Sensors and Signals

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Chapter 1.

Introduction

1.1. Sensors and Transducers

Sensors in the natural world include those which equip us with our five senses – sight, hearing, smell, taste and touch. These convert the various and diverse inputs to electrochemical signals that can be used to inform or control the living organism.

In a similar way, in man-made devices, sensors are also used to measure various stimuli. However, because of the broad range of potential inputs and outputs, the accepted definition of a sensor is refined. In this definition, all devices that convert input energy into output energy are referred to as *transducers*, and sensors form a small subset of the group as defined below:

"A sensor is a transducer that receives a input signal or stimulus and responds with an electrical signal bearing a known relationship to the input " [2]

Many measuring and sensing devices, as well as loudspeakers, thermocouples, microphones, and phonograph pickups, may be termed transducers.

Systems of sensors and transducers are constructed for a variety of applications including surveillance, imaging, mapping and target tracking. In some cases, the sensors provide their own source of *illumination* and are referred to as active sensors. Passive sensors, on the other hand, do not provide illumination and depend on variations of natural conditions for detection.

1.1.1. Active Sensors

Active sensors require the application of external power for their operation. This *excitation signal* is modified by the sensor to produce an output signal. They are restricted to frequencies that can be generated and radiated fairly easily. This excludes part of the far infrared (above 3×10^{12}Hz), parts of the ultraviolet band and the gamma ray region. However, inroads are being made into these regions with the development of Terahertz sources and detectors based on artificial photonic crystals.

Semi-active sensors use a man-made excitation signal generated by (or radiated from) a source that is not coincident with the sensor. Such systems include multistatic radar that uses mobile phone or commercial broadcasts as the source and are proving to be particularly effective in detecting stealth aircraft.

1.1.2. Passive Sensors

Passive sensors directly generate an electric signal in response to a stimulus. That is, the input stimulus is converted by the sensor into output energy without the need for an additional source of power to illuminate the environment. The salient characteristics of most passive sensors are as follows:

- Do not emit radiation (or an excitation signal) as part of the measurement process.
- Rely on a locally generated or natural source of radiation (light from the sun), an available energy field (gravity) or even a chemical gradient
- Passive sensors can exploit EM radiation of any frequency in which some natural phenomenon radiates and for which a detection mechanism exists. This can extend from ELF (below 3×10^3Hz) up to gamma rays (above 3×10^{19}Hz).
- They can exploit acoustic energy (vibration) from infrasound frequencies <1Hz from earthquakes or explosions up to the ultrasound

Table 1.1:Advantages of active and passive sensors

PASSIVE	ACTIVE
Low power requirement (long life)	Measurement requirements matched to transmitter characteristics
Cannot be detected (covert)	Range measurement by temporal correlation
Simple principles (sometimes)	Radiation pattern constrains observation
Good reliability due to simplicity	High range and angle resolutions possible
Field of view constrains observation	Long range operation possible
High angular resolution possible	
Large variety	

Table 1.2: Disadvantages of active and passive sensors

PASSIVE	ACTIVE
Targets of interest must radiate or modify the field (electrical, gravity)	Large power requirement
Prone to feature ambiguity and errors of scale (eg angle only)	Easy to detect (not covert)
Typically short range, though not always (astronomy etc)	Complex Rx and Tx processes
Availability not guaranteed (no light, contrast etc)	Reliability determined by two elements, Rx and Tx

1.1.3. Sensor Systems

Sensors do not operate in isolation, they are always part of a larger system which may include other transducers, signal processing networks and often some from of actuation or data recording capability. An autonomous vacuum cleaner is a good example of a typical system.

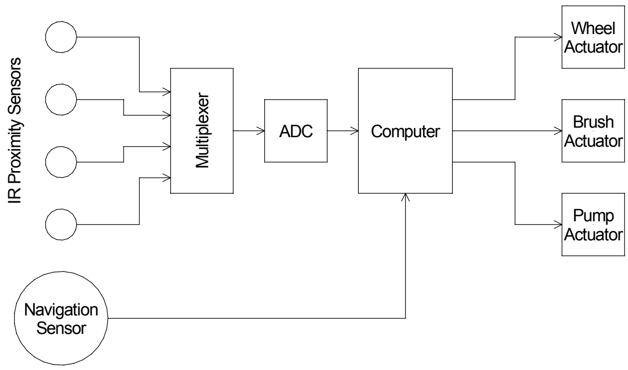

Figure 1.1: Sensors and actuators in an autonomous vacuum cleaner. The IR proximity sensors are active, while the navigation sensor is passive and relies on the earth's magnetic and gravity fields

1.2. Frequency Band Allocations for the Electromagnetic Spectrum

Sensors can be made to operate over a very broad band of frequencies for both electromagnetic (EM) and acoustic applications.

