Communications Basics
Lecture 1

Modulation

Orga

Textbook:

Rodger E. Ziemer & William H. Tranter, Principles of Communications **… READ!**

Our content comes from chps. 2-7 (according to edition 5)

Chp. 2 (Signals & Systems – separate course) … **polish your Fourier transforms**

Chp. 3 (Modulation + Demodulation)

Chp. 4 (Probability – separate course) … roll a couple of dice ☺ **… we'll bascially need Random variables, (multivariate) Gaussians, expected values, variances, covariances**

Chp. 5 (Random Processes & Noise)

Chp. 6 (Noise in Modulation Systems)

Chp. 7 (Binary Data Transmission)

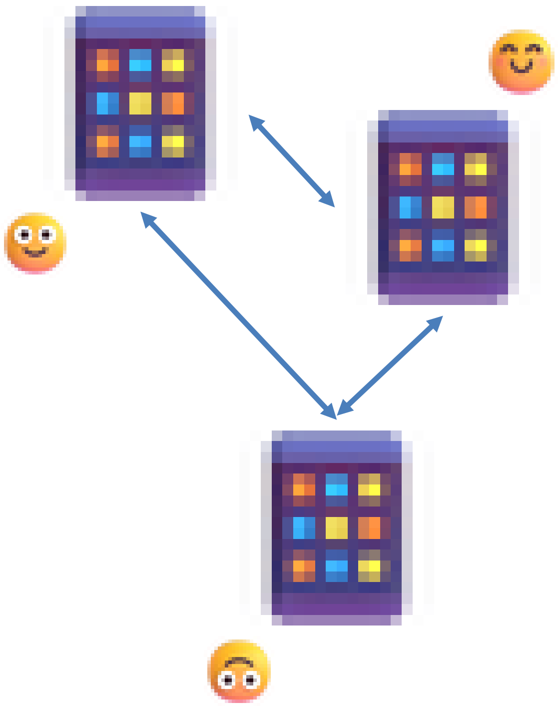
Main platform: campusnet … course page !!!

Teaching in person … slides will be on campusnet … but make sure to take your own notes!

TA: Yasmine Ammouze … tutorials

Exam: Written, no cheat sheets (expected end of January), 2 hours, details as announced by the registrar (should show in campusnet)

Communications … discuss



Why all this communication (cell phones etc.)?

How to enable all that?

What are the challenges?

- Distance
- Multi-user
- Noise
- Dispersion
- Distortions (e.g. reflections, non-linearities …)
- Privacy

How to adress them?

Lecture 1

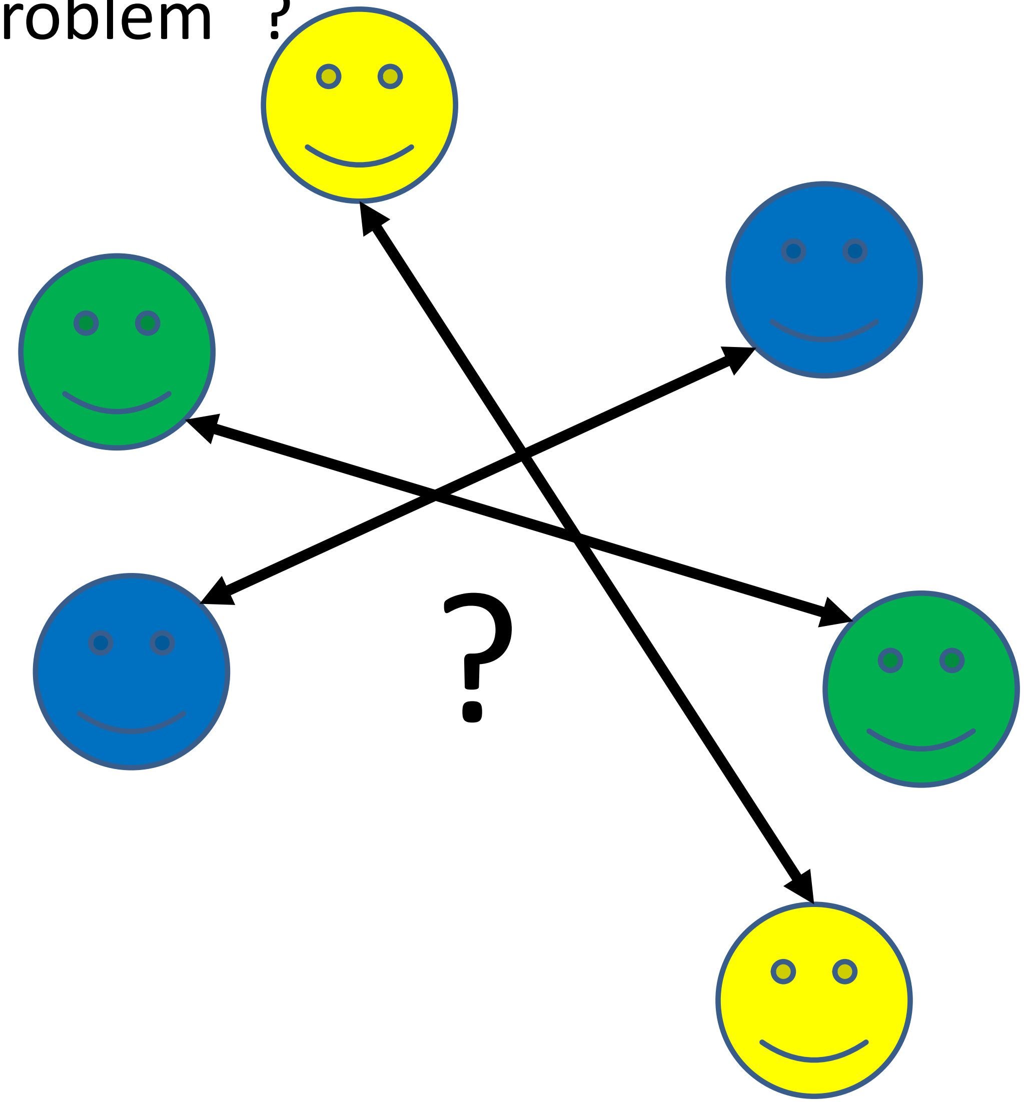
Do you know the ``Cocktail Party Problem´´?

