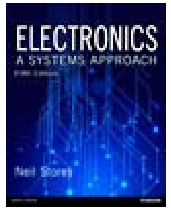
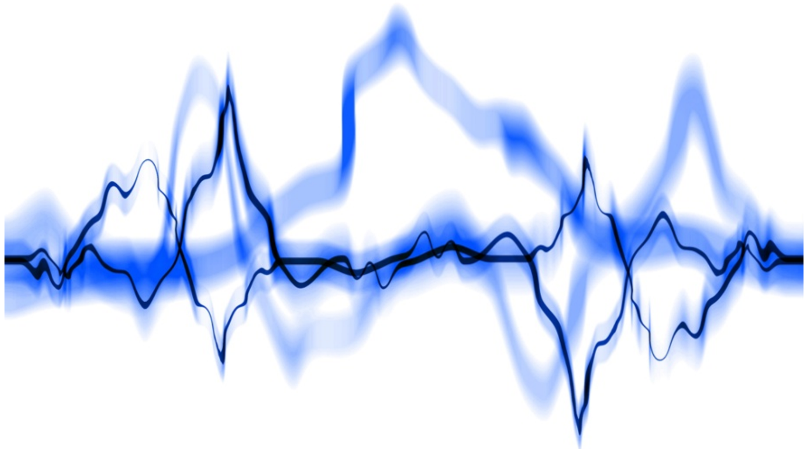
Last time:
Noise and Electromagnetic Compatibility



Chapter 22

- Introduction
- Noise sources
- Representing noise sources within equivalent circuits
- Noise in bipolar transistors
- Noise in FETs
- Signal-to-noise ratio
- Noise Figure
- Designing for low-noise applications
- Electromagnetic compatibility
- Designing for EMC

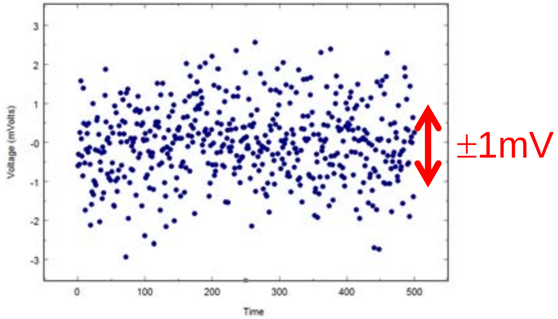


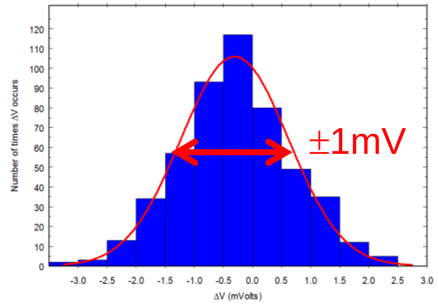
Last time: Device noise

- Thermal or Johnson noise $V_{n(\text{rms})} = \left(4 \cdot k \cdot T \cdot R \cdot BW\right)^{½}$
  - Random thermal motion of charge carriers in resistive materials (both BJT and FET's)
  - Gaussian and white
- Shot noise (current noise) $I_{n(\text{rms})} = \left(2 \cdot e \cdot I \cdot BW\right)^{½}$
  - Statistical fluctuations in the number of charge carriers flowing
  - Most apparent at low current levels
  - Source of noise in BJT transistors from low I_B flow across p-n potential barriers.
  - ~Gaussian and white
- 1/*f* noise
  - Variety of sources.
  - Most common is ***flicker noise***, the variation of diffusion of charge carriers in devices
  - Common source of noise in FET devices
  - Power increases at low frequencies $\Rightarrow$ "red" (6dB/octave) or "pink" (3dB/octave) noise

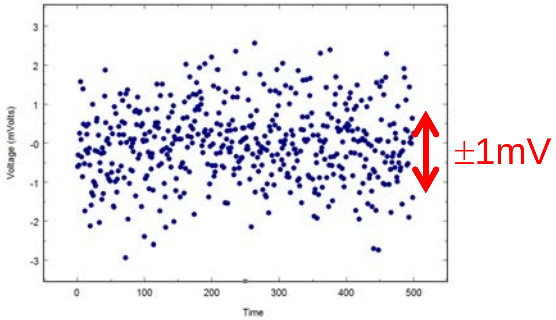
Definition of Gaussian white noise:

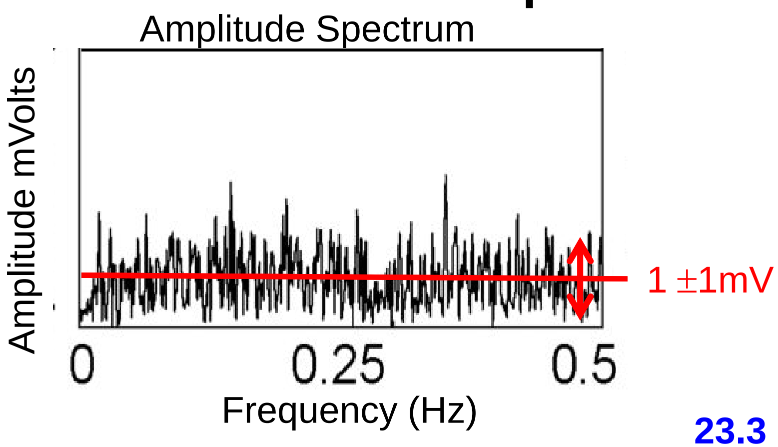
- Gaussian=deviations follow normal distribution





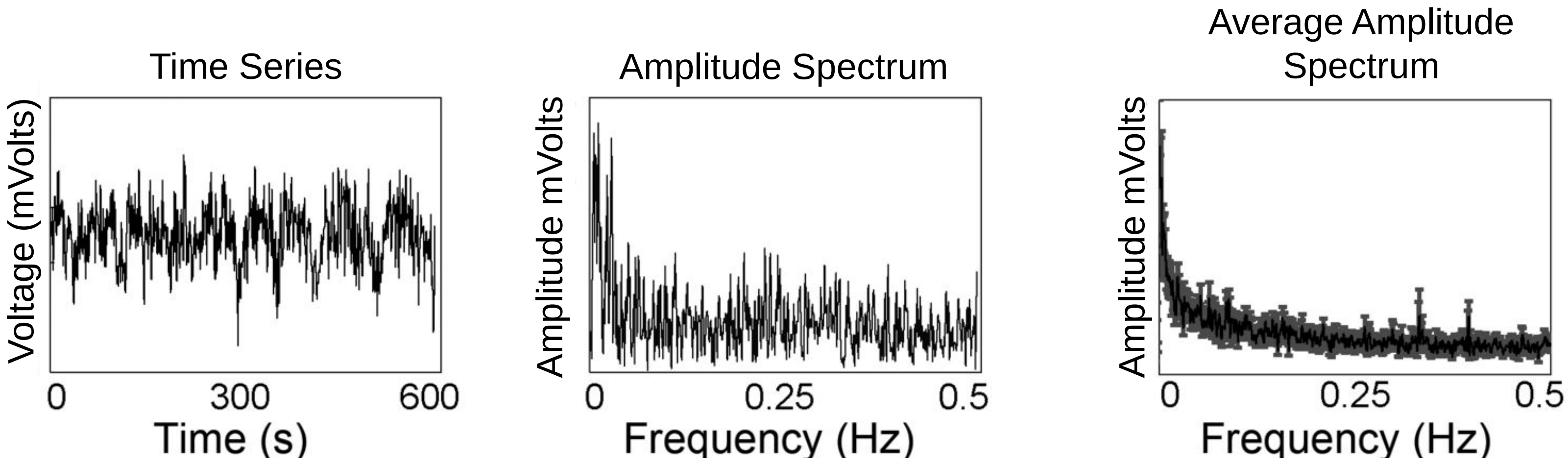
- White-all frequencies have the same amplitude





Red or pink noise

- Lower frequencies have higher amplitudes



- More power at low frequencies
  - Red increases 6dB/octave, Pink 3dB/octave, as frequency decreases
  - Example: a drifting baseline on detector with thermal noise

Figures of merit

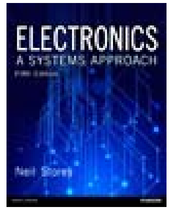
- Signal quality: Signal to noise ratio
  - Average voltage level divided by RMS noise: $\text{S/N ratio} = \left(\dfrac{V_s}{V_n}\right)$
  - Expressed in dB as: $\text{S/N ratio }(dB) = 20\ \log_{10}\left(\dfrac{V_s}{V_n}\right)\ \text{dB}$
  - Can get V_s by averaging input samples

- Circuit quality: Noise figure
  - Measured output RMS noise divided by Measured input RMS noise times the gain of the circuit:

$$\text{NF}(dB) = 20\ \log_{10} \frac{\text{rms noise output voltage from amplifier}}{\text{rms noise output voltage from noiseless amplifier}}$$

- Questions?

