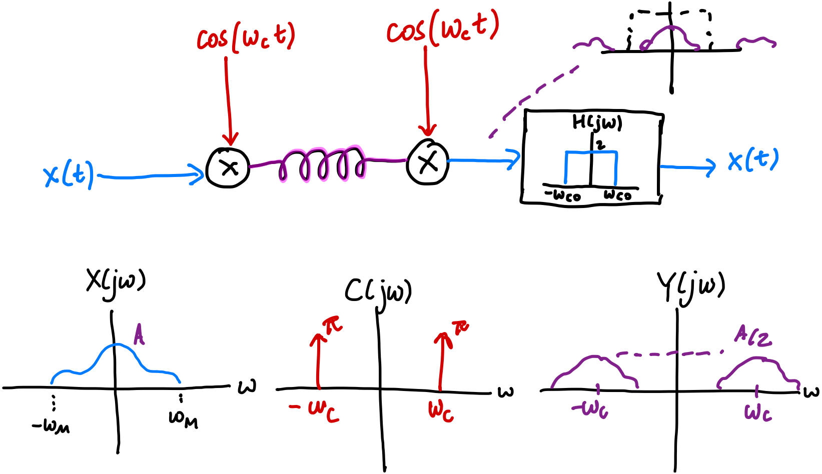
ELEC 221 Lecture 20
Modulation and communication systems

Thursday 21 November 2024

Announcements

- Assignment 4 due ~~Saturday~~ Sunday 23:59
- Tutorial assignment 4 due Monday 23:59
- Monday tutorial assignment 5: prepare five 1-2s audio samples
- No office hours tomorrow; Tuesday class on Zoom
- Quiz 9 on Tuesday

We did sinusoidal amplitude modulation with a real carrier signal:



We distinguished between synchronous and asynchronous modulation.

Today

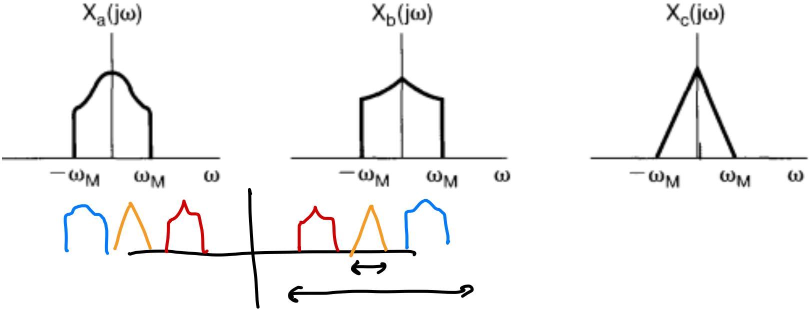
Partially an “infotainment” lecture.

Learning outcomes:

- describe frequency- and time-division multiplexing
- perform single-sideband modulation
- explain (at a high level!) how cell phone communication works

Frequency-division multiplexing (FDM)

Suppose we have more than one signal we wish to transmit:



Modulation can help us send them at the same time!

Image credit: Oppenheim 8.3

Frequency-division multiplexing (FDM)

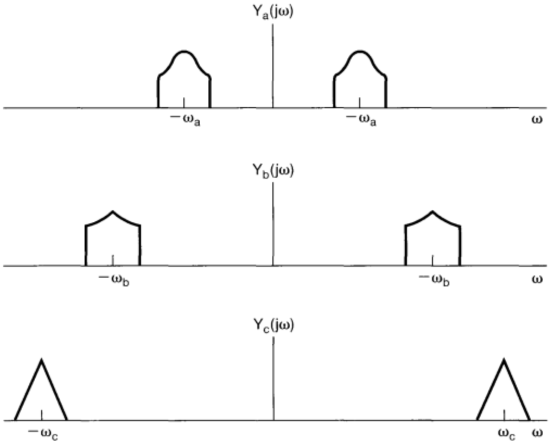
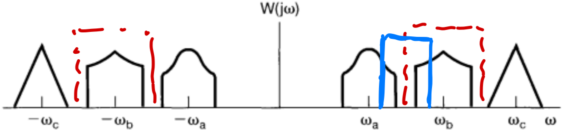


Image credit: Oppenheim 8.3

This is called *frequency-division multiplexing*.