You find it hard to understand your partner?

Too much interference?

What to do?

→ **Discuss!**



Cocktail Party Problem

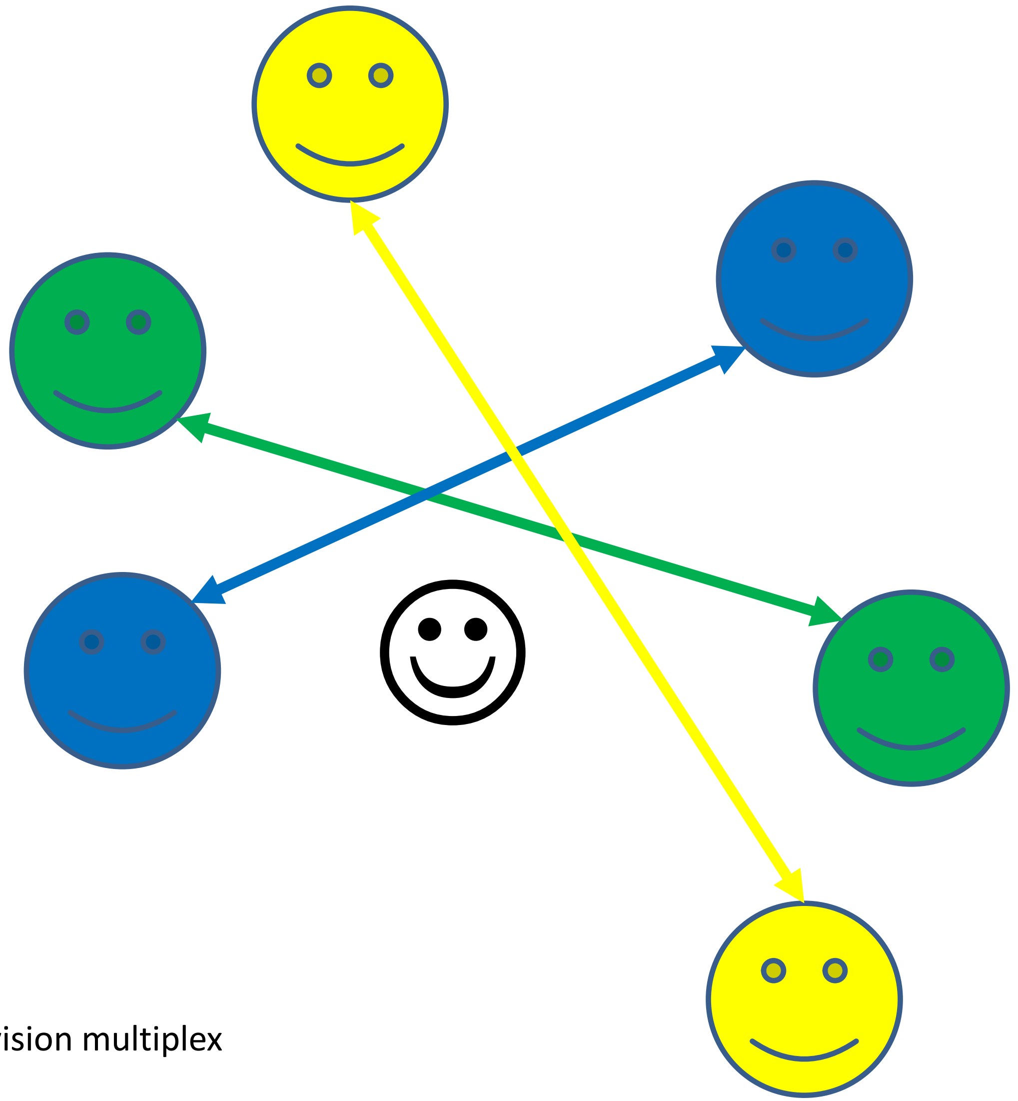
Use Modulation …

… many options like

- Carriers with different frequencies (FDM)
- Carriers with different time slots (TDM)
- (Pseudo –) random carriers (CDM)

→ Reduce interference (how?)

→ Provide some privacy (how?)



