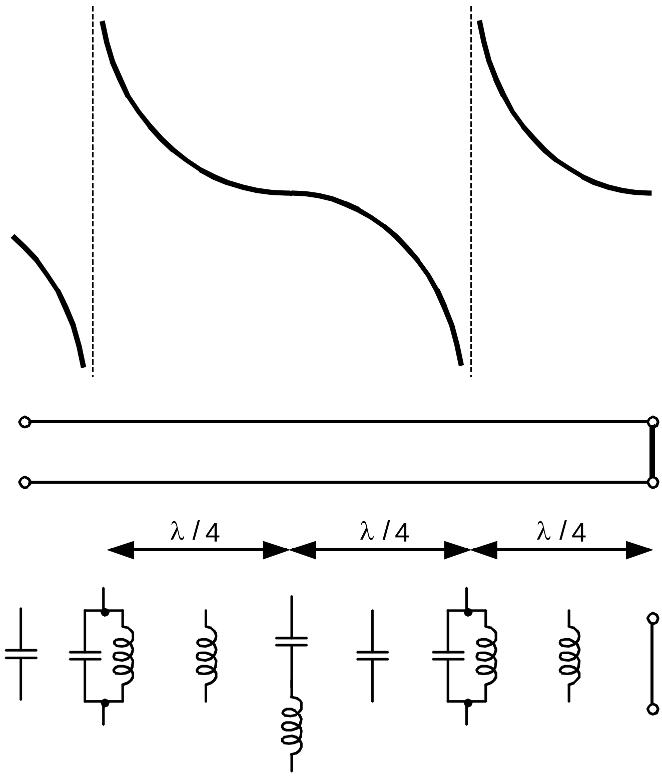
The Comprehensive Guide To RF & Microwave Engineering For Passive Components



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Preface

Access to information has never been so easily available for all people around the world. The demand for increased bandwidth and faster communication channels is growing on a daily basis. The high technology used today in an ultra-modern product is tomorrow’s standard low cost appliance.

Electronics has been driven previously by the stationary computer market in the early 80s for nearly twenty years. Each new generation had a faster computer with faster peripherals that could send more and more data to each other. Mobile access devices have replaced many of the stationary computers and the requirement for greater bandwidth for each new mobile device has dominated the recent developments in electronics. The latest development trends require direct access to distant positioned electronic devices via the internet and cloud services.

Regardless of the platform being a stationary PC, mobile device or access to a distant unit via a cloud service; one common platform for all these devices is the need for greater bandwidth and faster operating speeds. To be able to meet the increasing requirements in the mass market it has been necessary to operate at higher frequencies for greater bandwidth.

To meet the bandwidth requirements, traditional communication systems have moved from the radio frequency region (LF, MF, HF and UHF) to the RF, microwave and mm-wave region. To ease developments in RF, microwave and mm-wave regions, there are a variety of modular components which can be purchased of the shelf. These components are designed as separate units with matched custom input and output stages. Microwave design can be made from readymade component modules and the complete system design can be analysed by understanding the usage of each specific component block.

System designers need a descriptive explanation of the function, in order to make best use of the components. An overview of all the components enables evaluation of alternative system solutions. By selecting the best combination will provide the optimum product for the available cost budget.

Component design engineers should have a broad overview of all the available components to obtain new ideas for circuit solutions. The knowledge of experienced engineers should always be utilized as much as possible. As well as usage of computer simulations to design and optimize the components which simplifies the mathematical workload considerably, but it is still vital to correctly choose the appropriate circuit solution.

Technicians and test engineers need a descriptive explanation of the complete system, which is not burdened with mathematical models. A technician needs to be able to quickly understand complete circuit diagrams or special test setups. Sales representatives and purchasers require a general understanding of the microwave components since they must understand requirements for price negotiations.

Thus, there are now many roles who work with RF, microwave and mm-wave technology requiring a broad knowledge of high frequency components, as well as an understanding of the special characteristics exploited in microwave and high frequency design.

