# DIGITAL SIGNAL PROCESSING THEORY AND APPLICATIONS WITH EXAMPLES

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National Research Foundation

SARAO
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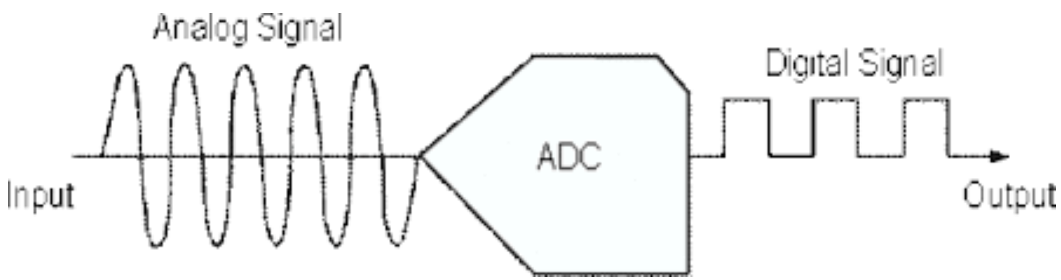
# Introduction



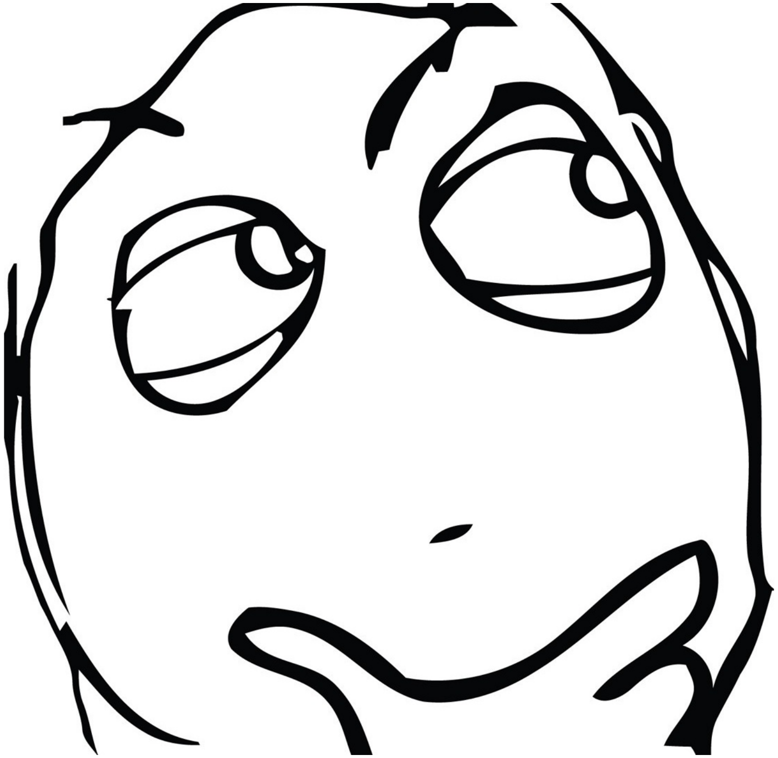
## Digitization



# Signal Processing Theory



## What operations can we perform on Signals?



# Signal Processing Theory



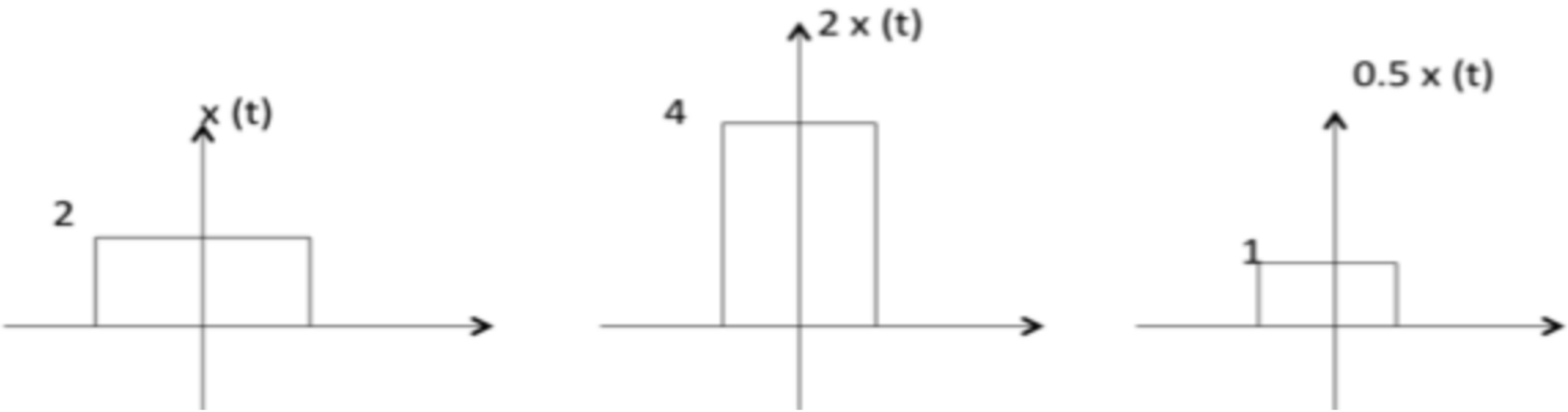
These are the basic operations that can be performed on signals:

