FDM and Spectrum

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FDM Example

- The FM radio in the US is assigned a frequency band 88.0 MHz to 108.0 MHz. The band is divided into 100 channels, each 200 kHz (200 kHz) wide.

Call Sign	Freq.	Dist./Signal	City
KJTY	88.1 FM	11.9 mi.	Topeka, KS
KINW	88.5 FM	41.9 mi.	Kansas City, MO
KGLV	88.9 FM	42.8 mi.	Manhattan, KS
KCUR	89.3 FM	42.3 mi.	Kansas City, MO
KKFI	90.1 FM	42.4 mi.	Kansas City, MO
KBUZ	90.3 FM	42.9 mi.	Topeka, KS
KJHK	90.7 FM	1.0 mi.	Lawrence, KS
KCIU (LPFM)	91.1 FM	1.3 mi.	Lawrence, KS
KANU	91.5 FM	1.0 mi.	Lawrence, KS
KCCV	92.3 FM	22.0 mi.	Olathe, KS
KMXN	92.9 FM	22.1 mi.	Osage City, KS
KMXV	93.3 FM	40.3 mi.	Kansas City, MO

From: Radio Locator

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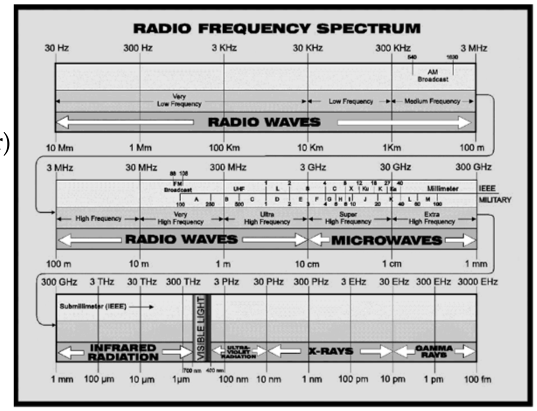
Links: physical media

Wireless signal carried in electromagnetic spectrum

- no physical "wire"
- broadcast and "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- terrestrial microwave
- Wireless LAN (WiFi)
- wide-area (e.g., cellular)
- satellite



Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

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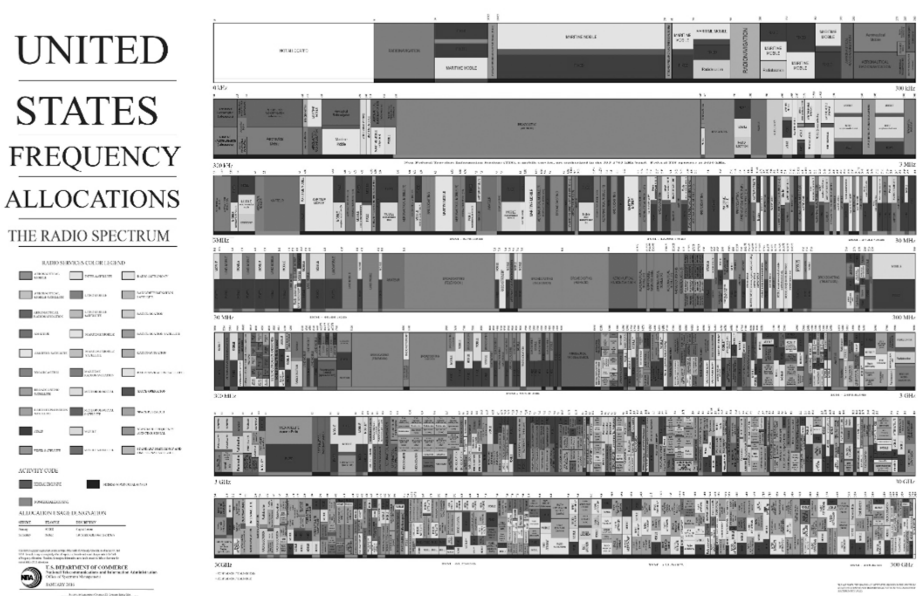

See: http://www.ittc.ku.edu/~frost/EECS_562/us-frequency-allocations.jpg

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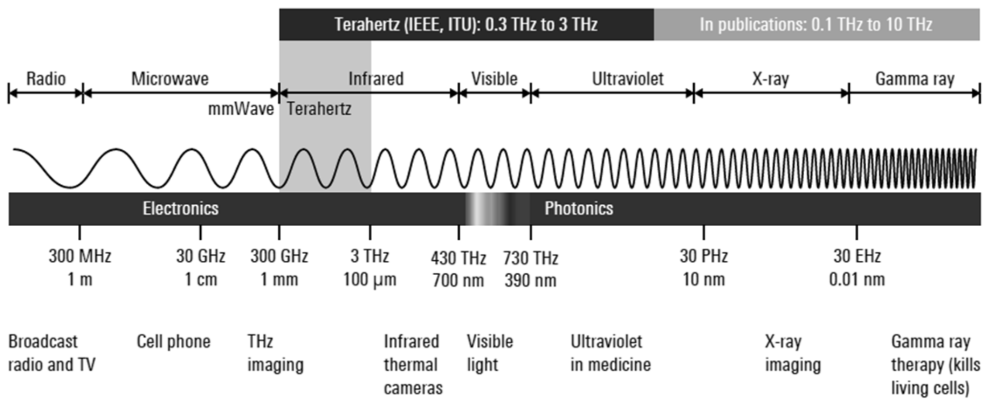
Figure 6: The electromagnetic spectrum and applications with the terahertz spectrum on the borderline between electronics and photonics