FDM, TDM, CDM: Frequency-, time-, code-division multiplex

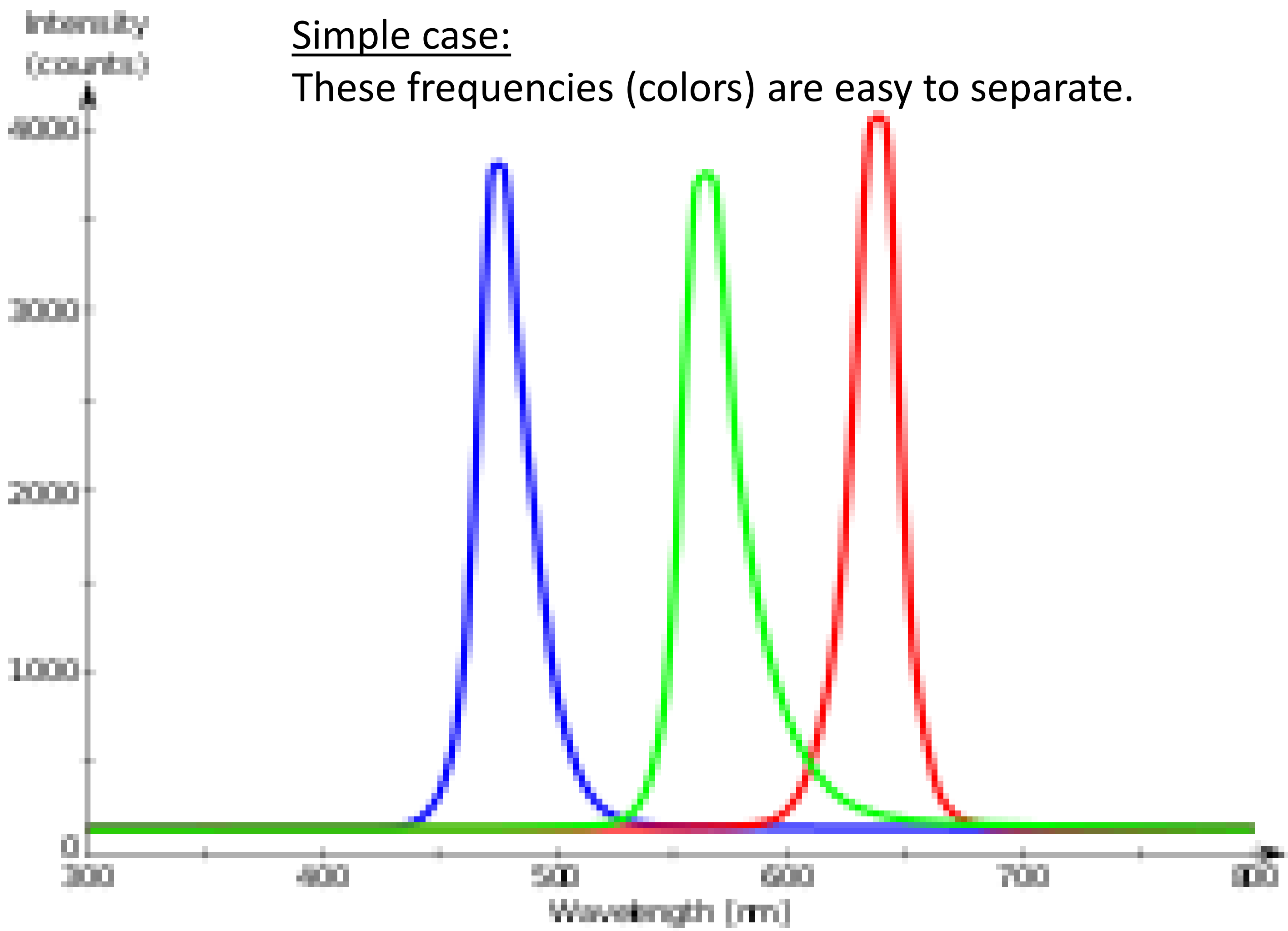
Lecture 1

https://en.wikipedia.org/wiki/Light-emitting_diode

Use LEDs with different colors

<u>Simple case:</u>

These frequencies (colors) are easy to separate.