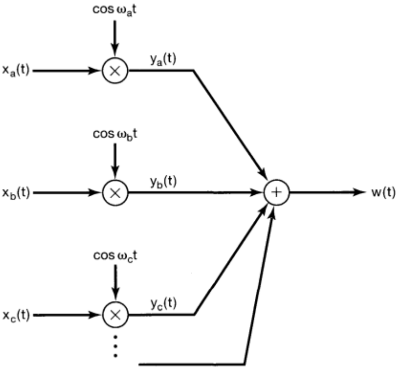


Image credit: Oppenheim 8.3

How to separate out the channels?

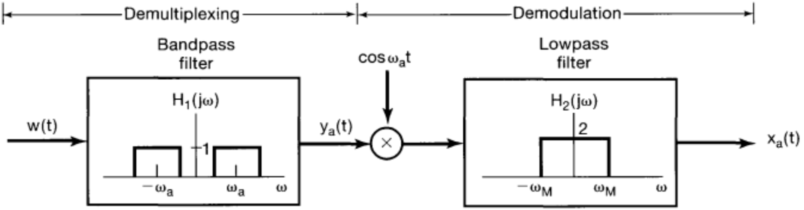
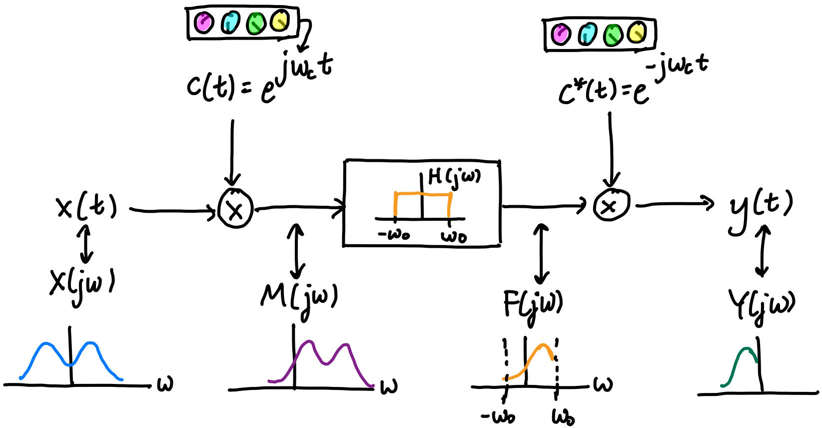


Image credit: Oppenheim 8.3

Example: frequency-selective filtering with variable centre frequency



"Superheterodyne receiver" (Tutorial assignment 5!)

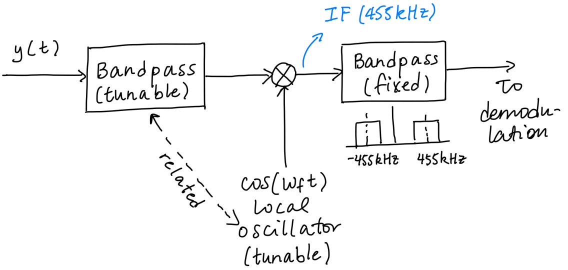
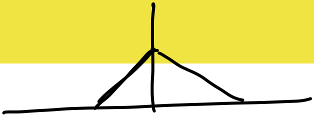
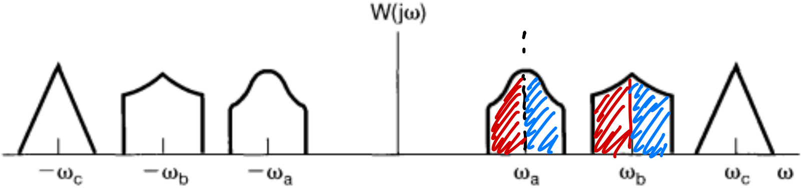


Image: `https://www.euronics.ee/UserFiles/Products/Images/162391-panasonic-rf-2400d-radio.png`

Single-sideband modulation (SSB)



This is inefficient...



We are using twice as much bandwidth as we need to!

