Lecture_1_2 Introduction to RF hardware and software tools

1 RF hardware

Radio-frequency (RF) engineering **Error! Reference source not found.**is a subset of electronic engineering involving the application of transmission line waveguide antenna and electromagnetic field principles to the design and application of devices that produce or utilize signals within the radio band the frequency range of about 20 kHz up to 300 GHz. It is incorporated into almost everything that transmits or receives a radio wave which includes but is not limited to mobile phones radios Wi-Fi and two-way radios. RF engineering is a highly specialized field that typically includes the following areas of expertise:

- Design of antenna systems to provide radiative coverage of a specified geographical area by an electromagnetic field or to provide specified sensitivity to an electromagnetic field impinging on the antenna.
- Design of coupling and transmission line structures to transport RF energy without radiation.
- Application of circuit elements and transmission line structures in the design of oscillators amplifiers mixers detectors combiners filters impedance transforming networks and other devices.
- Verification and measurement of performance of radio frequency devices and systems.

To produce quality results the RF engineer needs to have an in-depth knowledge of mathematics physics and general electronics theory as well as specialized training in areas such as wave propagation impedance transformations filters and microstrip printed circuit board design.

Radio electronics is concerned with electronic circuits which receive or transmit radio signals. Typically such circuits must operate at radio frequency and power levels which imposes special constraints on their design. These constraints increase in their importance with higher frequencies. At microwave frequencies the reactance of signal traces becomes a crucial part of the physical layout of the circuit.

Radio electronics hardware wide used in RF communications is presented below:

- RF oscillators: Phase-locked loop PLL, Voltage-controlled oscillator VCO
- Oscilloscopes;
- Signal generator
- Spectrum analyzer
- Transmitters: Transmission lines RF connectors

- Antennas: Antenna theory
- Receivers Tuners
- Amplifiers
- Modulators Demodulators Detectors
- RF filters
- RF shielding Ground plane
- DSSS Noise power
- Digital radio
- RF power amplifiers
- MOSFETs: Power MOSFET LDMOS
- Bipolar junction transistors
- Baseband processors (CMOS)
- RF CMOS (mixed-signal integrated circuits)
- Millimeter wave transmission lines and waveguides ; RF cables;

Radio frequency (RF) is the oscillation rate (fig.1) of an alternating electric current or voltage or of a magnetic electric or electromagnetic field or mechanical system in the frequency range from around 20 kHz to around 300 GHz. This is roughly between the upper limit of audio frequencies and the lower limit of infrared frequencies; these are the frequencies at which energy from an oscillating current can radiate off a conductor into space as radio waves. Different sources specify different upper and lower bounds for the frequency range.

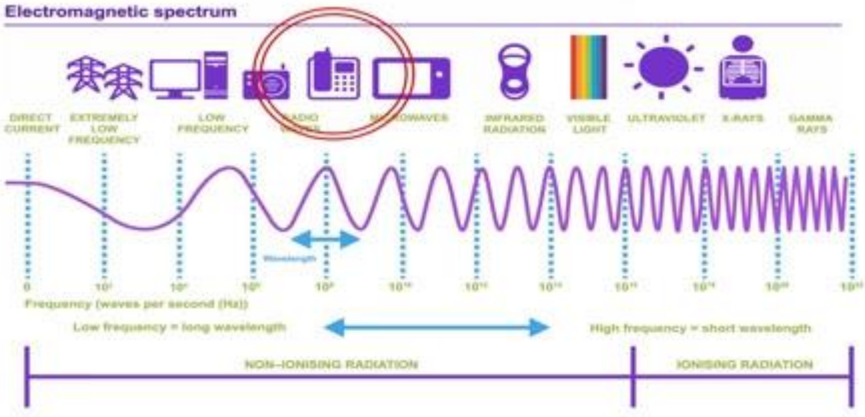


figure 1 Radio frequency

Oscillation is the repetitive variation typically in time of some measure about a central value (often a point of equilibrium) or between two or more different states. The term vibration is precisely used to describe mechanical oscillation. Familiar examples of oscillation include a swinging pendulum and alternating current.

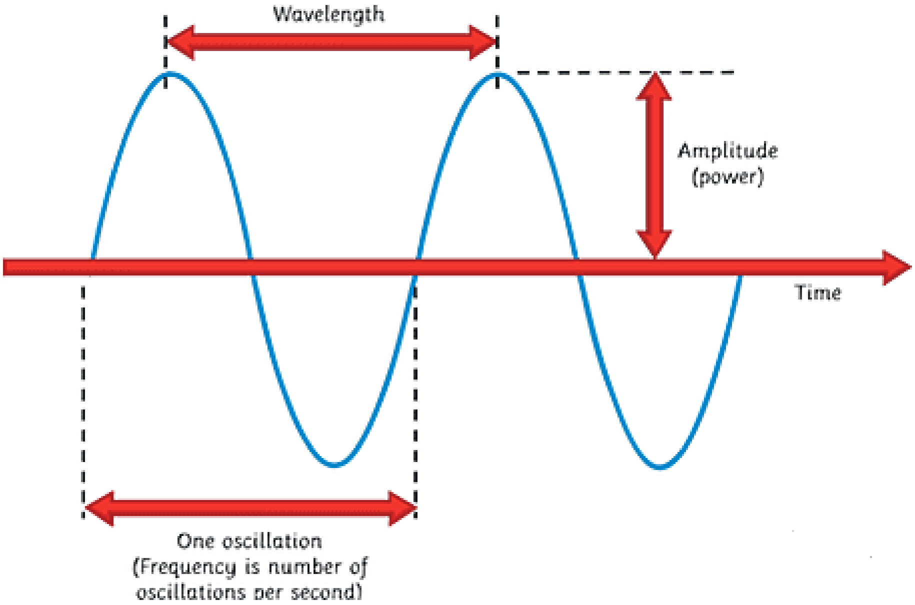


figure 2 Oscillation

Oscillations occur not only in mechanical systems but also in dynamic systems in virtually every area of science: for example the beating of the human heart (for circulation) business cycles in economics predator–prey population cycles in ecology geothermal geysers in geology vibration of strings in guitar and other string instruments periodic firing of nerve cells in the brain and the periodic swelling of Cepheid variable stars in astronomy.

A PLL or **phase-locked loop** is a control system that generates an output signal whose phase is related to the phase of an input signal. There are several different types; the simplest is an electronic circuit consisting of a variable frequency oscillator and a phase detector in a feedback loop. The oscillator generates a periodic signal and the phase detector compares the phase of that signal with the phase of the input periodic signal adjusting the oscillator to keep the phases matched.

Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same. Consequently in addition to synchronizing signals a phase-locked loop can track an input frequency or it can generate a frequency that is a multiple of the input frequency. These properties are used for computer clock synchronization demodulation and frequency synthesis.

Phase-locked loops are widely employed in radio telecommunications computers and other electronic applications. They can be used to demodulate a signal recover a signal from a noisy communication channel generate a stable frequency at multiples of an input frequency (frequency synthesis) or distribute precisely timed clock pulses in digital logic circuits such as microprocessors. Since a single integrated circuit can provide a complete phase-locked-loop building block the technique is widely used in modern electronic devices with output frequencies from a fraction of a hertz up to many gigahertz.

A **voltage-controlled oscillator** (VCO) is an electronic oscillator whose oscillation frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency. Consequently a VCO can be used for frequency modulation (FM) or phase modulation (PM) by applying a modulating signal to the control input. A VCO is also an integral part of a phase-locked loop. VCOs are used in synthesizers to generate a waveform whose pitch can be adjusted by a voltage determined by a musical keyboard or other input.

