Physics 590B

Electrical signals generation and measurements

Torpedo nobiliana (Giant electric ray)

Typical pulse: 50 A, 60 V
Connecting resistors in series

\[ I_1 = I_2 = I_3 = I \]
\[ V_1 = IR_1 \quad V_2 = IR_2 \quad V_3 = IR_3 \]
\[ V = V_1 + V_2 + V_3 \]

\[ V = IR_{eq} \quad \text{(same I and V as before)} \]

\[ R_{eq} = R_1 + R_2 + R_3 \]
Connecting resistors in parallel

\[ I = I_1 + I_2 + I_3 \]

\[ V = V_1 = V_2 = V_3 \]

\[ V = I_1R_1 \quad V = I_2R_2 \quad V = I_3R_3 \]

\[ V = IR_{eq} \quad \text{(same I and V as before)} \]

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}
\]
Kirchhoff’s rules

Junction rule: Sum of currents entering a junction equals the sum of the currents leaving it.

Loop rule: The sum of the changes in potential around a closed loop is zero.
Resistivity measurements
Real circuit

\[ R_V \]

\[ R_{A} \]

\[ R_{\text{batt}} \]

\[ R_{\text{lead}} \]

\[ R_{\text{contact}} \]
Solution: four point contact measurement
Simplest circuit: voltage divider

\[ V_{\text{out}} = V_{\text{in}} \frac{R_1}{R_1 + R_2} \]
Batteries
Analog power supplies
Voltage regulators

Block Diagram

XX=05, 06, 08, 09, 10, 12, 15, 18, 24V
Adjustable voltage regulators

LM350: 3V-35V
Current sources

(from a voltage divider or perhaps a signal)
Electrometers
Current meters
Digital volt meter (DVM)
Digital to analog converters (DAC)
Analog to digital converters (ADC) - flash
Analog to digital converters (ADC)  
"voltage to time"
Analog to digital converters (ADC) “successive approximation”
"Sample and hold circuit"

Diagram:

- Signal input to amplifier
- Diode and FET switch
- Output
- S/H input
- Capacitor with 0.001 µF (external)
- 30 kΩ and 300 Ω resistors

Graph:

- Capacitor voltage
- Time
- Acquisition time
- Charge injection ("hold step")
- Droop
- Hold
- Sample
- Time arrow
Signal amplification (OpAmps)

Inverting amplifier

Non-inverting amplifier - "voltage follower"

Differential amplifier
LF411 internal schematics
Example - 1kV piezo driver (2V/μs)

- 1kV piezo driver (2V/μs)

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*use five resistors in series

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0–1kV piezo driver
1000V pp to 1kHz

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protection circuit

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Oscillators

A

20MHz low-distortion Colpitts oscillator

B

Hartley LC oscillator
Quartz oscillators

A. Pierce oscillator

B. Colpitts oscillator

C.

D.

E.

CMOS inverter

MC12060 (100kHz–2MHz)
MC12061 (2MHz–20MHz)

+5V

sine outputs

TTL out

sine in

out

5 4 7 11
6 8 14 15
2 3 10

20pF

10MΩ

10MΩ

100k

32,768Hz

20pF

1mH

8.2k

4.7k

+10V

+24V

1000pF

1000pF

1000pF

1000pF

1MΩ

1MΩ

1.0k

270pF

100k

2N5485

2N5485

2N4124

output

output

output

output

output
Noise reduction techniques

Main sources of noise:

1) interference excitation of currents in circuit due to EM waves

2) Johnson noise - thermal excitation in resistors:

\[ V_J = (4kTRB)^{1/2} \]

e.g. \( T=300 \), \( R=10\, k\Omega \): \( V_J = 1.3 \, \mu V \)
3) shot noise (due to quantization of charge)

\[ I = (2eI_{dc}B)^{1/2} \]

e. g. at 10 kHz bandwidth

1A current has noise of 57 nA (0.000006%)

1μA current has noise of 6 nA (0.006%)

1pA current has noise of 56 fA (5.6%)
4) flicker noise $1/f$

Resistors

Carbon composite 0.1 μV - 3.0 μV
Carbon film 0.05 μV - 0.3 μV
Metal film 0.02 μV - 0.2 μV
Wire wound 0.01 μV - 0.2 μV
Filters

Diagram showing a filter circuit with component values and a graph plotting attenuation (dB) against frequency (kHz).
Shielding

- Use a shielded cable to connect the devices.
- Include a capacitor (e.g., 0.01 μF) and a resistor (e.g., 10-100 Ω) in the circuit to reduce interference.
- Connect the shields to the circuit ground.
Noise cancellation
Lock-in measurements

Diagram showing the process of lock-in measurements:

1. Experiment
2. Low-noise amplifier
3. Phase detector
4. Low-pass filter (~1Hz or less)
5. Meter
6. Chart recorder
7. Computer
8. Data logger

Modulation and 'knobs' are used to adjust the signal.

Signal Recovery

Stanford Research Systems