Image credit: Oppenheim 8.3

Single-sideband modulation (SSB)

A modulated signal's spectrum can be divided into upper/lower *sidebands*:

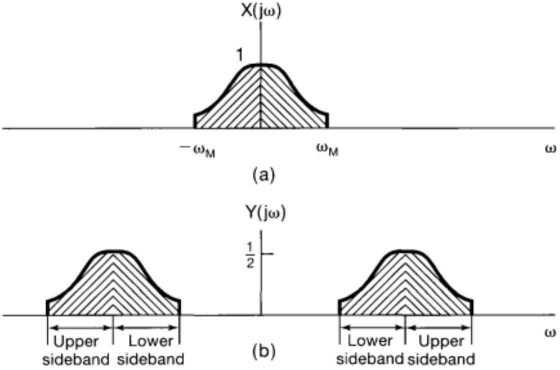
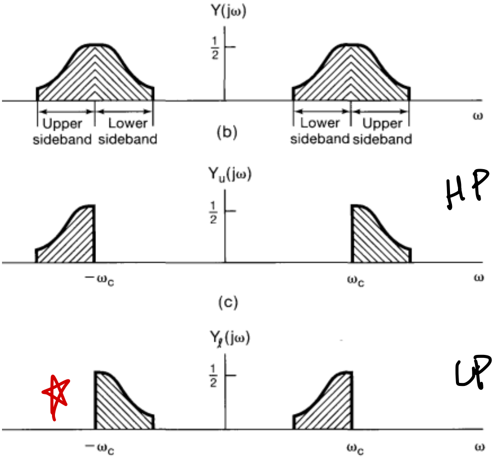


Image credit: Oppenheim 8.4

Single-sideband modulation (SSB)

In single-sideband modulation, keep and transmit only one band:



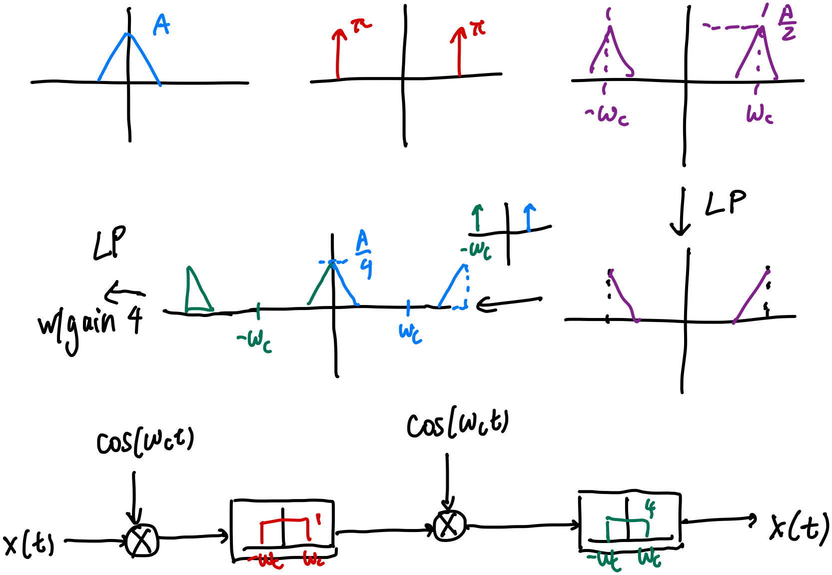
HP filter

LP filter

How do you think this is done? How to demodulate?

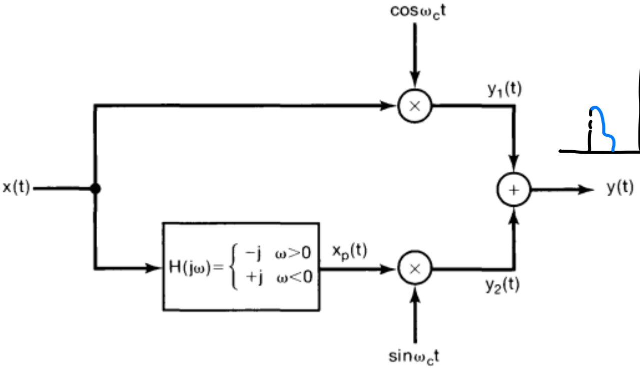
Image credit: Oppenheim 8.4

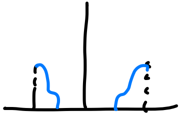
Single-sideband modulation (SSB)



Single-sideband modulation (SSB)

Alternative: "90* phase-shift network"