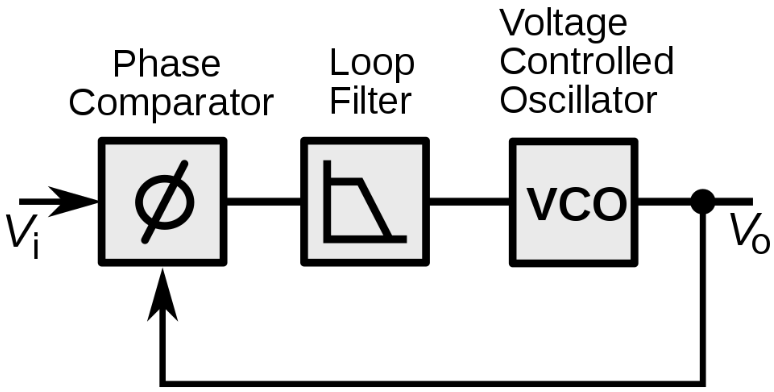


figure.3 VCO

A voltage-to-frequency converter (VFC) is a special type of VCO designed to be very linear in frequency control over a wide range of input control voltages.

An **oscilloscope**, previously called an **oscillograph** and informally known as a scope or o-scope, CRO (for **cathode-ray oscilloscope**), or DSO (for the more modern digital storage oscilloscope), is a type of electronic test instrument that graphically displays varying signal voltages, usually as a calibrated two-dimensional plot of one or more signals as a function of time. The displayed waveform can then be analyzed for properties such as amplitude, frequency, rise time, time interval, distortion, and others. Originally, calculation of these values required manually measuring the waveform against the scales built into the screen of the instrument. Modern digital instruments may calculate and display these properties directly.

The oscilloscope can be adjusted so that repetitive signals can be observed as a persistent waveform on the screen. A storage oscilloscope can capture a single event and display it continuously, so the user can observe events that would otherwise appear too briefly to see directly.

Oscilloscopes are used in the sciences, medicine, engineering, automotive and the telecommunications industry. General-purpose instruments are used for maintenance of electronic equipment and laboratory work. Special-purpose oscilloscopes may be used to analyze an automotive ignition system or to display the waveform of the heartbeat as an electrocardiogram, for instance.

Early oscilloscopes used cathode ray tubes (CRTs) as their display element (hence they were commonly referred to as CROs) and linear amplifiers for signal processing. Storage oscilloscopes used special storage CRTs to maintain a steady display of a single brief signal. CROs are later largely superseded by digital storage oscilloscopes (DSOs) with thin panel displays, fast analog-to-digital converters and digital signal processors. DSOs without integrated displays (sometimes known as digitisers) are available at lower cost and use a general-purpose computer to process and display waveforms.

A **signal generator** is one of a class of electronic devices that generates electronic signals with set properties of amplitude, frequency, and wave shape. These generated signals are used as a stimulus for electronic measurements, typically used in designing, testing, troubleshooting, and repairing electronic or electroacoustic devices, though it often has artistic uses as well.

There are many different types of signal generators with different purposes and applications and at varying levels of expense. These types include function generators, RF and microwave signal generators, pitch generators, arbitrary waveform generators, digital pattern generators, and frequency generators. In general, no device is suitable for all possible applications.

A signal generator may be as simple as an oscillator with calibrated frequency and amplitude. More general-purpose signal generators allow control of all the characteristics of a signal. Modern general-purpose signal generators will have a microprocessor control and may also permit control from a personal computer. Signal generators may be free-standing self-contained instruments, or may be incorporated into more complex automatic test systems.

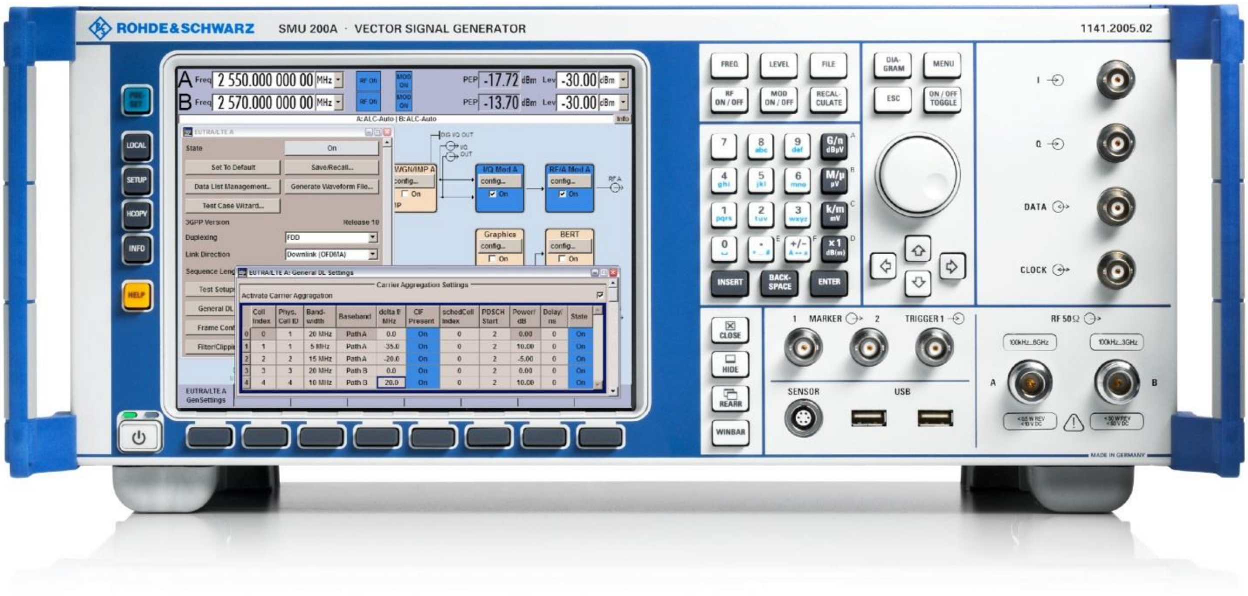


figure 4 Signal generator

A **spectrum analyzer** measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals. The input signal that most common spectrum analyzers measure is electrical; however, spectral compositions of other signals, such as acoustic pressure waves and optical light waves, can be considered through the use of an appropriate transducer. Spectrum analyzers for other types of signals also exist, such as optical spectrum analyzers which use direct optical techniques such as a monochromator to make measurements.

figure 5 Spectrum analyzer

By analyzing the spectra of electrical signals, dominant frequency, power, distortion, harmonics, bandwidth, and other spectral components of a signal can be observed that are not easily detectable in time domain waveforms. These parameters are useful in the characterization of electronic devices, such as wireless transmitters.

The display of a spectrum analyzer has frequency on the horizontal axis and the amplitude displayed on the vertical axis. To the casual observer, a spectrum analyzer looks like an oscilloscope and, in fact, some lab instruments can function either as an oscilloscope or a spectrum analyzer.

Main Types of Spectrum Analyzers

Spectrum Analyzers can be classified in 3 basic categories in reference to their architecture – Swept Spectrum Analyzers (SA) and Vector Signal Analyzers (VSA) and Real-time Spectrum Analyzers (RSA).

Swept Spectrum Analyzers (SA)

The swept-tuned, superheterodyne spectrum analyzer is the traditional architecture and is best suited for observing controlled, static signals. The SA makes power vs. frequency measurements by downconverting the signal of interest and sweeping it through the passband of a resolution bandwidth (RBW) filter. The RBW filter is followed by a detector that calculates the amplitude at each frequency point in the selected span. While this method can provide high dynamic range, its disadvantage is that it can only calculate the amplitude data for one frequency point at a time. Consequently, measurements are only valid for relatively stable, unchanging input signals Consequently, measurements are only valid for relatively stable, unchanging input signals

Vector Signal Analyzers (VSA)

Analyzing signals carrying digital modulation requires vector measurements that provide both magnitude and phase information. A VSA digitizes all the RF power within the passband of the instrument and puts the digitized waveform into memory. The waveform in memory contains both the magnitude and phase information which can be used by digital signal processing (DSP) for demodulation, measurements, or display processing. While the VSA has added the ability to store waveforms in memory, it is limited in its ability to analyze transient events. The serial nature of batch processing common in means that the instrument is effectively blind to events that occur between acquisitions. Single or infrequent events cannot be discovered reliably, so external triggering may be necessary and requires impractical prior knowledge of these transient events. Other limitations of the VSA include challenges in isolation of weak signals in the presence of larger ones and signals that change in frequency but not amplitude.