Today:
Noise and Electromagnetic Compatibility



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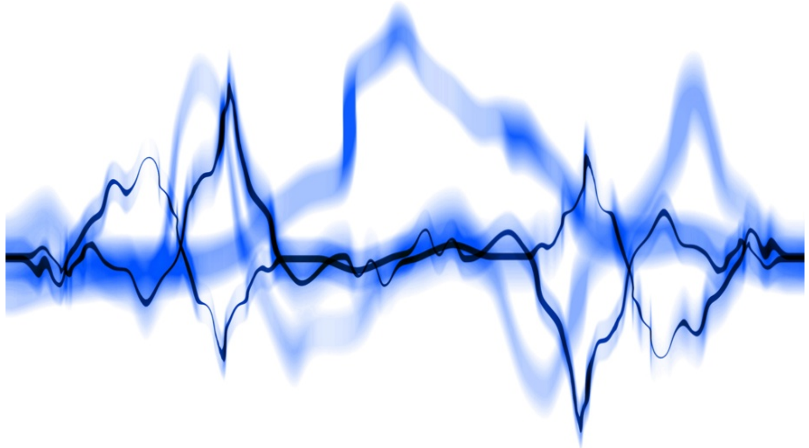


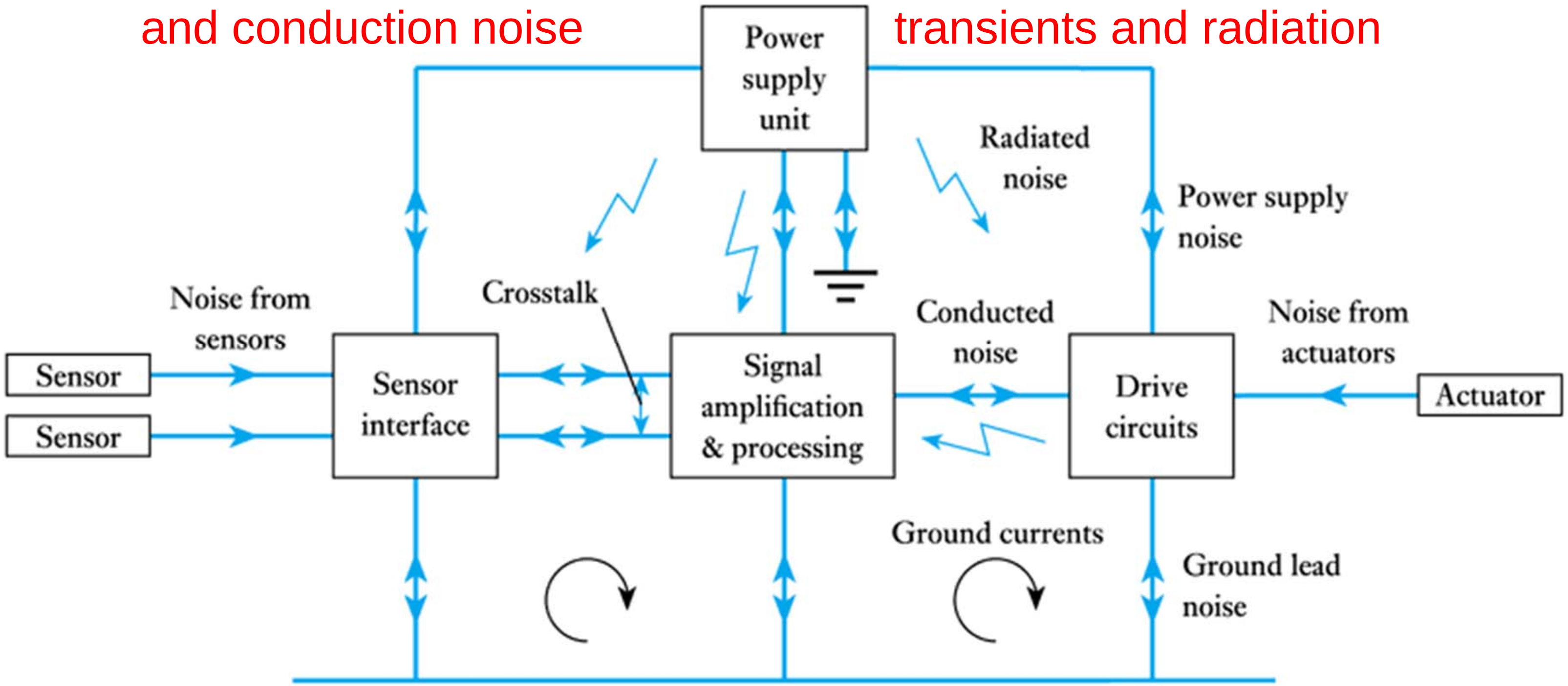
Other sources of noise

- Interference
  - – Pick-up of electro-magnetic radiation in circuit
    - One part of the circuit to another
    - External sources of EM radiation

- Electromagnetic coupling between stages

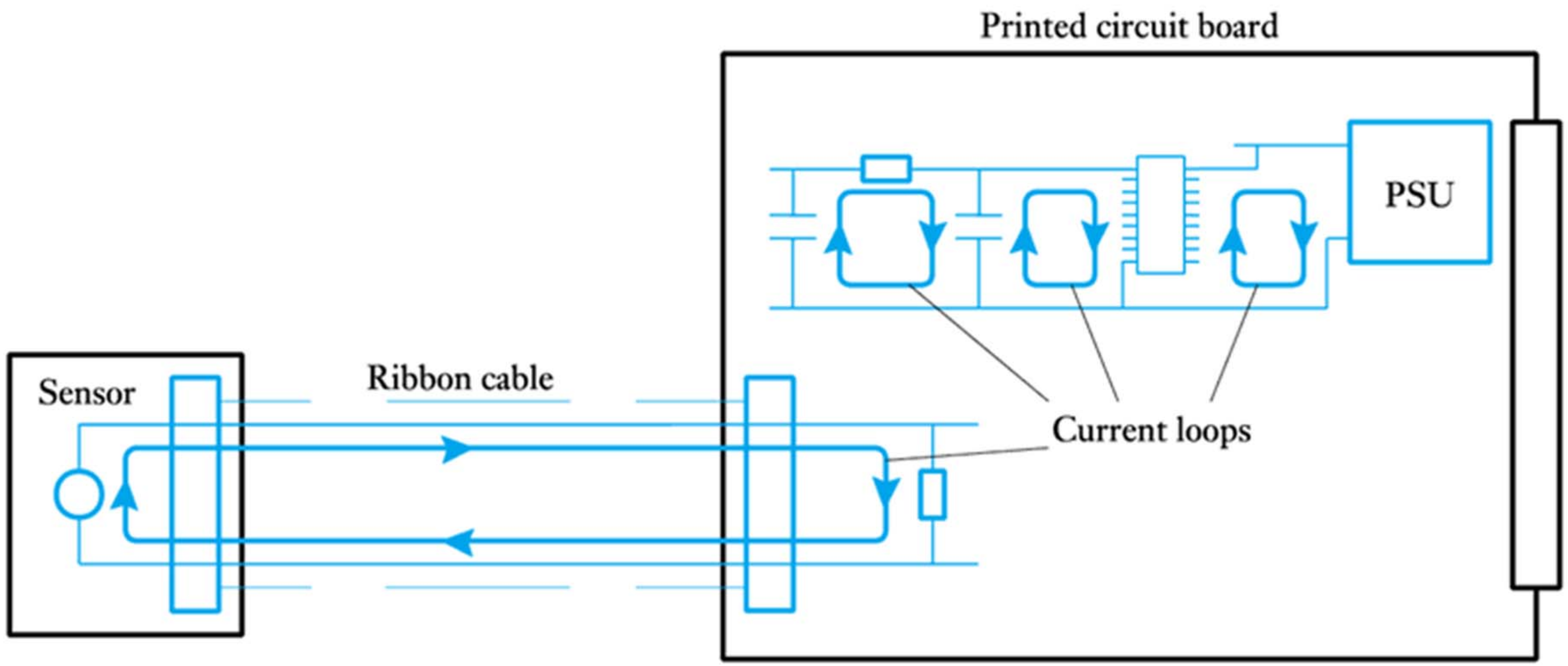
Linear PS have ripple and conduction noise