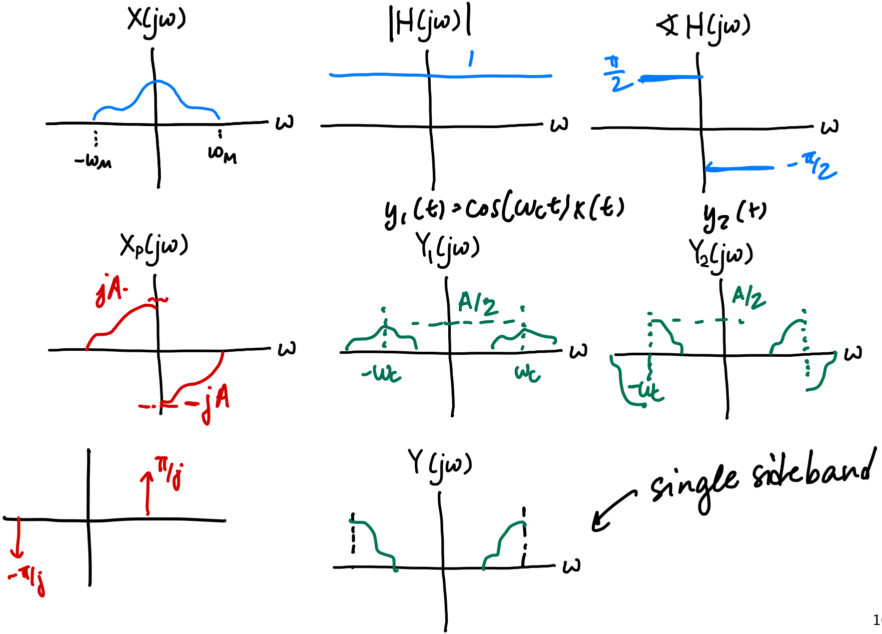




Exercise: see how this works by analyzing what happens to the spectra of $x_p(t)$, $y_1(t)$, $y_2(t)$, and $y(t)$ in the frequency domain.

Image credit: Oppenheim 8.4

Single-sideband modulation (SSB)



AM with pulse-train carrier

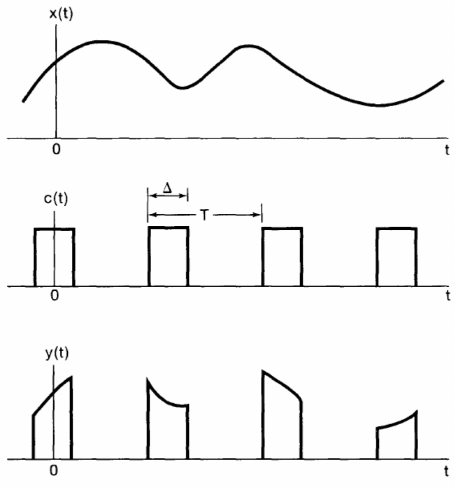
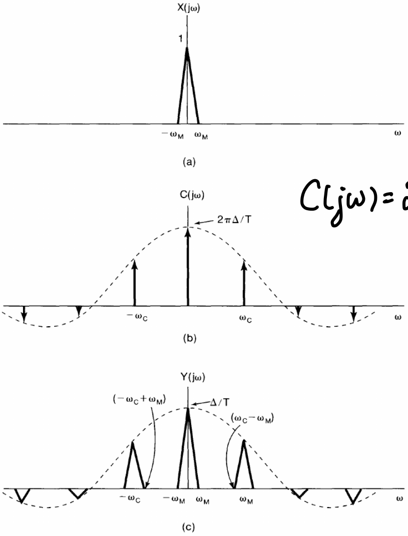


Figure 8.23 Amplitude modulation of a pulse train.