- Amplitude Scaling
- Time Scaling
- Time Reversal
- Time Shifting

## Signal Processing Theory



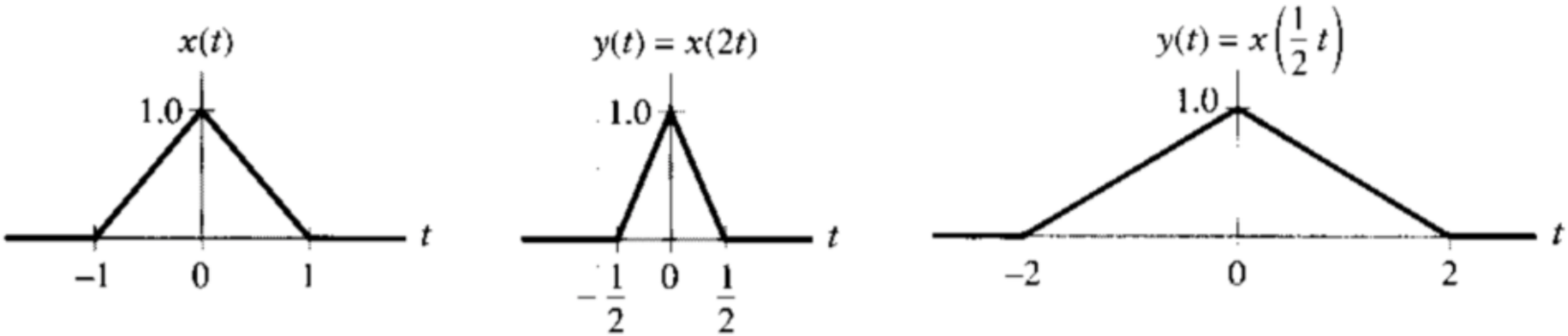
***Amplitude Scaling*** compressed or expands the amplitude of a signal



# Signal Processing Theory



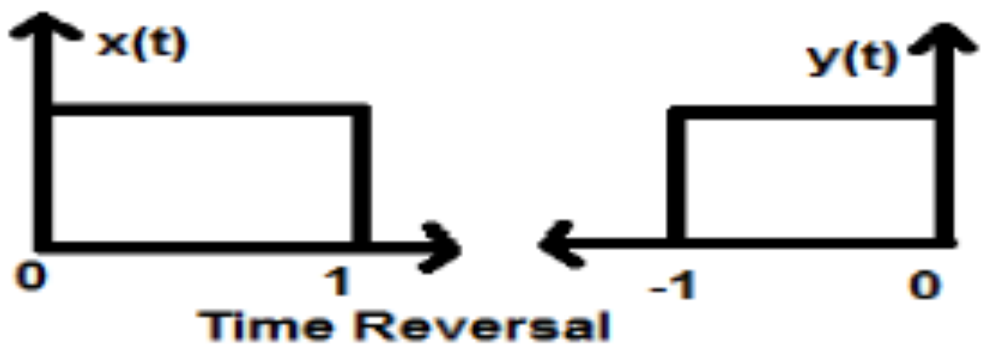
***Time Scaling*** compressed or expands the signal along the time axis