The goal of the book is to provide an overview and introduction working with RF, microwave and high frequency components. With over 700 figures to illustrate the practical and comprehensive descriptions of high frequency components with the mathematics kept to the minimum.

Contents

Introduction

Microwave Frequency Band

Microwaves are electromagnetic waves with a wavelength shorter than radio/TV but longer than light waves. Microwave wavelength is between 1 cm and 1 m which means that with practical dimensions; components can be designed utilizing the wavelength characteristics.

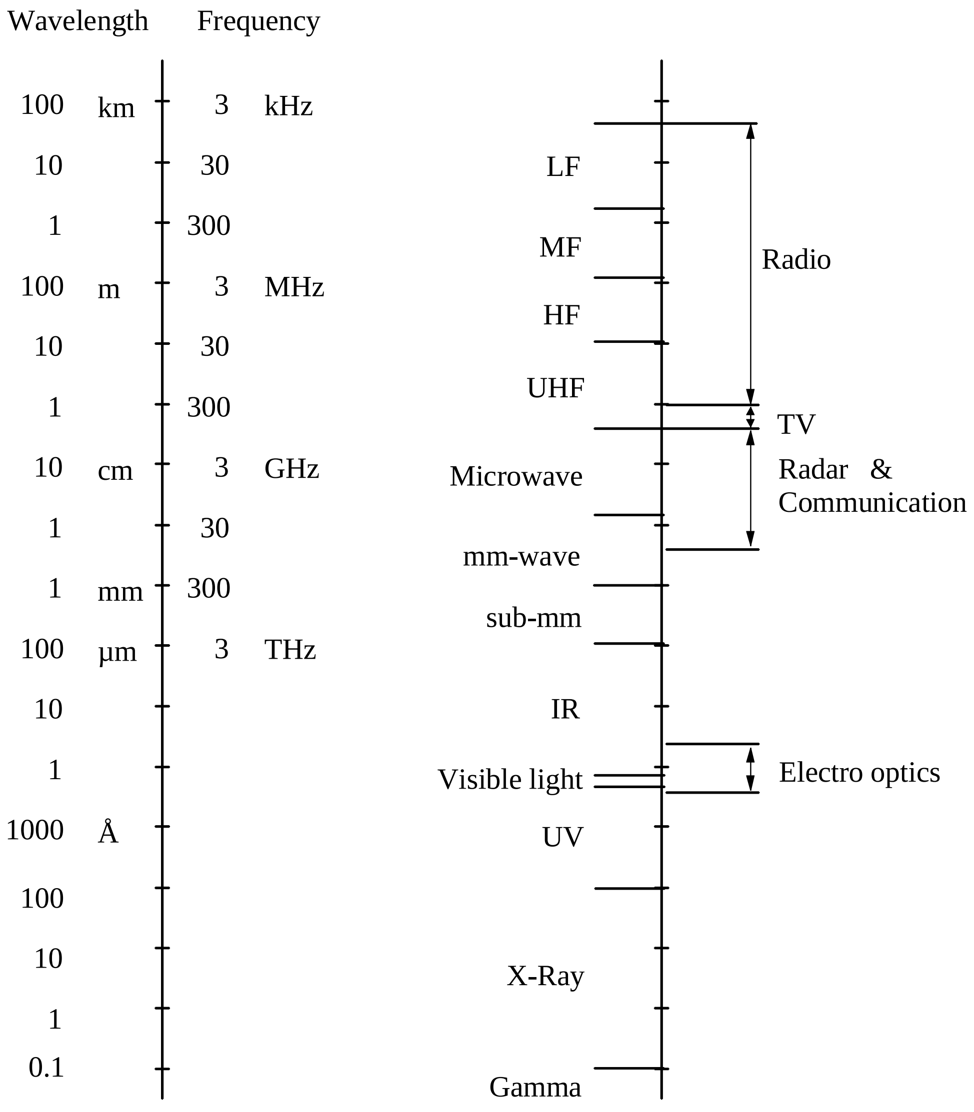
Normally, the frequency is specified instead of the wavelength. Frequency range is approximately from 0.5 GHz to 20 GHz. Microwave frequency band is usually divided into several smaller frequency bands. A common sub division uses the octave bands.