Switching PS produces transients and radiation

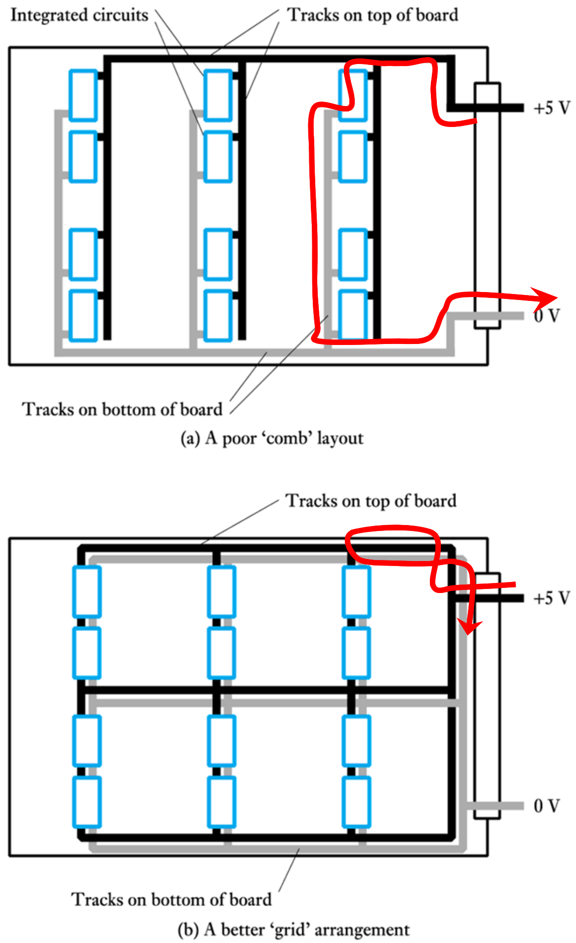


Designing for EMC

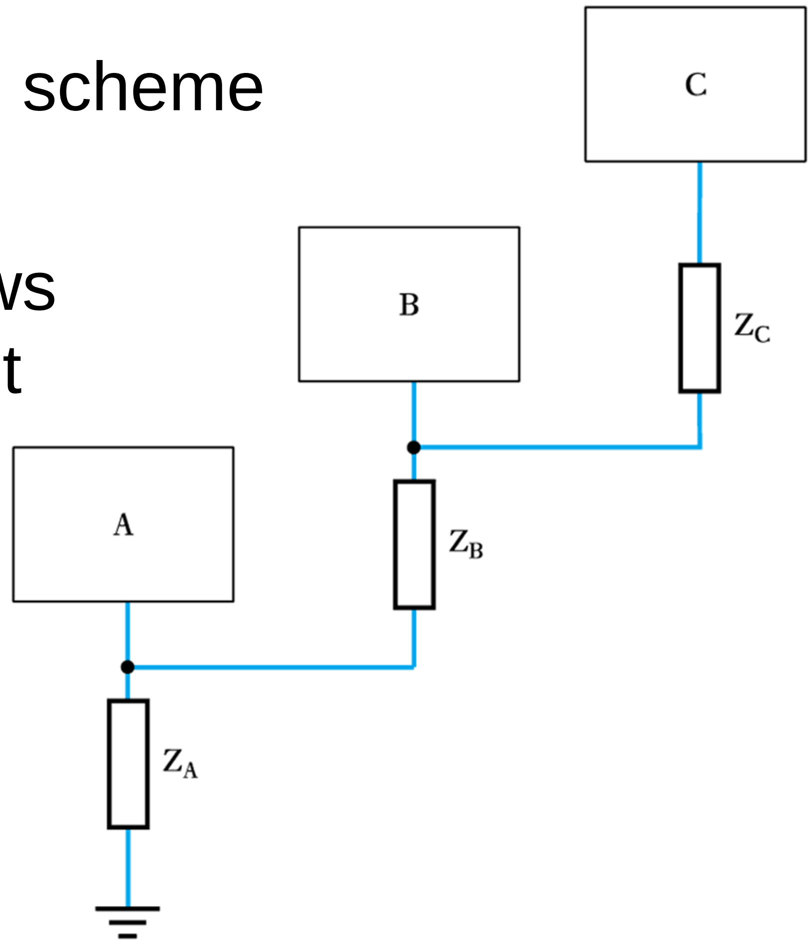
- Examples of current loops (or antennae) within circuits



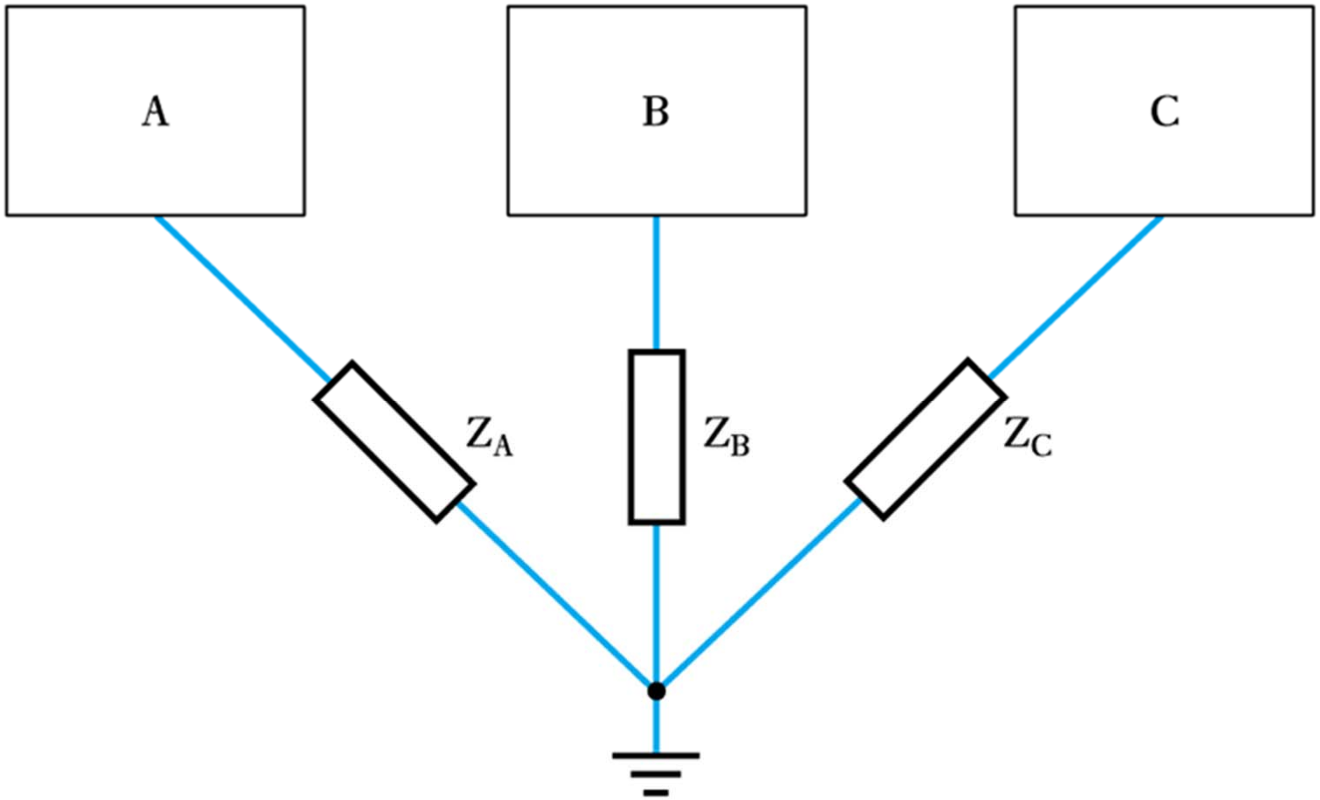
- Examples of power supply routing methods
- 2-Rail technique can allow large current loops to form
- Better to use grid
- Use rounded corners to reduce field strength
- Extend to power plane and ground plane in multi level boards



- A simple series grounding scheme
- If module B suddenly draws power, large return current will raise the potential of the ground point in A