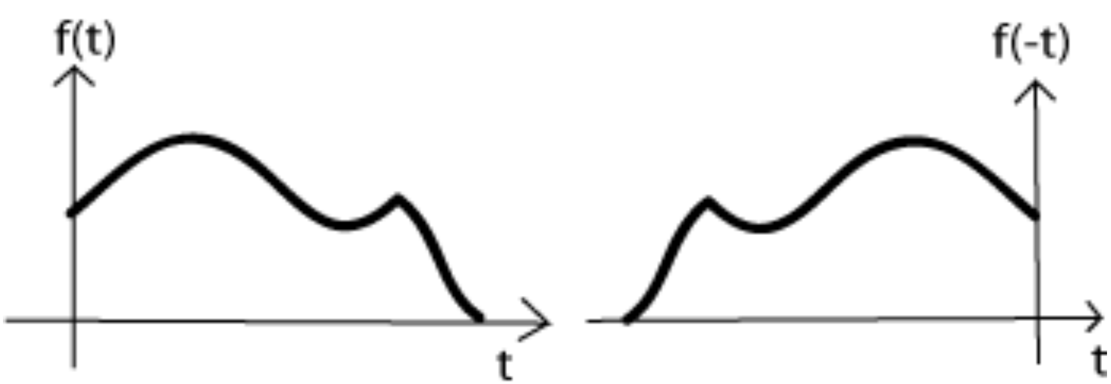


# Signal Processing Theory



***Time Reversal*** reflects the signal around t=0 (it revers the signal around the time axis).

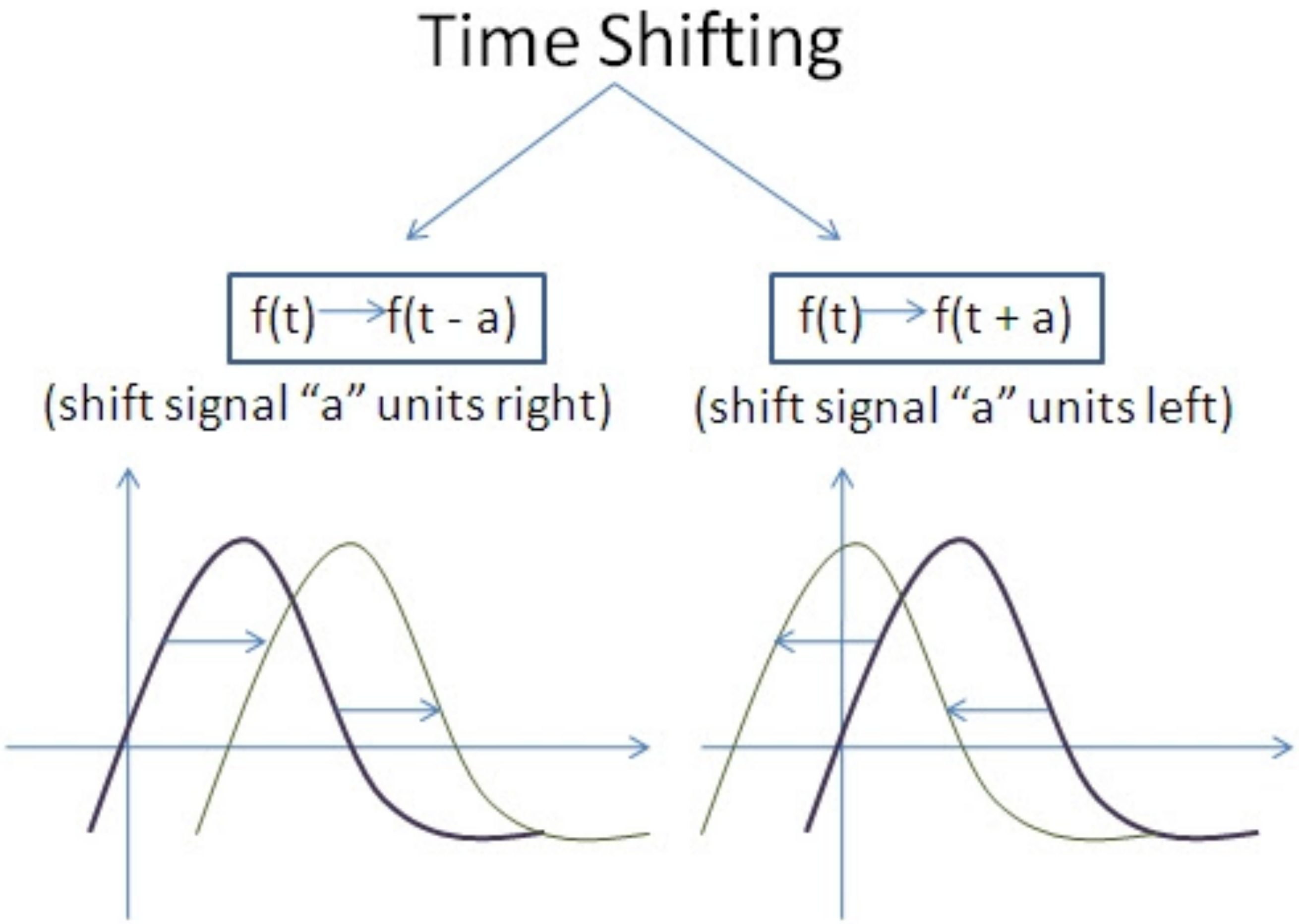


# Signal Processing Theory



***Time Shift*** moves the signal on the time axis



# Signal Processing