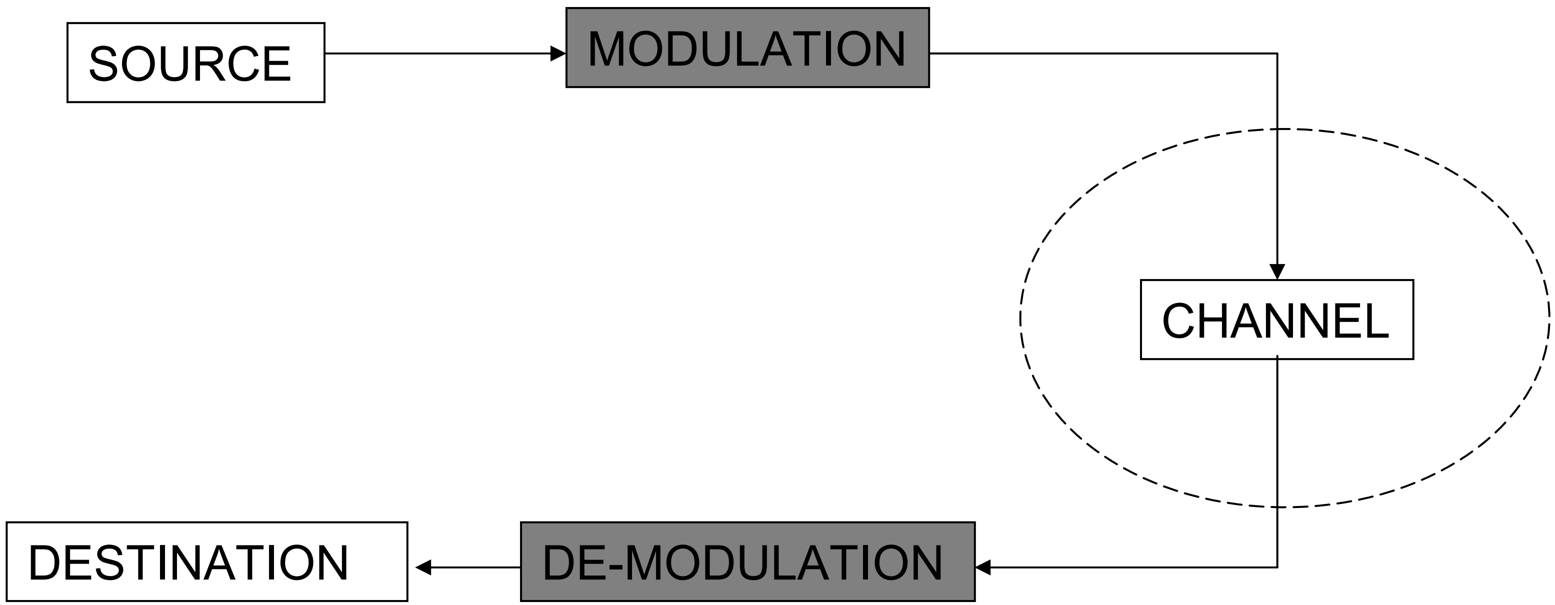
Modulation

Modulation

- Modulation is the process when information is transformed into a signal with such a form and characteristics that it could be transported over the present medium.
- In the definition modulation there are a lot of aspects included, these aspects are dependent on the medium that the information transport take place over.
- At radio transmission the information transportation is conducted with electromagnetic waves.
- The wave can be varied (modulated) in **amplitude**, **phase** and **frequency.**

Modulation



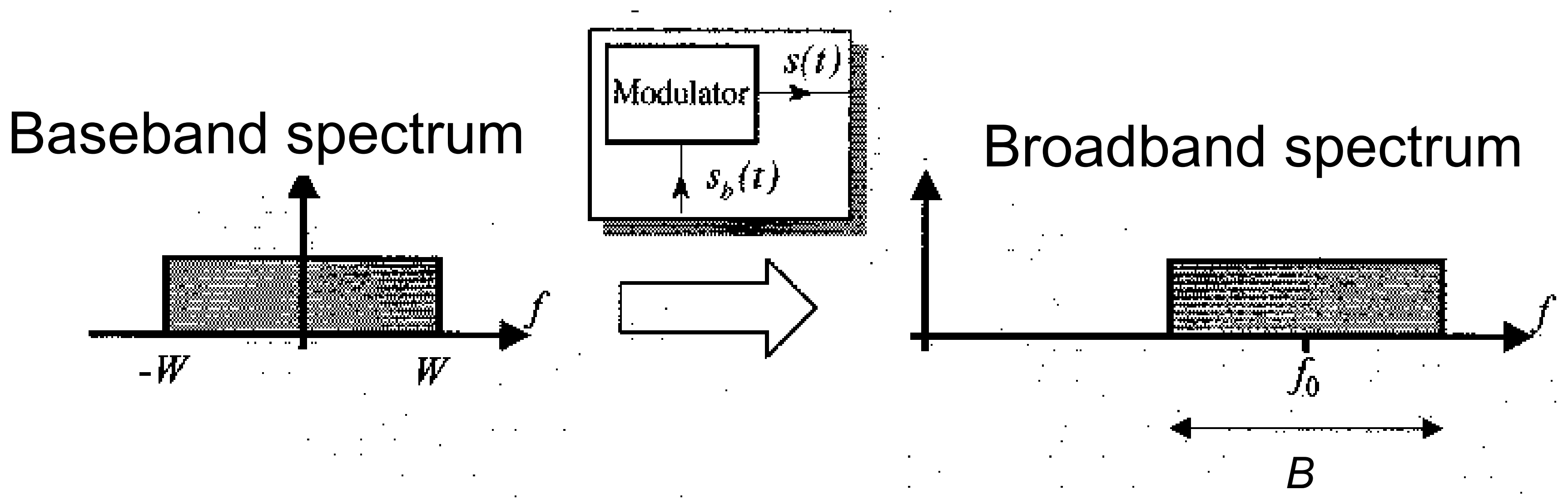
In an ideal world would not the channel induce any changes on the information transported over the channel.

This is however never true since the physical channel always influences the information.

Modulation

- Baseband
- Broadband

A **broadband** signal is a **baseband** signal transformed into a higher frequency than the baseband signal.



