Measurements and Instrumentation for Telecommunications - MIT

Lesson One - Introduction

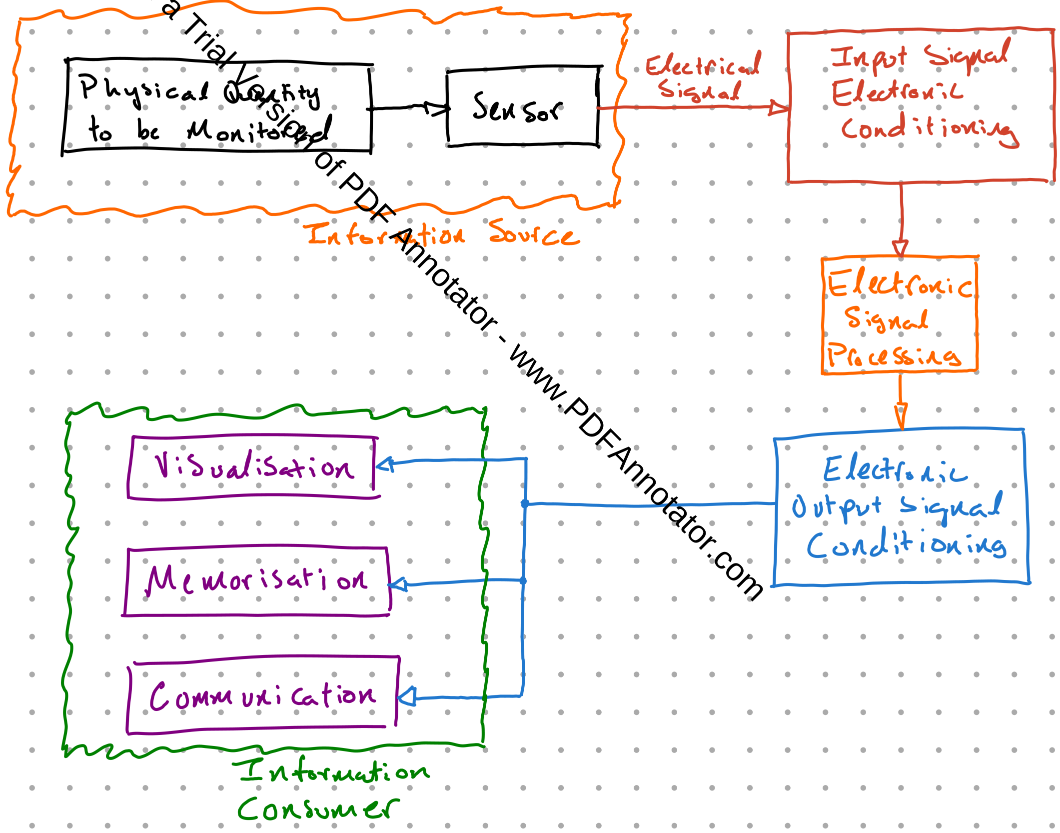
When Do We Measure?

- Design Phase
  - Validate Design Idea
  - Check Application of New Tech.
  - Performance assessment of New Tech.
- Prototyping Phase
  - Check Conformance to Spec.
  - Measure EM Characteristics
  - Check Performance in Env. Cond.
- Production Eng.
  - Tuning design & product (by successive approx.)
  - Reliability Tests
  - Compatability Measurements (EMC)
- Bringing New Eq. into Service
  - Checking Vital Sys. parameters
  - Checking Compatability with other devices
- During operation (In-Service Maintain.)
  - Monitoring correct function
  - Monitoring of operating Costs
  - Pricing to Third Parties
- When Maintaing the eq./sys. (Out-Service maintain)
  - The live traffic is removed from the link
  - A known test signal can be used

Why Do We Measure?

Introduction to Electronic Measuring Systems

The Measuring Chain



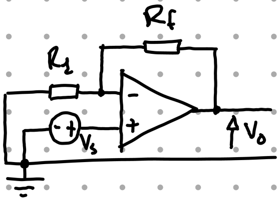
The Measuring Chain: Signal Processing

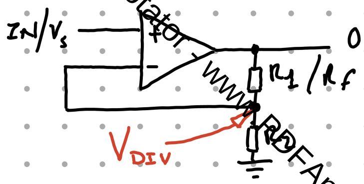
- Analog Processing
  - Linear amplification, addition, difference
  - Integration, derivation, linear filtering
  - Non-linear amplification, multiplication, division
  - Scansion (I don't know what this is)
- Analogue to Digital Conversion
  - Sampling
  - Conversion
- Digital Processing
  - Hardware
  - Software

Introduction to Electronic Measuring Systems cont...

