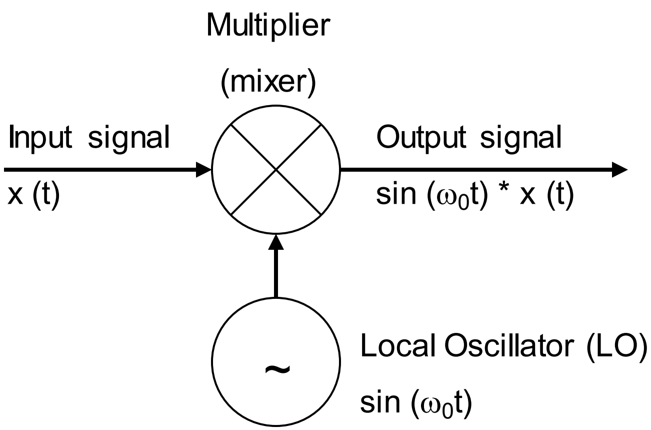
AM



If x (t) = sin (ω_mt), then:

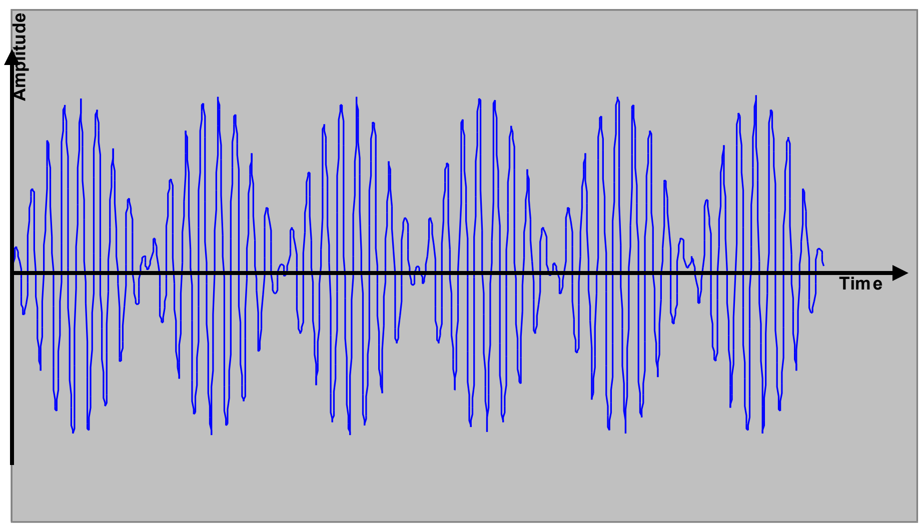
Output signal = sin (ω_mt) * sin (ω_0t) = 0.5 * [cos ((ω_0 - ω_m)t) - cos ((ω_0 + ω_m)t)]

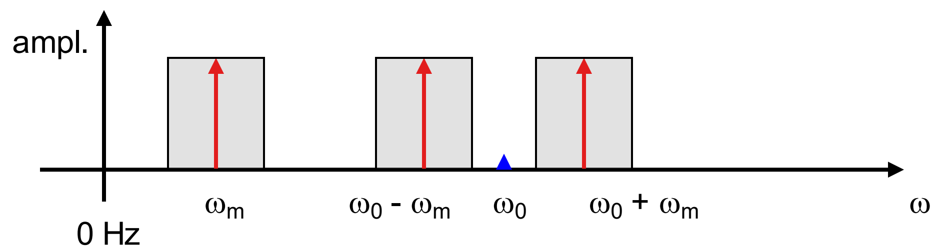
→ Double sideband, suppressed carrier (DSB / SC)

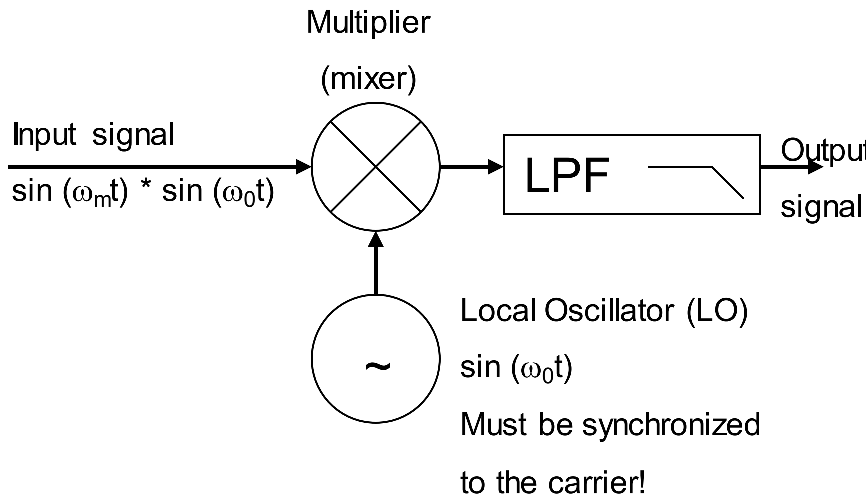
→ Bandwidth: double of the baseband bandwidth

In general:

The spectrum of the modulating signal appears above and below the carrier







Demodulation of a DSB / SC signal:

→Problem: the envelope contains the absolute value of the modulating signal

→ Solution: coherent demodulator

→ Requires sophisticated circuits (carrier recovery stage (PLL), multiplier, etc.); in practice, a very small proportion of the carrier is also transmitted to help the receiver to synchronize

→ Expensive receiver

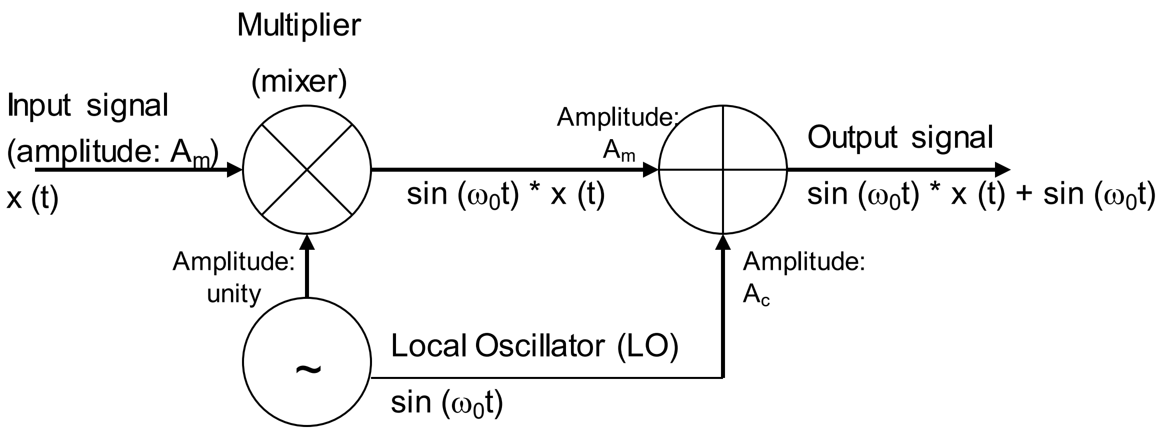
Demodulation:

$(\sin(\omega_m t) * \sin(\omega_0 t)) * \sin(\omega_0 t) = 0.5 * [1 - \cos(2\omega_0 t)] * \sin(\omega_m t)$

After low-pass filtering (LPF):

Output signal = $0.5 * \sin(\omega_m t)$

Receiver simplification: "conventional" AM



If x (t) = A_m * sin (ω_mt) and the carrier's amplitude is A_c, then:

Output signal = A_m* sin (ω_mt) * sin (ω_0t) + A_c sin (ω_0t) =

0.5 * A_m* [cos ((ω_0 - ω_m)t) - cos ((ω_0 + ω_m)t)] +

A_c * sin (ω_0t)

→ Double sideband, non-suppressed carrier (DSB)