The modulator transforms the baseband signal, *W*, into a broadband signal *B* with a center frequency f_0. The expansion in bandwidth is given as the ratio: B/W

Analog Modulation

- Amplitude modulation (AM) {*linear*}
- Phase modulation (PM) {*nonlinear*}
- Frequency modulation (FM) {*nonlinear*}

envelop

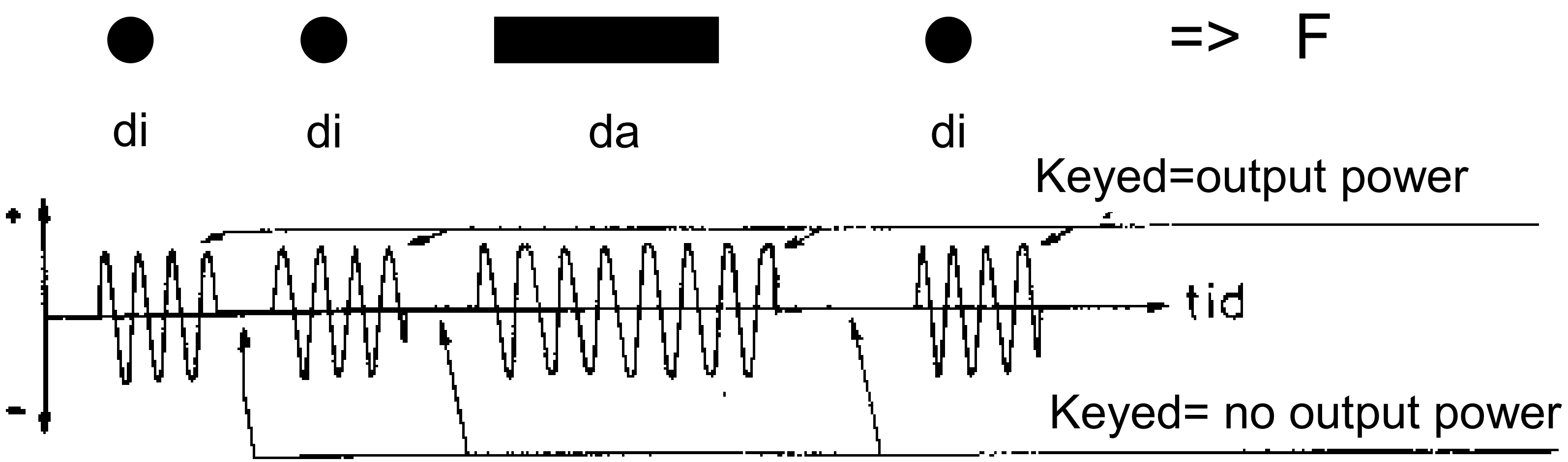
phase

$$s(t) = a(t)\cos(2\pi f_c + \rho(t))$$

Since the relation between the parameters inside the **cos(🕐)** function, ❐*(t)*, and the signal, *s(t)* ,is nonlinear. FM and PM are said to be nonlinear while AM is linear since it affects *a(t)*.

Continuous wave (CW)

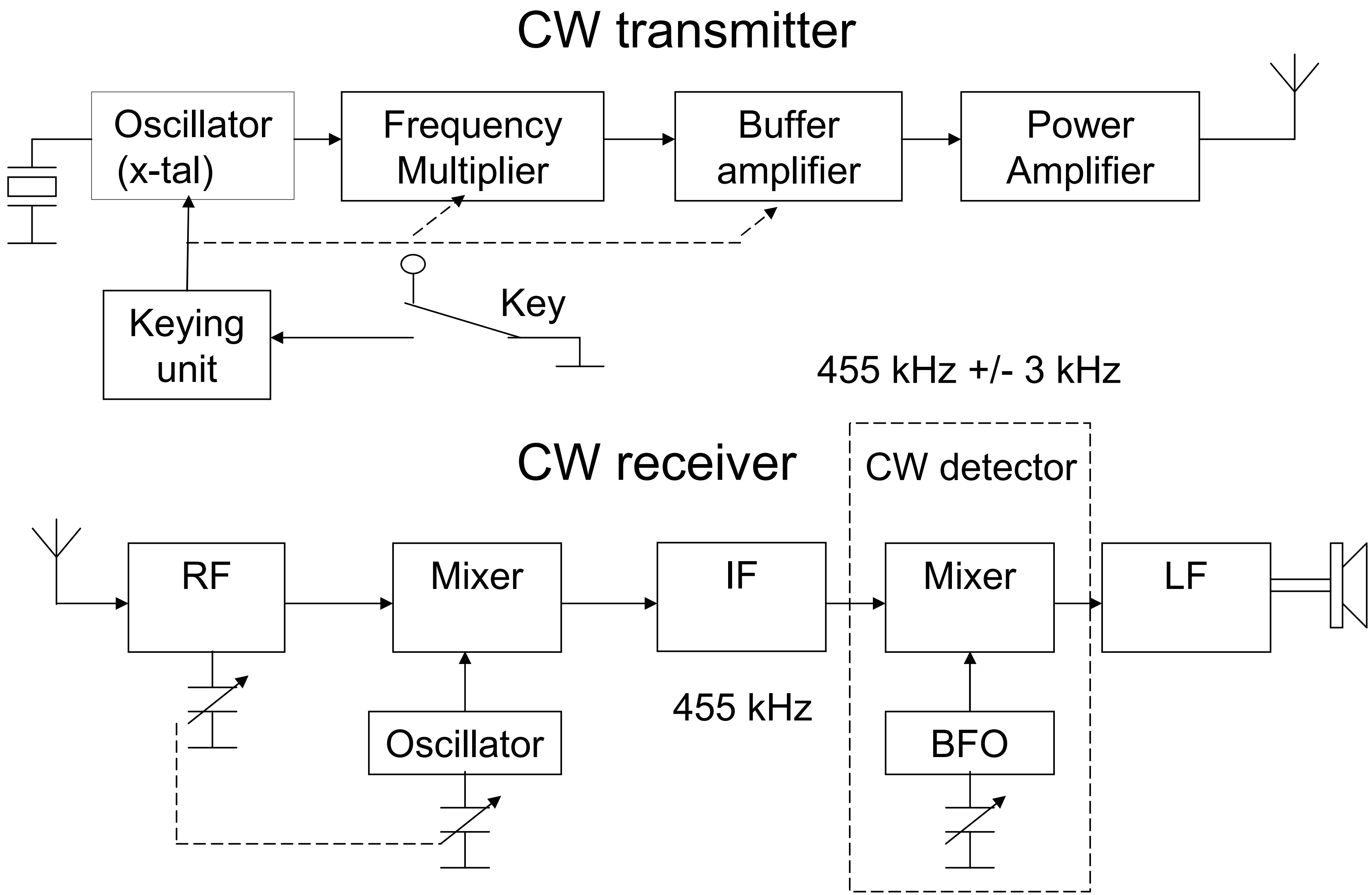
On-off keying (telegraphy) using Morse code is the oldest and simplest way to transport information.



$$s(t)=a(t)a_c cos(2\pi f_c) \qquad a(t) = 0, 1$$

Very narrow banded (a couple of 100 Hz), the band-spread is actually generated by the starting and stopping of the continuous wave.