Real-time Spectrum Analyzers (RSA)

The RSA performs signal analysis using real-time digital signal processing (DSP) that is done prior to memory storage as opposed to the post-acquisition processing that is common in the VSA architecture. Real time processing allows the user to discover events that are invisible to other architectures and to trigger on those events allowing their selective capture into memory. The data in memory can then be extensively analyzed in multiple domains using batch processing. The real-time DSP engine is also used to perform signal conditioning, calibration and certain types of analysis.

Analog voltmeter

Measurement of voltage in electronic circuits in telecommunications differs from similar measurements in electrical (power) inspections. This is due to the specific features of the electrical signals used in telecommunications as:

- Extremely wide frequency range - from constant voltage and infrared frequency (parts of hertz) to high frequencies (1GHz and more);
- Wide range of voltage measurements by value (from parts of a microvolt to tens, even hundreds of kilovolts);

- Measures voltage in communications is difficult because uses a lot of voltages of different shapes. This requires the use of different methods.

A moving coil galvanometer can be used as a voltmeter by inserting a resistor in series with the instrument. The galvanometer has a coil of fine wire suspended in a strong magnetic field. When an electric current is applied, the interaction of the magnetic field of the coil and of the stationary magnet creates a torque, tending to make the coil rotate. The torque is proportional to the current through the coil. The coil rotates, compressing a spring that opposes the rotation. The deflection of the coil is thus proportional to the current, which in turn is proportional to the applied voltage, which is indicated by a pointer on a scale.

One of the design objectives of the instrument is to disturb the circuit as little as possible and so the instrument should draw a minimum of current to operate. This is achieved by using a sensitive galvanometer in series with a high resistance, and then the entire instrument is connected in parallel with the circuit examined.

Amplified voltmeter

The sensitivity and input resistance of a voltmeter can be increased if the current required to deflect the meter pointer is supplied by an amplifier and power supply instead of by the circuit under test. The electronic amplifier between input and meter gives two benefits; a rugged moving coil instrument can be used, since its sensitivity need not be high, and the input resistance can be made high, reducing the current drawn from the circuit under test. Amplified voltmeters often have an input resistance of 1, 10, or 20 megohms which is independent of the range selected. A once-popular form of this instrument used a vacuum tube in the amplifier circuit and so was called the vacuum tube voltmeter (VTVM). These were almost always powered by the local AC line current and so were not particularly portable. Today these circuits use a solid-state amplifier using field-effect transistors, hence FET-VM, and appear in handheld digital multimeters as well as in bench and laboratory instruments. These largely replaced non-amplified multimeters except in the least expensive price ranges.

Most VTVMs and FET-VMs handle DC voltage, AC voltage, and resistance measurements; modern FET-VMs add current measurements and often other functions as well. A specialized form of the VTVM or FET-VM is the AC voltmeter. These instruments are optimized for measuring AC voltage. They have much wider bandwidth and better sensitivity than a typical multifunction device.

A **digital voltmeter** (DVM) measures an unknown input voltage by converting the voltage to a digital value and then displays the voltage in numeric form. DVMs are usually designed around a special type of analog-to-digital converter called an integrating converter.

DVM measurement accuracy is affected by many factors, including temperature, input impedance, and DVM power supply voltage variations. Less expensive DVMs often have input resistance on the order of 10 MΩ. Precision DVMs can have input resistances of 1 GΩ or higher for the lower voltage ranges (e.g. less than 20 V). To ensure that a DVM's accuracy is within the manufacturer's specified tolerances, it must be periodically calibrated against a voltage standard such as the Weston cell.

Simple AC voltmeters use a rectifier connected to a DC measurement circuit, which responds to the average value of the waveform. The meter can be calibrated to display the root mean square value of the waveform, assuming a fixed relation between the average value of the rectified waveform and the RMS value. If the waveform departs significantly from the sinewave assumed in the calibration, the meter will be inaccurate, though for simple wave shapes the reading can be corrected by multiplying by a constant factor. Early "true RMS" circuits used a thermal converter that responded only to the RMS value of the waveform. Modern instruments calculate the RMS value by electronically calculating the square of the input value, taking the average, and then calculating the square root of the value. This allows accurate RMS measurements for a variety of waveforms.

In electronics and telecommunications a **radio transmitter** or just **transmitter** is an electronic device which produces radio waves with an antenna. The transmitter itself generates a radio frequency alternating current which is applied to the antenna. When excited by this alternating current the antenna radiates radio waves.

Transmitters are necessary component parts of all electronic devices that communicate by radio such as radio and television broadcasting stations cell phones walkie-talkies wireless computer networks Bluetooth enabled devices garage door openers two-way radios in aircraft ships spacecraft radar sets and navigational beacons. The term transmitter is usually limited to equipment that generates radio waves for communication purposes; or radiolocation such as radar and navigational transmitters. Generators of radio waves for heating or industrial purposes such as microwave ovens or diathermy equipment are not usually called transmitters even though they often have similar circuits.

The term is popularly used more specifically to refer to a broadcast transmitter a transmitter used in broadcasting as in FM radio transmitter or television transmitter. This usage typically includes both the transmitter proper the antenna and often the building it is housed in.

In electrical engineering a **transmission line** is a specialized cable or other structure designed to conduct electromagnetic waves in a contained manner. The term applies when the conductors are long enough that the wave nature of the transmission must be taken into account. This applies especially to radio-frequency engineering because the short wavelengths mean that wave phenomena arise over very short distances (this can be as short as millimeters depending on frequency).

Transmission lines are used for purposes such as connecting radio transmitters and receivers with their antennas (they are then called feed lines or feeders) distributing cable television signals trunk lines routing calls between telephone switching centers computer network connections and high speed computer data buses. RF engineers commonly use short pieces of transmission line usually in the form of printed planar transmission lines arranged in certain patterns to build circuits such as filters. These circuits known as distributed-element circuits are an alternative to traditional circuits using discrete capacitors and inductors.

Ordinary **electrical cables** suffice to carry low frequency alternating current (AC) and audio signals. However they cannot be used to carry currents in the radio frequency range above about 30 kHz because the energy tends to radiate off the cable as radio waves causing power losses. RF currents also tend to reflect from discontinuities in the cable such as connectors and joints and travel back down the cable toward the source. These reflections act as bottlenecks preventing the signal power from reaching the destination. Transmission lines use specialized construction and impedance matching to carry electromagnetic signals with minimal reflections and power losses. The distinguishing feature of most transmission lines is that they have uniform cross sectional dimensions along their length giving them a uniform impedance called the characteristic impedance to prevent reflections. The higher the frequency of electromagnetic waves moving through a given cable or medium the shorter the wavelength of the waves. Transmission lines become necessary when the transmitted frequency's wavelength is sufficiently short that the length of the cable becomes a significant part of a wavelength.