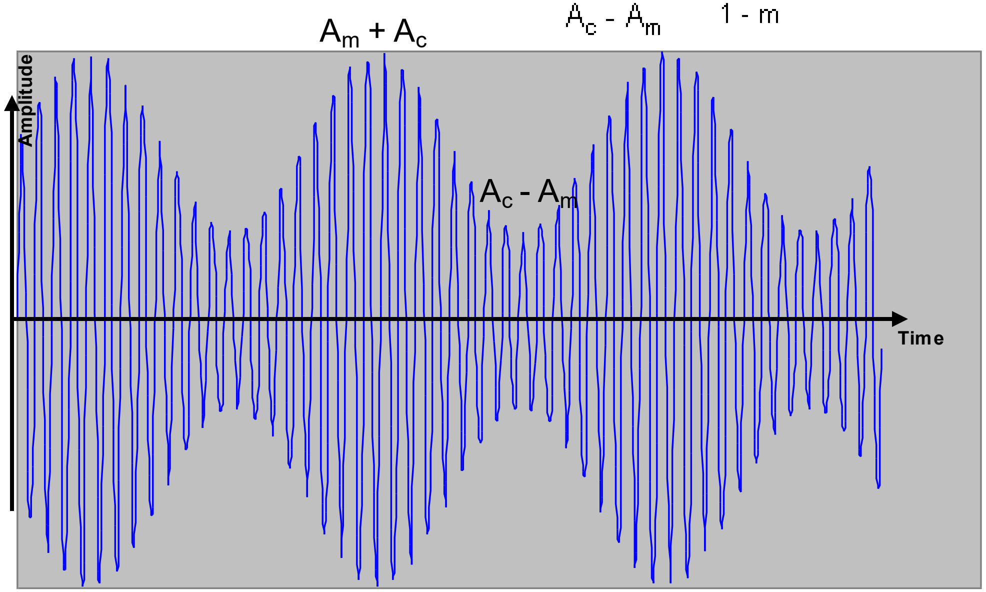
→ Modulation depth: $m = A_m / A_c$

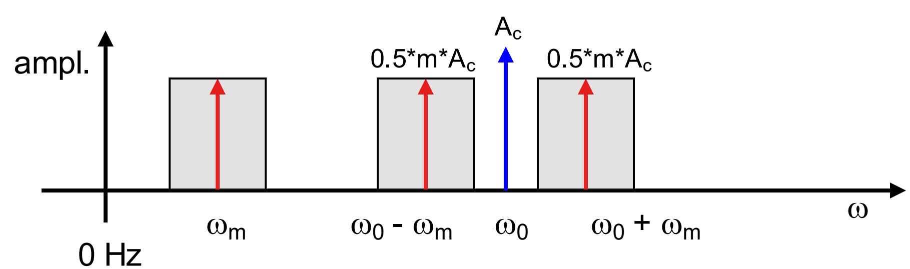
→ If m= 100% AND the modulating signal is a sine wave, then the two sidebands are 6 dB below the carrier

In general:

The spectrum of the modulating signal appears above and below the carrier + the carrier also has power

$$\frac{A_m + A_c}{A_c - A_m} = \frac{1 + m}{1 - m}$$

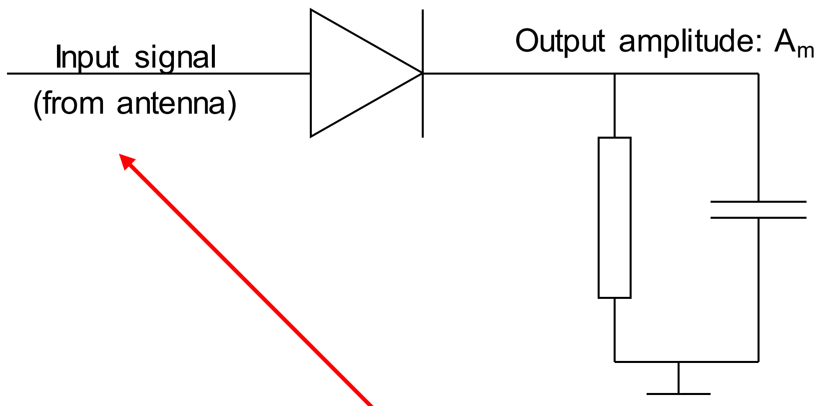


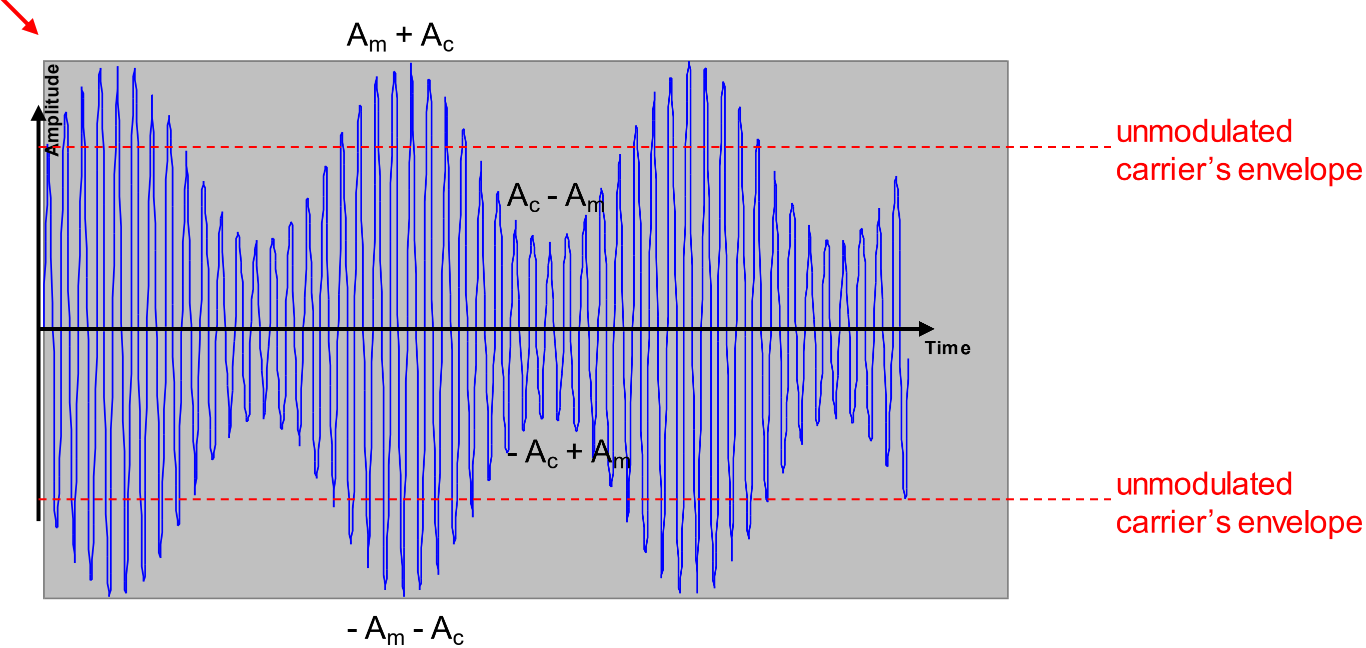


Simple receiver: envelope detector

→ The envelope of the MODULATED signal swings around the envelope of the (unmodulated) carrier

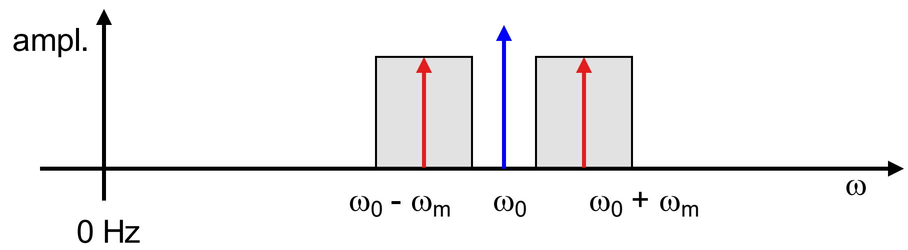
→ Demodulation: rectification (either the positive or the negative envelope is rectified)