Frequency Band Designation	Frequency (GHz)
UHF	0.5 - 1
L	1 - 2
S	2 - 4
C	4 - 8
X	8 - 12
Ku	12 - 18

The letter designations can vary since there are several different designations for reserved frequency bands. The same letter designation can have different frequency bands so it is wise to specify the frequency limits as well. Frequency band designations should only be used when it is clearly understood which frequency band will be used.

Frequency band for radar and communication are significantly narrower. Working with radar in the X-band usually is a narrow frequency area around 9 GHz. There are components and measurement equipment which can handle a decade frequency range which will cover the whole microwave frequency band.

Electromagnetic Spectrum Divisions



1 Å (Ångström) = 10^{-10} m

Figure 1 – Electromagnetic spectrum

Microwave is well established definition for approximately 1 to 18 GHz. Each band is basically sorted according to the wavelength in either cm or dm. Frequency region for mm-waves corresponds to the wavelengths in mm; mm-waves have shorter wavelength than microwaves.

Advantages with Microwaves

Main advantages of microwaves are the large information capabilities and the small antenna size with good directivity.

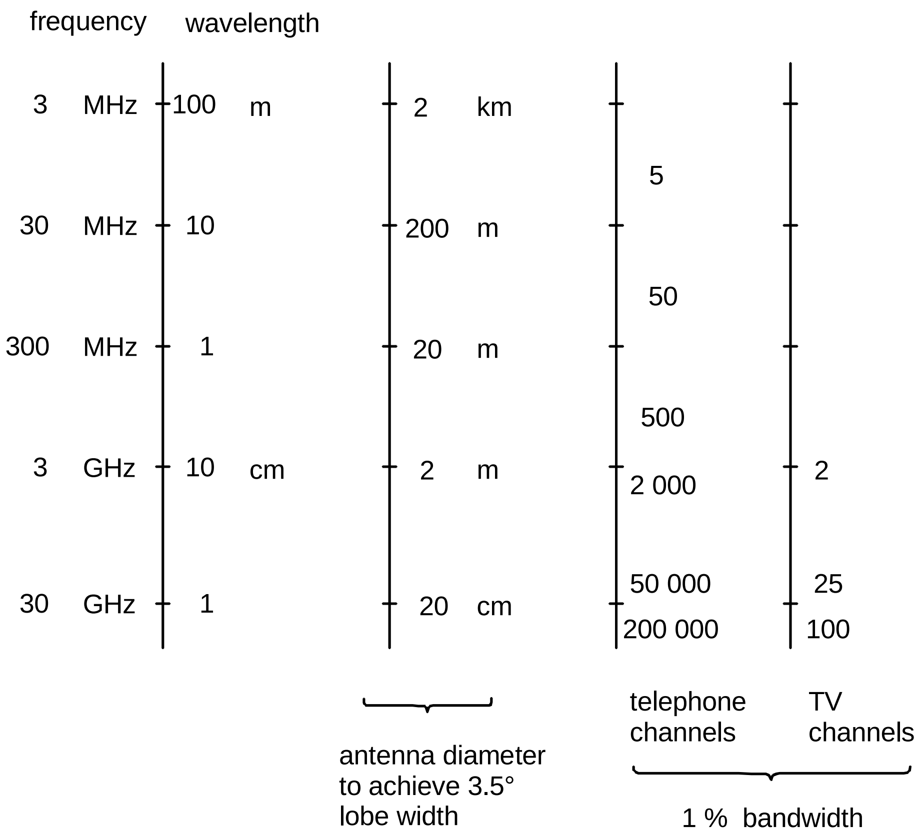


Figure 2 – Frequency, wavelength and bandwidth

Sometimes a directional antenna is required for positioning towards a specific object. Directivity of an antenna is proportional to the antennas size in wavelengths. With microwaves, a good directional antenna with reasonable dimensions is obtainable.