Continuous wave (CW)



Amplitude modulation

- Amplitude modulation double sideband with carrier (AM-DSBC).
- Amplitude modulation double sideband with suppressed carrier (AM-DSBSC).
- Amplitude modulation single sideband (AM-SSB).

AM-DSBC

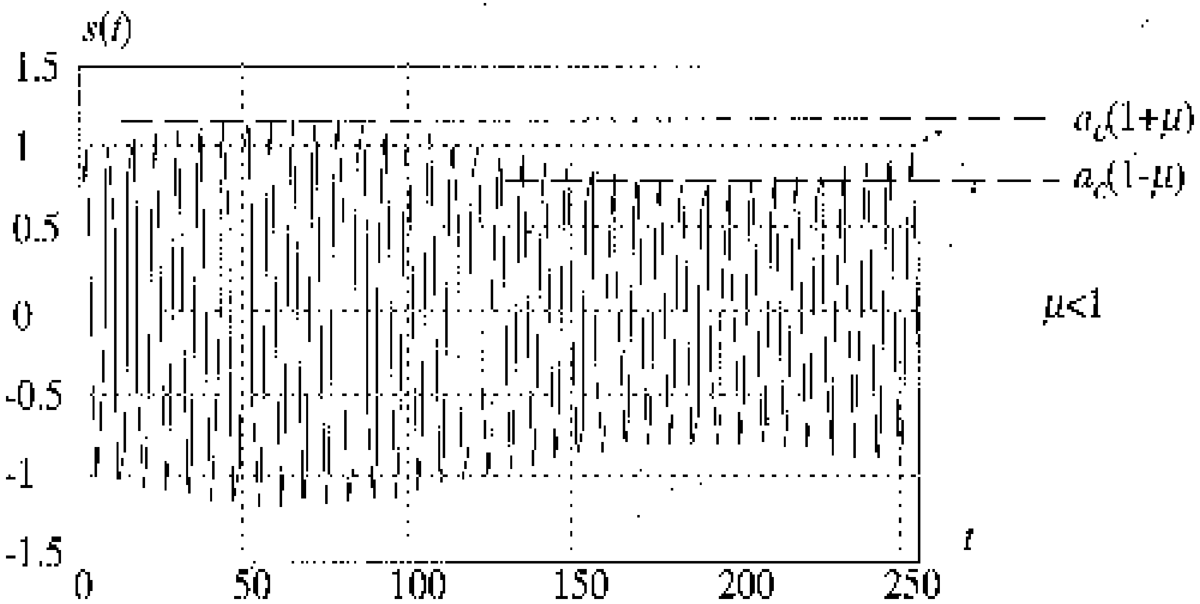
$s(t) = a_c a(t)\cos(2\pi f_c t)$

where

$a(t) = 1 + \mu x(t)$

a_c = carrier amplitude

f_c = carrier frequency

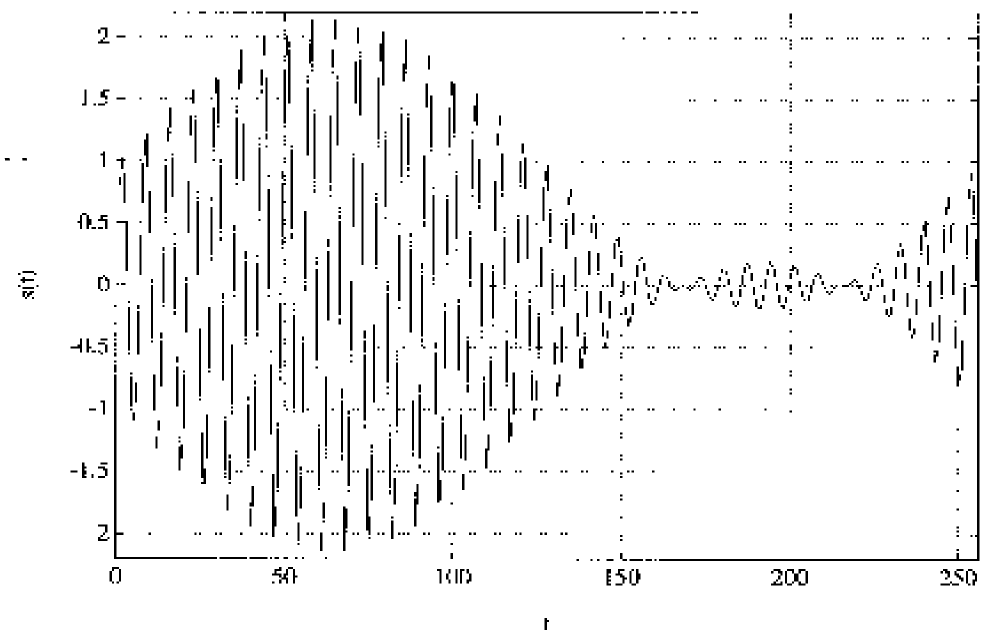


μ = modulation index ($0 \le \mu \le 1.$

$x(t)$ = information (message) $|x(t)|$

Which means that $E\{x^2(t)\} \le 1$

=> the signal power is $S_x \le 1$



AM-DSBC - bandwidth

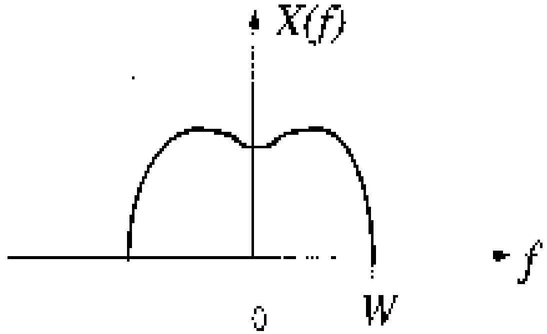
To find out the channel bandwidth the Fourier transform of the signal, *s(t),* is used:

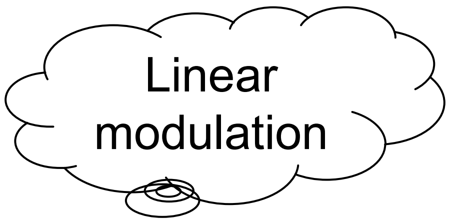
$$S(f) = A(f) \times \frac{a_c}{2}\delta(|f| - f_c) + \frac{\mu}{2} a_c X(|f| - f_c)$$

A(*f*)=*F*{ *a(t)* } information signal spectrum

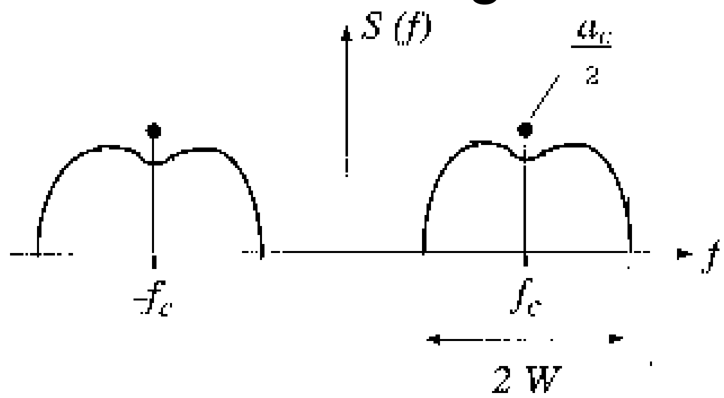
♎(❁*f* ❁ - f_c) the carrier spectrum

Baseband signal



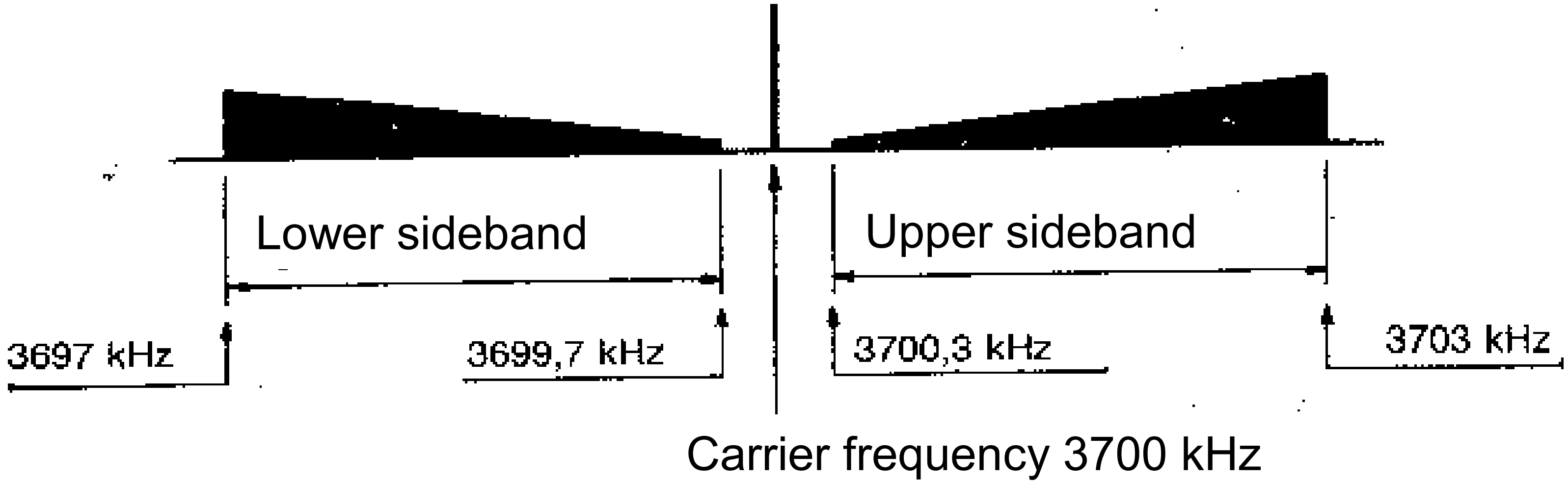


Broadband signal



AM-DSBC – bandwidth example

Assume a voice source which is band limited to 300-3000 Hz, and a carrier frequency of 3700 kHz.



Upper sideband boarder: 3700 + 0,3 kHz = 3700,3 kHz
3700 + 3 kHz = 3703 kHz

Lower sideband boarder: 3700 – 0,3 kHz = 3699,7 kHz
3700 – 3 kHz = 3697 kHz

AM-DSBC power efficiency

The ratio between **information carrying power** and the **total power** in the signal is:

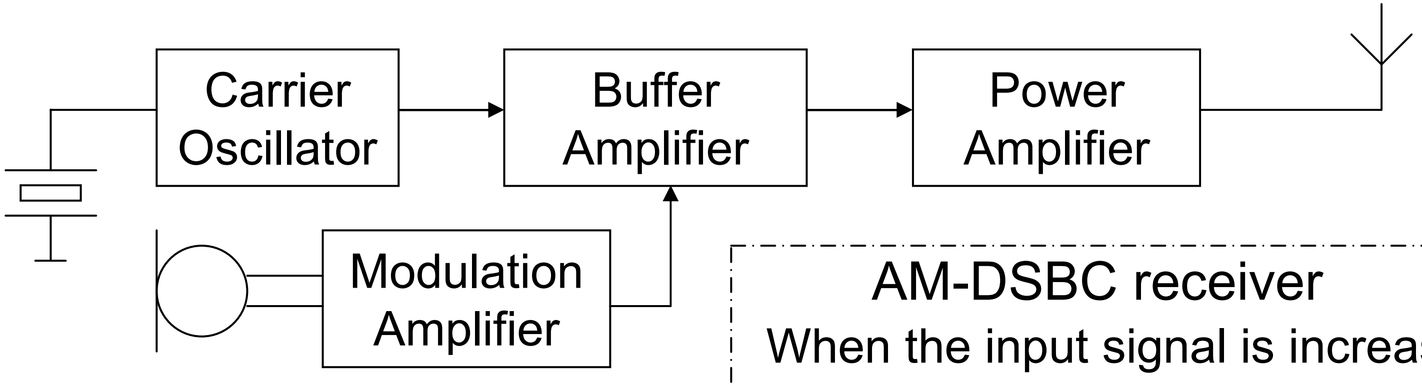
$$\frac{a_c^2 \frac{\mu^2}{2} S_x}{a_c^2 \frac{1}{2}(1+\mu^2 S_x)} = \frac{1}{\frac{1}{\mu^2 S_x}+1} \le \frac{1}{2}$$

since we know that $\mu \le 1$ and $S_x \le 1$.