Cocktail Party Problem

Use Modulation …

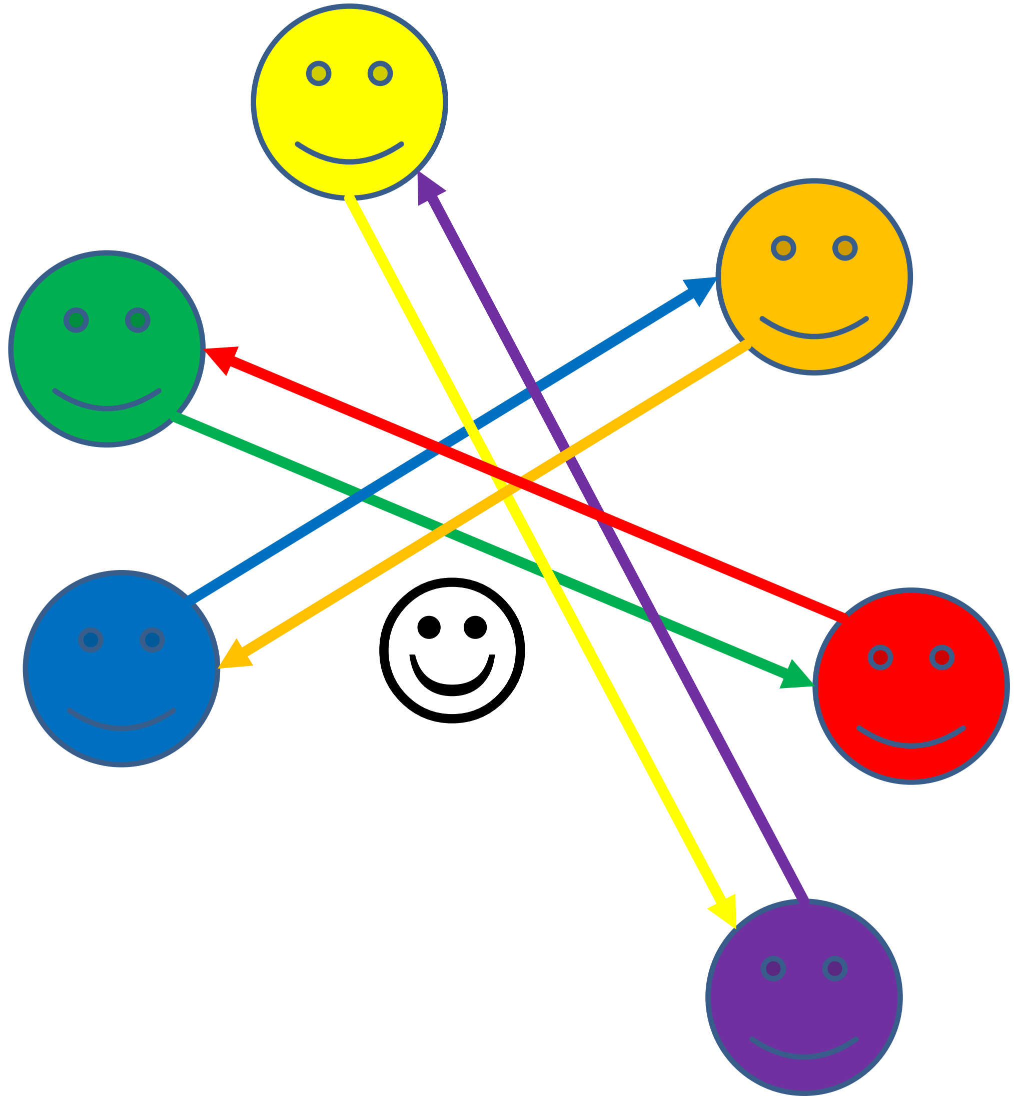
… many options like

- Carriers with different frequencies (FDM)
- Carriers with different time slots (TDM)
- (Pseudo –) random carriers (CDM)

→ Reduce interference

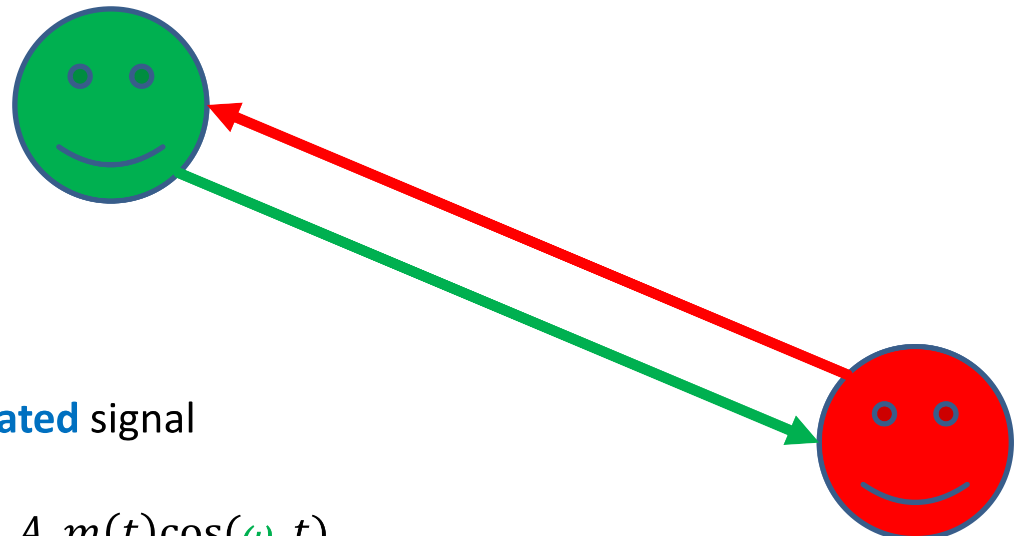
→ Provide some privacy

We can also use different carriers for the two partners …



Lecture 1

Linear Modulation (DSB) + Coherent Demodulation



Green wants to transmit a message $m(t)$ …

Via a carrier $A_c \cos(\omega_c t)$

Simple Method: Green sends a **modulated** signal

$$x_c(t) = A_c m(t) \cos(\omega_c t)$$

Assume: … no interference … no other changes during the transmission
➔Signal received by Red: $x_r(t) = x_c(t)$

Red **demodulates** the received signal via another multiplication with the carrier signal:

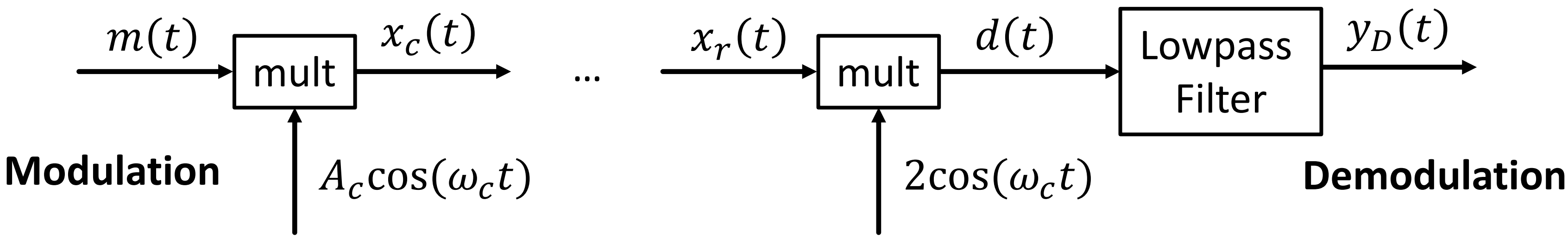
$$d(t) = A_c m(t) \cos(\omega_c t) \cdot 2 \cos(\omega_c t) = A_c \underline{m(t)} + A_c m(t) \underline{\cos(2\omega_c t)}$$

Finally, a low-pass filter can recover the original message.

Mind the frequencies:
Difference and sum …
$\omega_c - \omega_c$ and $\omega_c + \omega_c$

Lecture 1

Linear Modulation (DSB) + Coherent Demodulation



Modulation: $x_c(t) = A_c m(t)\cos(\omega_c t)$

Ideal channel: $x_r(t) = x_c(t)$

Mind:

$$\cos^2(\omega_c t) = \frac{1}{2} + \frac{1}{2}\cos(2\,\omega_c t)$$

Demodulation:

$$d(t) = A_c m(t)\cos(\omega_c t)\cdot 2\cos(\omega_c t) = A_c m(t) + A_c m(t)\cos(2\omega_c t)$$

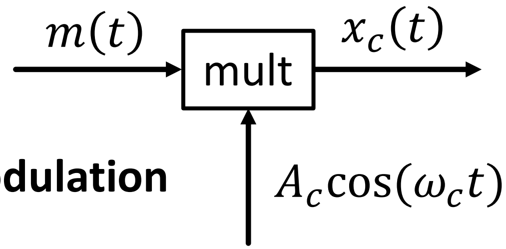
+ Lowpass → $y_D(t) = m(t)$ (or scaled)

Frequency response

Lecture 1

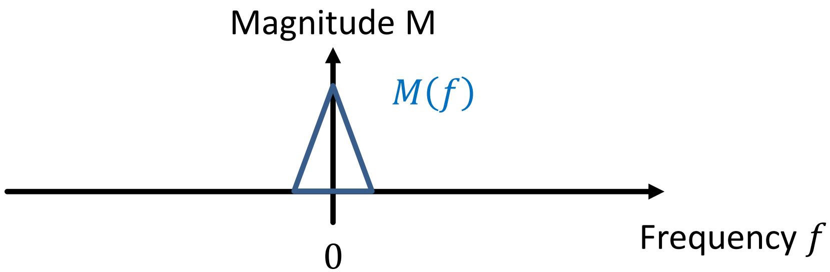
Linear Modulation

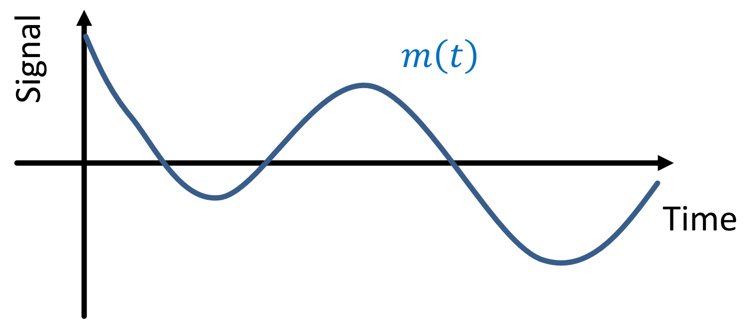
(DSB = Double or dual sideband)