From FUNDAMENTALS OF THz TECHNOLOGY FOR 6G,
White Paper, Version 01.02, Dr. Taro Eichler, Robert Ziegler, Rohde & Schwarz

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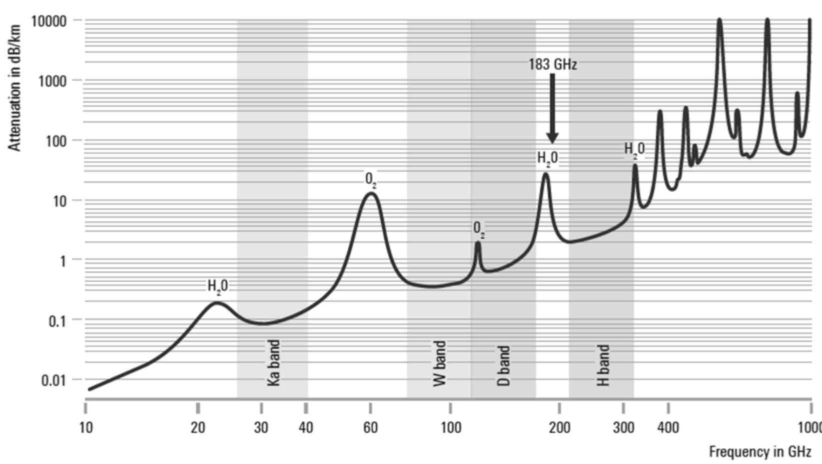
Figure 7: Specific atmospheric attenuation within the millimeterwave and THz spectrum

At air pressure of 1013 hPa, temperature of +15 °C and water vapor density of 7.5 g/m³. The rotational excitations of different molecules present in the atmosphere (i.e. water, oxygen) are reflected in the absorption spectra.



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Wireless Channels

- Usable transmission bandwidth for a wireless communication system is limited by
  - Carrier frequency f_c (Hz) (wavelength $\lambda=c/f_c$ were c speed of propagation in free space)
  - The available frequency spectrum; the allocated bandwidth
  - Physical characteristics of the transmission medium
  - As the carrier frequency increases, the usable transmission bandwidth also increase, but
    - Typically, the usable transmission bandwidth is on the order of 10% (= f_c /10) of the carrier frequency.
    - Increased propagation loss at higher frequencies
    - Signal penetration through obstacles, e.g., walls, is limited at higher frequencies

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Wireless Channels

- Carrier frequencies in the range of 700 MHz to 900 MHz are better suited for providing wider coverage and better penetration through buildings and other obstacles, higher value spectrum.
- Higher frequency bands such as 2.5 GHz and bands in the millimeter-wave (mmWave) range (24 GHz and above) offer increased usable bandwidth.
- mmWave technology allows for increased usable bandwidth and thus higher data transfer rates compared to legacy networks, making it suitable for high-bandwidth applications such as video streaming and virtual reality. Millimeter-wave (mmWave) technology is an important component of wireless system deployments for 5G and beyond.

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Wireless Channels

- Millimeter-wave (mmWave) carrier frequencies are in the range of 24 GHz to 300 GHz. The mmWave spectrum lies between microwave and infrared frequencies. The mmWave wavelengths range from about 1 mm to 12.5 mm.
- Attributes of mmWave technology include but are not limited to:
  - Atmospheric effects: mmWave transmissions are attenuated by rain and fog.
  - Shadowing: Shadowing is a term used in wireless communication to describe the attenuation of a signal due to obstacles and other physical obstructions in the signal's path. In mmWave transmissions, shadowing can have a significant impact on the signal strength and quality, as the shorter wavelength of mmWave signals makes them more susceptible to blockage and attenuation.
  - Antenna Size: The shorter wavelength used for mmWave transmissions results in physically smaller antennas.

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Wireless Channels

- Continued-Attributes of mmWave technology include but are not limited to:
  - Greater network capacity: mmWave system can support more devices and higher data traffic due to their wider bandwidth and higher frequency range, making them well suited for densely populated areas such as stadiums, convention centers, and airports.
  - Reduced adjacent channel interference: mmWave networks operate in a higher frequency range than legacy networks, which reduces interference from other devices and networks.
  - Enhanced security: When mmWave systems use beamforming and other advanced techniques to transmit signals in tightly constrained physical directions, the risk of unauthorized access is reduced.

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