Which means that only half of the power is possible to utilize for information carrying, when AM-DSBC is used.

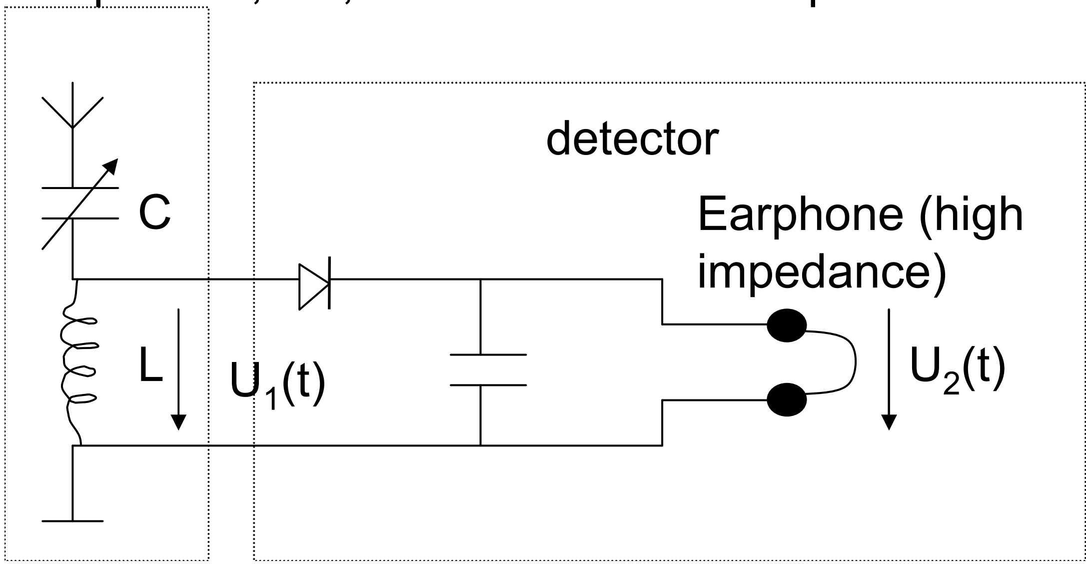
AM-DSBC

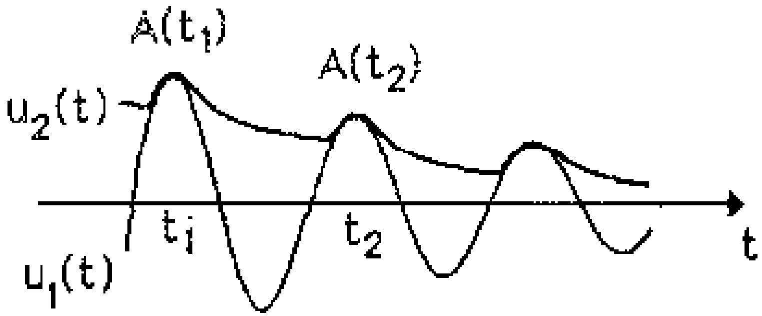
AM-DSBC transmitter



AM-DSBC receiver

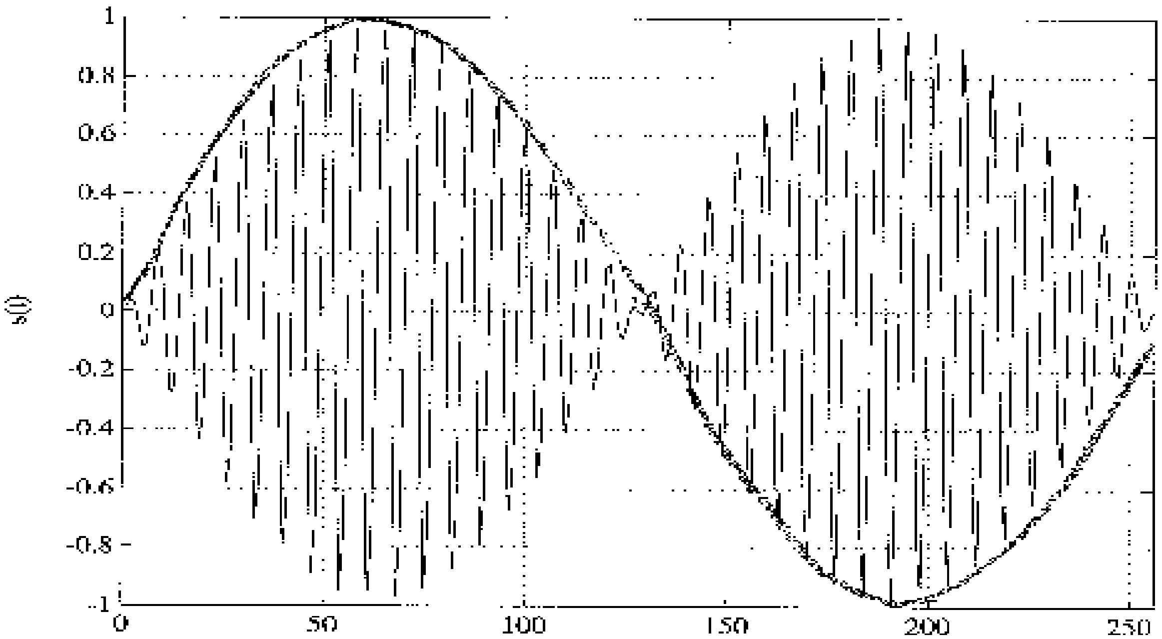
When the input signal is increasing the diode is leading and the capacitor is charged to the same value as the maximum of the input signal. During the rest of the period the diode is not leading which means that the charge decreases by the current through the resistive earphones, i.e., we detect the envelop.