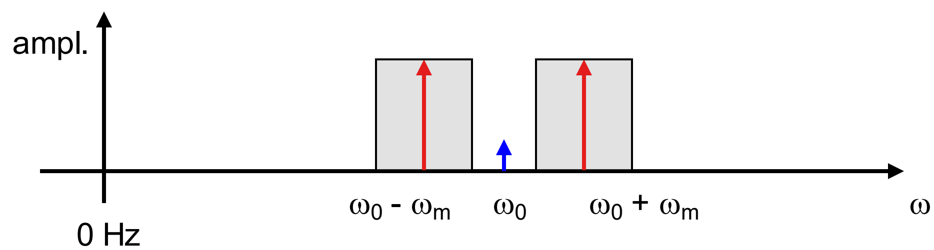
AM "variants"

The most commonly used (and hystorically the first) version: double-sideband (non-suppressed carrier): DSB



Double-sideband, suppressed carrier: DSB-SC

→ In practice a small proportion of the carrier is transferred to help the receiver to synchronize

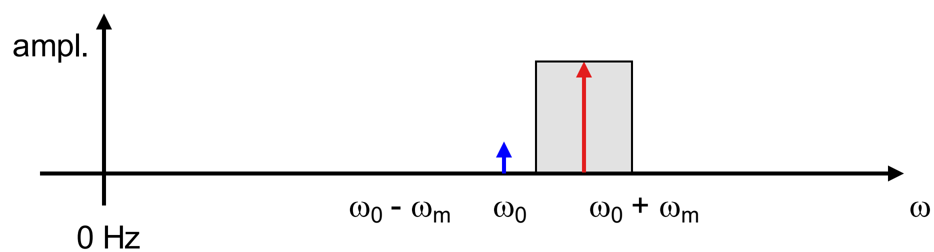


Single sideband, suppressed carrier (upper sideband): SSB-SC / USB

→ saves bandwidth (one sideband already contains the whole information)

→ also requires a coherent receiver

→ In practice a small proportion of the carrier is transferred to help the receiver to synchronize

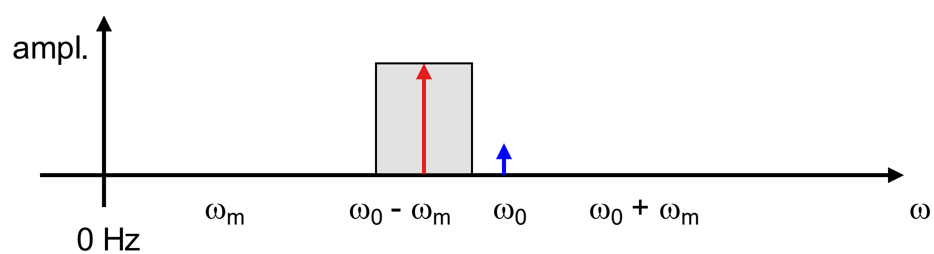


Single sideband, suppressed carrier (lower sideband): SSB / LSB

→ saves bandwidth (one sideband already contains the whole information)

→ also requires a coherent receiver

→ In practice a small proportion of the carrier is transferred to help the receiver to synchronize



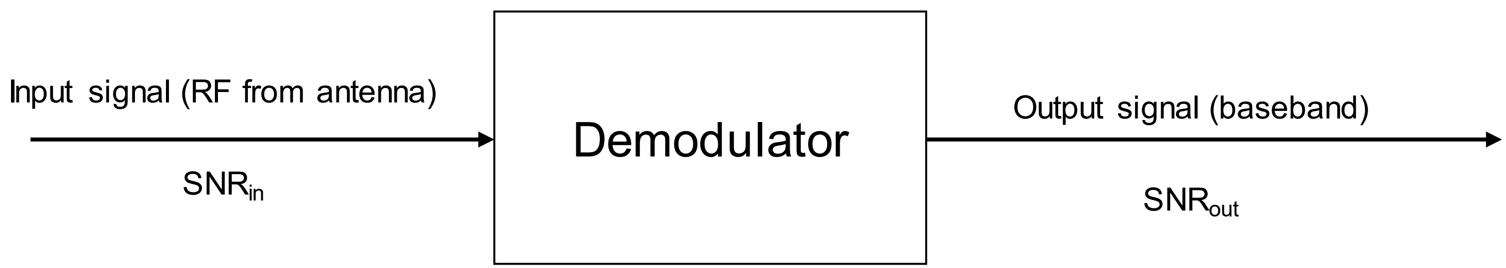
Demodulation analysis: demodulation gain

In general, (nearly) every circuit degrades the signal-to-noise ratio (SNR) of a signal passing through it

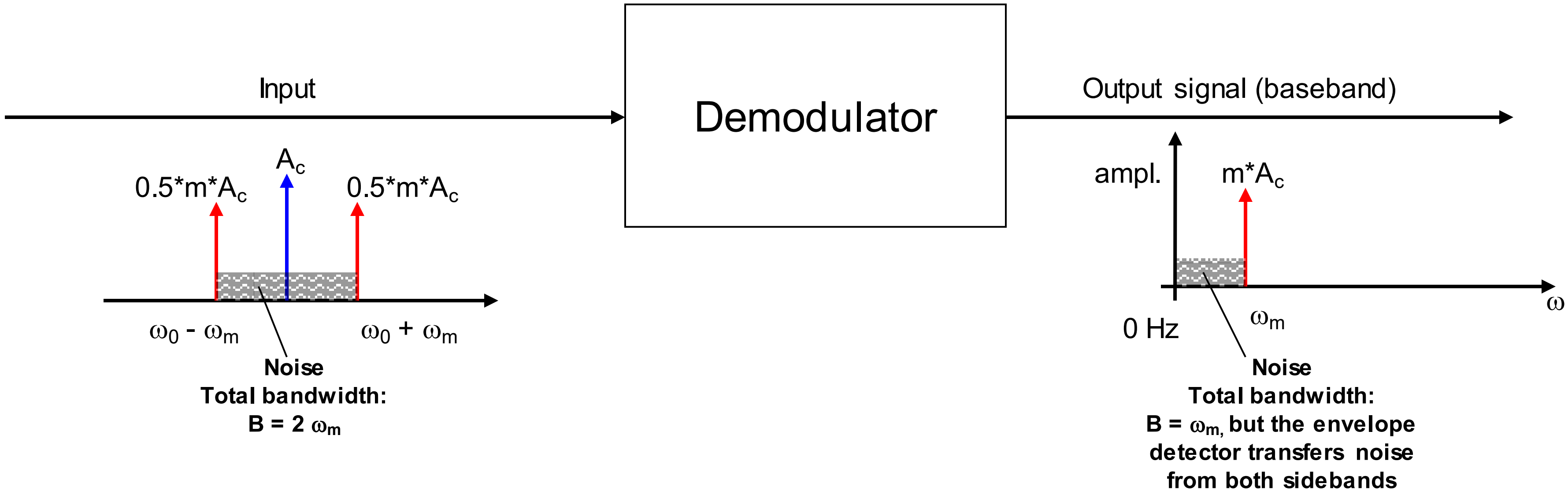
Concept: theoretical analysis of the SNR before and after the demodulator and determining their ratio, assuming that

→ the input signal has a relatively good SNR (> 25 dB, i.e. the receiver is not close to failure)

→ the demodulator itself is ideal (has no distortion and noise)