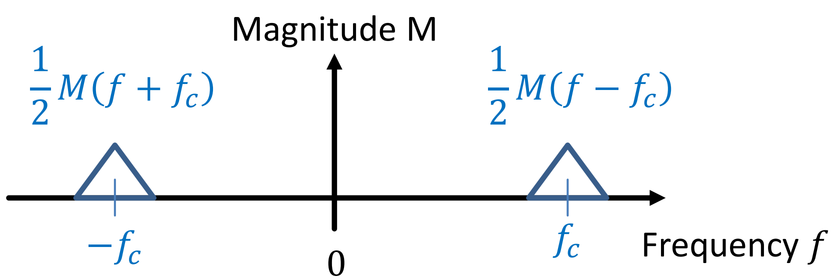


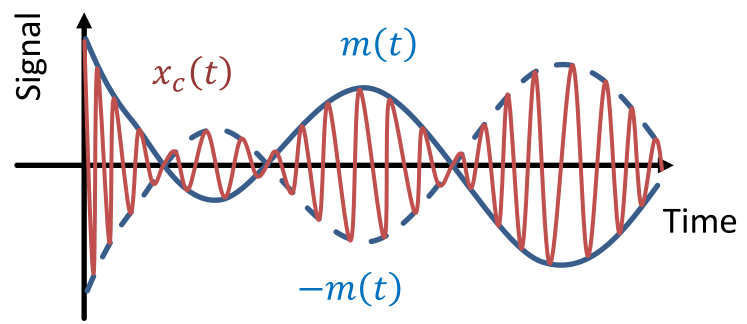
Modulation

$$x_c(t) = A_c m(t) \cos(\omega_c t)$$



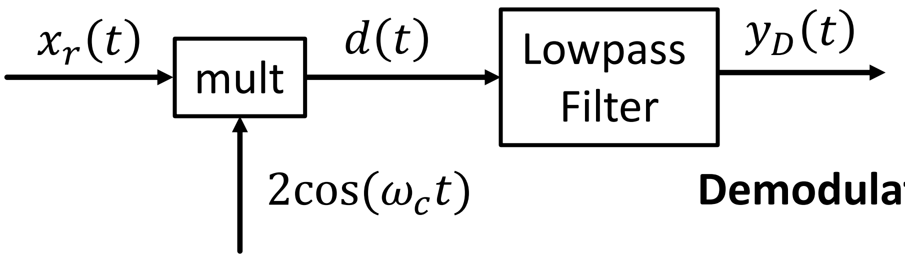






Symbolic spectra

DSB – Coherent Demodulation

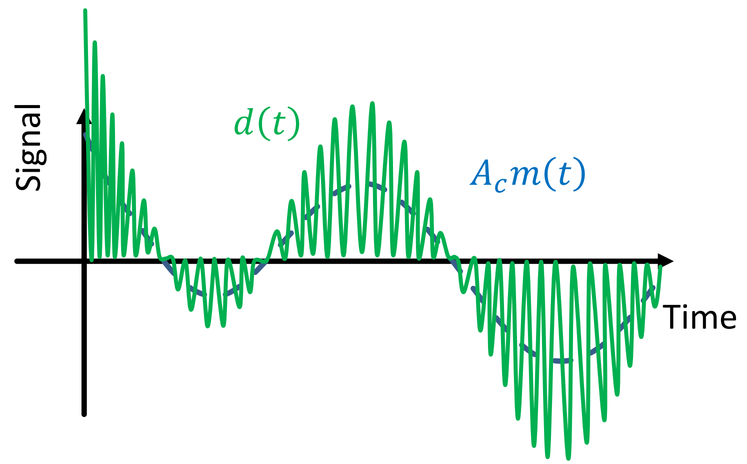


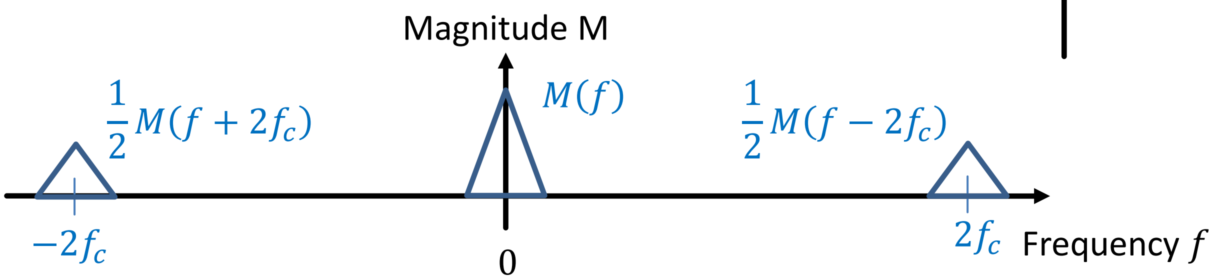
Demodulation

$$d(t) = A_c m(t)\cos(\omega_c t)\cdot 2\cos(\omega_c t)$$

$$= 2A_c m(t)\cos^2(\omega_c t)$$

$$= A_c m(t) + A_c m(t)\cos(2\omega_c t)$$

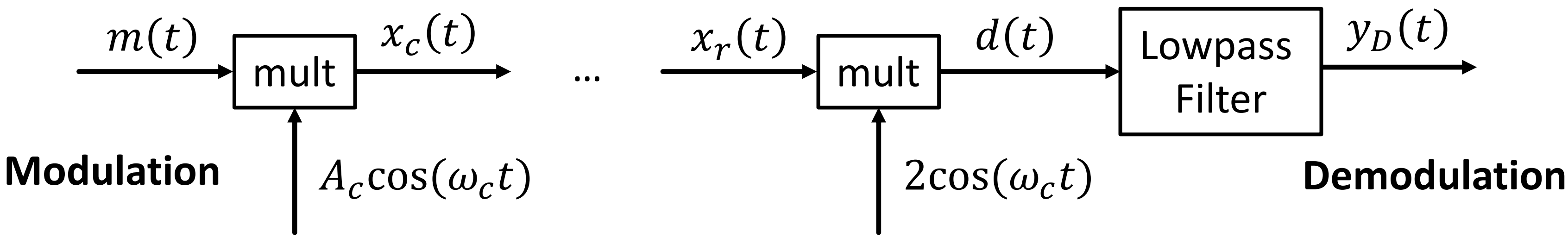




Symbolic spectra

Lecture 1

Linear Modulation (DSB) + Coherent Demodulation

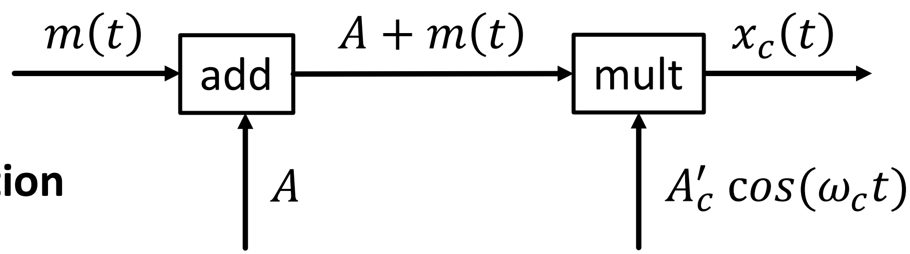


Discuss:

- Local oscillator for the receiver
  - synchronized with the transmitter?
  - derived from the signal?
- What if the transmitter/receiver moves … to a new position … at a certain speed?
  - phase?
  - frequency?