In theory, though the EM spectrum extends below one Hz, in practise, radiation, detection and data-rate limitations at such low frequencies is impractical. An existing extra low frequency (ELF) application is the communication with submerged submarines at about 80Hz (a wavelength of 3750km).

At the other extreme, Positron Emission Tomography (PET) scanners generate and detect gamma rays with an energy of 511keV, equivalent to a frequency of 1.23×10^{20} Hz or a wavelength of only 2.43×10^{-12} m.

As a matter of convenience, the EM spectrum is broken up into overlapping bands.

- Gamma rays
- X-rays
- UV
- Visible
- Infra red
- Microwave
- Radio

Many of these general bands are further subdivided to convey more information, as with near and far infrared, or from an historical motive as with the radar band designations.

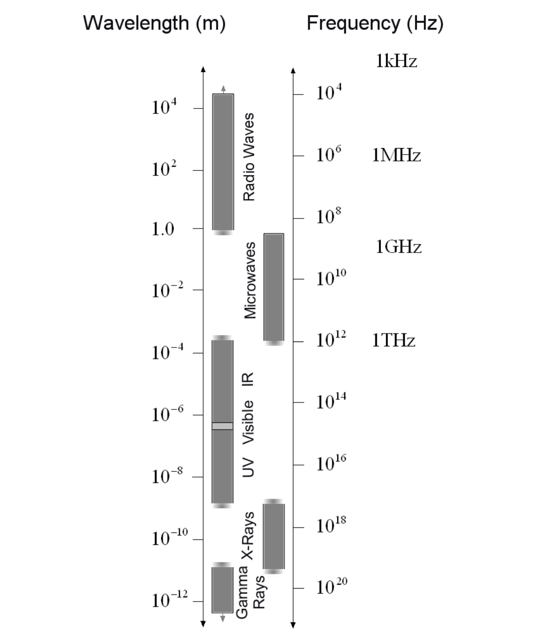

Figure 1.2: The Electromagnetic Spectrum

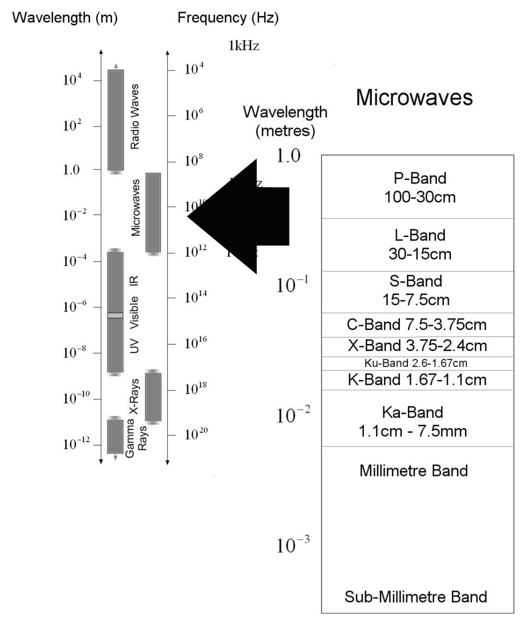

Figure 1.3: The Microwave Band

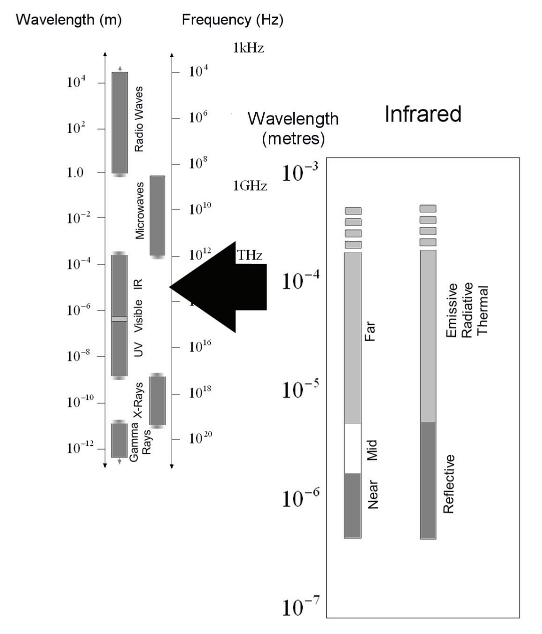

Figure 1.4: The Infrared Band

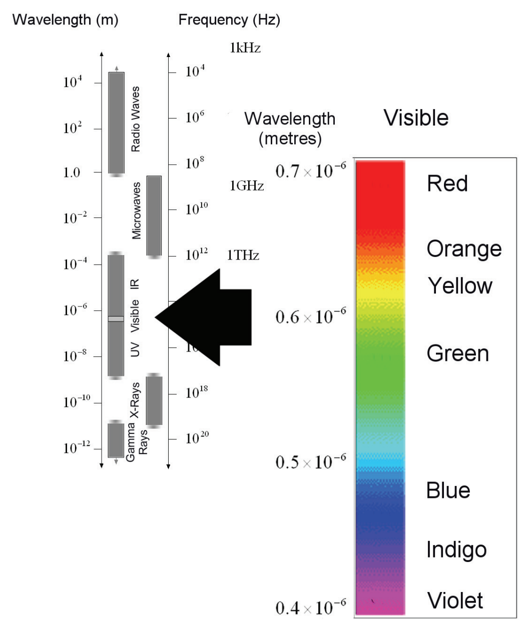

Figure 1.5: The Visible Band

The subdivision of the frequency allocations in the microwave band can be confusing as there are various different standards in use. In this book, the United States Microwave and radar nomenclature is used.

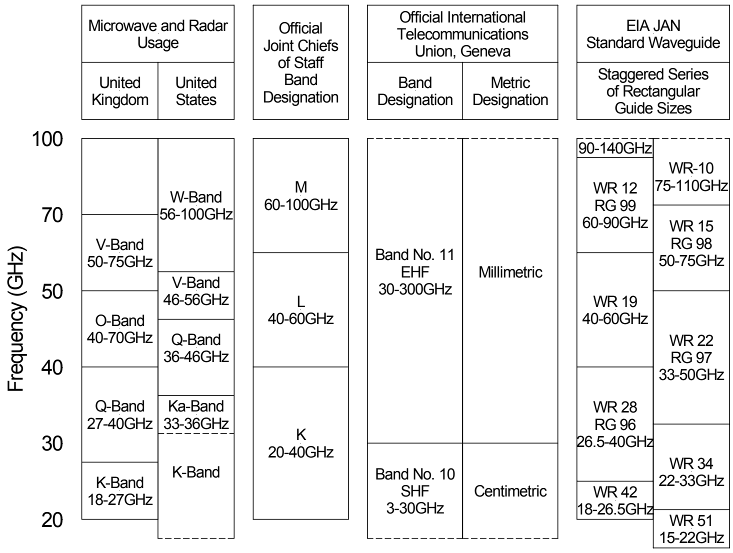

Figure 1.6: Nomenclature for Electromagnetic Spectrum Designation [3]

Useful EM radiation spans 16 orders of magnitude, from the ELF band below 3×10^3Hz up to Gamma Rays above 3×10^{19}Hz.

Table 1.3: Frequency bands and typical applications for electromagnetic systems

Band	Frequency	Wavelength	Applications
