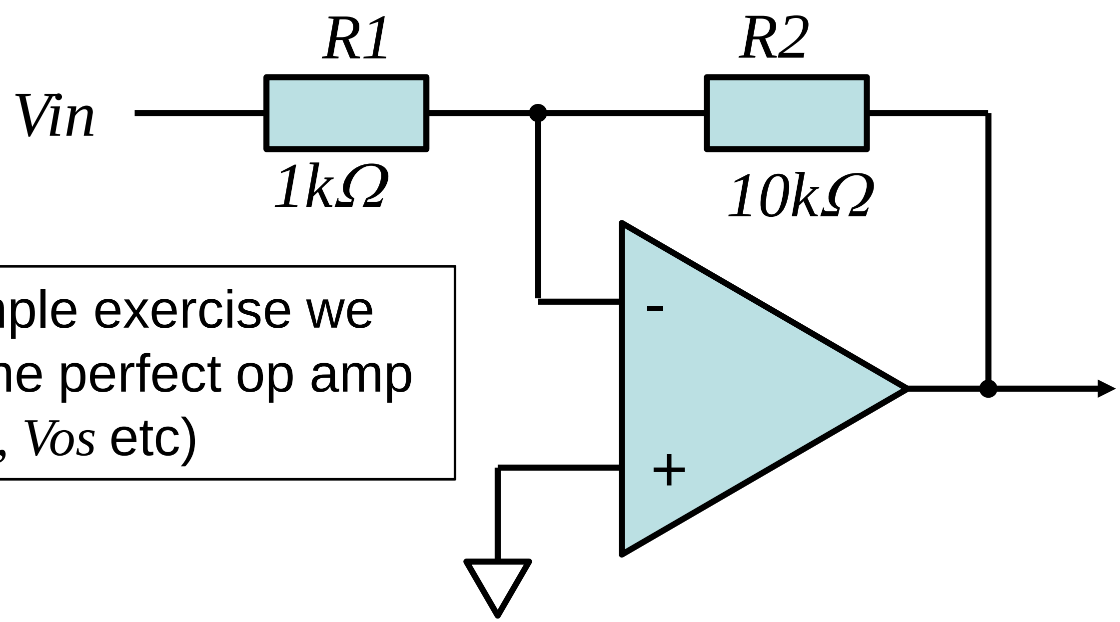
Multiply or Divide

If $Q = a\,.\,b\,.\,c \quad or \quad a/b$

$$\sigma \boldsymbol{Q} = \sqrt{\left(\left(\frac{\sigma_{\boldsymbol{a}}}{\boldsymbol{a}}\right)^2 + \left(\frac{\sigma_{\boldsymbol{b}}}{\boldsymbol{b}}\right)^2 + \left(\frac{\sigma_{\boldsymbol{c}}}{\boldsymbol{c}}\right)^2\right)}$$

Use relative numbers (%)

Revisit our simple amplifier..



$$Vout = \frac{-R2}{R1}$$

In this simple exercise we will assume perfect op amp (no *Ib*, *Ios*, *Vos* etc)

If we use resistors with 10% tolerance (3σ limit), how many amplifiers will have a gain of -10 +/- 0.5 ? (i.e. -10 +/- 5%)

Calculating the number of amplifiers

Since gain equation is:- $Vout = \frac{-R2}{R1}$

We use the second equation $$\sigma Vout = \sqrt{\left(\left(\frac{\sigma_a}{R1}\right)^2 + \left(\frac{\sigma_b}{R2}\right)^2\right)}$$

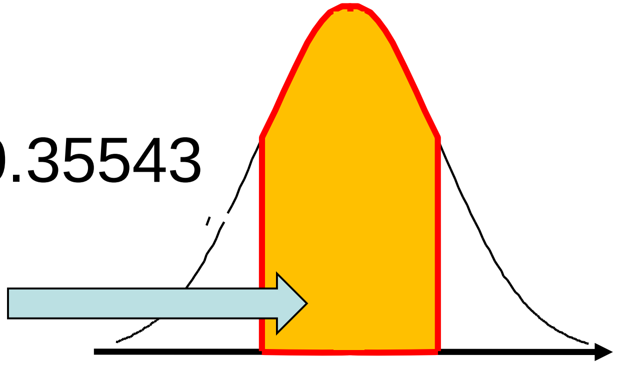
If Resistors are 10% tolerance (3σ) then 1σ = 3.33% $$\sigma Vout = \sqrt{\left((0.0333)^2 + (0.0333)^2\right)}$$