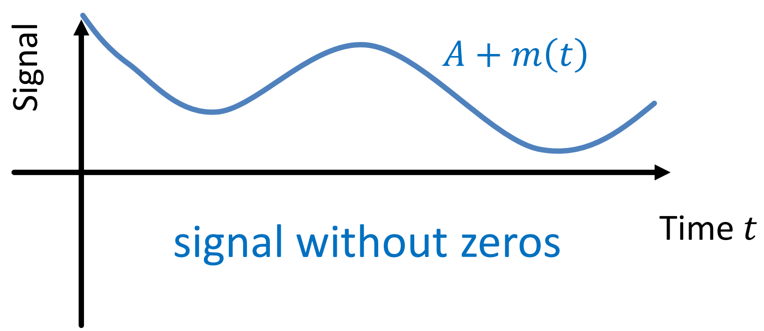
Linear Modulation (AM) + Envelope Detection

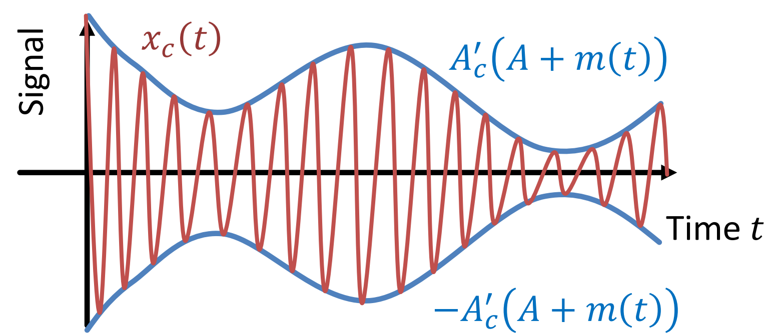
Modulation



Modulation: $x_c(t) = \big(A + m(t)\big)A_c' \cos(\omega_c t) =$ ``**DSB after offset**´´

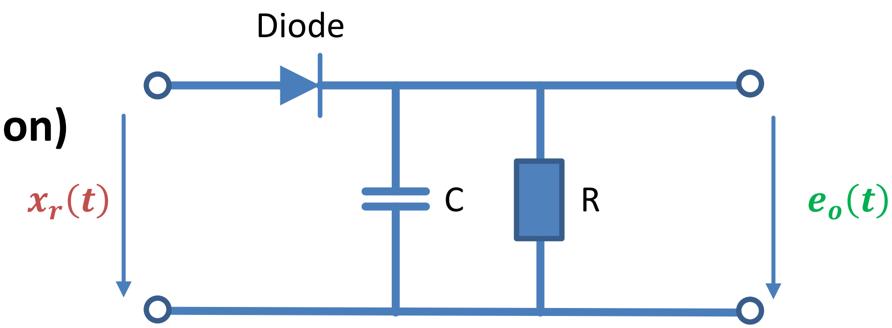
What‘s the point?

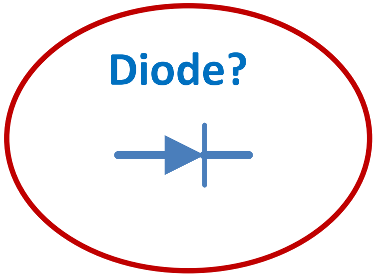




Linear Modulation (AM) + Envelope Detection

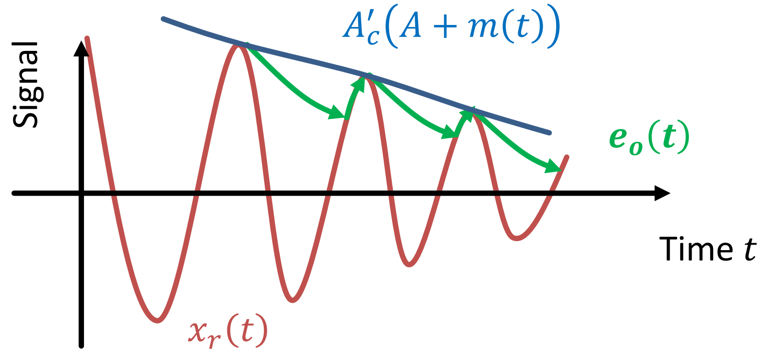
Demodulation (Envelope detection)





What‘s the point?