Different frequencies are affected individually with wave propagation effects and when passing through components. To avoid that the signal information is distorted the percentage of occupied bandwidth should remain small. Within microwaves it is possible to fit a large amount of information in 1% of bandwidth. The number of channels that can be fitted in the bandwidth depends on the method of modulation. Figure 2 illustrates an average number of channels that can be employed at a given frequency. At the lower frequencies it can be seen that the amount of information bandwidth is not practical compared to the higher frequencies.

Radio Frequency Region

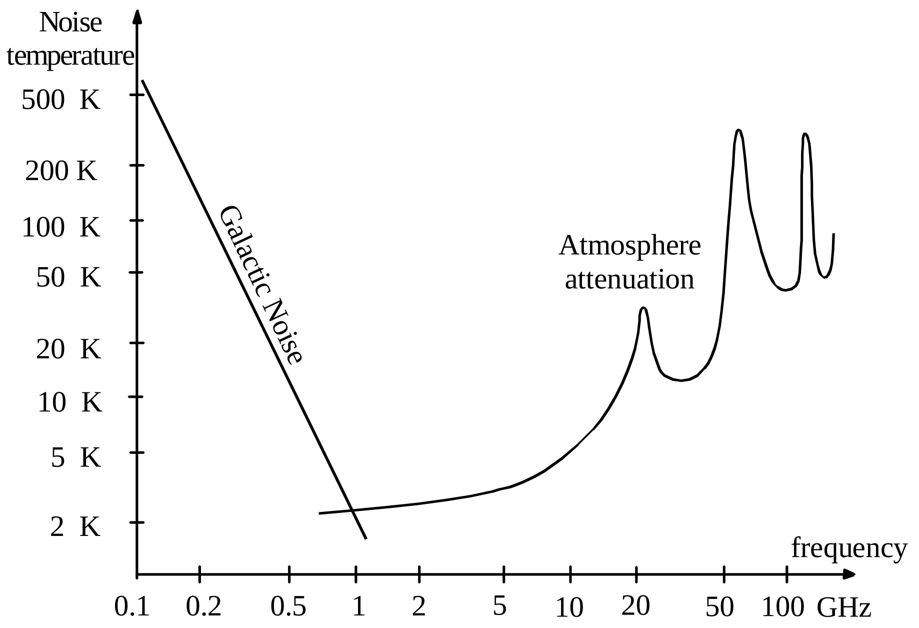


Figure 3 – Noise across the radio transmission region

Electron noise decreases with increased frequency; therefore, the frequency should be increased as much as possible. To avoid that the signal is attenuated too much through the atmosphere, the frequency should be kept below approx. 20 GHz. This region between approx. 1 - 20 GHz is known as microwave.

2 GHz Threshold

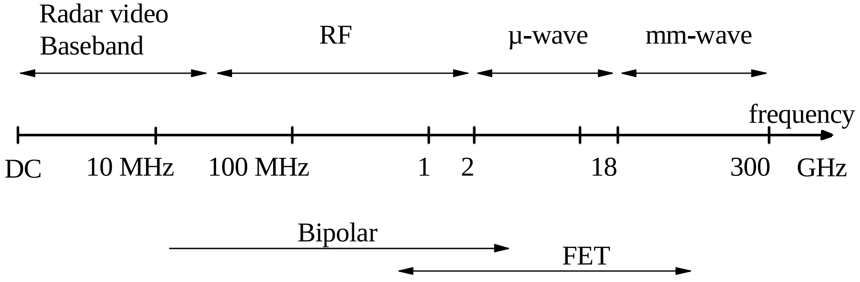


Figure 4 – Frequency spectrum divided according to design principles

One method to divide the frequency spectrum is according to the design principles employed and existing broadband systems. Traditional circuit design with discrete components has worked well up to about 2 GHz; the bandwidth is typically from 10

MHz to 2 GHz. Distributed components are common with the wavelength determining the components function for frequencies higher than 2 GHz. Up to 2 GHz, it is common with the bipolar transistor. Around 2 GHz threshold, the most common FET is the MOSFET in Silicon CMOS (Complementary Metal Oxide Semi-conductor) processes. For frequencies much greater than 2 GHz then the FET transistor uses a gallium-arsenide (GaAs) process.