Image credit: Oppenheim 8.5

AM with pulse-train carrier



$$C(j\omega) = 2\pi \sum_{k=-\infty}^{\infty} a_k \delta(\omega - k\omega_c)$$

$$a_k = \frac{\sin\left(k\omega_c \frac{\Delta}{2}\right)}{\pi k}$$

Image credit: Oppenheim 8.4

Time-division multiplexing

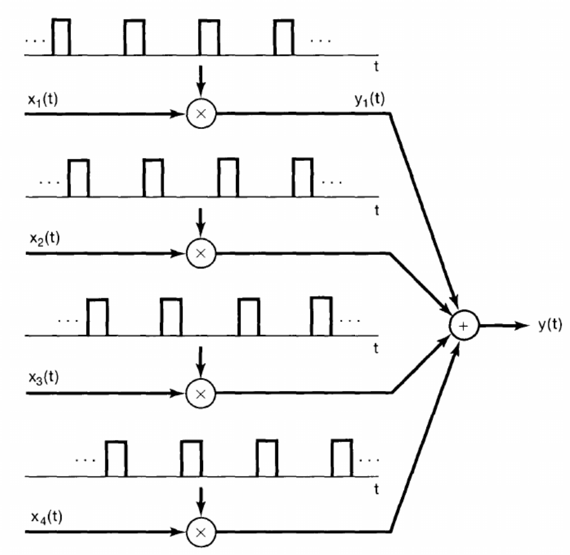


Image credit: Oppenheim 8.5

Pulse-amplitude modulation (PAM)

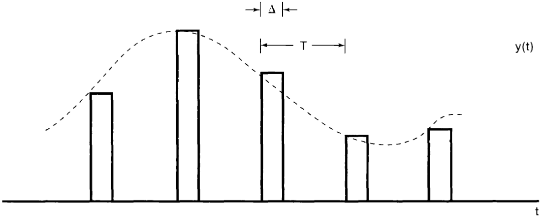
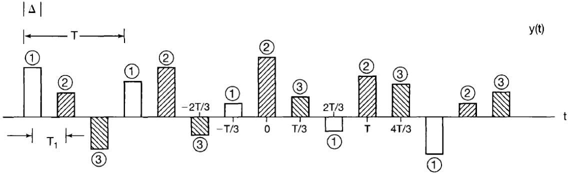


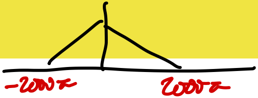
Figure 8.26 Transmitted waveform for a single PAM channel. The dotted curve represents the signal $x(t)$.



Discretized version (pulse code modulation) widely used for digital data transmission.

Image credit: Oppenheim 8.6

Example: TDM



8.12. Consider a set of 10 signals $x_i(t)$, $i = 1, 2, 3, \ldots, 10$. Assume that each $x_i(t)$ has Fourier transform such that $X_i(j\omega) = 0$ for $|\omega| \geq 2{,}000\pi$. All 10 signals are to be time-division multiplexed after each is multiplied by a carrier $c(t)$ shown in Figure P8.12. If the period T of $c(t)$ is chosen to have the maximum allowable value, what is the largest value of Δ such that all 10 signals can be time-division multiplexed?

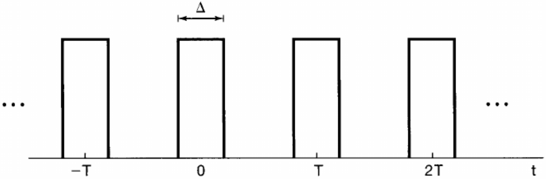
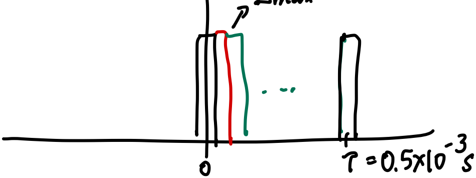


Figure P8.12

$\omega_s > 4000\pi$

$\Rightarrow T_s \leq \frac{2\pi}{4000\pi} = 0.5 \times 10^{-3}\,s$

$\Delta_{max} = 0.5 \times 10^{-4}\,s$



☆ FM is not part of course learning outcomes; just showing for exposure and for interest.

Model frequency modulation as

$$y(t) = A\cos(\theta(t))$$

where $\theta(t)$ depends on a modulating signal $x(t)$.

Phase modulation:

depend on $x(t)$

$$y(t) = A\cos(\omega_c t + \theta_c(t))$$

Frequency modulation.

$$\frac{d\theta(t)}{dt} = \omega_c + k_f x(t)$$

Phase modulation with $x(t)$ is equivalent to frequency modulation with $dx(t)/dt$:

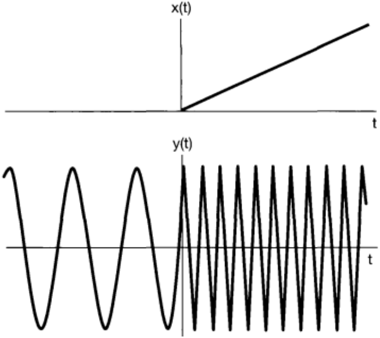


Image credit: Oppenheim 8.7

Frequency modulation with a square wave

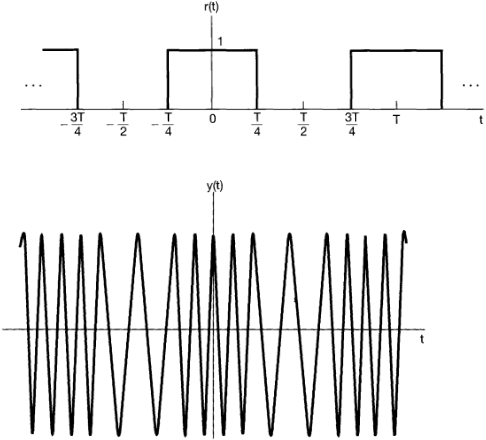


Image credit: Oppenheim 8.7

Frequency modulation with a square wave

$r(t)$

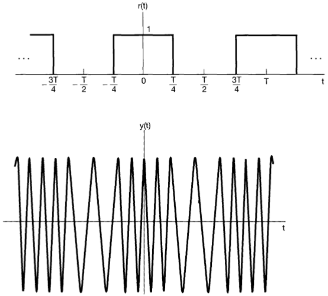


Image credit: Oppenheim 8.7

Suppose the square wave changes the frequency between $\omega_c + \Delta\omega$ and $\omega_c - \Delta\omega$.

We can write

$$y(t) = r(t)\cos((\omega_c + \Delta\omega)t) + r\left(t - \frac{T}{2}\right)\cos((\omega_c - \Delta\omega)t)$$

$$= y_1(t) + y_2(t)$$

What are we doing to these signals?

This is two AM signals!

Their combined spectrum is the sum of the individual spectra:

$$Y_1(j\omega) = \frac{1}{2}\left[R(j(\omega + (\omega_c + \Delta\omega))) + R(j(\omega - (\omega_c + \Delta\omega)))\right]$$

$$Y_2(j\omega) = \frac{1}{2}\left[R_T(j(\omega + (\omega_c - \Delta\omega))) + R_T(j(\omega - (\omega_c - \Delta\omega)))\right]$$

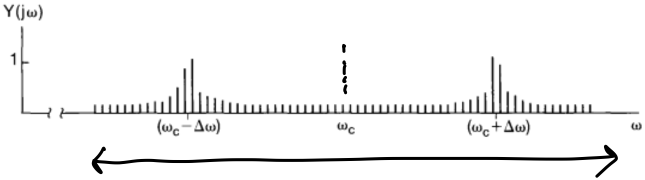


Image credit: Oppenheim 8.7

Main takeaways:

- FM is more complicated to analyze than AM
- FM radio uses more bandwidth than AM radio

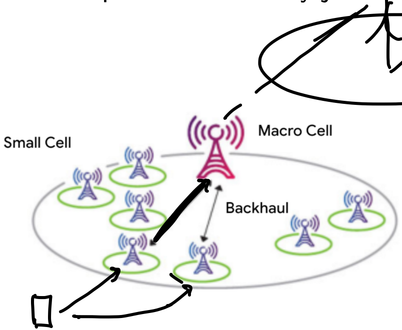
FM radio is allocated the frequencies between 88-108 MHz.

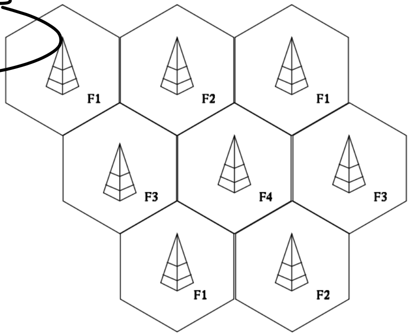
Channels are allocated 200kHz each; the station frequency is the centre of this band (all FM stations end in odd decimals!).