σVout = 0.047 = 4.7%

If 1σ = 4.7% then 5% = 1.06σ

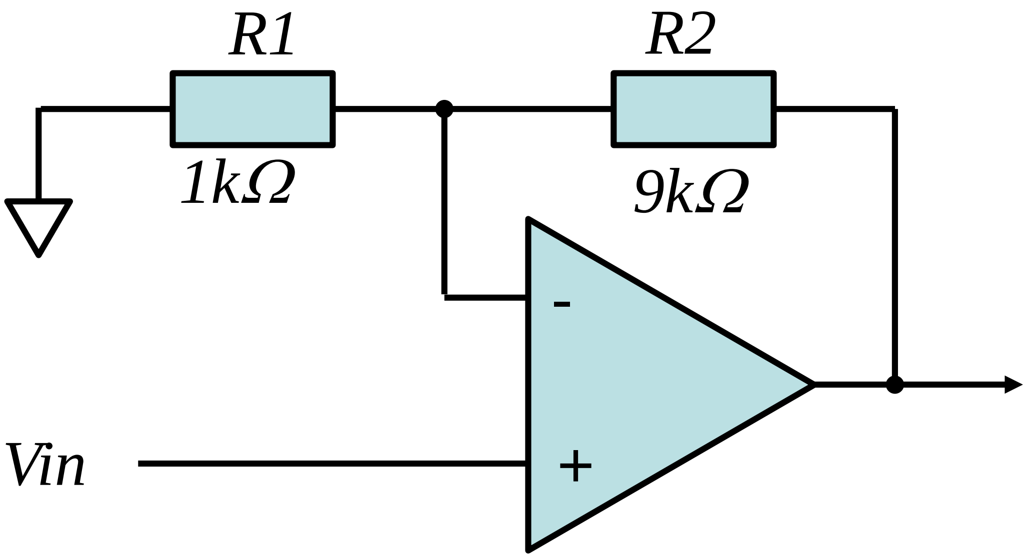
Referring to probability tables z=1.06 ==0.35543

Since we want +/- 5% then 2 * 0.355 = 0.71



Therefore 71% amplifiers have gain of -10, +/- 5%

Analysing Non-inverting amplifier



$$Vout = \frac{R1+R2}{R1}$$

The calculation involves Addition <u>AND</u> division of σ

Assume all resistors are 10% tolerance

Non-Inverting (contd 2)

Calculate variation of *R1+R2 = 1K + 9K*

If 10% (3σ) resistors then R1 σ = 33.3Ω, R2 σ = 300Ω

Combined $\sigma = \sqrt{33.3^2 + 300^2} = 301.84\ \Omega$

Convert to $\%$ error $= 3.02\%$ and then use division formula

$$\sigma \boldsymbol{Q} = \sqrt{\left(\left(\frac{\sigma_{\boldsymbol{a}}}{\boldsymbol{R1}}\right)^{2} + \left(\frac{\sigma_{\boldsymbol{b}}}{\boldsymbol{R1}+\boldsymbol{R2}}\right)^{2}\right)} = \sqrt{\mathbf{0.0333^2 + 0.0302^2}} = \mathbf{0.045}$$

Therefore, 1σ Non-Inv amplifier gain error is 4.5%

Non- Inv Amplifier (contd 3)

If, 1σ Non-Inv amplifier gain error is +/- 4.5%

Need to calculate proportion of amplifiers within +/- 5%

$z = 5/4.5 = 1.11$

Referring to Probability tables, for $z = 1.11$, $P = 0.36650$

So 73.3% of amplifiers have gain of +10, +/-5%

Circuit tricks to improve performance

Our analysis shows only ~70% of amplifiers meet spec

Can we improve this using the same grade of components?

We know… $Q = a + b + c + d$

And… $\sigma_Q = \sqrt{\sigma_a{}^2 + \sigma_b{}^2 + \sigma_c{}^2 + \sigma_d{}^2}$

If we let Ra = Rb = Rc = Rd (assume 10% tolerance)

For 1000Ω resistor can use 4 x 250Ω (10%; σ = 3.33%=8.325Ω)

$$\sigma_Q = \sqrt{\sigma_a{}^2 + \sigma_b{}^2 + \sigma_c{}^2 + \sigma_d{}^2} = \sqrt{4 \,.\, \sigma^2} = 16.653\Omega$$

(contd)

$$\sigma_Q = \sqrt{\sigma_a{}^2 + \sigma_b{}^2 + \sigma_c{}^2 + \sigma_d{}^2} = \sqrt{4\,.\,\sigma^2} = 16.653\Omega$$