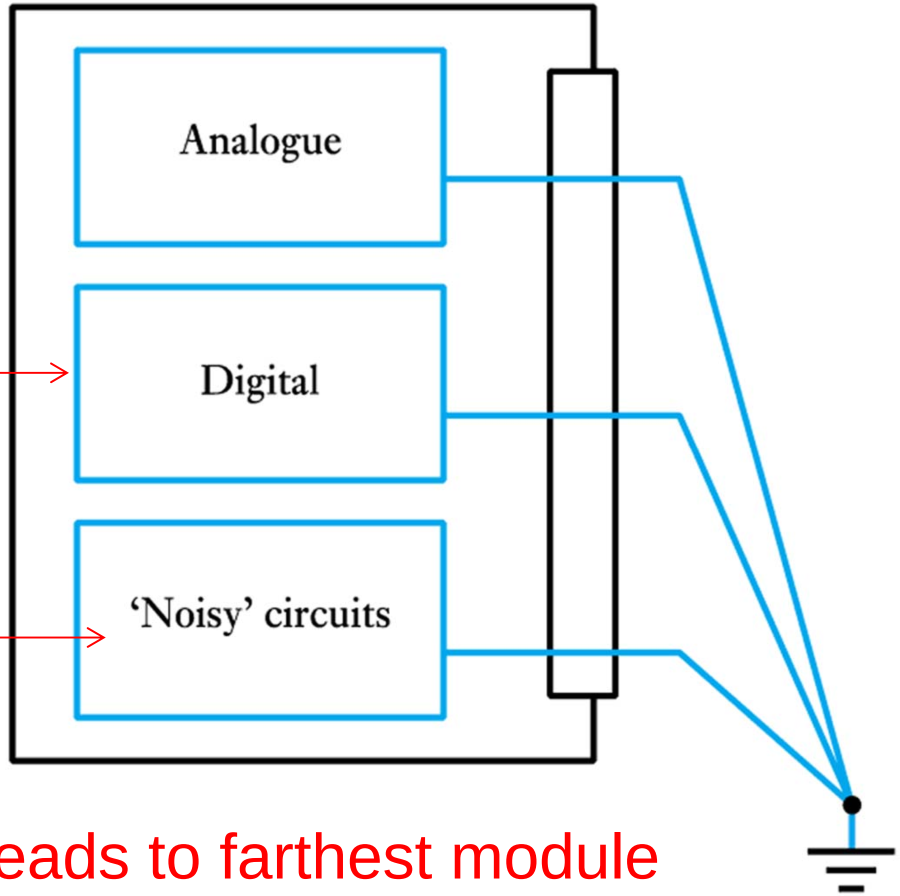
- A single-point grounding scheme uncouples modules



- System partitioning to reduce EMC problems

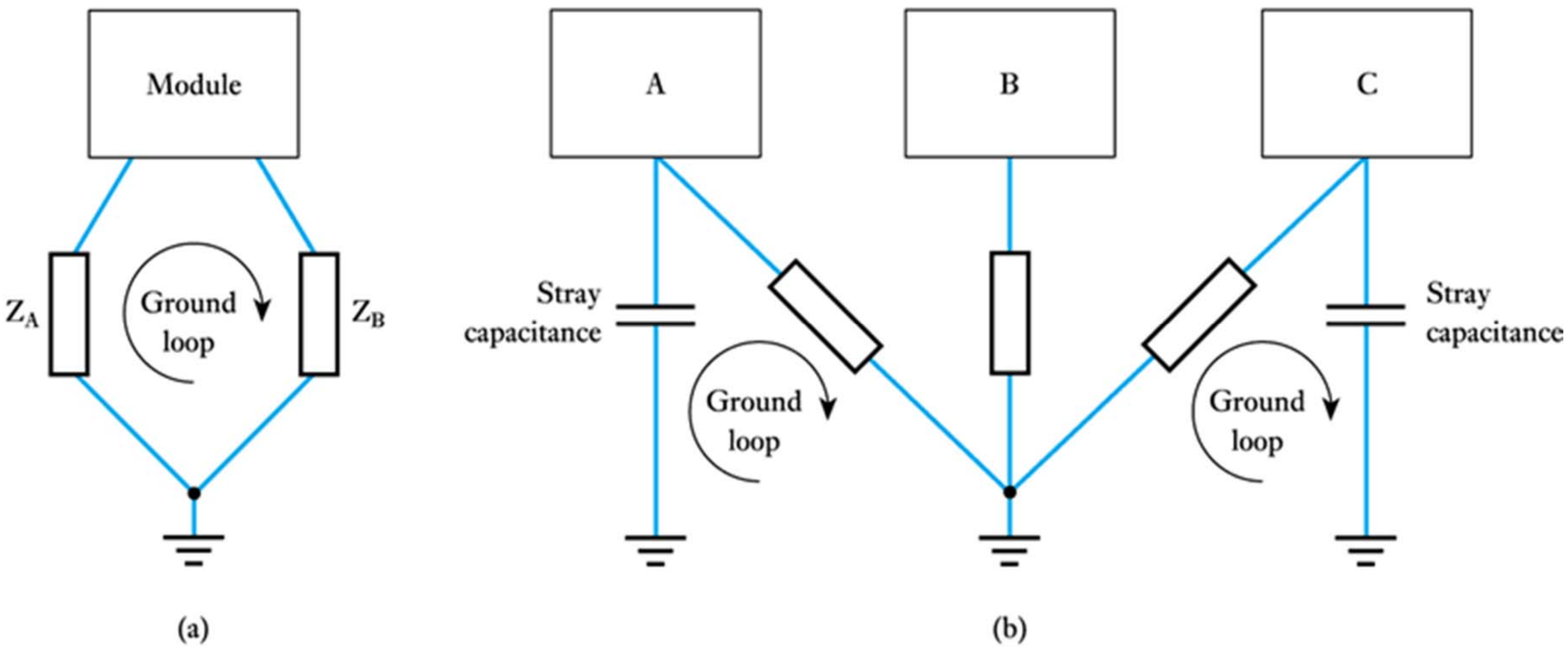
Less sensitive to noise
But better at producing it!
Clock signals & switching

E.g. power supplies, oscillators, relays etc.

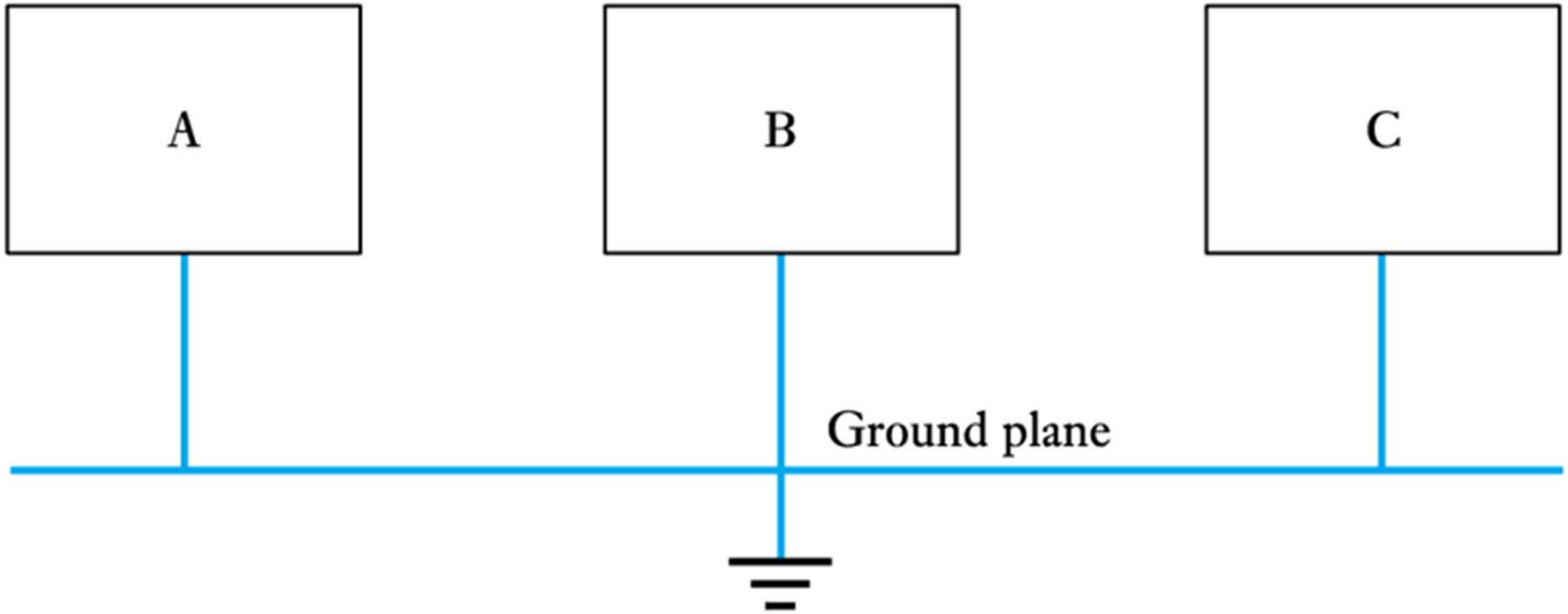


But can create long ground leads to farthest module

- Multiple paths to ground create Ground loops
- Stray capacitance at high frequency (> 1 MHz) can create loops where you least expect them