Non-Inverting Amplifier

This is a very common and essential configuration of the ideal op-amp. It uses two resistors in a feedback configuration which can give a net gain on the input voltage signal ($A_V \geq 1$).
Specifically the resistors are placed in a voltage divider configuration feeding into the inverting input (-ve terminal) with the input signal connected to the +ve terminal.
This circuit is drawn in a number of ways:





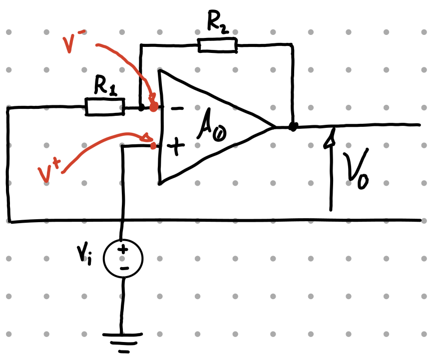
$$V_{DIV} = \frac{R_1}{R_1 + R_2} \times V_o$$

$\boxed{\text{Remember Op-amp's output is trying to make: } V^- = V^+}$

Let's say:

$$D = \frac{R_1}{R_1 + R_2}$$

$$\frac{1}{D} = k = A_V \quad \text{(Gain)}$$



$$\left.V^- = \beta V_o = \frac{R_1}{R_2 + R_1} V_o\right\} \text{In this scheme } \beta = f$$

$$G_{loop} = -\beta A_o = -\frac{R_1 \times A_o}{R_1 + R_2}$$

A_o = Open loop gain

G_{loop} = Closed loop gain

$$\underset{\text{(Amplification)}}{A} = \frac{V_o}{V_i} = \frac{A_o}{1 - G_{loop}} = \underbrace{\frac{1}{\beta + 1/A_o} \simeq}_{\boxed{A_o \longrightarrow \infty}} \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

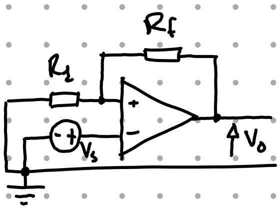
Typical Characteristics:
- Accurate gain: low tolerance resistors, small values of amplification, A
- High input impedance
- Typical Values:
  - Gain/Amplification: $1 \leq G \leq 100 \sim 1000$
  - $R_2 \approx 2 \sim 100\,k\Omega$

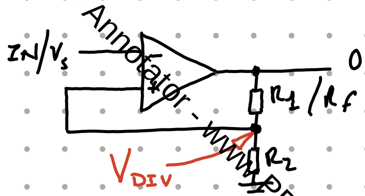
Frequency Response and Gain Bandwidth Product (GBW)

The op-amp has an open loop gain, G_{OL}/A_{OL}, which is a function of frequency $A_{OL}(f)$. There is a commonly used metric related to this frequency response called the Gain-Bandwidth product - GBW this is the frequency where $A_{OL} = 1$
For ideal op-amp models gain is assumed to be approx. infinite across all frequencies.
However, realistically op-amps A_{OL} begins to decrease long before GBW.

Introduction to Electronic Measuring Systems cont...

Inverting Amplifier





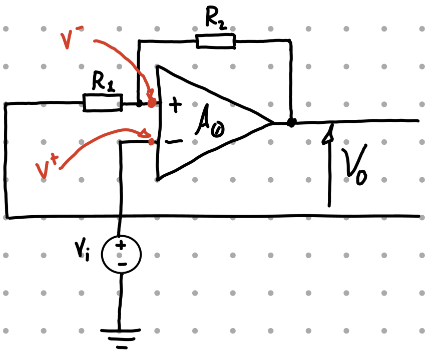
$$V_{DIV} = \frac{R_1}{R_1 + R_2} \times V_0$$

Remember Op-amp's output is trying to make:
$V^- = V^+$

Let's say:

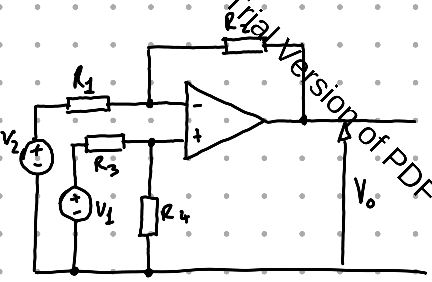
$$D = \frac{R_1}{R_1 + R_2}$$

$$\frac{1}{D} = k = A_v$$
(Gain)



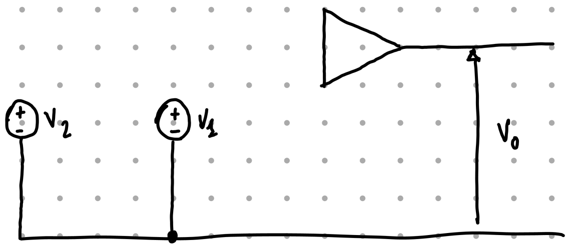
Introduction to Electronic Measuring Systems cont...