Video is the detected radar pulse which can go down to DC. The video signal has normally a bandwidth of approx. 1 - 10 MHz. Very short pulses contain higher frequency contents up to 1 GHz. Within communication the detected signal is known as baseband. Audio sound has a small bandwidth; TV/Video has approx. 6 MHz bandwidth. Digital signals have normally a speed up to 140 Mb/s but there are also systems for Gb/s data transfer.

Applications

Radar

Radar measures the time difference between the transmitted and received signal which is a measure of the distance. Normally the RF signal is pulsed to obtain a high power and simple time measurement. The frequency can also be swept (FMCW) to distinguish the transmitted and received signal. This gives a high resolution when measuring the distance. Radar systems use antennas with a high directivity. With high directivity the environment surroundings can be established.

Radar is used to maintain surveillance and track airplanes in the environment. With radar systems, the airplane can be tracked at great distances despite the time of day or weather conditions. Radar is also used to navigate ships between islands and other ships. Height radar has a fixed antenna directed towards the ground. Weather radar keeps surveillance over traitorous weather conditions so these regions can be avoided to give a safer flight conditions. Doppler radar can distinguish between different speeds. Airplanes can then be distinguished from strong ground reflections. Impulse radar (very short pulse) can be used to see objects underneath the ground or via a drilled hole find cracks or air pockets in bedrock.

Radio Link

Radio links are used for data transport of a large number of telephone channels, or transport of radio and TV programs. Data transfer is from ”Point to Point” (P-P) in a long chain, or ”Point to Multi Point” (P-MP) where a central station has simultaneous contact with several radio stations. P-MP is also the term for systems with a link station sending radio and TV programs direct to homes.

Communication within 1 to 3 GHz band is used in several countries for mobile use and to P-MP systems. Long distance links with high capacity normally use the 4 GHz and 6 GHz band (3.4 to 4.2 GHz, 5.925 to 6.425 GHz and 6.430 to 7.11 GHz). This is a good compromise between range distance, capacity, quality, wave propagation and cost.

In cities, there is a need for higher data rates so the bands 15 GHz, 18 GHz and 23 GHz (14.3 - 15.35 GHz, 17.7 – 19.7 GHz & 21.2 – 23.6 GHz) are utilized. Generally, 2 Mb/s data rate is used but 8 Mb/s, 34 Mb/s and 140 Mb/s are available as well. With Synchronous Digital Hierarchy (SDH) the data rate is 155 Mb/s. Future digital systems have a capacity of 622 Mb/s and 2.5 Gb/s.

Satellite TV

Television programs sent from satellite direct to the home.

TVRO Television Receive Only in USA at 3.7 - 4.2 GHz.

DBS Direct Broadcast Satellite in Europe and Japan at 12 GHz band (10.7 – 12.75 GHz). Up-link operates at 12.75 – 13.25 GHz and 14.0 – 14.8 GHz.

HDTV High Definition TV concept is to send from a satellite at 17.3 – 17.8 GHz in America and 21.4 - 22 GHz for other regions in the world.

Wireless Data Networks

Wireless LAN, WLAN. Computer networks can be interconnected with microwaves instead of using cables; this gives a simpler and quicker installation especially for temporary or mobile applications. However, this is not a full replacement for cables since the disadvantages are limited bandwidth (data rates), more disturbances and higher costs.