Case 1: AM-DSB transmission demodulated with conventional envelope detector

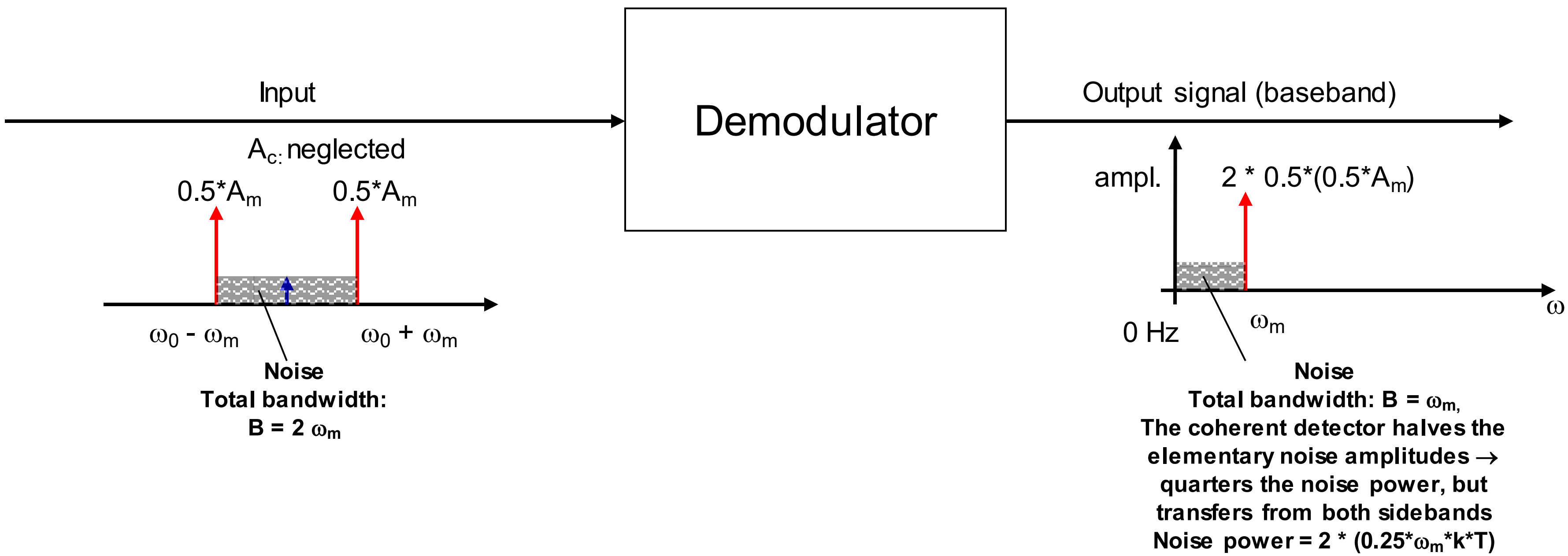


	Input	Output
Signal power	$A_c^2 + 2 * (0.5mA_c)^2$	$(mA_c)^2$
Noise power	$(2f_m) * k * T$	$2 * (f_m * k * T)$

$$\Rightarrow \frac{SNR_{out}}{SNR_{in}} = \frac{m^2}{1 + m^2/2}$$

- Always < 1 → always degrades
- Best case when m = 1 (100% modulation depth) → 2/3

Case 2: AM-DSB / SC transmission demodulated with coherent receiver



	Input	Output
Signal power	$2 * (0.5A_m)^2$	$0.25*A_m^2$
Noise power	$(2f_m) * k * T$	$0.5 * f_m * k * T$

$$\Longrightarrow \frac{SNR_{out}}{SNR_{in}} = 2$$

- Theoretical improvement!
- More complicated receiver, but better performance!

Further cases without deduction:

Case 3: AM-DSB (non-suppressed carrier), demodulated with coherent demodulator

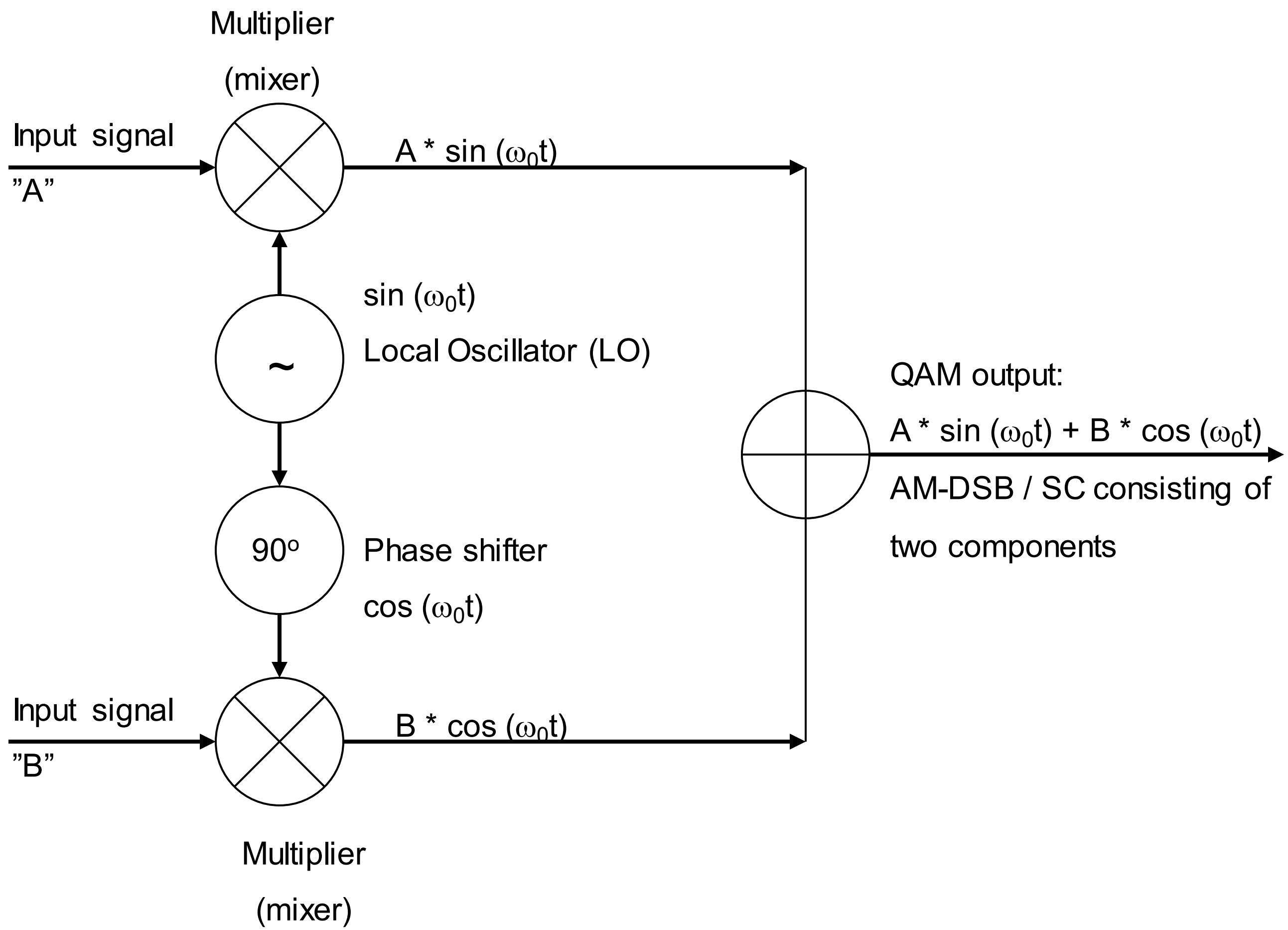
Possible, but $\frac{SNR_{out}}{SNR_{in}} = \frac{m^2}{1 + m^2/2}$, like in case of the envelope detector $\rightarrow$ it doesn't make sense to demodulate a non-suppressed carrier transmission with a coherent receiver

Case 4: AM-SSB / SC (LSB or USB, suppressed carrier), demodulated with coherent demodulator

$\frac{SNR_{out}}{SNR_{in}} = 1$, i.e. worse than the DSB/SC but still better than the non-suppressed carrier transmission