Theory

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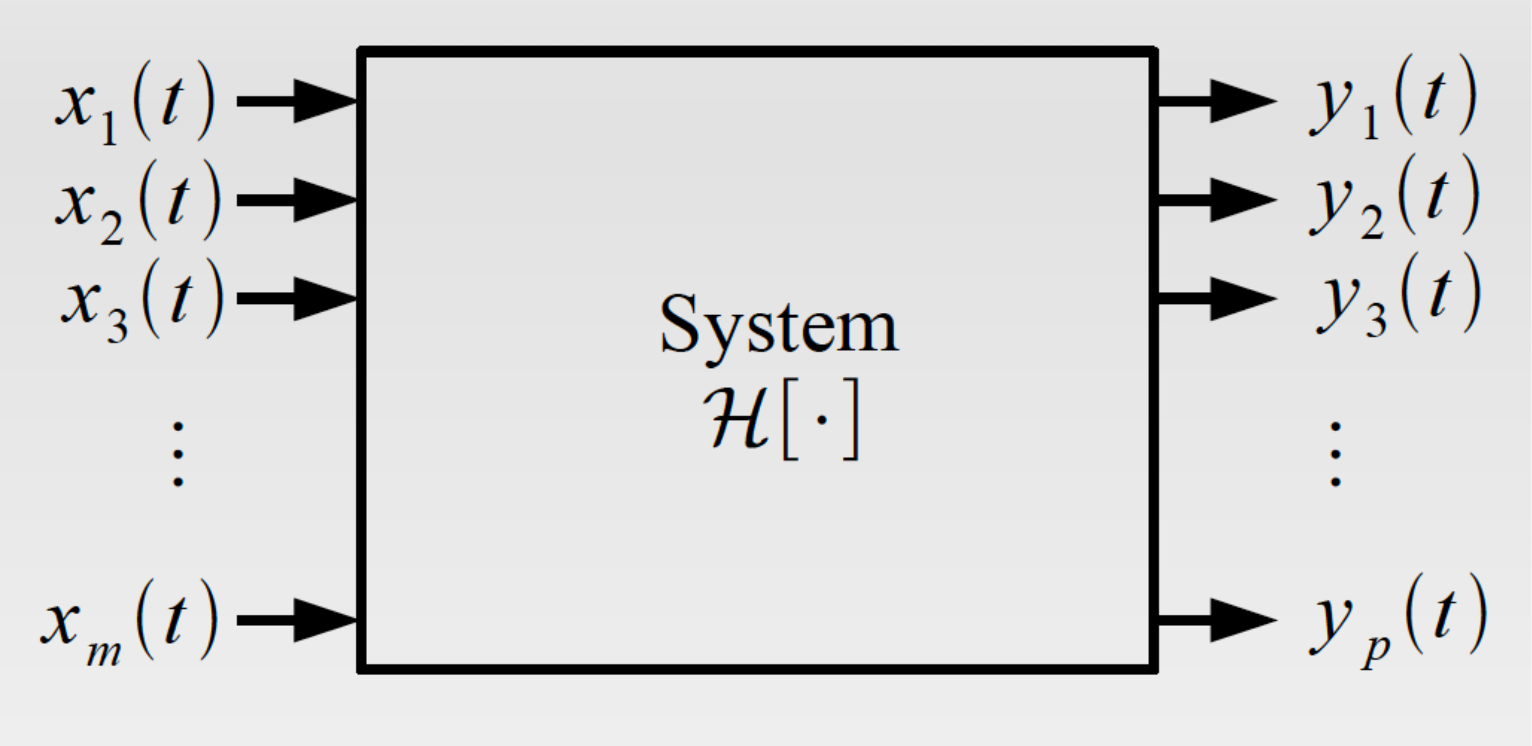
## *System Representations*

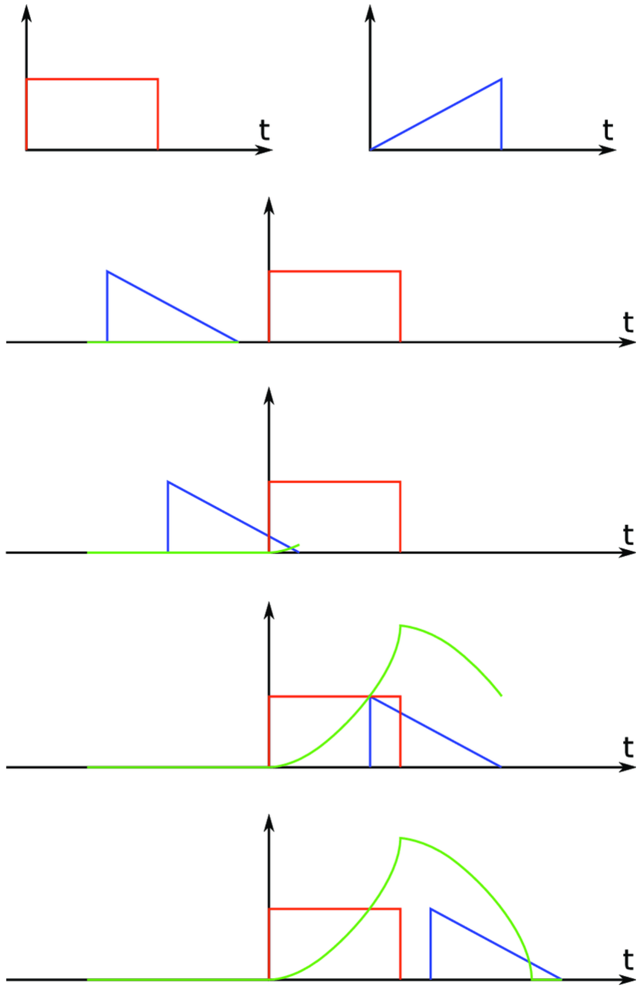



$$y(t) = \mathcal{H}[x(t)]$$

# Signal Processing Theory



Convolution is a mathematical way of combining two signals to form a third signal