IEEE 802.11 specifications are primarily for WLAN in the ISM band 2.4 GHz (2.400 - 2483 MHz). It is also possible to use the 5 GHz band (5150 - 5350 MHz and 5470 - 5725 MHz), IEEE 802.11ac standard and 60 GHz (IEEE 802.11ad). Finished products which are tested and compliant are called Wi-Fi. The maximum data rate for 2.4 GHz (IEEE 802.11g) is up to 54 Mb/s and for 60 GHz up to 6.912 Gb/s.

Mobile Telephones

The majority of systems for mobile telephones have started with the frequency band 900 MHz. In order to handle the need of increased telephone channels, higher frequency bandwidths have been introduced to compliment the demand. GSM system is standard within Europe and is the most common system in the world. The exact frequency bands can differ depending on the region.

1G First generation of mobile system based upon analogue non-encrypted techniques with a channel bandwidth up to 30 kHz. The Nordic region used NMT.

2G Second generation of mobile system based upon digital encrypted techniques with a channel bandwidth up to 200 kHz. GSM is the most common standard at the 900 MHz band and CDMA standard is employed in the U.S. at the 800 MHz band. For higher capacity GSM is also applied at the 1800 MHz band. In U.S. it is known as Personal Communication Network (PCN) at the 1900 MHz band

3G Third generation of mobile system designed for mobile broadband data which uses 1920-1980 MHz up-link and 2110-2170 MHz down-link.

4G Fourth generation mobile system uses a very flexible modulation at the air interface and a network that can handle a user data rate of 100Mb/s. It can be used in any frequency band that is intended for mobile communication.

LEO Low Earth Orbit is a satellite system under development which targets the rural areas which are not covered by the existing base stations. This system is a viable option for developing countries which do not have an existing mobile infrastructure.

Mobile telephones operate at 1610 - 1626.5 MHz or 2483.5 - 2500 MHz. Globestar is a system which uses 48 satellites, each with 6 fixed antenna lobes.

Heating and Drying

There are large microwave ovens for industrial use, up to 10 or 100 kW. Small microwave ovens for households are at 300 - 1000 W. The frequency is typically 2.45 GHz.

RFID

RF Identification or commonly known as RF tags. Microwave can be used for identification and automatic transfer of data. A fixed unit can transmit a query request which can be answered by a simpler transponder tag when in the vicinity.

Transponders can be active. SART (Search and Rescue Transponder) is an emergency transmitter for lifeboats which give a clear indication on radar. They can also be passive and very simple. Shoplifting protection devices are normally small patches that contain an antenna and a diode which radiate overtones when they are in the vicinity of the transponders placed at the shop entrance. Same principle is also used in ski equipment to search for skiers after an avalanche.

Transponder can contain a memory for more precise identification and information. Car factories use transponders to inform about the assembly. To simplify logistics for transport storage containers when located in large harbour ports. Railway carriages and locomotives use RFID to keep track of their location. Their location can still be read even when passing at 320 km/hr.

There are systems at very low frequencies (<500 kHz) and at mid-high frequencies (1.7 - 28 MHz). Microwaves mostly use 908 - 920 MHz, 1812 - 1830 MHz and 2.45 GHz. Compared with bar-code readers, RFID works at longer distances and does not need to be visible; data can be read whilst passing, insensitive for dirt, rain and heat.

Car Tolls

RFID is also used in car tolls for use of roads which are chargeable. Payment occurs automatically when passing by without the need to stop. Digital transfer of information occurs with FSK, PSK or ASK. Data speed is in the region of 1 - 3 Mb/s.

Frequency range which is used is 2400 – 2483.5 MHz and 5850 - 5925 MHz. In Europe (CEPT-91) 5795 - 5805 MHz which possibly shall be expanded to 5815 MHz.