AM-DSBSC

$$s(t) = a_c x(t)\cos(s\pi f_c)$$



where

a(t) = ❍*x(t)*

a_c = carrier amplitude

f_c = carrier frequency

❍ = modulation index *(*0 ⭘ ❍ ⭘ 1.0*)*

x(t) = information (message) ✿*x(t)*✿ ⭘1

Which means that $E\{x^2(t)\}$ ⭘1

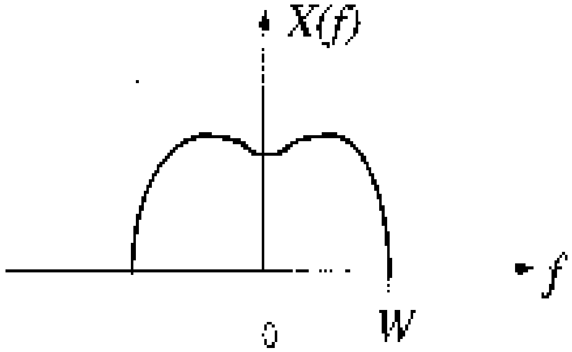
=> the signal power is S_x ⭘1

AM-DSBSC – bandwidth

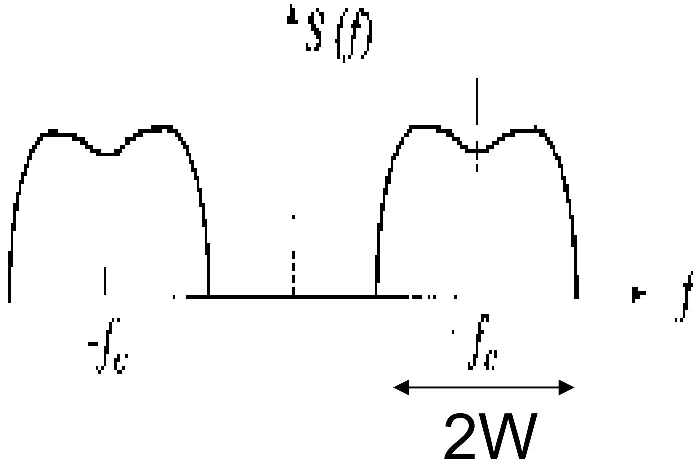
To find out the channel bandwidth the Fourier transform of the signal, *s(t),* is used:

$$S(f) = X(f) \times \frac{a_c}{2} \delta(|f| - f_c)$$

Baseband signal



Broadband signal



AM-DSBSC – power efficiency

The power of the AM-DSBSC is:

$$E\left[s^2(t)\right] = E\left[x^2(t)a_c^2\left(\frac{1}{2}-\frac{1}{2}\cos(2\pi f_c t)\right)\right] = \frac{a_c^2}{2}E\left[x^2(t)\right] = \frac{a_c^2}{2}S_x$$

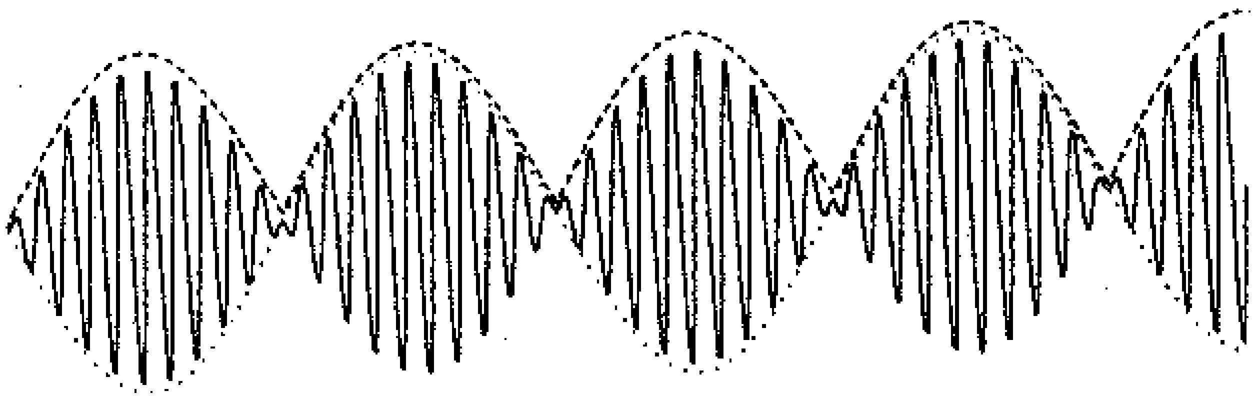
This means that all power can be used for information carrying. No parts of the spectrum is independent of the information that is transmitted.

Information transmitted with AM-DSBSC contains twice the amount of power compared to AM-DSBC.

We can conclude that the SNR as performance measure is dependent on the type of modulation in use.

AM-DSBSC

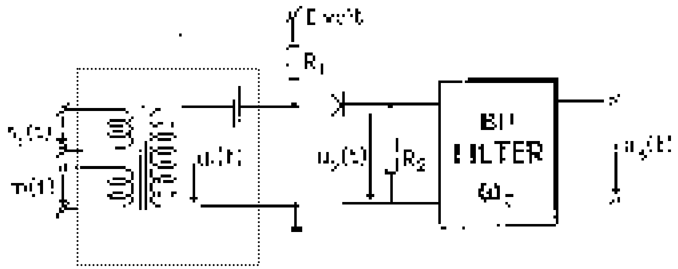
- The AM-DSBSC is twice as efficient as the AM-DSBC.
- AM-DSBSC has no carrier component in the transmitted signal, i.e., it is more power efficient.
- AM-DSBSC can however not be detected with the simple diode detector as the AM-DSBC can, i.e., we need a coherent detector which uses a phase locked local oscillator.



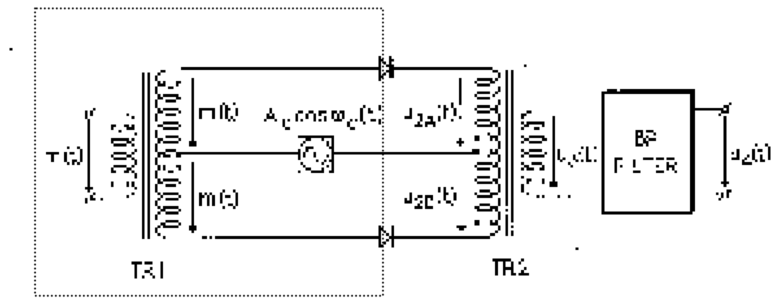
AM-DSBSC

AM-DSBSC transmitter (it differs since it mixes the carrier, $s_c(t)$, and the information signal, $m(t)$).