# Signal Processing Theory

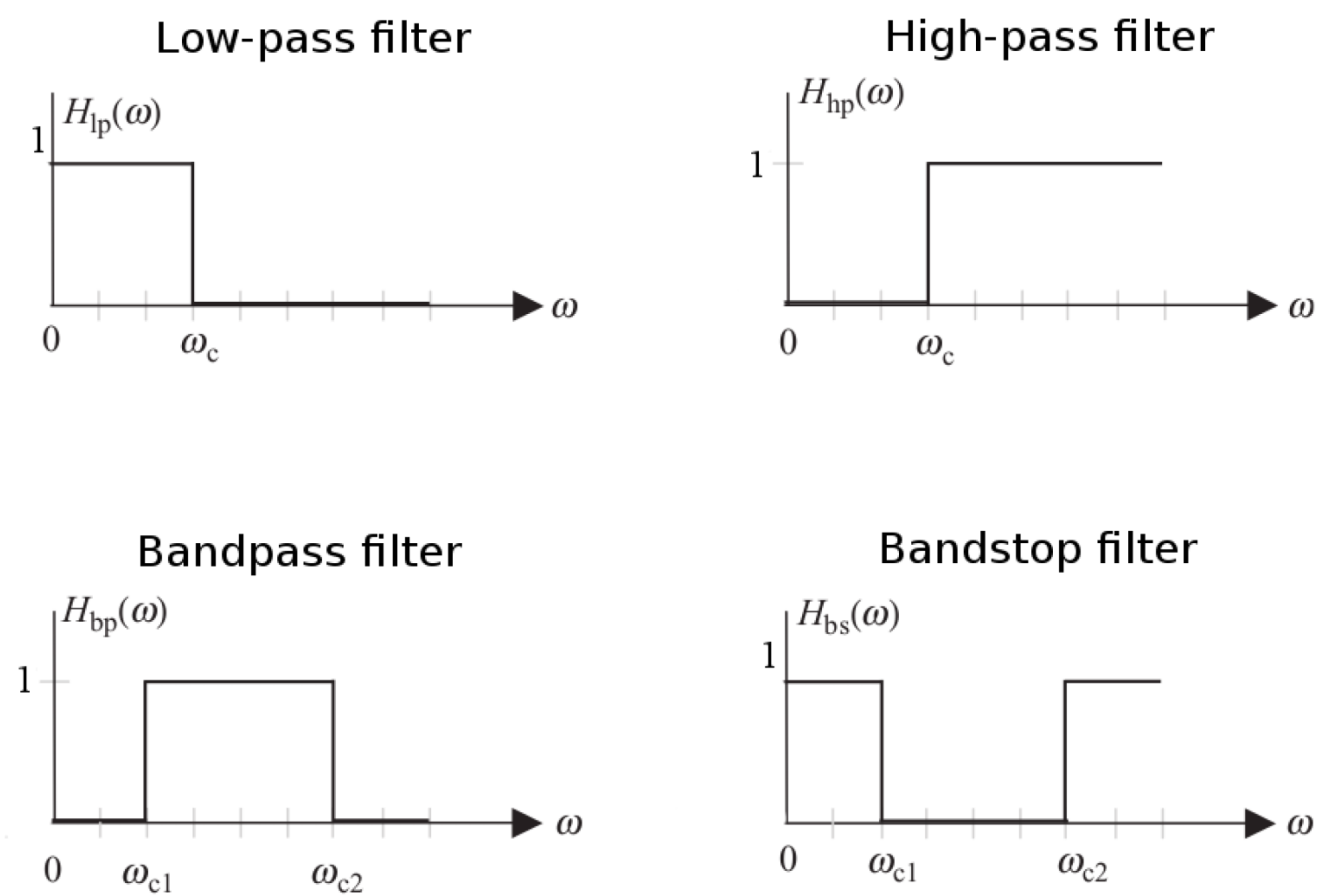


## *Filters*

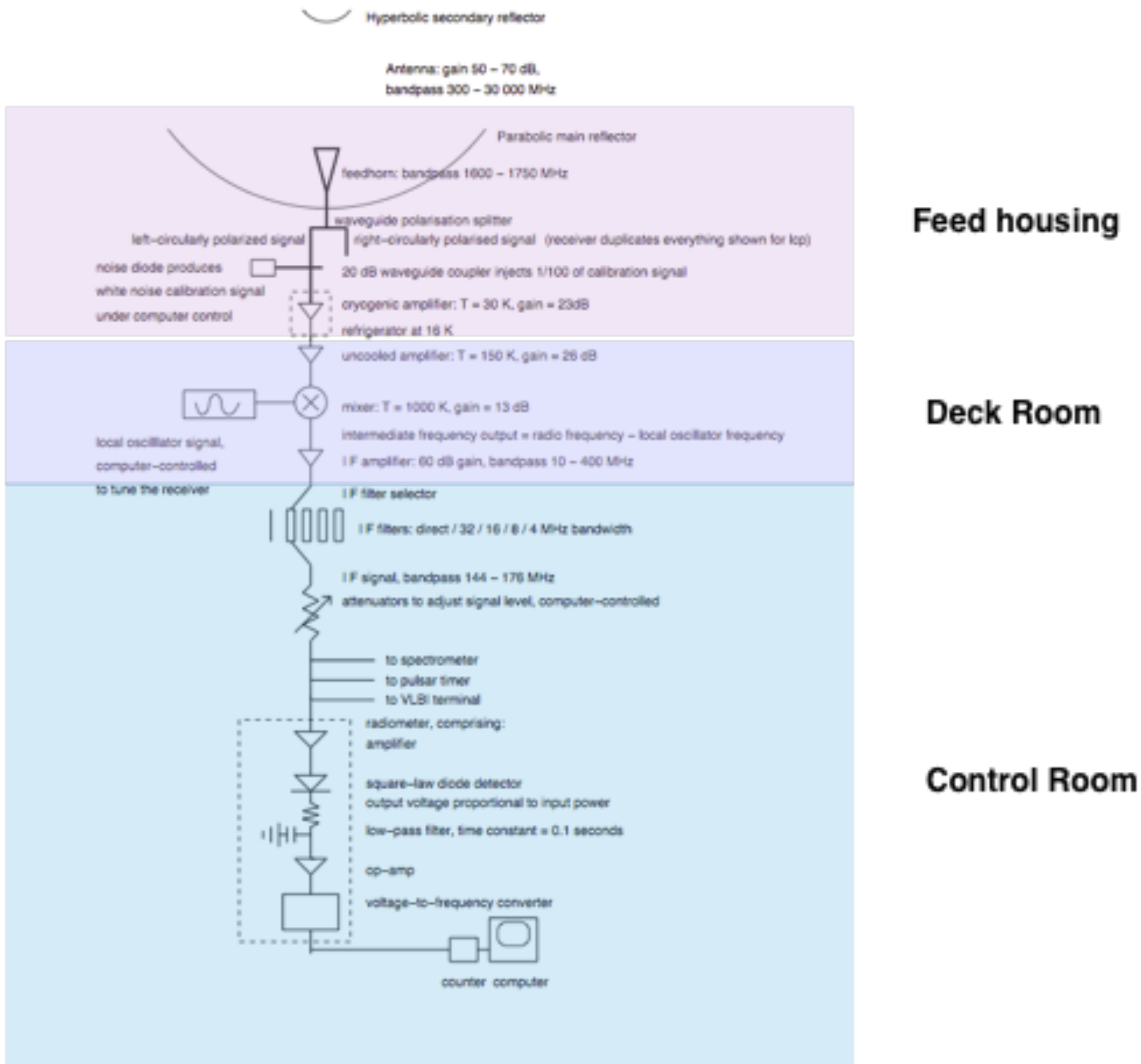
- Low-pass filter: $H_{\mathrm{lp}}(\omega)=\begin{cases}1, & |\omega|\le\omega_c\\ 0, & |\omega|\ge\omega_c\end{cases}$
- High-pass filter: $H_{\mathrm{hp}}(\omega)=\begin{cases}0, & |\omega|\le\omega_c\\ 1, & |\omega|\ge\omega_c\end{cases}$
- Bandpass filter: $H_{\mathrm{bp}}(\omega)=\begin{cases}1, & \omega_{c1}\le|\omega|\le\omega_{c2}\\ 0, & |\omega|<\omega_{c1},\ \omega_{c2}<|\omega|<\infty\end{cases}$