VHF	30-300MHz	1m-10m	Over the Horizon
UHF	300-1000MHz	30-100cm	Ground penetrating
L	1-2GHz	15-30cm	Ground Surveillance, Astronomy
S	2-4GHz	7.5-15cm	Ground Surveillance
C	4-8GHz	3.75-7.5cm	Space SAR
X	8-12.5GHz	2.4-3.75cm	Fire Control , Proximity, Airborne/Space SAR
Ku	12.5-18GHz	16.7-24mm	Collision Avoidance, Speed Traps
K	18-26.5GHz	11.3-16.7mm	Fire Control Radar
Ka	26.5-40GHz	7.5-11.3mm	FCR, Surveillance
Millimetre	30-300GHz	1-10mm	Imaging & astronomy, Collision Avoidance
Sub-mm		50μm-1mm	Astronomy
Far infrared		14-50μm	Properties of molecules
Longwave IR		8-14μm	Laser radar, Forward looking IR
Near IR		1-3μm	Personnel Detection
Very near IR		0.76-1	Imaging, Laser ranging (industrial)
Visible		380-760nm	Imaging, Astronomy
UV		100-380nm	Missile plume detection, Gas fire detection

1.3. Frequency Band Allocations for the Acoustic Spectrum

Useful acoustic signals span eight orders of magnitude from the lower infrasound at below 1Hz for earthquake and structural vibration measurements up to extreme ultrasound at about 1GHz for microscopy.

Table 1.4: Frequency bands and typical applications for acoustic systems

Designation	Frequency Range	Applications
Infrasound	Below 50Hz	Weather monitoring, earthquakes, nuclear explosion detection
Audio	50Hz to 20kHz	Audio communications, acoustic modem, range measurement, hydro-acoustic positioning, seismic prospecting
Ultrasound	20kHz to 200kHz 200kHz to 500kHz ≈1GHz	Range measurement, Imaging Underwater Sonar Microscopy

1.4. References

[1] Joseph J. Carr, *Electronic Circuit Guidebook: Sensors,* Prompt, 1997

[2] Jacob Fraden, *Handbook of Modern Sensors 2nd ed.,* Air Press, 1996

[3] *Jane's Radar and Electronic Warfare Systems, 1995-1996*