e.g., 89.1 FM is range 89.0 – 89.2 MHz

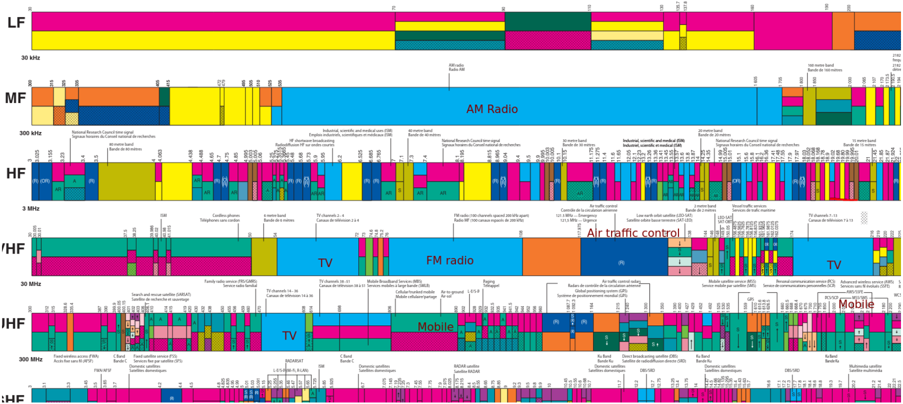
Image credit: `https://www.mcintoshlabs.com/products/tuners/MR87`

A cell phone is basically just a really fancy radio.





Infotainment: cell phone communication systems



See the full graphic here:

`https://ised-isde.canada.ca/site/spectrum-management-telecommunications/sites/default/files/attachments/2022/2018_Canadian_Radio_Spectrum_Chart.PDF`

Infotainment: cell phone communication systems

3500 MHz band spectrum auction

From: Innovation, Science and Economic Development Canada

Backgrounder

3500 MHz band

The Government of Canada is committed to ensuring that Canadians have access to high-quality wireless services and benefit from ubiquitous coverage and affordable prices. In a globalized world, the deployment of 5th generation—or "5G"—telecommunications standards and technologies is essential to Canada's economic competitiveness. The deployment of 5G will also help ensure that Canadians continue to benefit from world-class wireless infrastructure.

In June 2018, Innovation, Science and Economic Development Canada (ISED) released *Spectrum Outlook 2018 to 2022*, which included plans to release spectrum that would support 5G services. The Outlook indicated that releasing the 3450–3650 MHz band (referred to as the 3500 MHz band), a key band for 5G, was a high priority. In June 2019, ISED published the *Decision on Revisions to the 3500 MHz Band to Accommodate Flexible Use and Preliminary Decisions on Changes to the 3800 MHz Band* as the first step toward making this band available.

Through the release of the *Policy and Licensing Framework for Spectrum in the 3500 MHz Band*, ISED is setting the rules for the upcoming spectrum auction, the next step toward making this band available for 5G services.

Spectrum to be auctioned

ISED is making 200 MHz of spectrum available in the 3500 MHz band for "flexible use" licensing that allows licensees to choose the type of services they will deploy, such as mobile (5G) or fixed wireless services (e.g. Internet-to-the-home). Through the transition process, existing licensees are eligible

Image credit: https://www.canada.ca/en/innovation-science-economic-development/news/2020/03/3500-mhz-band-spectrum-auction.html

Different "generations" of service use different bands.

Higher frequencies enable transmission of more information (more available bandwidth), at the cost of working better for shorter distances.

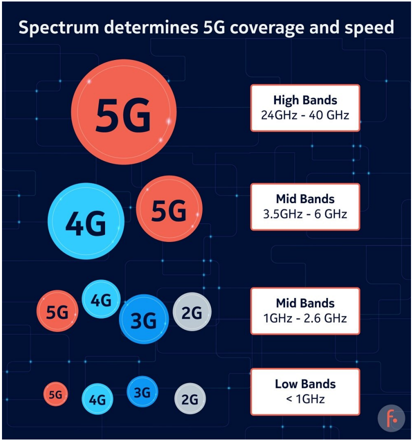


Image credit: `https://www.nokia.com/networks/insights/spectrum-bands-5g-world/`

Learn more:

https://en.wikipedia.org/wiki/Cellular_network

https://www.myamplifiers.com/articles/
lte-frequency-bands-of-us-and-canada-carriers/

https://en.wikipedia.org/wiki/LTE_frequency_bands

https://www.nokia.com/networks/insights/spectrum-bands-5g-world/

For next time

Content:

- the Laplace transform

Action items:

1. Assignment 4 due Saturday 23:59
2. Tutorial assignment 4 due Monday 23:59
3. Tutorial assignment 5 on Monday
4. Quiz 9 on Tuesday (class on Zoom)

Recommended reading:

- From this class: Oppenheim 8.5-8.6
- Suggested problems: 8.7-8.10, 8.28-8.30, 8.40
- For next class: Oppenheim 9.0-9.4