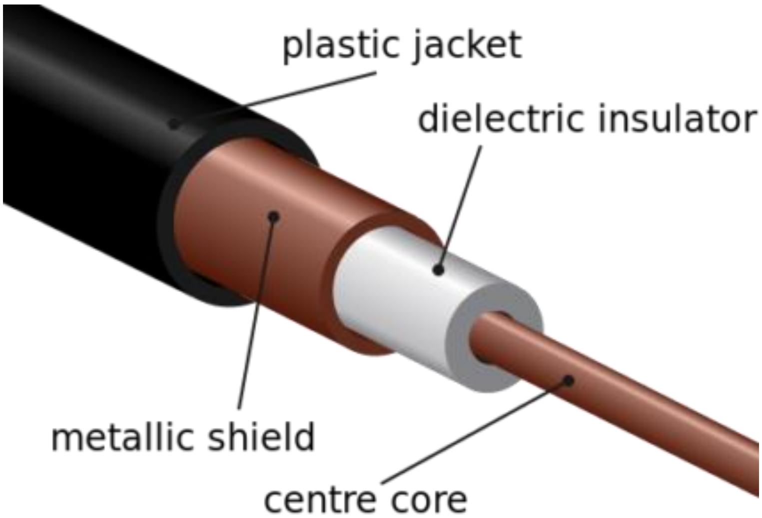
At microwave frequencies and above power losses in transmission lines become excessive and waveguides are used instead which function as "pipes" to confine and guide the electromagnetic waves. At even higher frequencies in the terahertz infrared and visible ranges waveguides in turn become loss and optical methods (such as lenses and mirrors) are used to guide electromagnetic waves.

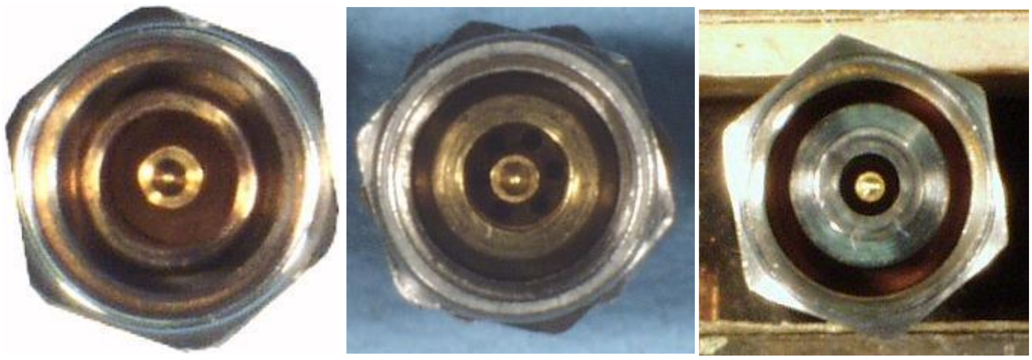
A **coaxial RF connector** (radio frequency connector) is an electrical connector designed to work at radio frequencies in the multi-megahertz range. RF connectors are typically used with coaxial cables and are designed to maintain the shielding that the coaxial design offers. Better models also minimize the change in transmission line impedance at the connection in order to reduce signal reflection and power loss. As the frequency increases transmission line effects become more important with small impedance variations from connectors causing the signal to reflect rather than pass through. An RF connector must not allow external signals into the circuit through electromagnetic interference and capacitive pickup.

Mechanically RF connectors may provide a fastening mechanism (thread bayonet braces blind mate) and springs for a low ohm electric contact while sparing the gold surface thus allowing very high mating cycles and reducing the insertion force. Research activity in the area of radio-frequency (RF) circuit design has surged in the 2000s in direct response to the enormous market demand for inexpensive high-data-rate wireless transceivers.

Common types of RF connectors are used for television receivers two-way radio certain Wi-Fi devices with removable antennas and industrial or scientific measurements instruments using radio frequencies.

Coaxial transmission lines are structured as 2 concentric conductors: An inner conductor (of diameter) is surrounded by a dielectric insulator and an outer, shielding conductor :





3.5mm , 2.4mm , 1.8 mm

Specified to26.5GHz Specified to 50GHz Specified to 65GHz

figure 6 Coaxial cables and connectors

A **waveguide** is a structure that guides waves, such as electromagnetic waves or sound, with minimal loss of energy by restricting the transmission of energy to one direction. Without the physical constraint of a waveguide, wave intensities decrease according to the inverse square law as they expand into three dimensional space.

figure 7 Waveguide

There are different types of waveguides for different types of waves. The original and most common meaning is a hollow conductive metal pipe used to carry high frequency radio waves, particularly microwaves. Dielectric waveguides are used at higher radio frequencies, and transparent dielectric waveguides and optical fibers serve as waveguides for light. In acoustics, air ducts and horns are used as waveguides for sound in musical instruments and loudspeakers, and specially-shaped metal rods conduct ultrasonic waves in ultrasonic machining.

The geometry of a waveguide reflects its function; in addition to more common types that channel the wave in one dimension, there are two-dimensional slab waveguides which confine waves to two dimensions. The frequency of the transmitted wave also dictates the size of a waveguide: each waveguide has a cutoff wavelength determined by its size and will not conduct waves of greater wavelength; an optical fiber that guides light will not transmit microwaves which have a much larger wavelength. Some naturally occurring structures can also act as waveguides. The SOFAR channel layer in the ocean can guide the sound of whale song across enormous distances. Any shape of crossection of waveguide can support EM waves. Irregular shapes are difficult to analyze. Commonly used waveguides are rectangular and circular in shape.

In radio an **antenna** or aerial is the interface between radio waves propagating through space and electric currents moving in metal conductors used with a transmitter or receiver. In transmission a radio transmitter supplies an electric current to the antenna's terminals and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception an antenna intercepts some of the power of a radio wave in order to produce an electric current at its terminals that is applied to a receiver to be amplified. Antennas are essential components of all radio equipment.

An antenna is an array of conductors (elements) electrically connected to the receiver or transmitter. Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas) or preferentially in a particular direction (directional or high-gain or “beam” antennas). An antenna may include components not connected to the transmitter parabolic reflectors horns or parasitic elements which serve to direct the radio waves into a beam or other desired radiation pattern.

Radio receiver also known as a receiver a wireless or simply a radio is an electronic device that receives radio waves and converts the information carried by them to a usable form. It is used with an antenna. The antenna intercepts radio waves (electromagnetic waves) and converts them to tiny alternating currents which are applied to the receiver and the receiver extracts the desired information. The receiver uses electronic filters to separate the desired radio frequency signal from all the other signals picked up by the antenna an electronic amplifier to increase the power of the signal for further processing and finally recovers the desired information through demodulation.

Radio receivers are essential components of all systems that use radio. The information produced by the receiver may be in the form of sound moving images (television) or digital data. A radio receiver may be a separate piece of electronic equipment or an electronic circuit within another device. The most familiar type of radio receiver for most people is a broadcast radio receiver which reproduces sound transmitted by radio broadcasting stations historically the first mass-market radio application. A broadcast receiver is commonly called a "radio". However radio receivers are very widely used in other areas of modern technology in televisions cell phones wireless modems and other components of communications remote control and wireless networking systems.

A **tuner** is a subsystem that receives radio frequency (RF) transmissions and converts the selected carrier frequency and its associated bandwidth into a fixed frequency that is suitable for further processing usually because a lower frequency is used on the output. Broadcast FM/AM transmissions usually feed this intermediate frequency (IF) directly into a demodulator that converts the radio signal into audio-frequency signals that can be fed into an amplifier to drive a loudspeaker.

More complex transmissions like PAL/NTSC (TV) DAB (digital radio) DVB-T/DVB-S/DVB-C (digital TV) etc. use a wider frequency bandwidth often with several subcarriers. These are transmitted inside the receiver as an intermediate frequency (IF).

Subcarriers are then processed like real radio transmissions but the whole bandwidth is sampled with an analog-to-digital converter (A/D) at a rate faster than the Nyquist rate (that is at least twice the IF frequency).