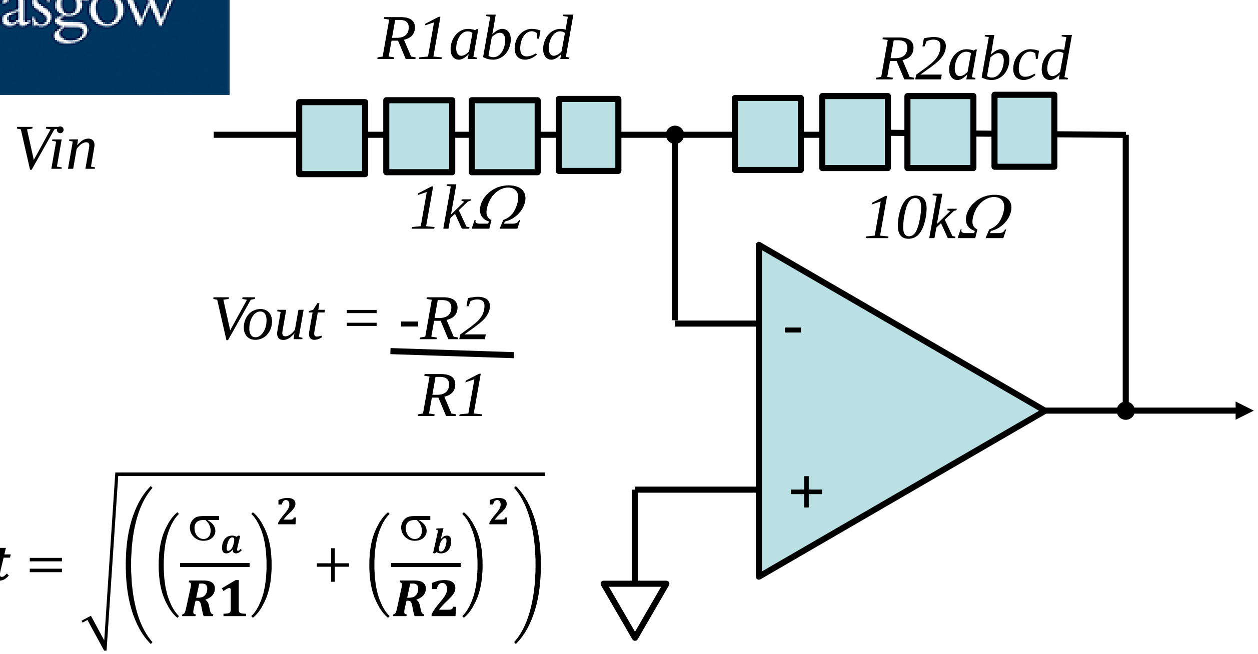
The above σ is for 4 x 250 Ω resistors (=1kΩ)

By using 4 x 250 Ω resistors in series the σ = 16.653Ω (1.65%)
Using a single 1kΩ resistor, σ = 33.305Ω (3.33%)

We have **improved** the resistor variation by $\sqrt{N}$, where N is number of resistors (can be in series or parallel)

Now apply this approach to the amplifier…

(Contd)



$$Vout = \frac{-R2}{R1}$$

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$$\sigma \boldsymbol{Vout} = \sqrt{\left(\left(\frac{\sigma_a}{\boldsymbol{R1}}\right)^2 + \left(\frac{\sigma_b}{\boldsymbol{R2}}\right)^2\right)}$$

If Resistors are 10% tolerance, we get a $\sqrt{N} improvement$

$$\sigma \boldsymbol{Vout} = \sqrt{\left((\mathbf{0.0165})^2 + (\mathbf{0.0165})^2\right)}$$

σVout = 0.0235 = 2.3%

How many amplifiers now?

If new σVout = 0.0235 = 2.35%

Need to calculate proportion of amplifiers within +/- 5%

z = 5% / 2.35% = 2.13

Referring to Probability tables, for z = 2.13, P = 0.48341

So now, 96.7% of amplifiers have gain of -10, +/-5%

We are only losing 3.3% of amplifiers now…
= $$$$$!!!!

Summary

- We have looked at the Process capability
- We have seen how data can be extracted from datasheets for analysis
- Component variation has been incorporated into circuit design
- You have been shown circuit ‘tricks’ to improve the performace using low cost components
- <u>Next lecture</u>
  - We look at Six sigma design

Reading List

TLV2721 Datasheet

Probability Tables

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Thank you
谢谢