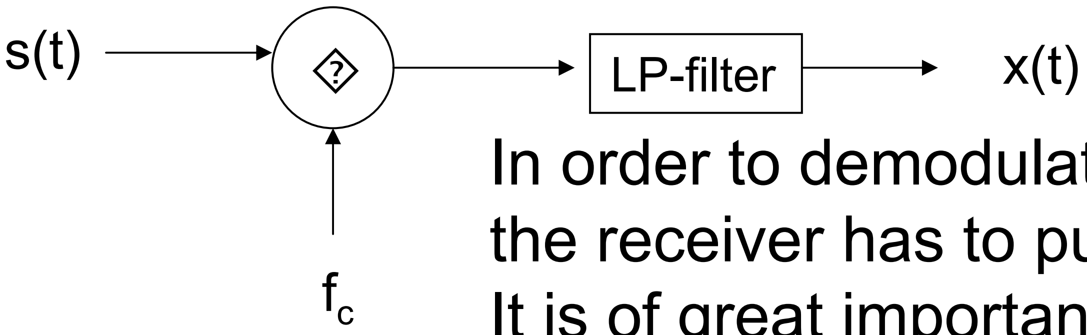
AM-DSBC (unbalanced mixer)



AM-DSBSC (balanced mixer)



AM-DSBSC receiver (direct conversion)



In order to demodulate the AM-DSBC signal the receiver has to put back the carrier signal. It is of great importance that the carrier is put back in phase and frequency. A phase error decreases the received signal and become zero at opposite phase.

AM-SSB

Since both sidebands contain the same information it is enough to transmit one of them.

$$S_{us}(t) = a_c x(t)\cos(2\pi f_c t) - a_c \tilde{x}(t)\sin(2\pi f_c t)$$

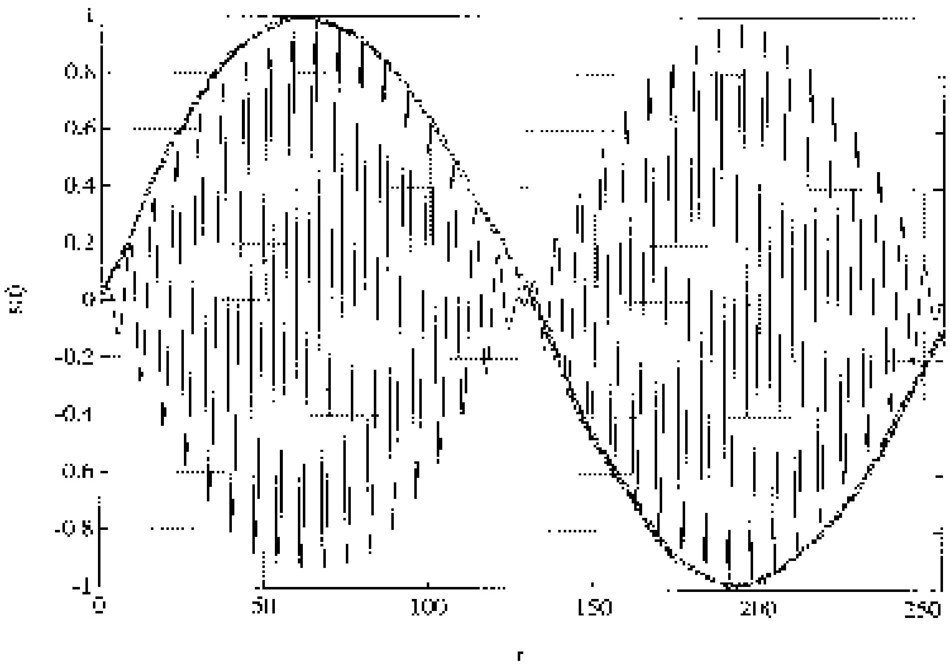
$$S_{ls}(t) = a_c x(t)\cos(2\pi f_c t) + a_c \tilde{x}(t)\sin(2\pi f_c t)$$

where

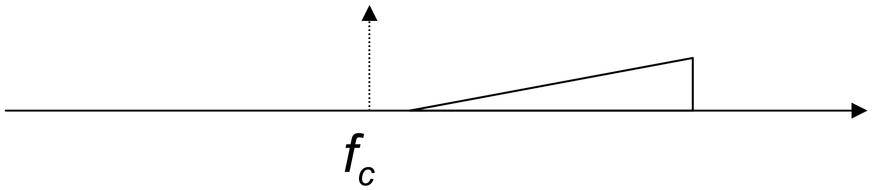
a_c = carrier amplitude

f_c = carrier frequency

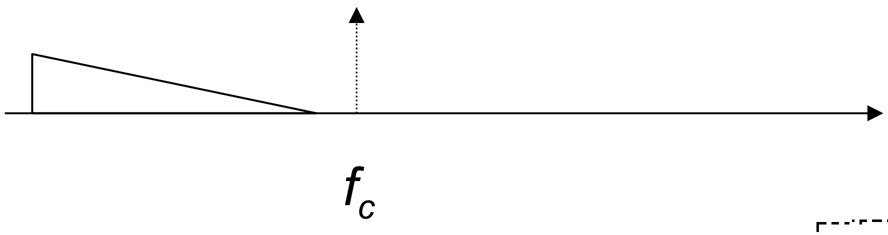
x(t) = Hilbert transform of x(t)