Ideal channel: $x_r(t) = x_c(t)$



Discuss:

Easy and cheap …

No need to synchronize …

But:

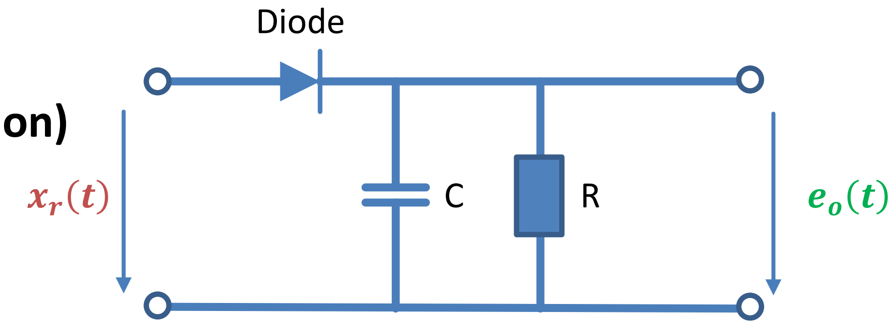
Needs higher power …

Extra effort to separate different messages/bands …

Understand:
Discharge & charge

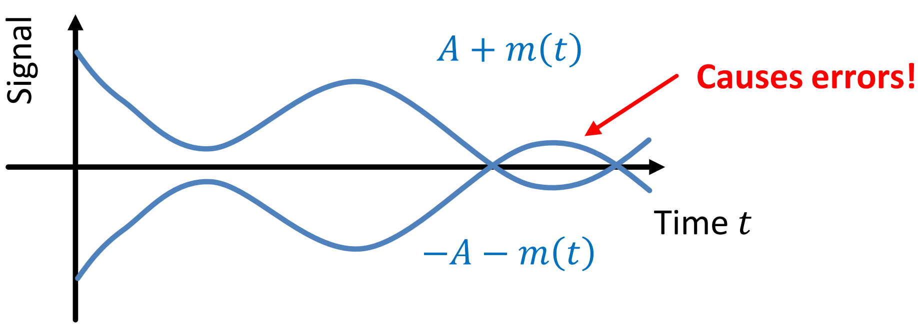
Linear Modulation (AM) + Envelope Detection

Demodulation (Envelope detection)



What's the point?

Suppose, the offset A is too small ...



Discuss:

Envelopes are interesting!

For a mathematical access ...

... we need a formal concept:

Envelope of a signal $x(t)$

Lecture 1

Digestion Guide

Digestion Guide ...

Euler‘s formula

Trigonometric identities like $cos^2(\omega t) = \frac{1}{2} + \frac{1}{2} cos(2\omega t)$

How to find those identities?

Calculate:

1) What happens, when we use coherent demodulation for a DSB signal, if the local oscillator‘s frequency is wrong? Consider two cases: ``just a little bit´´ versus ``way off´´ … how much is ``a bit´´ ? How can this happen?
2) What happens, if the local oscillator‘s frequency is right but its phase is wrong? What is a relevant difference? How can this happen?

For coherent demodualtion of DSB signals, would it help to (additionally) transmit the carrier signal alone? How could this be done?

Make sure you understand your Fourier transforms (recap in our textbook, chp. 2)

Start reading chp. 3 of our textbook (DSB + AM)

Lecture 1

Some formulas

Convolution with a delta-peak in time domain:

$$\delta(t) * x(t) = \int_{-\infty}^{\infty} \delta(t-\tau)x(\tau)\,d\tau = x(t)$$

Convolution with a delta-peak in frequency domain:

$$\delta(f) * X(f) = \int_{-\infty}^{\infty} \delta(f-s)X(s)\,ds = X(f)$$

Euler

$$\cos\varphi = \frac{e^{j\varphi}+e^{-j\varphi}}{2}, \qquad \sin\varphi = \frac{e^{j\varphi}-e^{-j\varphi}}{2j}$$

$$e^{j\varphi} = \cos\varphi + j\sin\varphi$$

$$e^{-j\varphi} = \cos\varphi - j\sin\varphi$$

Lecture 1

Euler

$$\cos\varphi = \frac{e^{j\varphi}+e^{-j\varphi}}{2}, \qquad \sin\varphi = \frac{e^{j\varphi}-e^{-j\varphi}}{2j}$$

Use Euler

$$e^{j\varphi} = \cos\varphi + j\sin\varphi$$

$$e^{-j\varphi} = \cos\varphi - j\sin\varphi$$

Find trigonometric identity:

$$\cos^2\varphi = \frac{\left(e^{j\varphi}+e^{-j\varphi}\right)^2}{4}$$

$$= \frac{e^{j2\varphi}+2+e^{-2j\varphi}}{4}$$

$$= \frac{2}{4} + \frac{e^{j2\varphi}+e^{-2j\varphi}}{4} = \frac{1}{2} + \frac{1}{2}\cos 2\varphi$$

Lecture 1

Euler

$$\cos\varphi = \frac{e^{j\varphi} + e^{-j\varphi}}{2}, \qquad \sin\varphi = \frac{e^{j\varphi} - e^{-j\varphi}}{2j}$$

Use Euler

$$e^{j\varphi} = \cos\varphi + j\sin\varphi$$

$$e^{-j\varphi} = \cos\varphi - j\sin\varphi$$

Modulation:

$$\cos\omega_m t\cos\omega_c t = \frac{e^{j\omega_m t} + e^{-j\omega_m}}{2}\cdot\frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2}$$

$$= \frac{e^{j(\omega_m+\omega_c)t} + e^{-j(\omega_m+\omega_c)t}}{4} + \frac{e^{j(\omega_m-\omega_c)t} + e^{-j(\omega_m-\omega_c)t}}{4}$$

$$= \frac{1}{2}\cos(\omega_m + \omega_c)t + \frac{1}{2}\cos(\omega_m - \omega_c)t = \frac{1}{2}\cos(\omega_c + \omega_m)t + \frac{1}{2}\cos(\omega_c - \omega_m)t$$

Realize: Sums and differences

Thank you for your attention!

See you soon …