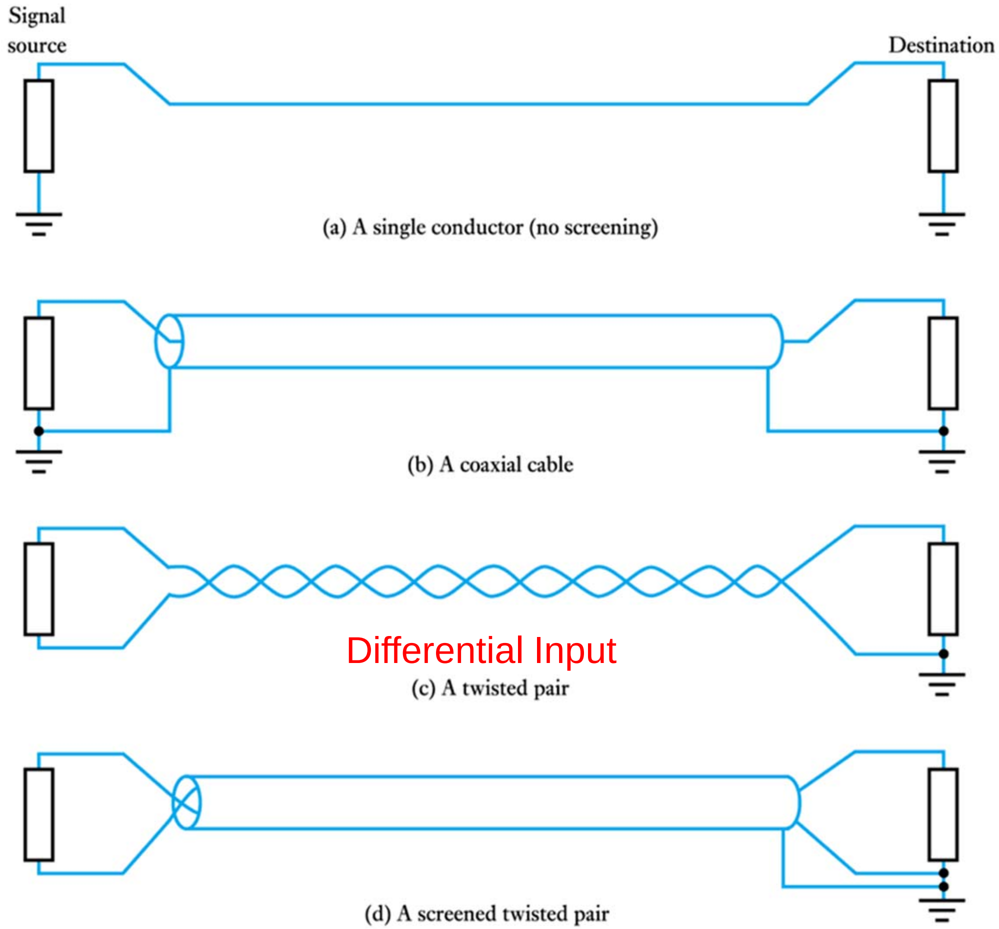


- A multipoint grounding scheme (good at high frequencies or modules where you don’t know how they are grounded internally)

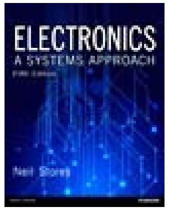


- Cable-screening techniques

- Can have separate Signal and Chassis grounds, tied at a single point.



(a) A single conductor (no screening)
(b) A coaxial cable
(c) A twisted pair
(d) A screened twisted pair



Video 22C Further Study

Further Study

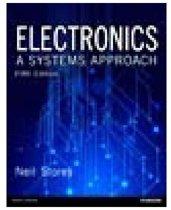
- The Further Study section at the end of Chapter 22 considers the implications of EMC for safety critical systems, such as those found within cars.

- Identify some of the safety-related systems within a modern car and consider how EMC related factors could affect their operation. Then, watch the video for a discussion of some of the issues involved.

Key points

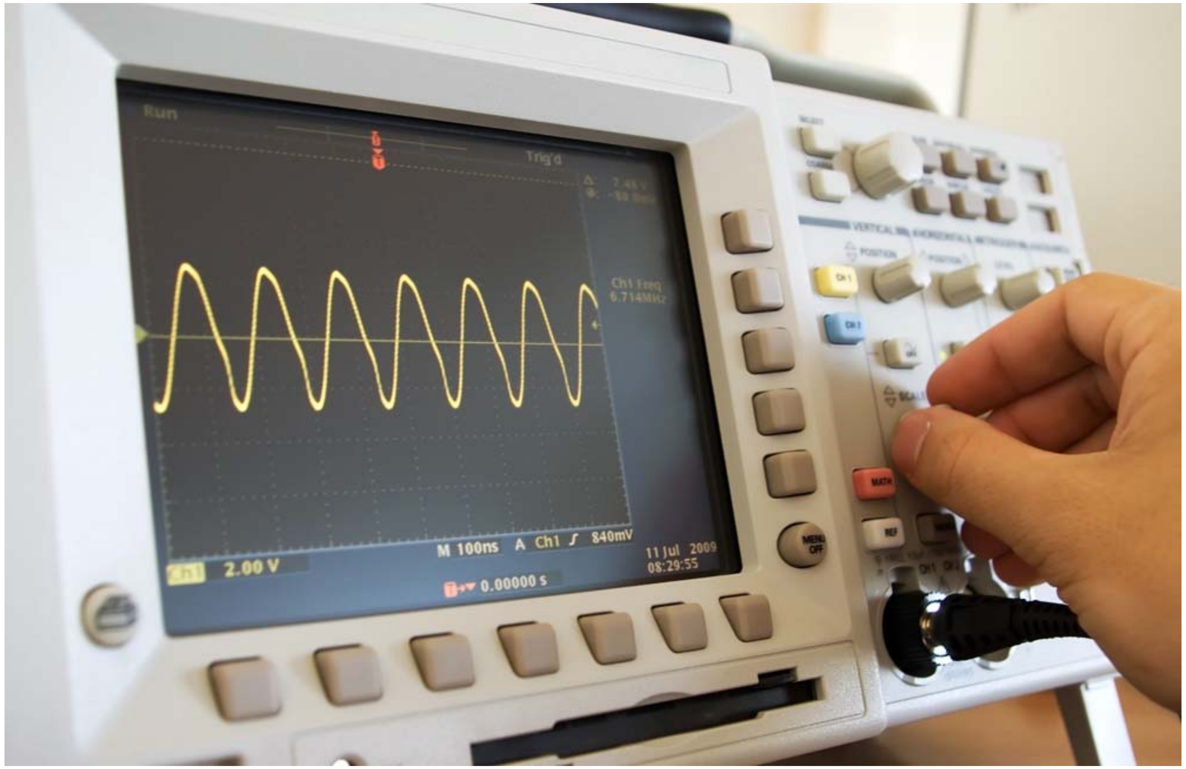
- Noise in electronic circuits can be of various forms, including thermal noise, shot noise, 1/f noise and interference
- Both bipolar transistors and FETs suffer from noise
- Electromagnetic compatibility (EMC) is concerned with the ability of a system to operate in the presence of interference and to not interfere with other equipment (or itself)
- Circuit layout plays a major role in determining EMC performance

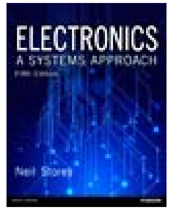
Positive feedback, oscillators and stability



Chapter 23

- Introduction
- Oscillators
- Stability



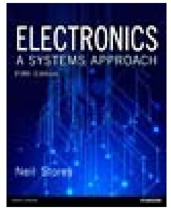


23.1

Introduction

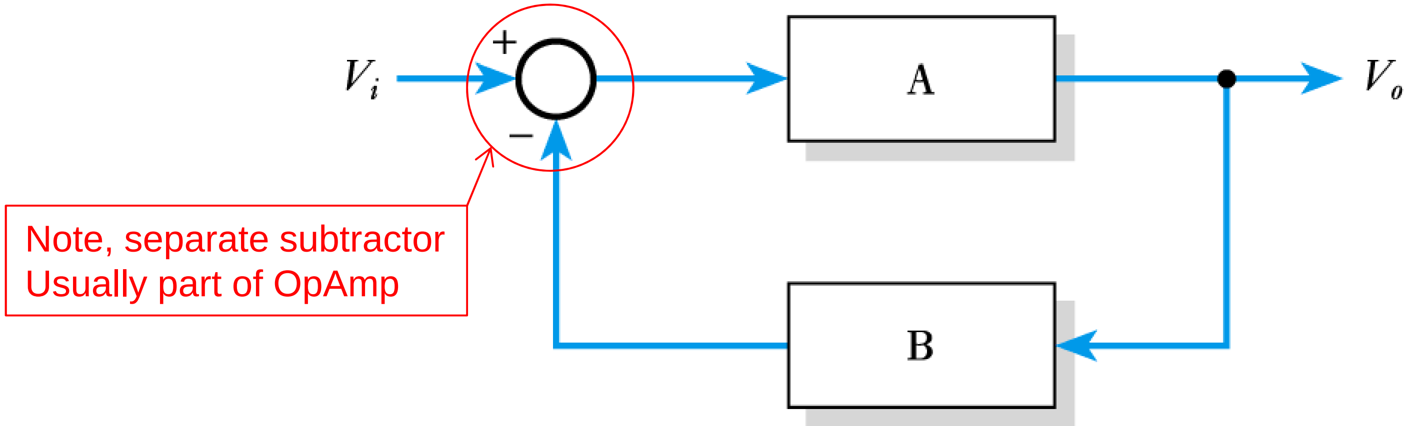
- Earlier we looked at feedback in general terms
  – in particular we concentrated on negative feedback
- In this chapter we will consider **positive feedback**
  – this is used in both analogue and digital circuits
  – it is used in the production of **oscillators**
  – positive feedback can also occur unintentionally within circuits, when it has implications for **stability**