AM-SSB – bandwidth

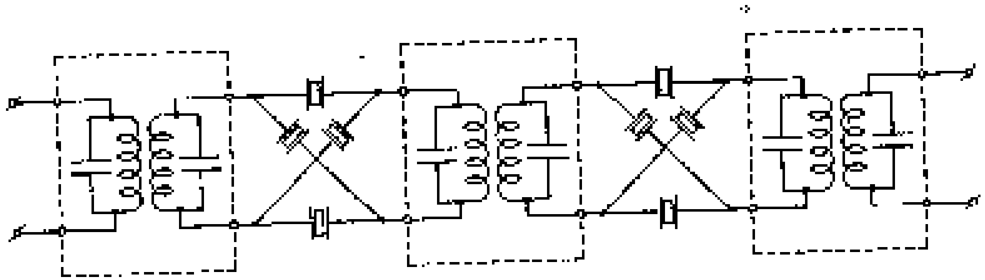


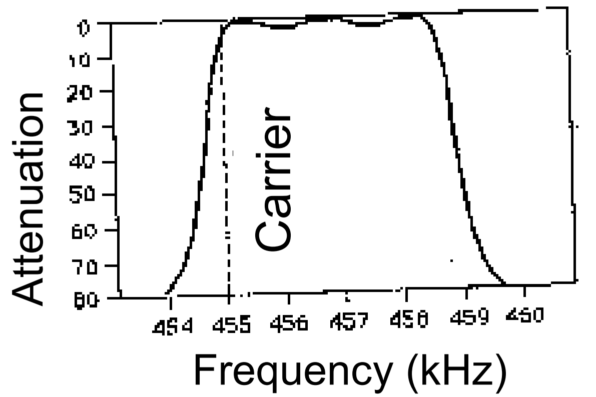
Upper sideband



Lower sideband

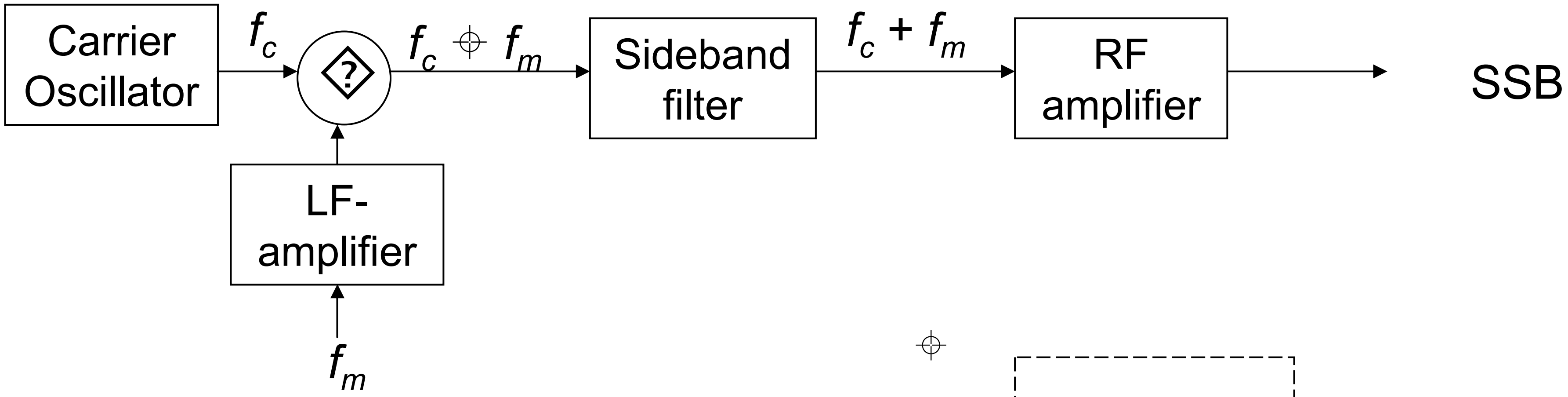
As we already have seen a balanced modulator gives two sidebands without any carrier. The simplest way to create SSB is to use a step filter and simply filter out one of the side bands. The filters used for this process is often crystal filters.



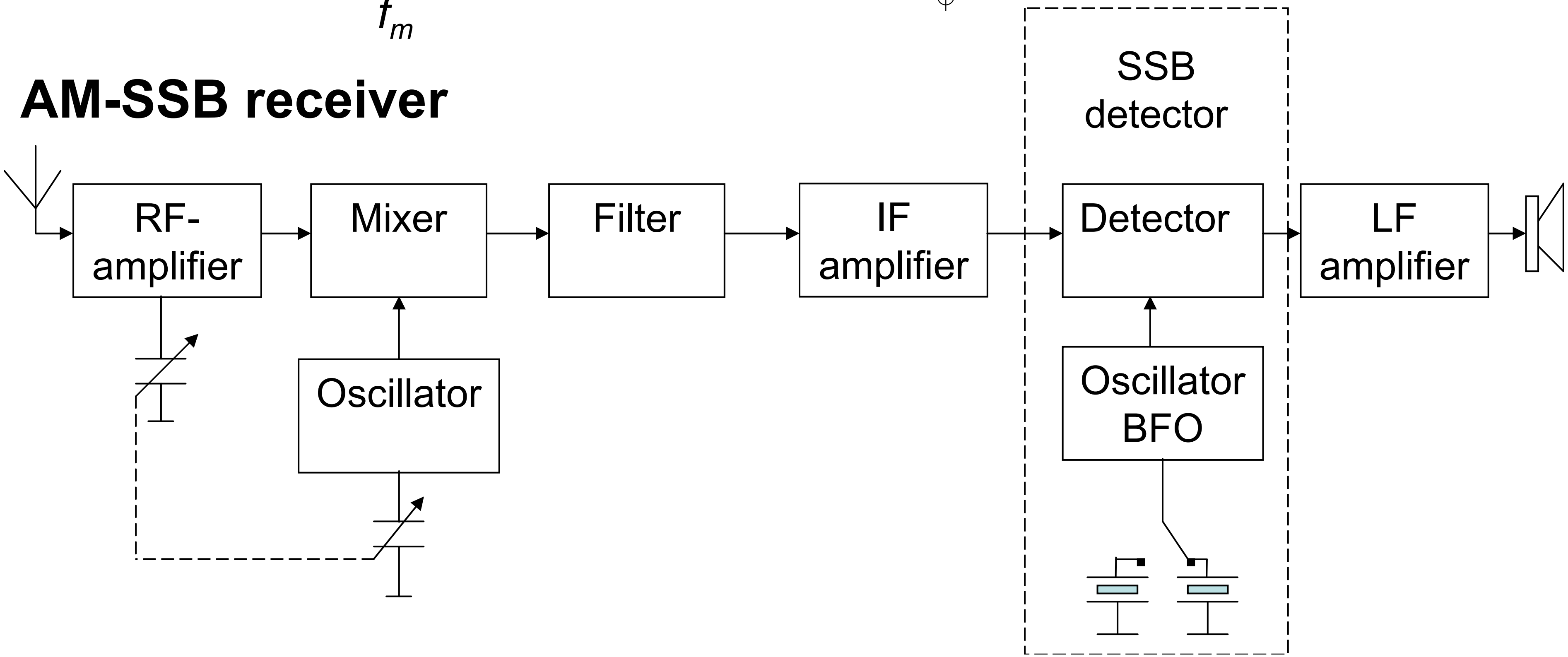


AM-SSB

AM-SSB transmitter



AM-SSB receiver



Frequency Modulation