Difference Amplifier



Common Mode Rejection Ratio

Summing Amplifier



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Integrator

Approximate Integrator

Differentiator

Introduction to Electronic Measuring Systems cont...

Instrumentation Amplifier

Operational Amplifier – Small Signal Behaviour

Operational Amplifier : Selecting the Right one

Ideal Linear Filters

Butterworth Filters

Second Order L.P. Filter

Second Order High Pass Filter

Measurements in the Frequency Domain

Introduction

Spectrum Measurements

Decibel

Cardinal Values

Measurements in the Frequency Domain Cont...

"Absolute" Decibel Values

dBV ⟷ dBm Conversions

Gain and Loss Calculations (Power)

Gain and Attenuation Calculations (Voltage)

Measurements in the Frequency Domain cont...

Multiple Blocks

Examples

Bank of Filters → Spectrum Analyser

Sampled Waveforms

Measurements in the Frequency Domain Cont...

Aliasing

FFT Properties

Digital (FFT-Based) Spectrum Analyser

Frequency Span and Resolution

Measurements in the Frequency Domain Cont...

Oversampling and Digital Filtering

Leakage (Frequency Dispersion)

Example: Hanning Window

Flat-top Window

Measurements in the Frequency Domain Cont...

Sine Wave Spectrum

Frequency Selection with a Tunable Filter

Frequency Shift of a Signal

Local Oscillator, Mixer + Band-Pass Filter

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Measurements in the Frequency Domain Cont...

Heterodyne (Swept) Spectrum Analyser

Intermediate Frequency Choice

Image Frequency

Output on a Digital Display

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Measurements in the Frequency Domain Cont...

Specification of a Swept Spectrum Analyser

Frequency Response Analysis: Amplitude

Frequency Response Analysis: Phase

Probability Density Function

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Measurements in the Frequency Domain Cont...

Noise Power

Power Spectral Density

Frequency Distribution of the Noise

Noise Equivalent Bandwidth

Measurements in the Frequency Domain Cont...

Noise and Decibels

Noise Measurement with a Spectrum Analyser

Phase Noise

Spectrum Analysers

Measurements in the Frequency Domain cont...

Band selectable Analysis with FFT Instruments

Real-Time Bandwidth of Digital Spectrum Analysers

Transient Analysis

Overlapping

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Measurements in the Frequency Domain Cont...

Real Time Spectrum Analyser

Spectrum Maps

Network Analysis

FFT Network Analyser

Measurements in the Frequency Domain Cont...

Transfer Function Measurements

Correlation Measurements

Auto-Correlation : Random Noise

Auto-Correlation : Periodic Signal

Auto-Correlation : Noisy Periodic Signal

Measurements for Fibre Optic Systems

Introduction to Fibre optic Systems and Measurements

Evolution of Modern Fibre Links

Transmitter

Optical Fibre

Fibre Losses

Optical Fibre Applications

Single Mode Fibres - Chromatic Dispersion

Optical Amplifiers / Repeaters

Receiver

Digital Transmission Over a Fibre Link

Multiple Wavelength Systems (WDM)

Measurements Specific to WDM

Characterisation of an Optical Fibre Digital Link

Waveform Analysis

Clock Jitter Measurements

Optical Power Measurements

Thermoelectric Detectors

p-i-n Photo-Detectors

PIN Photodiodes

Spectral Responsivity of Photo-Detectors

Optical Power Emitted by a Broadband Source

Optical Power Emitted by a Mono-Chromatic Source

Optical Power Emitted by an LED

Power Meters with Photo-Detectors

Non-Linearity of Power Meters

Photo-Detector Noise

Absolute Optical Power Measurements

Power Meter Calibration

Uncertainty of Optical Power Measurements

Optical Spectrum Analysis

Optical Spectrum Analyser

Fabry-Perot Filter (Etalon)

Diffraction Grating Based OSA

Focusing Optics

Input Stage of an OSA

Light Detection

Sensitivity

Spectral Measurements on Modulated Signals

Triggered-Sweep Mode

ADC-Trigger Mode

ADC-AC Mode

Wavelength Calibration of the OSA

Monitoring of Loss in an Installed Fibre

OTDR

Backscattering Analysis

Splicer Loss Measurement

Measurement of a Connector Insertion Loss

Bending Losses

Dark and Active Fibre Testing