Oscillators



Video 23A   23.2

- Earlier we looked at a generalised feedback system



- We also derived the closed-loop gain *G* of this

$$G = \frac{A}{(1 + AB)}$$

If either A or B (but not both) invert the signal (ie gain < 0), then the output will be 180° out of phase with the input)

- Looking at the expression

$$G = \frac{A}{(1+AB)}$$

  we note that when $AB = -1$, the <u>gain is infinite</u>

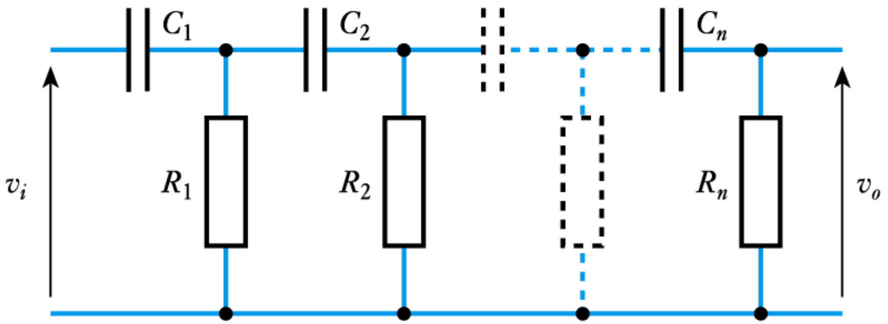
  – this represents the condition for oscillation

- The requirements for oscillation are described by the **Baukhausen criterion:**

  1. The magnitude of the loop gain AB must be 1.
  2. The phase shift of the loop gain AB must be 180°, or 180° plus an integer multiple of 360°

Solve this using a nodal analysis with $Z_C=-j/(\omega C)$, $Z_R=R$
Assign V to each of the nodes (note node 1 = V_i, node 3=V_o)
Assign currents at each node, and I = V/R.

- ***RC*** **or phase-shift oscillator**
  - one way of producing a phase shift of 180° is to use an ***RC*** **ladder network**



  - an arrangement with <u>three</u> identical stages gives a phase shift of 180° when $$f = \frac{1}{2\pi CR\sqrt{6}}$$
  - at this frequency the gain of the network is $$\frac{v_o}{v_i} = -\frac{1}{29}$$

Example solution 3 RC pairs:

$$\begin{bmatrix} -\frac{1}{ZC1} & \frac{1}{ZC1}+\frac{1}{ZC2}+\frac{1}{R1} & -\frac{1}{ZC2} & 0 \\ 0 & -\frac{1}{ZC2} & \frac{1}{ZC2}+\frac{1}{ZC3}+\frac{1}{R2} & -\frac{1}{ZC3} \\ 0 & 0 & -\frac{1}{ZC3} & \frac{1}{ZC3}+\frac{1}{R3} \end{bmatrix} \begin{bmatrix} Vi \\ V1 \\ V2 \\ Vo \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} -I\,\omega\,C & 2\,I\,\omega\,C+\frac{1}{R} & -I\,\omega\,C & 0 \\ 0 & -I\,\omega\,C & 2\,I\,\omega\,C+\frac{1}{R} & -I\,\omega\,C \\ 0 & 0 & -I\,\omega\,C & I\,\omega\,C+\frac{1}{R} \end{bmatrix} \begin{bmatrix} Vi \\ V1 \\ V2 \\ Vo \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Solving for V_i in terms of V_o to get V_o/V_i

Yields

$$\frac{v_o}{v_i} = \frac{1}{1-\frac{5}{(\omega CR)^2} - j\left(\frac{6}{\omega CR} - \frac{1}{(\omega CR)^3}\right)}$$

For real gain

$$\frac{6}{\omega \cdot C \cdot R} = \frac{1}{(\omega \cdot C \cdot R)^3}$$

Or

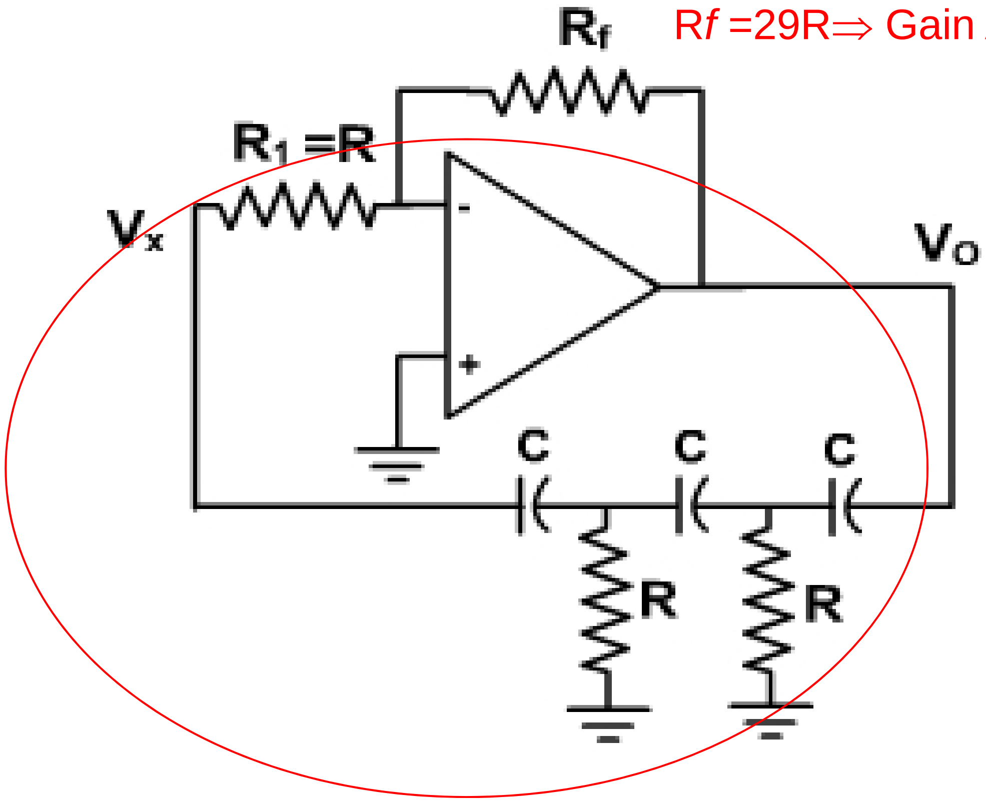
$$f = \frac{1}{2\pi CR\sqrt{6}}$$

And $\frac{v_o}{v_i} = -\frac{1}{29}$

Many different flavours! See supplemental material (Chapter from TI op amp book) for designs