A tuner can also refer to a radio receiver or standalone audio component that is part of an audio system to be connected to a separate amplifier. The verb tuning in radio contexts means adjusting the receiver to detect the desired radio signal carrier frequency that a particular radio station uses.

An **amplifier** electronic amplifier or (informally) amp is an electronic device that can increase the power of a signal (a time-varying voltage or current). It is a two-port electronic circuit that uses electric power from a power supply to increase the amplitude of a signal applied to its input terminals producing a proportionally greater amplitude signal at its output. The amount of amplification provided by an amplifier is measured by its gain: the ratio of output voltage current or power to input. An amplifier is a circuit that has a power gain greater than one.

An amplifier can either be a separate piece of equipment or an electrical circuit contained within another device. Amplification is fundamental to modern electronics and amplifiers are widely used in almost all electronic equipment. Amplifiers can be categorized in different ways. One is by the frequency of the electronic signal being amplified. For example audio amplifiers amplify signals in the audio (sound) range of less than 20 kHz RF amplifiers amplify frequencies in the radio frequency range between 20 kHz and 300 GHz and servo amplifiers and instrumentation amplifiers may work with very low frequencies down to direct current. Amplifiers can also be categorized by their physical placement in the signal chain; a preamplifier may precede other signal processing stages for example.

Modulation is the process of varying one or more properties of a periodic waveform called the carrier signal with a separate signal called the modulation signal that typically contains information to be transmitted. For example the modulation signal might be an audio signal representing sound from a microphone a video signal representing moving images from a video camera or a digital signal representing a sequence of binary digits a bitstream from a computer. The carrier is higher in frequency than the modulation signal. The purpose of modulation is to impress the information on the carrier wave which is used to carry the information to another location. In radio communication the modulated carrier is transmitted through space as a radio wave to a radio receiver. Another purpose is to transmit multiple channels of information through a single communication medium using frequency division multiplexing (FDM). For example in cable television which uses FDM many carrier signals each modulated with a different television channel are transported through a single cable to customers. Since each carrier occupies a different frequency the channels do not interfere with each other. At the destination end the carrier signal is demodulated to extract the information bearing modulation signal.

A **modulator** is a device or circuit that performs modulation. A demodulator (sometimes detector) is a circuit that performs demodulation the inverse of modulation. A modem (from modulator–demodulator) used in bidirectional communication can perform both operations. The frequency band occupied by the modulation signal is called the baseband while the higher frequency band occupied by the modulated carrier is called the passband.

In analog modulation an analog modulation signal is impressed on the carrier. Examples are amplitude modulation (AM) in which the amplitude (strength) of the carrier wave is varied by the modulation signal and frequency modulation (FM) in which the frequency of the carrier wave is varied by the modulation signal. These were the earliest types of modulation and are used to transmit an audio signal representing sound in AM and FM radio broadcasting. More recent systems use digital modulation which impresses a digital signal consisting of a sequence of binary digits (bits) a bitstream on the carrier. In frequency shift keying (FSK) modulation used in computer buses and telemetry the carrier signal is periodically shifted between two frequencies that represent the two binary digits. In digital baseband modulation (line coding) used to transmit data in serial computer bus cables and wired LAN computer networks such as Ethernet the voltage on the line is switched between two amplitudes (voltage levels) representing the two binary digits 0 and 1 and the carrier (clock) frequency is combined with the data. A more complicated digital modulation method that employs multiple carriers orthogonal frequency division multiplexing (OFDM) is used in WiFi networks digital radio stations and digital cable television transmission.

These terms are traditionally used in connection with radio receivers but many other systems use many kinds of demodulators. For example in a modem which is a contraction of the terms modulator/demodulator a demodulator is used to extract a serial digital data stream from a carrier signal which is used to carry it through a telephone line coaxial cable or optical fiber.

In radio a **detector** is a device or circuit that extracts information from a modulated radio frequency current or voltage.

In a superheterodyne receiver the term is also sometimes used to refer to the mixer the tube or transistor which converts the incoming radio frequency signal to the intermediate frequency. The mixer is called the first detector while the demodulator that extracts the audio signal from the intermediate frequency is called the second detector.

In microwave and millimeter wave technology the terms detector and crystal detector refer to waveguide or coaxial transmission line components used for power or Standing wave ratio (SWR) measurement that typically incorporate point contact diodes or surface barrier Schottky diodes.

RF filters represent a class of electronic filter designed to operate on signals in the megahertz to gigahertz frequency ranges (medium frequency to extremely high frequency). This frequency range is the range used by most broadcast radio television wireless communication (cellphones Wi-Fi etc.) and thus most RF and microwave devices will include some kind of filtering on the signals transmitted or received. Such filters are commonly used as building blocks for duplexers and diplexers to combine or separate multiple frequency bands.

Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials. Shielding is typically applied to enclosures to isolate electrical devices from their surroundings and to cables to isolate wires from the environment through which the cable runs. Electromagnetic shielding that blocks radio frequency (RF) electromagnetic radiation is also known as RF shielding.

The shielding can reduce the coupling of radio waves electromagnetic fields and electrostatic fields. A conductive enclosure used to block electrostatic fields is also known as a Faraday cage. The amount of reduction depends very much upon the material used its thickness the size of the shielded volume and the frequency of the fields of interest and the size shape and orientation of holes in a shield to an incident electromagnetic field.

In electrical engineering a ground plane is an electrically conductive surface usually connected to electrical ground. The term has two different meanings in separate areas of electrical engineering. In antenna theory a ground plane is a conducting surface large in comparison to the wavelength such as the Earth which is connected to the transmitter's ground wire and serves as a reflecting surface for radio waves. In printed circuit boards a ground plane is a large area of copper foil on the board which is connected to the power supply ground terminal and serves as a return path for current from different components on the board.

In telecommunication the term **noise power** has the following meanings:

The measured total noise in a given bandwidth at the input or output of a device when the signal is not present; the integral of noise spectral density over the bandwidth.

The power generated by a random electromagnetic process.

Interfering and unwanted power in an electrical device or system.

In the acceptance testing of radio transmitters the mean power supplied to the antenna transmission line by a radio transmitter when loaded with noise having a Gaussian amplitude-vs.-frequency distribution.

The metal–oxide–semiconductor field-effect transistor (MOSFET MOS-FET or MOS FET) also known as the metal–oxide–silicon transistor (MOS transistor or MOS) is a type of insulated-gate field-effect transistor that is fabricated by the controlled oxidation of a semiconductor typically silicon. The voltage of the covered gate determines the electrical conductivity of the device; this ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals.

A key advantage of a MOSFET is that it requires almost no input current to control the load current when compared with bipolar junction transistors (BJTs). In an enhancement mode MOSFET voltage applied to the gate terminal can increase the conductivity from the "normally off" state. In a depletion mode MOSFET voltage applied at the gate can reduce the conductivity from the "normally on" state. MOSFETs are also capable of high scalability with increasing miniaturization and can be easily scaled down to smaller dimensions. They also have faster switching speed (ideal for digital signals) much smaller size consume significantly less power and allow much higher density (ideal for large-scale integration) compared to BJTs. MOSFETs are also cheaper and have relatively simple processing steps resulting in high manufacturing yield.

MOSFETs can either be manufactured as part of MOS integrated circuit chips or as discrete MOSFET devices (such as a power MOSFET) and can take the form of single-gate or multi-gate transistors. Since MOSFETs can be made with either p-type or n-type semiconductors (PMOS or NMOS logic respectively) complementary pairs of MOSFETs can be used to make switching circuits with very low power consumption: CMOS (Complementary MOS) logic.

The name "metal–oxide–semiconductor" (MOS) typically refers to a metal gate oxide insulation and semiconductor (typically silicon). However the "metal" in the name MOSFET is sometimes a misnomer because the gate material can also be a layer of polysilicon (polycrystalline silicon). Along with oxide different dielectric materials can also be used with the aim of obtaining strong channels with smaller applied voltages. The MOS capacitor is also part of the MOSFET structure.