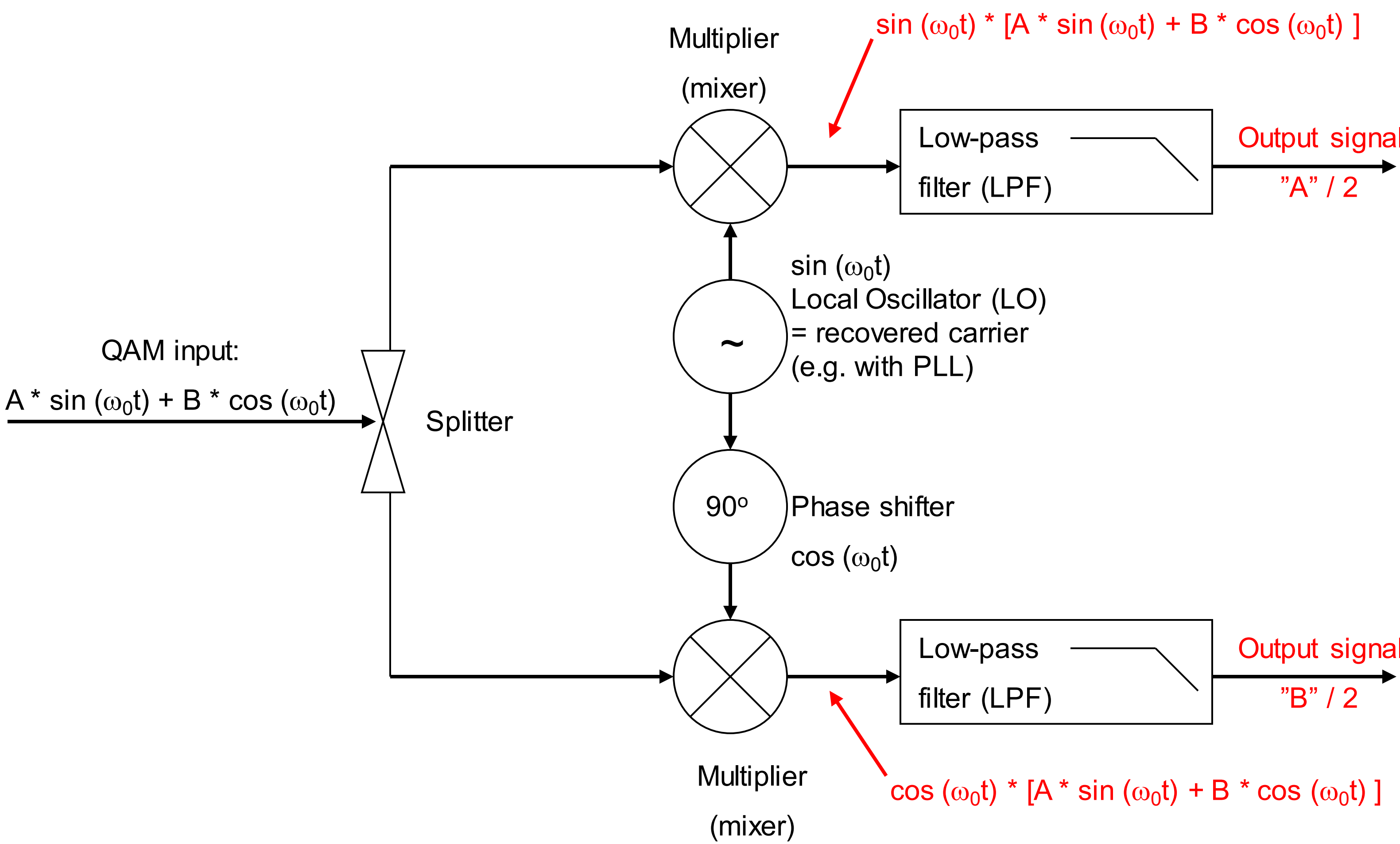
Transfer of two independent signals simultaneously on the same frequency: QAM

Quadrature Amplitude Modulation (QAM) = Vector Modulation

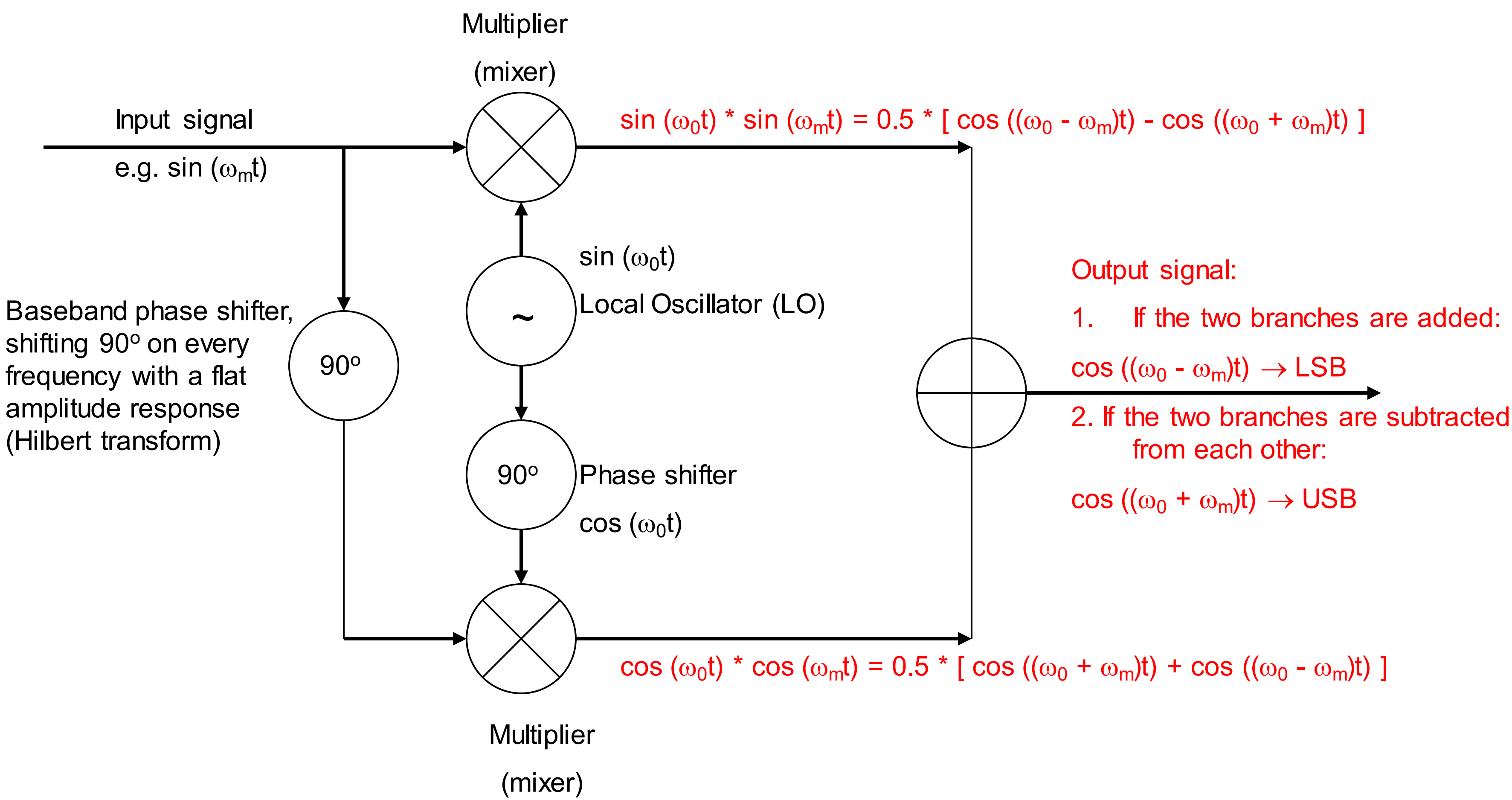


Transfer of two independent signals simultaneously on the same frequency: QAM

Demodulation: coherent detection on two parallel branches (requires carrier recovery)