- Therefore the complete oscillator is an op amp with

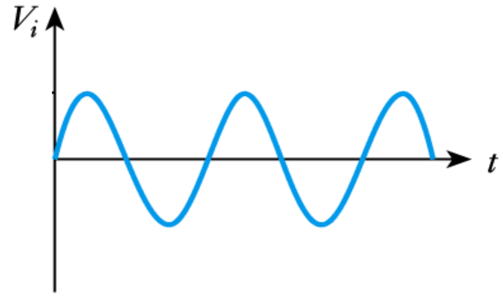
Gain of feedback path B = -1/29



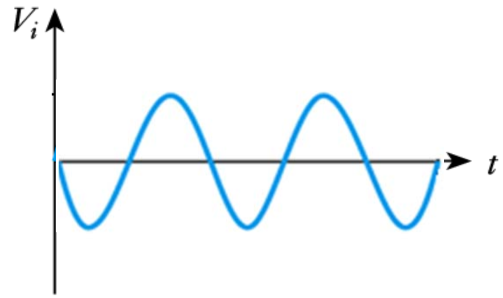
R*f* =29R⇒ Gain A= 29

So A·B = -1

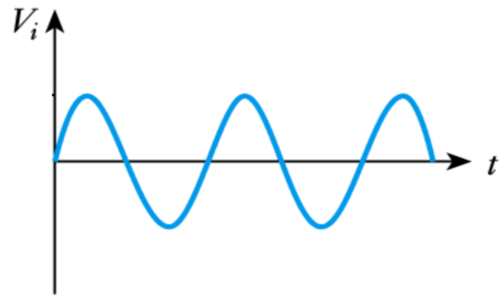
- Input at inverting input



- Output Voltage



- Feedback Voltage at inverting input

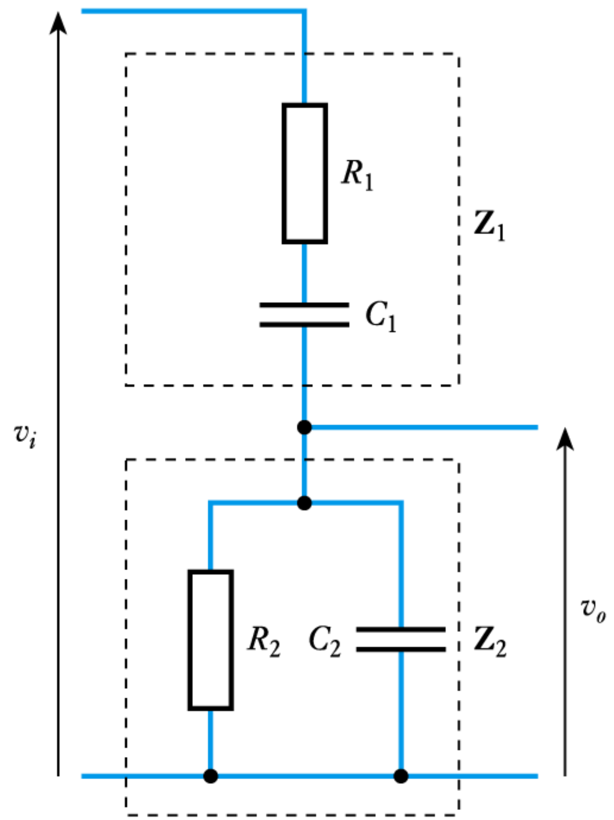


Wien-bridge oscillator

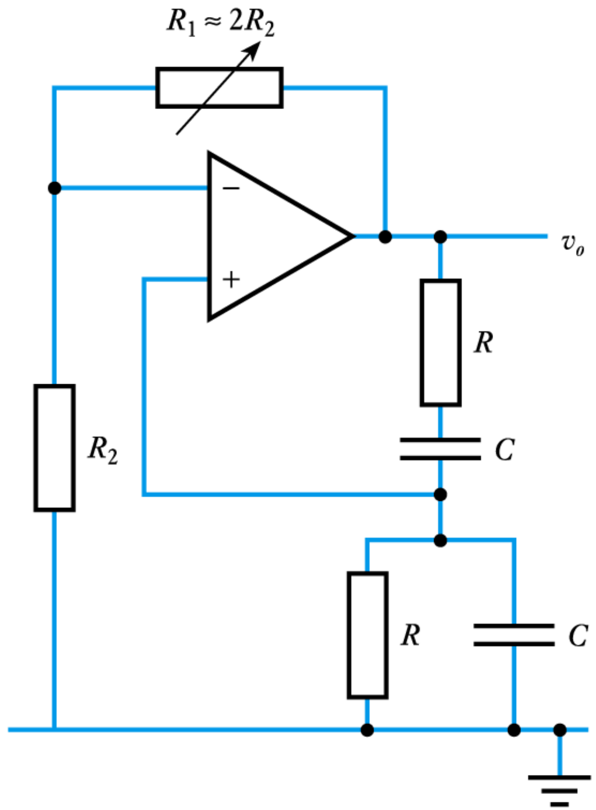
- uses a Wien-bridge network
- this produces a phase-shift of 0° at a single frequency, and is used with a non-inverting amplifier
- the selected frequency is

$$f = \frac{1}{2\pi CR}$$

- when the gain is 1/3



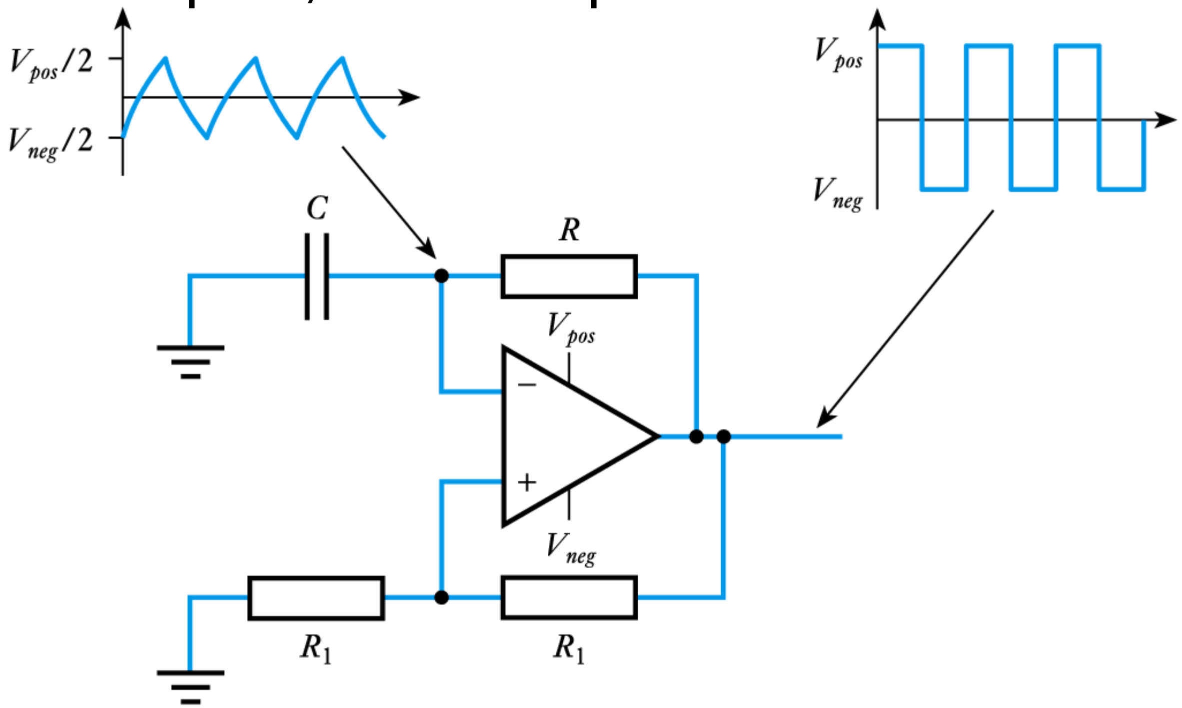
- A complete oscillator might look like



- **Amplitude stabilisation**
  - in both the oscillators above, the loop gain is set by component values
  - in practice the gain of the active components is very variable
    - if the gain of the circuit is too high it will saturate
    - if the gain of the circuit is too low the oscillation will die
  - real circuits need some means of stabilising the magnitude of the oscillation to cope with variability in the gain of the circuit
  - see **Section 23.2.3** in the course text for more discussion of this topic

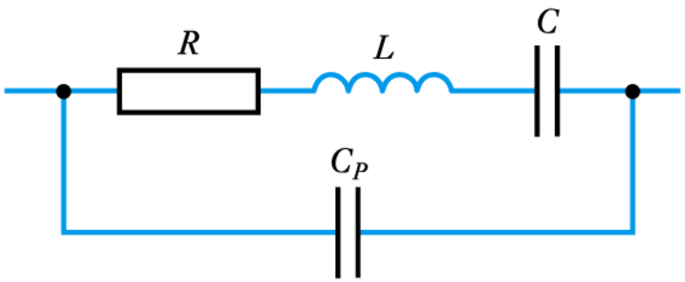
Video 23B

- **Digital oscillators**
  - many examples, for example the **relaxation oscillator**