A power MOSFET is a specific type of metal–oxide–semiconductor field-effect transistor (MOSFET) designed to handle significant power levels. Compared to the other power semiconductor devices such as an insulated-gate bipolar transistor (IGBT) or a thyristor its main advantages are high switching speed and good efficiency at low voltages. It shares with the IGBT an isolated gate that makes it easy to drive. They can be subject to low gain sometimes to a degree that the gate voltage needs to be higher than the voltage under control.

The power MOSFET is the most common power semiconductor device in the world due to its low gate drive power fast switching speed easy advanced paralleling capability wide bandwidth ruggedness easy drive simple biasing ease of application and ease of repair. In particular it is the most widely used low-voltage (less than 200 V) switch. It can be found in a wide range of applications such as most power supplies DC-to-DC converters low-voltage motor controllers and many other applications.

LDMOS (**laterally-diffused metal-oxide semiconductor**) is a planar double-diffused MOSFET (metal–oxide–semiconductor field-effect transistor) used in amplifiers including microwave power amplifiers RF power amplifiers and audio power amplifiers. These transistors are often fabricated on p/p+ silicon epitaxial layers. The fabrication of LDMOS devices mostly involves various ion-implantation and subsequent annealing cycles. As an example The drift region of this power MOSFET is fabricated using up to three ion implantation sequences in order to achieve the appropriate doping profile needed to withstand high electric fields.

The silicon-based RF LDMOS (radio-frequency LDMOS) is the most widely used RF power amplifier in mobile networks enabling the majority of the world's cellular voice and data traffic. LDMOS devices are widely used in RF power amplifiers for base-stations as the requirement is for high output power with a corresponding drain to source breakdown voltage usually above 60 volts.[6] Compared to other devices such as GaAs FETs they show a lower maximum power gain frequency.

Manufacturers of LDMOS devices and foundries offering LDMOS technologies include TSMC LFoundry Tower Semiconductor GLOBALFOUNDRIES Vanguard International Semiconductor Corporation STMicroelectronics Infineon Technologies RFMD NXP Semiconductors (including former Freescale Semiconductor) SMIC MK Semiconductors Polyfet and Ampleon.

A **bipolar junction transistor** (BJT) is a type of transistor that uses both electrons and electron holes as charge carriers. In contrast a unipolar transistor such as a field-effect transistor uses only one kind of charge carrier. A bipolar transistor allows a small current injected at one of its terminals to control a much larger current flowing between two other terminals making the device capable of amplification or switching.

A **baseband processor** (also known as baseband radio processor BP or BBP) is a device (a chip or part of a chip) in a network interface controller that manages all the radio functions (all functions that require an antenna); however this term is generally not used in reference to Wi-Fi and Bluetooth radios. A baseband processor typically uses its own RAM and firmware. Baseband processors are typically fabricated using CMOS (complementary metal–oxide–semiconductor) or RF CMOS technology and are widely used in radio-frequency (RF) and wireless communications.

RF CMOS is a metal–oxide–semiconductor (MOS) integrated circuit (IC) technology that integrates radio-frequency (RF) analog and digital electronics on a mixed-signal CMOS (complementary MOS) RF circuit chip. It is widely used in modern wireless telecommunications such as cellular networks Bluetooth Wi-Fi GPS receivers broadcasting vehicular communication systems and the radio transceivers in all modern mobile phones and wireless networking devices.

2 Software tools for RF measurements

2.1 Overview

The great variety of hardware elements and units in a given radio communication system, their physical capabilities to meet certain requirements, the various combinations and high cost are a prerequisite for the development of mixed-signal integrated circuit which is any integrated circuit that has both analog circuits and digital circuits on a single semiconductor die.

In real-life applications mixed-signal designs are everywhere for example in smart mobile phones sensor systems with on-chip standardized digital interfaces, voice related signal processing aerospace and space electronics IoT unmanned aerial vehicles (UAVs) automotive and other electrical vehicles.

Mixed-signal ICs also process both analog and digital signals together. For example an analog-to-digital converter (ADC) is a typical mixed-signal circuit. Mixed-signal circuits or systems are typically cost-effective solutions for building any modern consumer electronics industrial medical measurement space etc. applications. A mixed signal integrated circuit may also contain on-chip memory blocks like OTP which complicates the manufacturing compared to analog ICs. A mixed signal integrated circuit minimizes off-chip interconnects between digital and analog functionality in the system typically size and weight of the realization due to minimized packaging and reduced system board (PWB/PCB module substrate etc.) size and therefore increase the reliability of the system.

Mixed signal devices are available as standard parts but custom designed application-specific integrated circuits (ASICs) are designed for new applications or if new standards are emerging or new energy source(s) are implemented in the system and the production volumes are estimated to be high.

Availability of ready and tested analog and mixed signal IP blocks from foundries or dedicated design houses have lowered the gap to realize mixed signal ASICs. There also exists few mixed signal FPGAs and microcontrollers which typically may include analog-to-digital and digital-to-analog converter(s) operational amplifiers even wireless connectivity blocks etc. on the same chip with digital logic.

Mixed signal FPGAs are an extension of field-programmable analog arrays. These mixed signal FPGAs and microcontrollers are bridging the gap between standard mixed signal devices full custom ASICs and possibly embedded software world when products are under development or the volumes are too low for an effective full custom ASIC realization. However there can be few performance limitations typically with these type of FPGAs and microcontrollers like resolution of ADCs speed of digital to analog conversion (DAC) and limited number of inputs and outputs etc. Despite these possible limitations mixed signal FPGAs and microcontrollers can speed up the system architecture design prototyping and even small and medium scale production. They also can be backed-up with development boards development community and possibly also software support.

An integrated circuit or monolithic integrated circuit (also referred to as an IC a chip or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material usually silicon. Large numbers of tiny MOSFETs (metal–oxide–semiconductor field-effect transistors) integrate into a small chip. This results in circuits that are orders of magnitude smaller faster and less expensive than those constructed of discrete electronic components. The IC's mass production capability reliability and building-block approach to integrated circuit design has ensured the rapid adoption of standardized ICs in place of designs using discrete transistors. ICs are now used in virtually all electronic equipment and have revolutionized the world of electronics. Computers mobile phones and other digital home appliances are now inextricable parts of the structure of modern societies made possible by the small size and low cost of ICs such as modern computer processors and microcontrollers.

Integrated circuits were made practical by technological advancements in metal–oxide–silicon (MOS) semiconductor device fabrication. Since their origins in the 1960s the size speed and capacity of chips have progressed enormously driven by technical advances that fit more and more MOS transistors on chips of the same size – a modern chip may have many billions of MOS transistors in an area the size of a human fingernail. These advances roughly following Moore's law make computer chips of today possess millions of times the capacity and thousands of times the speed of the computer chips of the early 1970s.

ICs have two main advantages over discrete circuits: cost and performance. Cost is low because the chips with all their components are printed as a unit by photolithography rather than being constructed one transistor at a time. Furthermore packaged ICs use much less material than discrete circuits. Performance is high because the IC's components switch quickly and consume comparatively little power because of their small size and proximity. The main disadvantage of ICs is the high cost to design them and fabricate the required photomasks. This high initial cost means ICs are only commercially viable when high production volumes are anticipated.

In nowadays when CMOS transistors have picosecond switching speeds and transition frequencies in the tens to hundreds of GHz, there is an opportunity**Error!**

Reference source not found. for the integration of RF and microwave components into a complete system on a single integrated circuit. Single-chip transceivers for wireless LAN and femtocell base stations are already a commercial reality. As with complex digital systems, the demand for first-pass design success requires that accurate predictive models are available for the subsystem components of the whole system, enabling the system design to be simulated and any errors or faults remedied before the design is committed to hardware. This will save time and the cost of unnecessary fabrication and test of the complete system.