GPS

Global Positioning System (GPS) is a system for navigation which is based around 24 satellites. Each satellite sends a coded signal at 1575.42 MHz. The satellite contains an atom clock which deviates maximum a second every 300 000 years. The transmitted signal is therefore well defined with respect to time. A receiver measures the time when the transmitted signal is received and a calculation can be made to determine the distance to the satellite. By measuring the distance to three satellites, the position including height can be determined. By using a fourth satellite, the error can be compensated for in the receiver since this is only based on a quartz oscillator.

The civilian available code (SPS) has an accuracy of approx. 100 m. Differential GPS contains a fixed receiver of a known position which sends out correction data to the nearby GPS users which improves the SPS accuracy so that a few meters can be achieved. SPS broadcasts at a single frequency and the military version (PPS) uses two frequencies. The accuracy of both the civilian system and military system are similar but the security and susceptibility to interference is greater for the military system.

Navigation for Cars

Navigation equipment determines your locational position and indicates how to navigate to arrive at a specific destination. The system can contain a calculation of movement with help of the wheel revolutions, together with a gyro compass (dead reckoning). The accuracy is 2 % of the distance travelled. To determine the position, then the map has to be matched to the position. i.e. only a probable position is indicated. The most common systems today use GPS navigator with stored digital maps.

Traffic, local maps and the "yellow pages" (restaurants, shops, companies, etc.) can be transmitted by FM radio to get wide coverage or with the nearest base station for mobile phone for better adaptation locally. It is also likely to use local radio beacons in the mm-wave band for correcting the position and transmission of information.

Police Radar

Police radar is used to measure the vehicle speed. It uses the Doppler displacement when something moves. The wavelength is compressed when the car approaches and stretched out when leaving. Doppler frequency is a measure of the velocity. Many systems have used a signal at X-band, such as 9.41 or 10.525 GHz. Newer systems use e.g. 34.3 or 24.15 GHz.

Fixed Wireless Access

Fixed Wireless Access (FWA) is a system which sends to several receivers simultaneously. It is similar to satellite TV but with the transmitter station on the ground. The main function is based upon a 2-way system which can be utilized for internet and interactive TV. Up-link is at 3410 - 3494 MHz and down-link at 3510 - 3594 MHz. Systems for FWA is using specifications such as WiMAX.

Motion Detector

The motion detector utilizes Doppler shift during movement. Doppler modules are used for automatic door openers, elevator control, intrusion alarm, traffic light and measurement of vibration on large machines.

Material Measurement

A materials dielectric value, dimension or displacement can be calculated by measuring the relative change in frequency, phase or amplitude. Measurement takes place without contact at a distance. Unfortunately, the measurement result is affected by several variables, such as temperature, density and moisture. Therefore measurements must use several parameters, such as resonance frequency and Q-value or phase and amplitude, or several frequencies, or a combination with other measurement techniques.

The resonance is measured (i.e. frequency and Q-value) so that the dielectric value (ε_r) can be determined. By measuring the dielectric value in a blended composition, the proportions of the composition can be determined. The dielectric value for a material is humidity dependent; therefore the humidity in a material can be measured and controlled. This is critical for materials where the price is based on weight such as paper, wood, soap and food.

Phase measurement can be used to read a very small movement. A metal sheet (1-10 mm) can be measured with an accuracy of ± 0.03 mm. The measurement time is only 20 ms. The measurement can therefore be used to automatically maintain the correct thickness during manufacture.

FMCW (Frequency Modulated Continuous Wave) radar can be used to measure the level of a tanker, with a precision of a few mm.

Some systems measure the phase and amplitude between the two antennas used in a transmission system. Alternatively, the amplitude and phase of the reflection from only one antenna can be measured. A typical sensor is a coaxial wire which is held against the object.

ISM-bands

ISM: Industrial, Scientific, Medical. Frequency bands which can be used without a license providing that the regulations are followed. When using spread spectrum techniques, a maximum of 1W can be transmitted.

The most common ISM bands are 433-435 MHz, 862-869 MHz, 902-928 MHz, 2400-2484 MHz, 5250-5350 MHz, 5725-5850 MHz and 24-24.25 GHz.