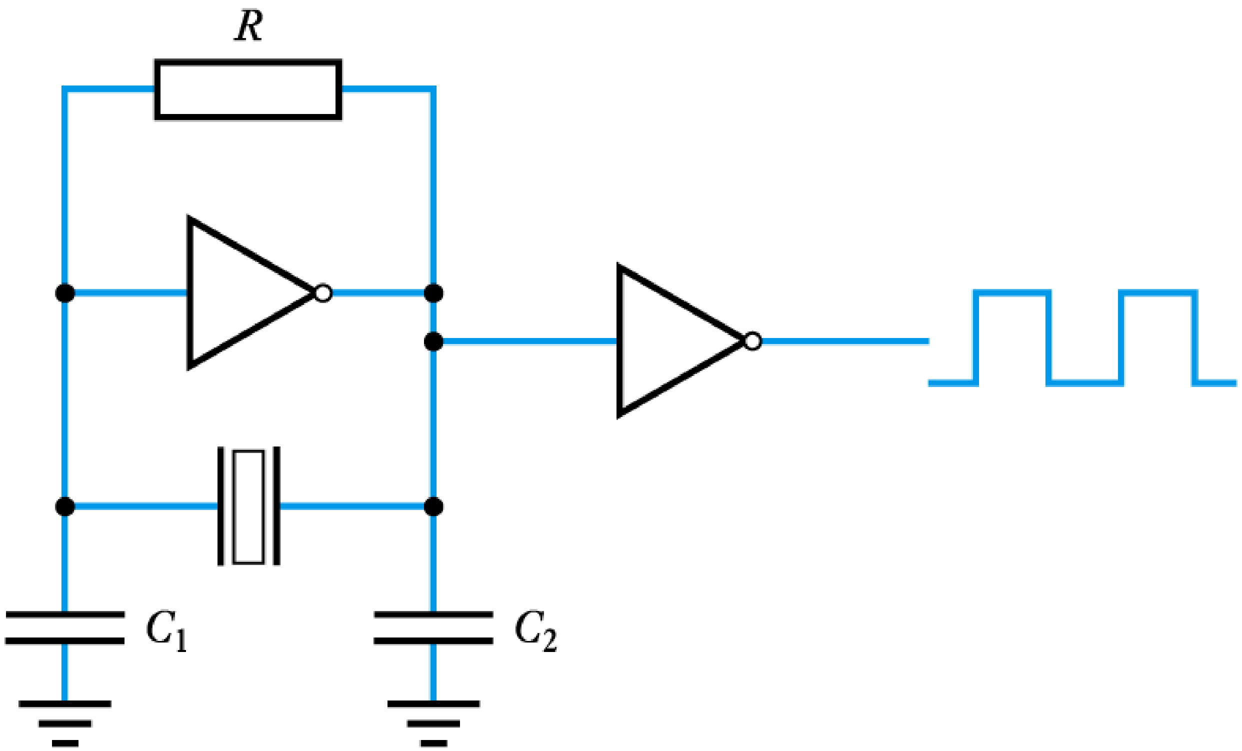
- **Crystal oscillators**
  - **frequency stability** is determined by the ability of the circuit to select a particular frequency
  - in tuned circuits this is described by the **quality factor, Q**
  - **piezoelectric crystals** act like resonant circuits with a very high Q – as high as 100,000

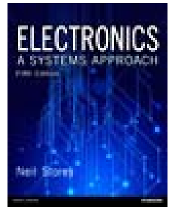
(a) Circuit symbol



(b) Equivalent circuit

- A typical crystal oscillator





Stability

- Earlier we used a general expression for the gain of a feedback network

$$G = \frac{A}{(1 + AB)}$$

- So far we have assumed that *A* and *B* are real gains
  – the gain of a *real* amplifier has not only a magnitude, but also a phase angle
  – a phase shift of 180° represents an inversion and so the gain changes polarity
  – this can turn *negative* feedback into *positive* feedback

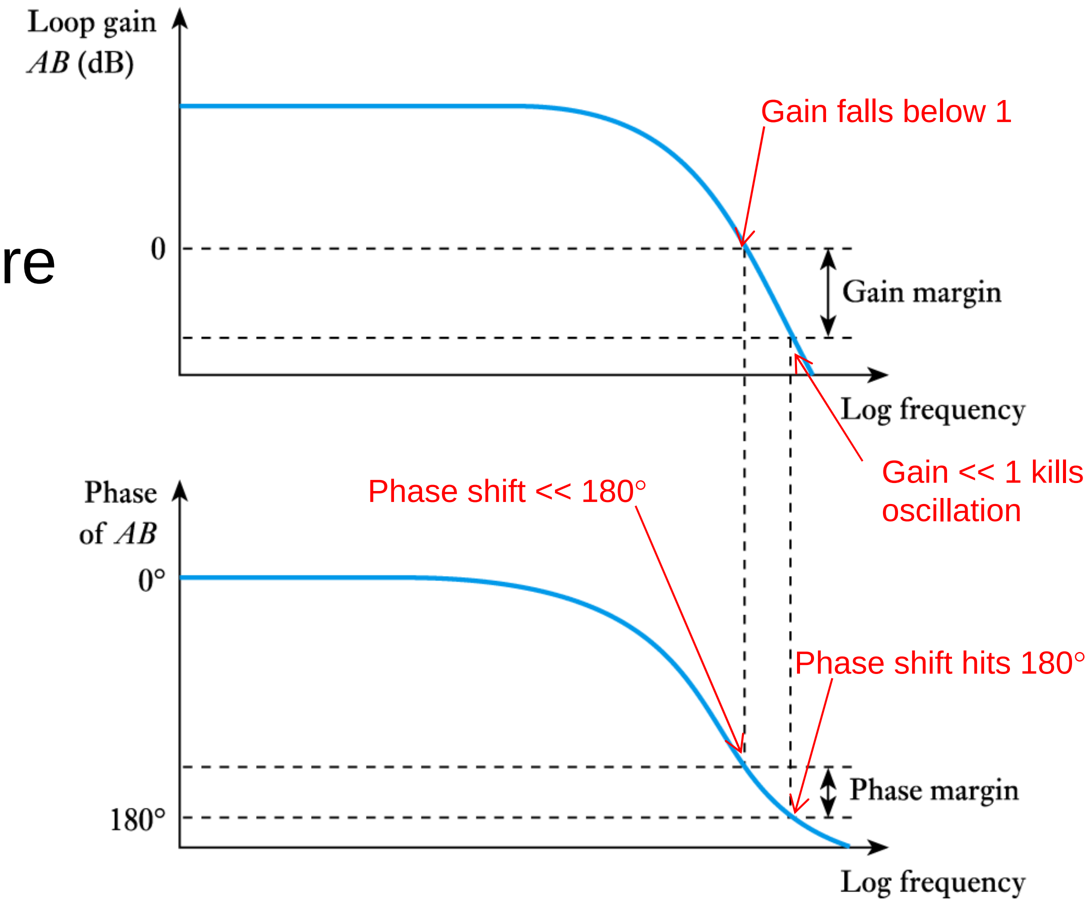
$$G = \frac{A}{(1+AB)}$$

You have a non-inverting amplifier with negative feedback

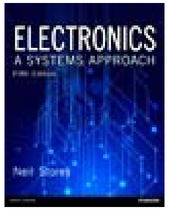
- AB is >0 and G < A and positive
  - V+ goes positive, Vo goes positive,
  - Vo (or some fraction) gets put into V-, and system stabilizes.
- There is a low pass element in the output circuit
  - This can be the fall off with gain at high frequency
  - This will be accompanied by a phase shift with frequency
- At high frequency feedback signal is shifted by 180°
  - V+ goes positive, Vo goes positive, but
  - V- is now driven negative, creating positive feedback ($|V_+ - V_-|$ bigger)
- AB is now effectively < 0 (with the 180° phase shift)
  - but need AB=-1 to grow oscillation
  - If |AB| <<1 when phase shift hits 180°, low gain kills oscillation

- The gain of all real amplifiers falls at high frequencies and this also produces a phase shift
- All multi-stage amplifiers will produce 180° of phase shift at *some* frequency
- To ensure stability we must ensure that the Baukhausen conditions for oscillation are *not* met
  - That is, $|AB|=1$ *and* 180° phase shift of B
  - to guarantee this we must ensure that the gain falls below unity before the phase shift reaches 180°

- **Gain and phase margins**
  - these are a measure of the stability of a circuit



- **Unintended feedback**
  - stability can also be affected by unintended feedback within a circuit
  - this might be caused by **stray capacitance** or **stray inductance**
  - if these produce positive feedback they can cause instability
  - a severe problem in high-frequency applications
  - must be tackled by careful design



Video 23C Further Study

Further Study

- The Further Study section at the end of Chapter 23 is concerned with amplitude stabilisation in sine wave oscillators.
- It considers a novel use of a light bulb as a stabilising element.

- Take a look at the task involved and then watch the video.

Key points

- Positive feedback is used in analogue and digital systems
- A primary use is in the production of oscillators
- The requirement for oscillation is that the loop gain *AB* must have a magnitude of 1, and a phase shift of 180° (or 180° plus some integer multiple of 360°)
- This can be achieved using a circuit that produces a phase shift of 180° together with a non-inverting amplifier
- Alternatively, it can be achieved using a circuit that produces a phase shift of 0° with an inverting amplifier
- For good frequency stability we often use crystals
- Care must be taken to ensure the stability of all feedback systems