System-level modeling and simulation for RF and microwave design have become very sophisticated in recent years. Commercial simulation tools with extensive libraries of signal sources, component models. The development of nonlinear behavioral models for the RF and microwave components such as amplifiers and mixers, and the ability to measure these subsystems accurately in a typical application environment have been significant enablers of these recent simulator advances.

Popular simulation software are Lab View, Matlab, GNU radio, RF.spice.

2.2 LabVIEW - stands for Laboratory Virtual Instrument Engineering Workbench. LabVIEW 1.0 was launched in the year 1986. It is a graphical programming language which uses icons instead of lines of text to create applications. LabVIEW programs are called VIs (Virtual Instruments). LabVIEW contains set of VIs and functions for acquiring, analyzing, displaying and storing data. It also include tools to represent data on computers in the form of charts, graphs, tables, 3D controls, 3D graphs, picture control, gauges, meters etc.

It is a highly productive developement environment for creating custom applications which interact with real world data or signals in fields of engineering science. LabVIEW contains numerous components which are required for test, measurement and control applications.

LabVIEW is different from traditional programming like C#, VB, MATLAB, Mathscript, Maple etc. It is based on drag and drop concept. Hence it is easy for use by non-programmers.

LabVIEW uses GUI application. VIs are used to test, control and design applications which helps in accurate analog and digital measurements. It can also be used to control external hardware devices from desktop PCs and for display purpose.

The VI has two panels front panel and block diagram. Front panel provides controls and indicators used as inputs and outputs respectively. Block diagram is the place where components or icons are wired together for some purpose. This is the accompanying program for the front panel. Front panel is the user interface of the VI. Every control or indicator on the front panel has corresponding terminal on the block diagram.

Benefits or advantages of LabVIEW

- It offers graphical user interface (GUI) so applications look good and easy to interact with user.
- It offers drag and drop a function which helps to create quick simulation block diagram (i.e. VI). It reduces programming time compare to text based programming languages.
- It supports modular design and multi platforms.
- It is flexible and scalable language.
- It helps in analyzing signals with built-in Math and signal processing functions.
- User can create their own VI if it is not available as built-in function.
- It facilitates data transfer over GPIB, USB, Ethernet, serial port etc.
- It offers object oriented design and can be used for algorithm design. One can create "C DLL" from their C code and use it as VI.

User can easily create both offline and online applications and license them to different users as per supplied MAC addresses. Offline applications does not require any RF equipments. Online applications work in real time and require RF VSG (Vector Signal Generator) and RF VSA (Vector Signal Analyzer). The drivers for real time signal acquisition and signal generation are developed by NI (National Instruments).

- It is widely used in industries for data acquistion, data analysis, data generation for test and measurement of transmitter and receiver functionalities of DUT.
- It provides open connectivity with other tools such as Multisim, Excel, Mathcad, Mathematica etc.
- It can communicate with wide variety of PLCs and automation devices. User can connect and use LabVIEW with different fieldbus such as TCP/IP, PROFIBUS, EtherNet/IP, OPC, Modbus and CANOpen.
- It is available at affordable cost. The different add-ons can be purchased as per need which include LabVIEW FPGA module, LabVIEW NXG Web module, LabVIEW Real time module and Vision Development module.

Disadvantages of LabVIEW

LabVIEW is single sourced which is distributed and licensed by NI.

Text programmers require little time to familiarize its built-in functions.

The cost of LabVIEW should be considered before its introduction.
It requires good amount of training before it can be used comfortably.
The debugging is complex compare to text based programming language

2.3 MATLAB

Advantage of MATLAB

The program can be used as a scratchpad to evaluate expressions typed at the command line, or it can be used to execute large prewritten programs. Applications may be written and changed with the built-in integrated development environment and debugged with the MATLAB debugger. Because the language is so simple to use, it is optimal for the fast prototyping of new applications. Many program development tools are supported to make the program easy to use. They contain an integrated editor/debugger, on-line documentation and manuals, a workspace browser, and extensive demos.

Platform Independence MATLAB is supported on different computer systems, providing a considerable measure of platform independence. The language is provided on Windows 2000/XP/Vista, Linux, various versions of UNIX, and the Macintosh. Applications written on any platform will run on the other entire platform, and information files written on any platform may be read apparently on any other platform. As a result, programs written in MATLAB can shift to new platforms when the needs of the user change.

Predefined Functions MATLAB comes complete with a huge library of predefined functions that provides tested and prepackaged solutions to many primary technical tasks. For example, suppose that we are writing a program that must evaluate the statistics associated with an input data set. In most languages, we would need to write our subroutines or functions to implement calculations such as the arithmetic mean, standard deviation, median, and so on. These and hundreds of other services are built right into the MATLAB language, making job much more comfortable.

In addition to the vast libraries of services built into the basic MATLAB language, there are many special-purpose toolboxes applicable to help solve complex problems in particular areas. For example, a user can buy standard toolkits to solve problems in signal processing, control systems, communications, image processing, and neural networks, etc. There is also a broad compilation of free user-contributed MATLAB programs that are shared through the MATLAB Web site.

Device-Independent Plotting MATLAB has many basic plotting and imaging commands. The plots and pictures can be displayed on any graphical output device provided by the computer on which MATLAB is running. This facility makes MATLAB an outstanding tool for visualizing technical information.

Graphical User Interface MATLAB contains a tool that allows a programmer to interactively design a Graphical User Interface (GUI) for his program. With this capability, the programmer can design refined data-analysis programs that can be operated by relatively inexperienced users.

MATLAB Compiler MATLAB's adaptability and platform independence are produced by compiling MATLAB applications into a machine-independent p-code and then interpreting the p-code instruction at runtime. This method is equivalent to that used by Microsoft's Visual Basic language. Unfortunately, the resulting applications can sometimes execute slowly because the MATLAB code is interpreted rather than compiled.

A separate MATLAB compiler is available. This compiler can compile MATLAB programs into a real executable that runs faster than the interpreted code. It is a great technique to convert a prototype MATLAB program into an executable suitable for sale and distribution to users.

Disadvantage of MATLAB There is two major disadvantage of MATLAB programming language:

Interpreted language - first disadvantage is that it is an interpreted language and, therefore, may execute more slowly than compiled language. This problem can be check by properly structuring the MATLAB program.

Cost A full copy of MATLAB is five to ten times more costly than a conventional C or FORTRAN compiler. This comparatively high cost is more than offset by the decreased time necessary for an engineer or scientist to create a working program, so MATLAB is cost-effective for businesses. However, it is too expensive for most individuals to consider purchasing. Fortunately, there is also an inexpensive Student Edition of MATLAB, which is an excellent tool for students wishing to learn the language. The Student Edition of MATLAB is virtually identical to the full edition.

2.4 **GNU Radio** - free software development toolkit that provides signal processing blocks to implement software-defined radios and signal-processing systems.

It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. It is widely used in hobbyist, academic, and commercial environments to support both wireless communications research and real-world radio systems. The GNU Radio software provides the framework and tools to build and run software radio or just general signal-processing applications. The GNU Radio applications themselves are generally known as "flowgraphs", which are a series of signal processing blocks connected together, thus describing a data flow.

As with all software-defined radio systems, reconfigurability is a key feature. Instead of using different radios designed for specific but disparate purposes, a single, general-purpose, radio can be used as the radio front-end, and the signal-processing software (here, GNU Radio), handles the processing specific to the radio application. These flowgraphs can be written in either C++ or the Python programming language. The GNU Radio infrastructure is written entirely in C++, and many of the user tools are written in Python.