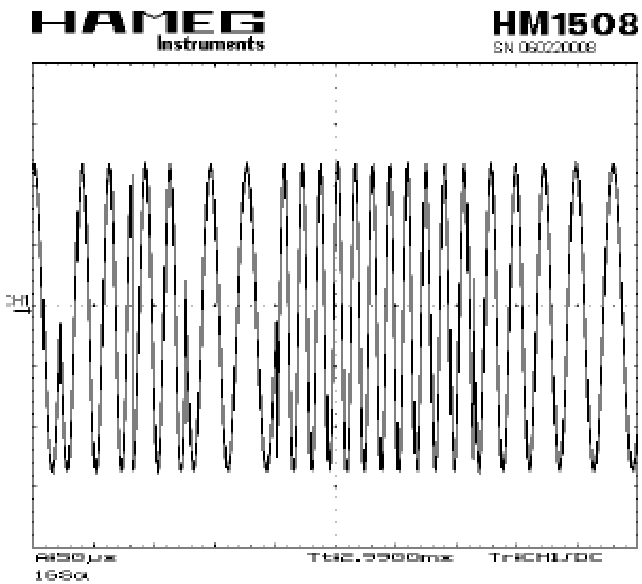
Special case: generation of SSB transmission with a QAM modulator

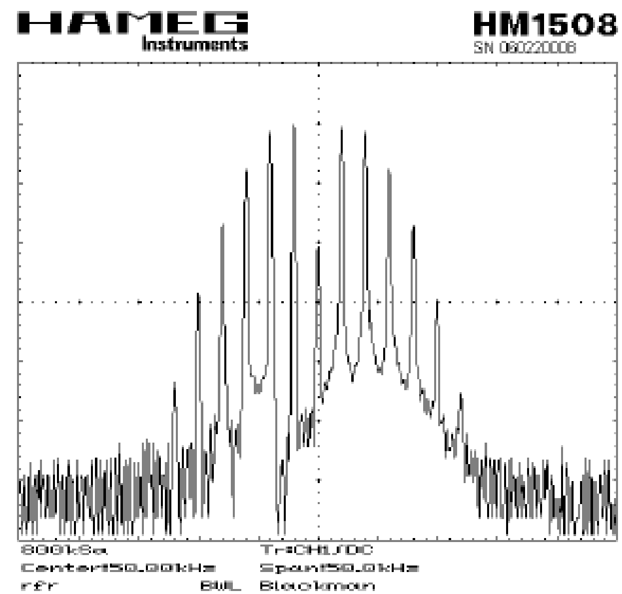


FM

- Frequency Modulation (FM)
  - The information is carried by the frequency of the carrier → the intantenous frequency of the carrier "swings" around its nominal value → maximal difference is the deviation f_D
  - The carrier's envelope is constant in time
  - The spectrum of the carrier is influenced by both the bandwidth and the amplitude of the baseband signal
  - Characterized by the modulation index: ratio of the deviation to the baseband signal's frequency

$$m_{FM} = \frac{f_D}{f_{max\ BB\ signal}}$$

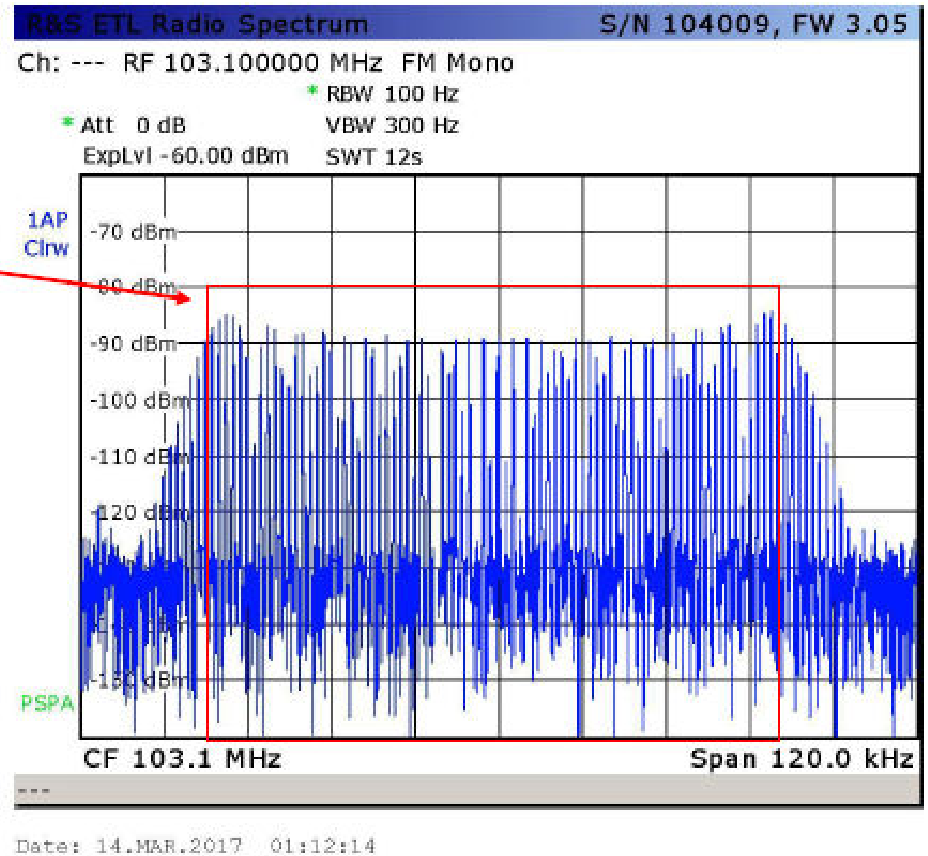




- Bandwidth: infinite (in principle, as described by Bessel functions), in practice approximated as

$$f_0 \pm (f_D + f_{max})$$

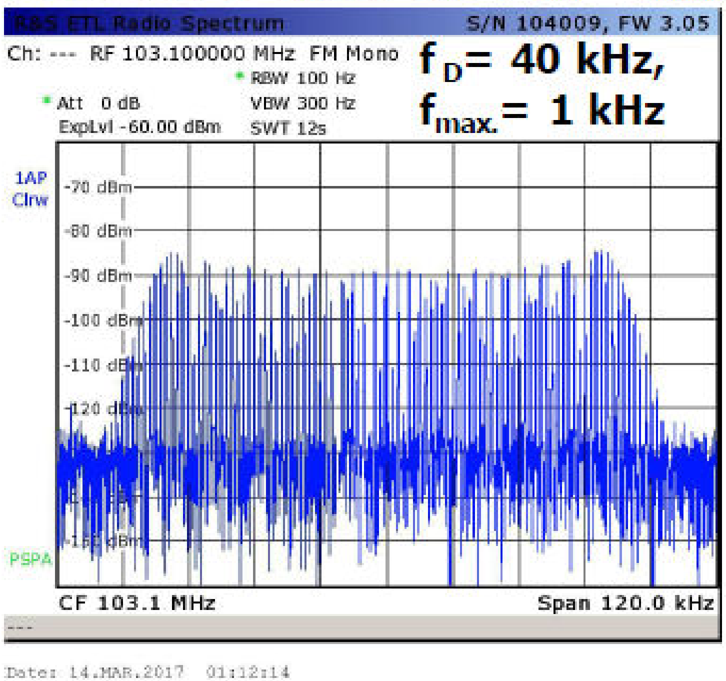
according to Carson, where f_{max} is the highest frequency component of the modulating signal and f_0 is the carrier frequency

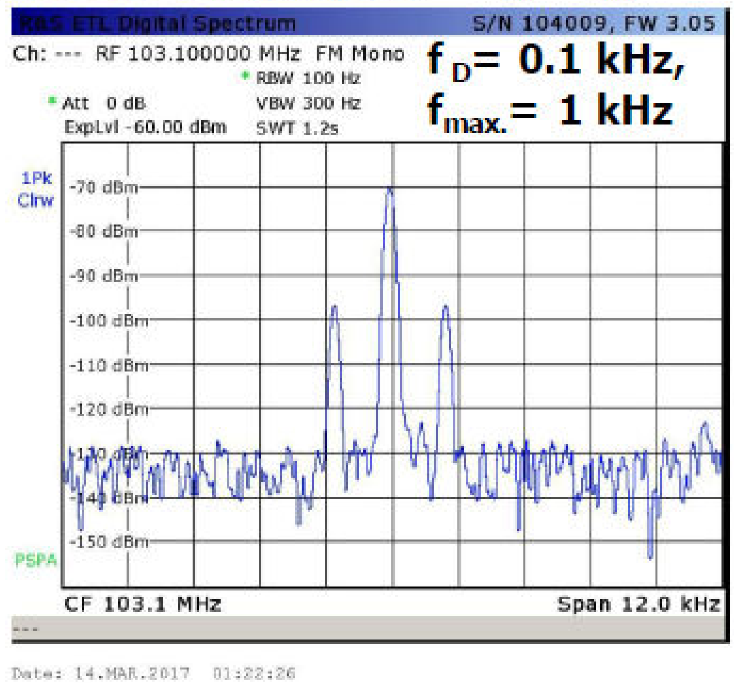


In this example
$f_0 = 103.1$ MHz, $f_D = 40$ kHz, $f_{max} = 1$ kHz

Mind that the actual bandwidth is higher than the one obtained with Carson's formula!