- Bandstop filter: $H_{\mathrm{bs}}(\omega)=\begin{cases}0, & \omega_{c1}\le|\omega|\le\omega_{c2}\\ 1, & |\omega|<\omega_{c1},\ \omega_{c2}<|\omega|<\infty\end{cases}$

# Signal Processing Theory

## *Filters*



# Signal Chain of a Telescope



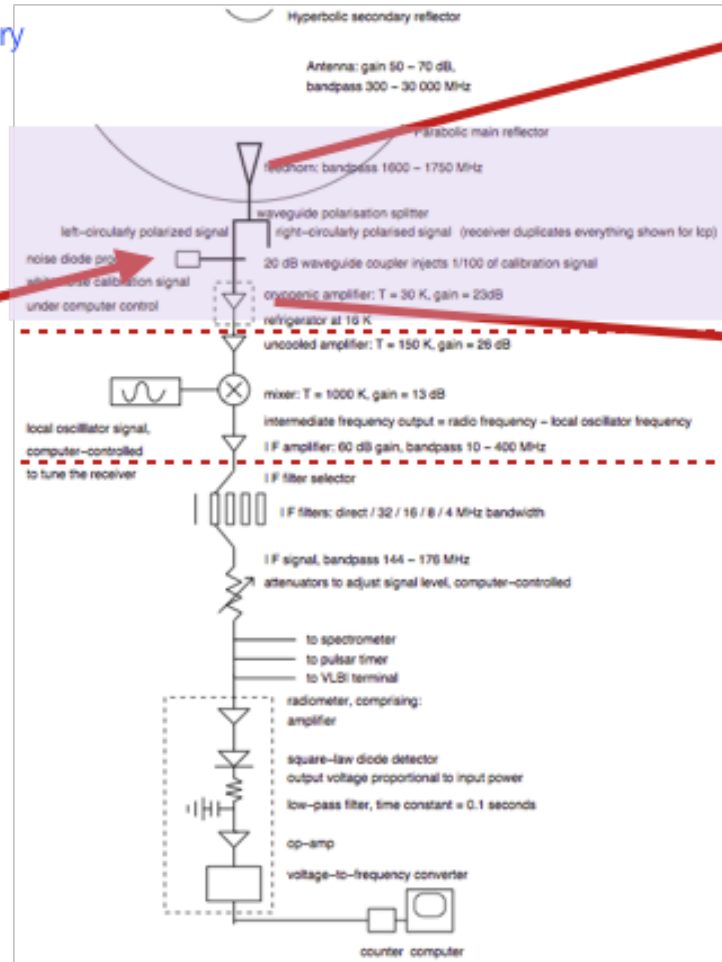
# Signal Chain of a Telescope



Signal chain: Main components of a typical **microwave receiver** and **radiometer**

**Incoming signal:** are very faint and noise like.

To calibrate the system a high stability **noise diode** injects a known noise signal which is split equally by a power divider between the LCP and RCP receiver chains.