GNU Radio is a signal-processing package and part of the GNU Project. It is distributed under the terms of the GNU General Public License (GPL), and most of the project code is copyrighted by the Free Software Foundatio

The term SDR stands for Software defined radio. It is programmable transceiver which supports various wireless technologies without the need to update hardware. It is required to have easy migration during product developments from one standard based device to the other. Examples of such standards include LTE to LTE-advanced or 4G to 5G or WiFi-11ac to WiFi-11ax and so on. SDR deals with software defined wireless communication protocols (e.g. PHY, MAC) rather than hardware based solutions.

There are various approaches to design and implement SDR modules on hardware platforms viz. GPP (General Purpose Processor), DSP (Digital Signal Processor) and FPGA (Field Programmable Gate Array) etc. Following table mentions comparison between different SDR design methods based on various parameters such as power efficiency, throughput, cost, execution etc. This table helps in selecting appropriate method for your SDR designs.

table 1

Parameters	GPP	DSP	FPGA
Computation	Fixed Arithmetic Engine	Fixed Arithmetic Engine	User Configurable Logic
Power Efficiency	Low	Moderate	High
Throughput	Low	Medium	High
Cost	Moderate	Low	Moderate
Input/Output	Dedicated ports	Dedicated ports	User Configurable Ports
Execution	Sequential	Partially Parallel	Highly Parallel
Form Factor	Large	Medium	Small

The figure depicts SDR architecture of transmitter and receiver modules. SDR transmitter consists of baseband modules such as FEC encoder, modulation, IFFT etc. The digital IF is converted to analog IF using DAC (D/A converter). Analog IF is converted to analog RF and is being amplified using Power Amplifier (PA) before transmission by antenna into the air. The SDR receiver usually consists of PA, tuner, ADC, digital front end modules (DDC, LPF) and signal processing modules (FFT, demodulator, FEC decoder etc.).

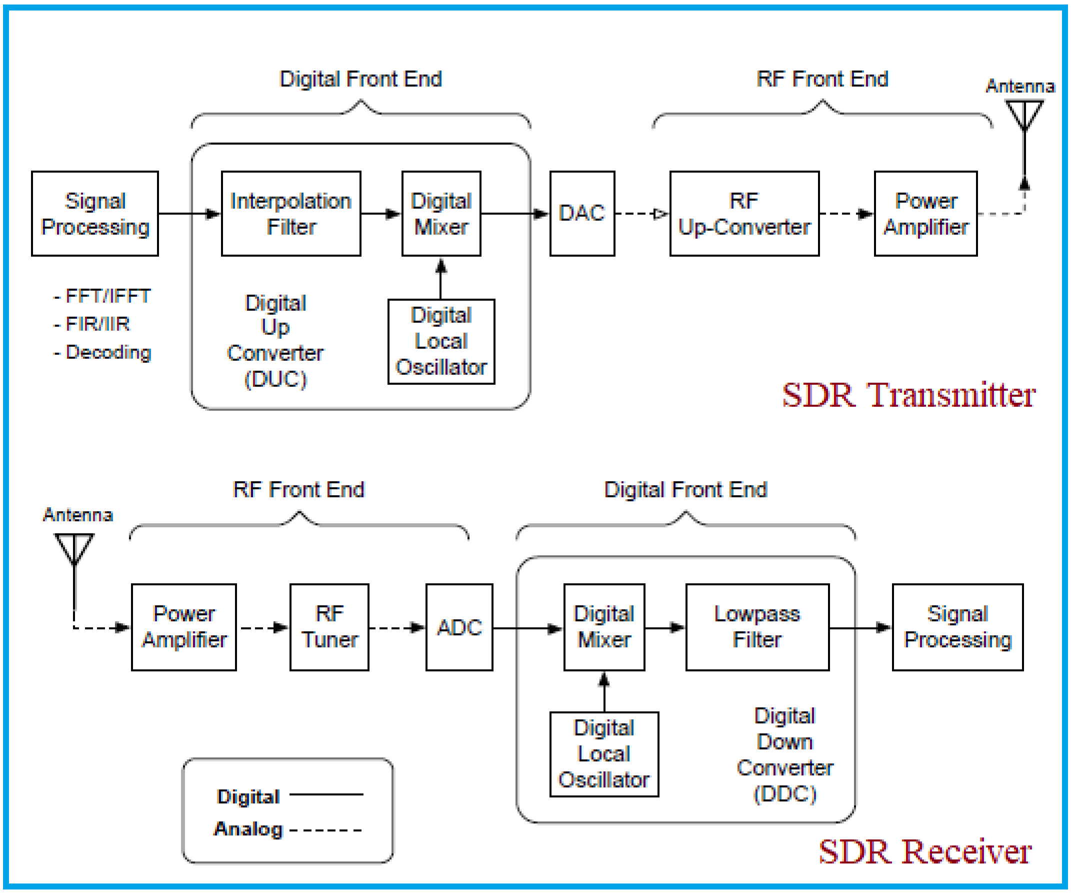


figure 8 SDR architecture

Following are the benefits or advantages of SDR:

SDR based prototypes help researchers and developers during realization of 3GPP or IEEE standard based communication protocols. SDR mainly used for physical layer and RF implementation as per WiFi (802.11b/a/g/n/ac/ax), Bluetooth, Zigbee, Zwave, WiMAX, LTE, 5G, 6G standards etc. Hence time to market can be met.

It offers flexible, reconfigurable and programmable framework. This helps to meet varied needs of different users in terms of hardware specifications. The same SDR hardware can be used for various radio system architectures.

SDR hardware prototypes are ready to adapt any future upgrades and protocols.

As same prototype hardware can be used, SDR approach leads to less development costs.

It helps in selection of RF carrier frequency, modulation type, FEC techniques, sampling frequency as per system requirements.

It offers high level of performance which can be tuned by software.

Following are the challenges or drawbacks or disadvantages of SDR commonly found during SDR implementations.

Poor dynamic range in some SDR prototype designs.

It is difficult to write software to support different target platforms.

SDR architecture consists of analog RF front end and digital front end. Hence it is challenging to implement interfacing between analog and digital modules or blocks.

ADC limits maximum frequency to be used by digital part of SDR (Software Defined Radio).

SDR development requires software and hardware engineers.

For few simple radio system designs, SDR platform may be very expensive to afford.

System-level characterization and modeling techniques for RF and microwave subsystem components are presented at following URL https://www.maximintegrated.com/en/design/technical-documents/tutorials/5/5542.html , where an RF transmitter with digital predistortion (DPD) is used as an example complex system.

2.5 **RF.Spice A/D™ -** powerful visual simulation environment for analysis and design of analog, digital, RF and mixed-signal circuits and systems. Rather than verifying circuit designs after the fact using real physical components with expensive laboratory test equipment, RF.Spice A/D allows to perform accurate and realistic simulations of your circuits without clipping wires or splashing solder.

The foundation of RF.Spice A/D has been built upon Berkeley Spice 3F5 and Georgia Tech XSpice simulation engines. The analog and digital circuit solvers have been integrated with an extensive library of RF devices, S-parameter-based multiport networks and a large variety of generic and physical transmission line types and transmission line discontinuity models. Featuring more than 25,000 preloaded devices, the parts database of RF.Spice A/D can easily be expanded by importing an unlimited number of external Netlist models or packaging user's existing circuits as parameterized subcircuit models.

RF.Spice A/D provides a large collection of functional and behavioral macormodels for waveform generation, analog and digital signal processing, spectral processing and various modulation schemes. It can use these so-called black-box virtual blocks to perform effective system-level simulations without having to deal with the internal details of individual subsystems.

Manual, tutorials and lessons are available at following link http://www.emagtech.com/wiki/index.php?title=RF.Spice_A/D