- Modulation index: $m_{FM} = f / f_D$, where f is a specific frequency component of the modulating signal
- Narrowband FM (NBFM): if $f_D < f_{max}$; in this case the bandwidth is $\approx f_0 \pm f_{max}$
- Wideband FM (WBFM): if $f_D > f_{max}$; in this case the bandwidth is $\approx f_0 \pm f_D$





Note that in extreme cases the FM spectrum may be similar to that of an AM-DSB signal

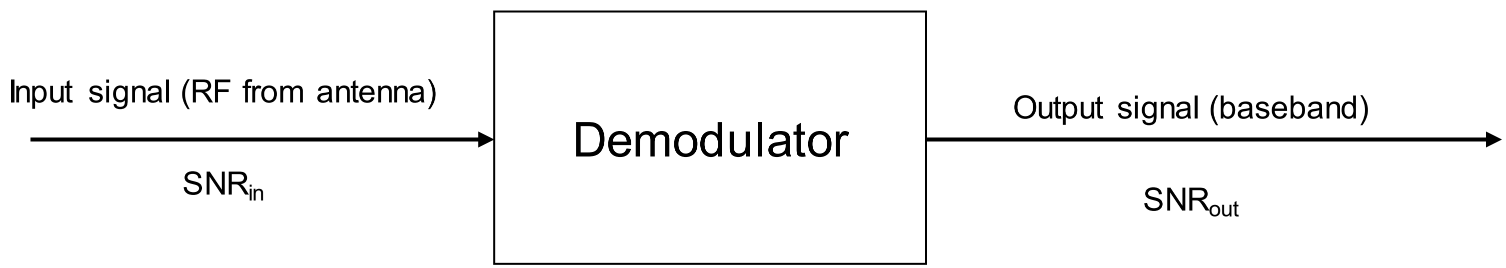
Demodulation gain: FM transmission demodulated with discriminator (slope detector)

In general, (nearly) every circuit degrades the signal-to-noise ratio (SNR) of a signal passing through it

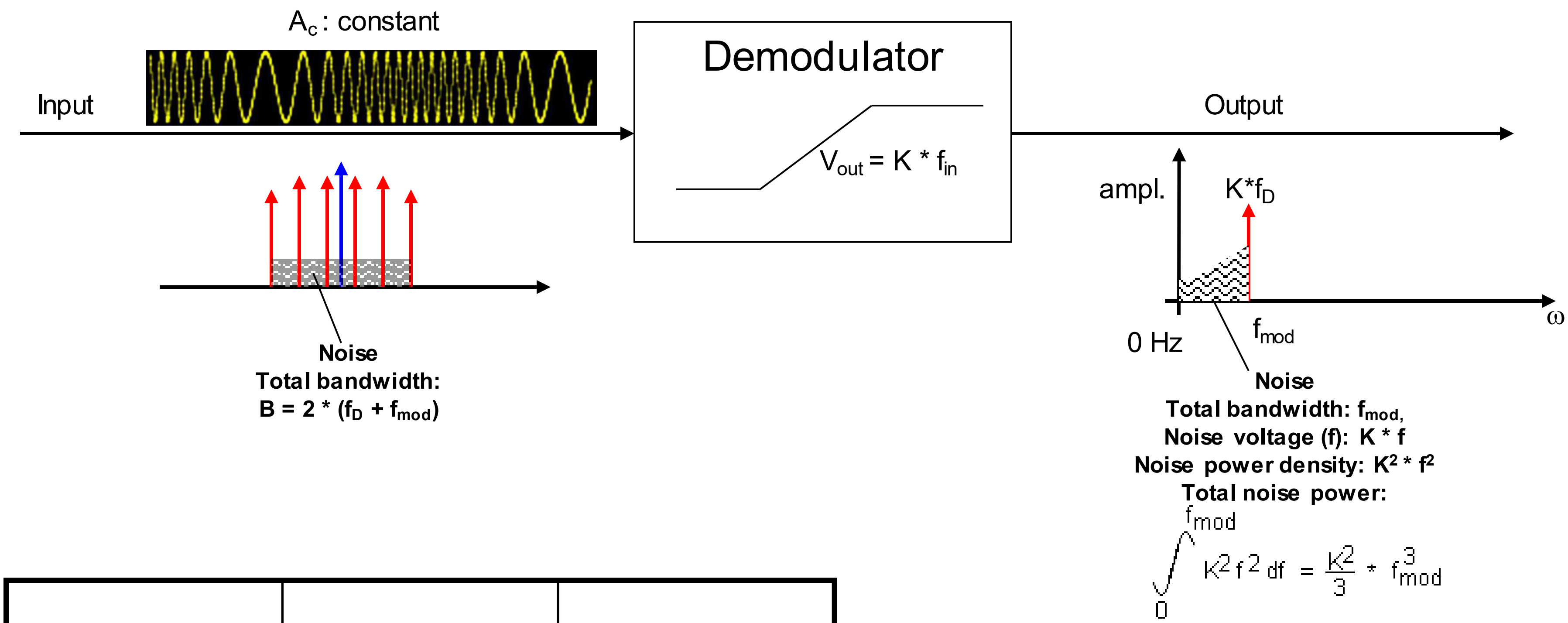
Concept: theoretical analysis of the SNR before and after the demodulator and determining their ratio, assuming that

→ the input signal has a relatively good SNR (> 25 dB, i.e. the receiver is not close to failure)

→ the demodulator itself is ideal (has no distortion and noise)



Demodulation gain: FM transmission demodulated with discriminator (slope detector)



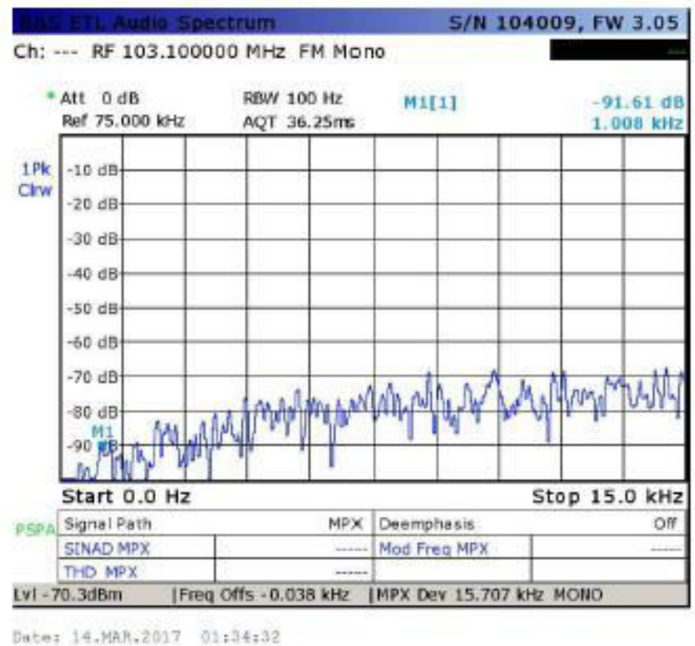
	Input	Output
Signal power	A_c^2	$K^2 * f_D^2$
Noise power	$2 * (f_D + f_m) * k * T$	$\frac{K^2}{3} * f_{mod}^3$

$$\Rightarrow \frac{SNR_{out}}{SNR_{in}} = Const. * \frac{f_D^2 \, (f_D + f_{mod})}{f_{mod}^3}$$