**Feed horn** and **waveguide** (to connect feed horn to first amplifier). All incoming signals are split into **LCP & RCP** by a hybrid waveguide polarisation splitter feeding LCP to one receiver chain and RCP to the other.

**Amplification** to a detectable level through a **low-noise amplifier.** Because the internal noise in the amplifiers is generally much larger than the signal, specially designed amplifiers that are **cryogenically cooled** are used to maximize sensitivity.

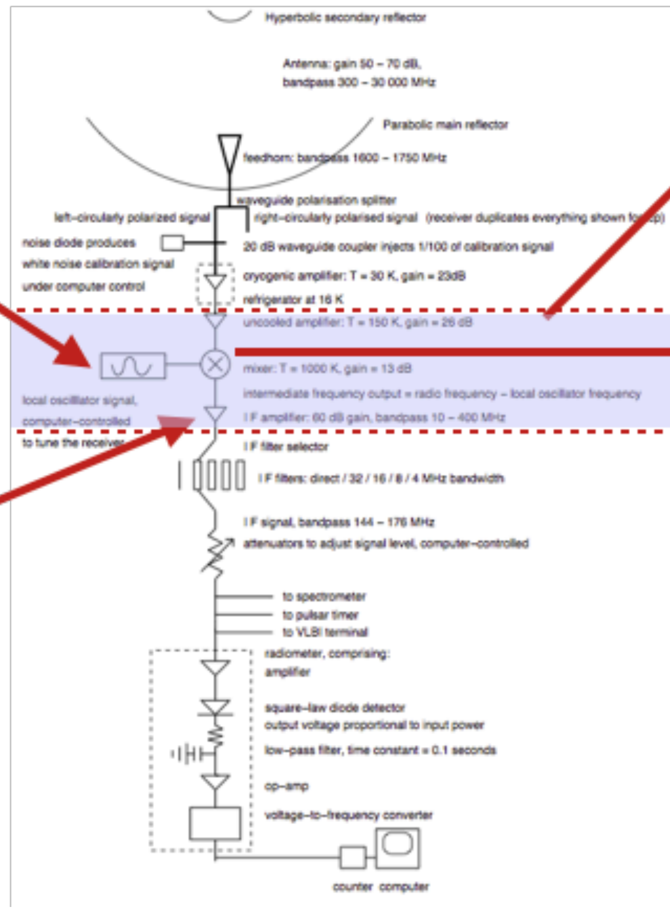
# Signal Chain of a Telescope



Signal chain: Main components of a typical **microwave receiver** and **radiometer**

**Local oscillator** signal: computer–controlled to tune the receiver

To get the final output the IF signal is amplified, this time using an **IF Amplifier**




RF signal is **down converted** to a lower frequency in order to minimise signal losses in co-axial cable).

The **mixer** multiplies the RF signal with the **local oscillator signal.** The output signal that is used is the difference frequency component (RF - LO) of the product and is called the **intermediate frequency (IF).**

# Signal Chain of a Telescope

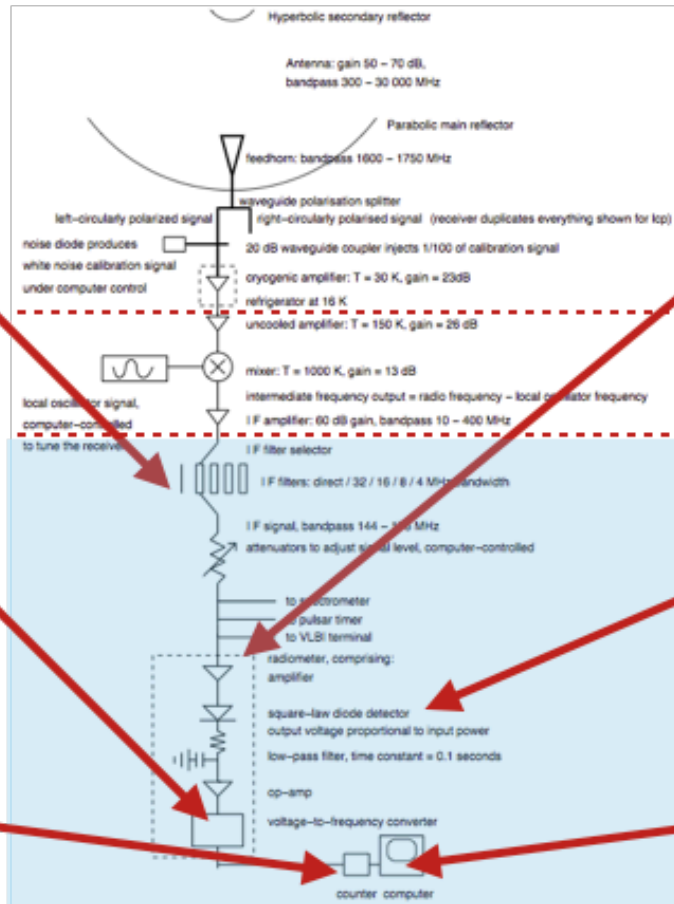


Signal chain: Main components of a typical **microwave receiver** and **radiometer**

IF signal can be used unfiltered, or passed through **4, 8, 16 or 32-MHz bandwidth filters** to exclude interference from external signals at some observing frequencies.

**Voltage to frequency converter** converts the signal to a square wave train (amplitude remains constant but the frequency is proportional to the DC voltage input).

These oscillations are then measured with a **counter** such that the count rate (in units of Hertz) is proportional to the original IF signal's power.




The **radiometer** is the basic instrument for measuring the power of the incoming signal. The simplest form of radiometer is the **"total power"** type shown

The signal is then detected by a **Square law detector** which converts the IF signal into an output DC voltage proportional to the input power.

Signals are loaded onto the Hart26m server in **FITS (Flexible Image Transport System)** format

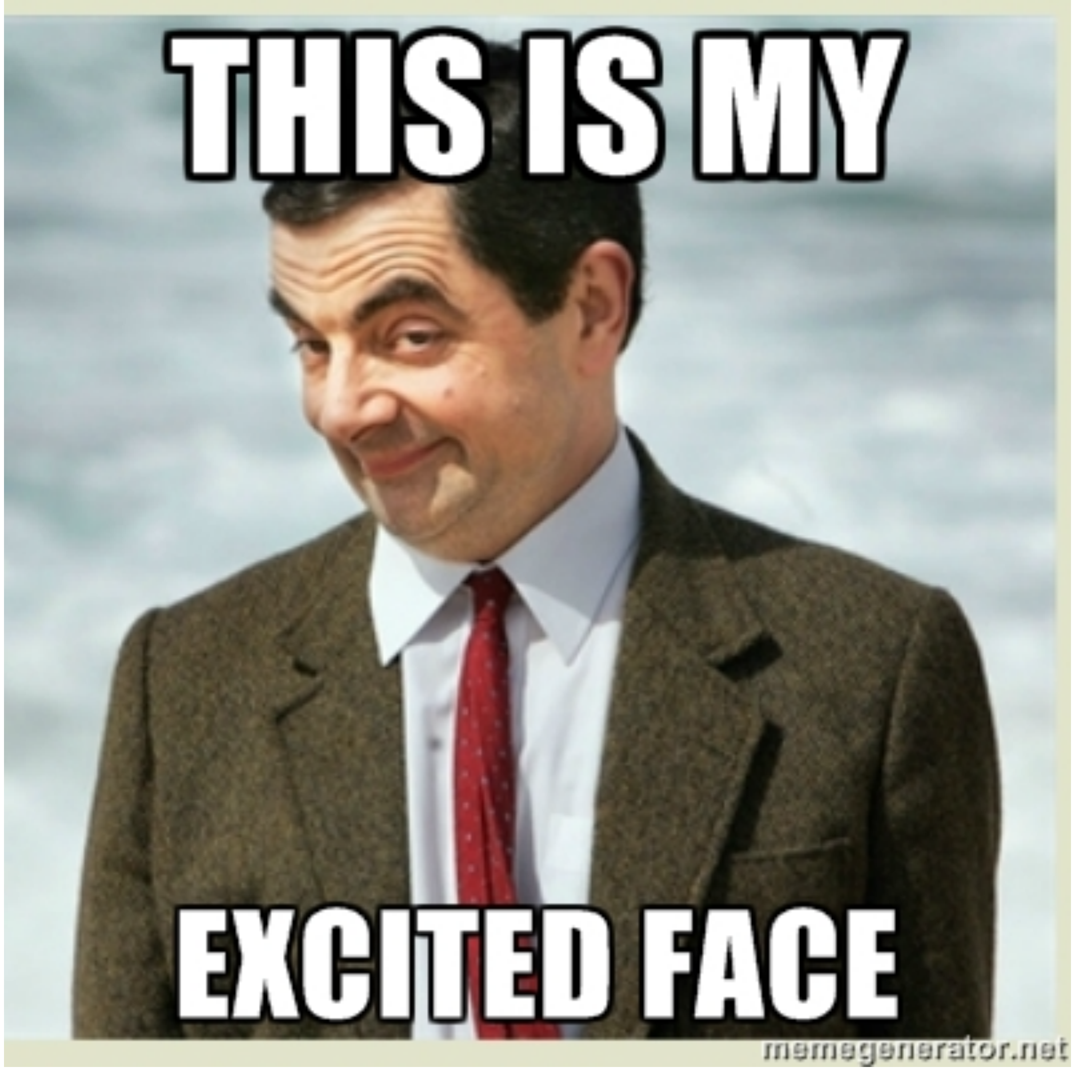
# Digital Signal Processing



***DSP is a*** Mathematical and algorithmic manipulation of discretized and quantized or naturally digital signals in order to extract the most relevant and pertinent information that is carried by the signal.

# Simulink Demonstration





# Digital Signal Processing



Advantages:

- Flexible
- Accurate
- Easier to mass produce
- Easier to design
- More deterministic and reproducible, less sensitive to component values
- Many things that cannot be done using analog processors can be done digitally.

# Digital Signal Processing

Disadvantages:

- Slower
- Sampling Issues
- Expensive
- Increased system complexity
- Consumes more power

# Questions