- For NBFM ($f_D << f_{mod}$): $\frac{f_D^2}{f_{mod}^2}$ **<< 1**
- For WBFM ($f_D >> f_{mod}$): $\frac{f_D^3}{f_{mod}^3}$ **>> 1**

Noise and demodulation gain in practice

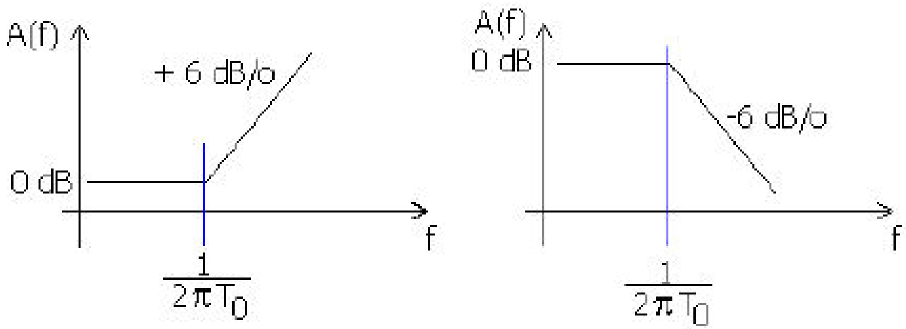
- Demodulation gain: the SNR of the demodulated signal relative to the SNR of the RF signal at the demodulator input
  - In case of NBFM: demodulation gain ~ m^2_{FM}
  - In case of WBFM: demodulation gain ~ m^3_{FM}
- The baseband noise power density increases with the frequency!



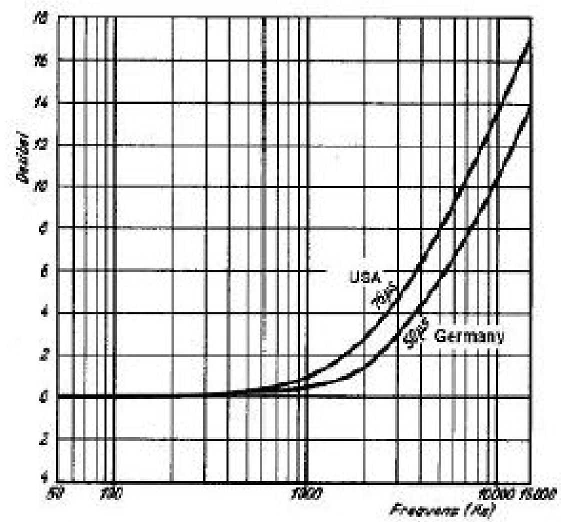
Noise and demodulation gain in practice

- The way to improve the baseband SNR: pre- and de-emphasis

The general principle:



...and as realized in the US and Europe*:



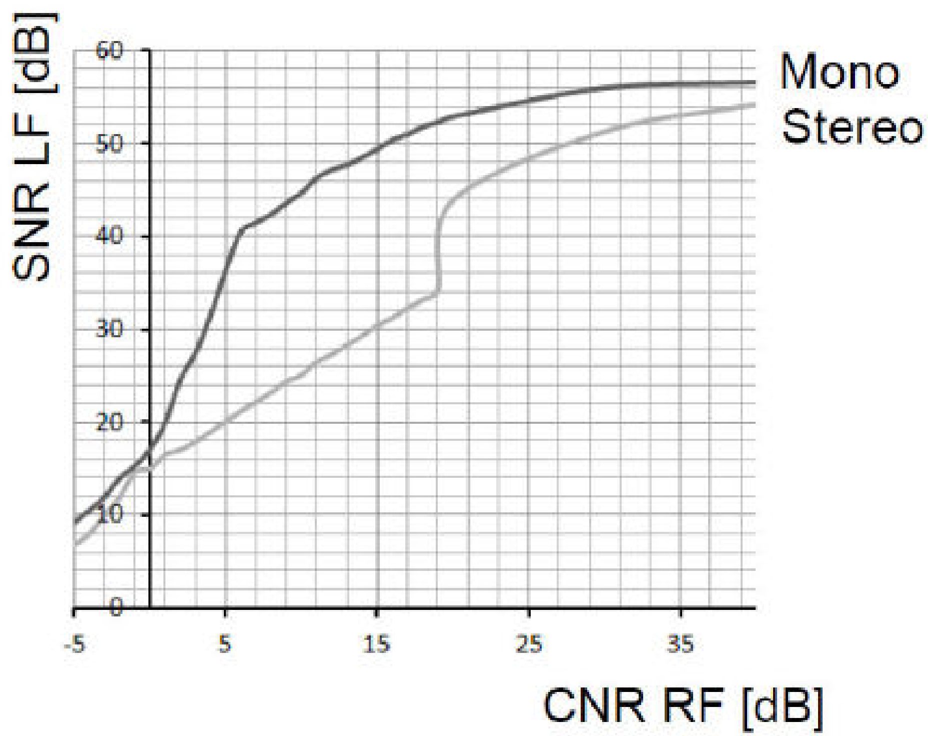
T_0 is 50 μs in Europe and 75 μs in the US

*Source: Mende, UKW-FM-Praktikum, Franzis Verlag

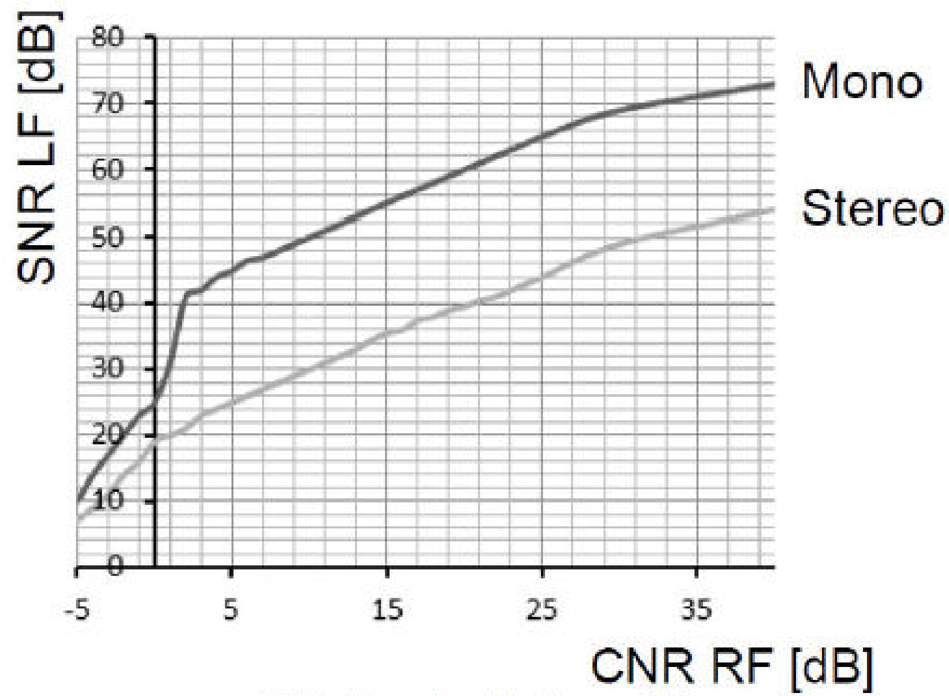
Noise and demodulation gain in practice

- The demodulation gain in practice: SNR out vs. CNR in*

For a car radio:



For an FM receiver:



40 kHz deviation, 50 us

*Source: R&S, 1MAT-Fi, Measurements on Terrestrial Broadcast Signals

- And the stereo transmission, pilot signal and RDS (and SCA, if applicable)