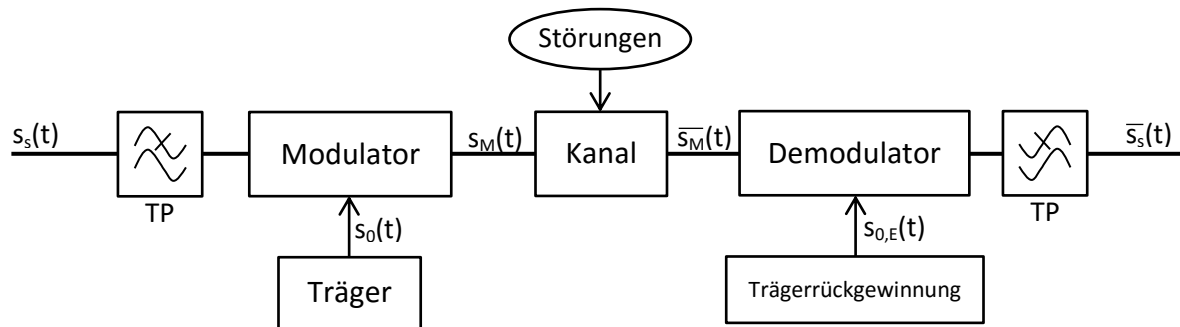


Modulation



$s_s(t)$ Basissignal

$s_0(t)$ Träger

$s_M(t)$ moduliertes Signal

$s_{0,E}(t)$ empfangsseitig zugesetzter Träger

$\bar{s}_s(t)$ demoduliertes Signal

Modulation ist die Veränderung von Signalparametern eines Trägers in Abhängigkeit eines zu modulierenden Signals. Die Demodulation ist die Rückgewinnung der in einer modulierten Trägerschwingung enthaltenen Signalinformation.

Gründe für Modulation:

- Mehrfachausnutzung des zur Verfügung stehenden Übertragungskanal
- Verbesserung der Signalanpassung an den Übertragungskanal
- Erzielung günstiger Störabstände

Modulation mit Sinusträger

Allgemeiner Sinusträger:

$$s(t) = \hat{s}(t) * \cos(\omega_0 t + \varphi(t))$$

Amplitudenmodulation
AM
Trägerfrequenz
Frequenzmodulation
FM, PM

Amplitudenmodulation

$$s_M(t) = \hat{s}_M(t) * \cos(\omega_0 t + \varphi_0)$$

$$\hat{s}_M(t) = \hat{s}_0 + s_s(t)$$

Trägeramplitude (Offset)

$$\cos(\alpha + \beta) = \cos\alpha * \cos\beta - \sin\alpha * \sin\beta$$

$$s_M(t) = \underbrace{[\hat{s}_0 + s_s(t)] * \cos(\varphi_0) * \cos(\omega_0 t)}_{s_I(t)} - \underbrace{[\hat{s}_0 + s_s(t)] * \sin(\varphi_0) * \sin(\omega_0 t)}_{s_Q(t)}$$

Inphase-Komponente Quadratur-Komponente

$$s_M(t) = s_I(t) + s_Q(t)$$

Gewöhnliche Amplitudenmodulation: $\varphi = 0$, $\hat{s}_0 > 0$

AM: $s_M(t) = [\hat{s}_0 + s_s(t)] * \cos(\omega_0 t)$

Signal (reiner Sinus): $s_s(t) = \hat{s}_s * \cos(\omega_s t)$

$$s_M(t) = \hat{s}_0 * \cos(\omega_0 t) + \hat{s}_s * \cos(\omega_s t) * \cos(\omega_0 t)$$

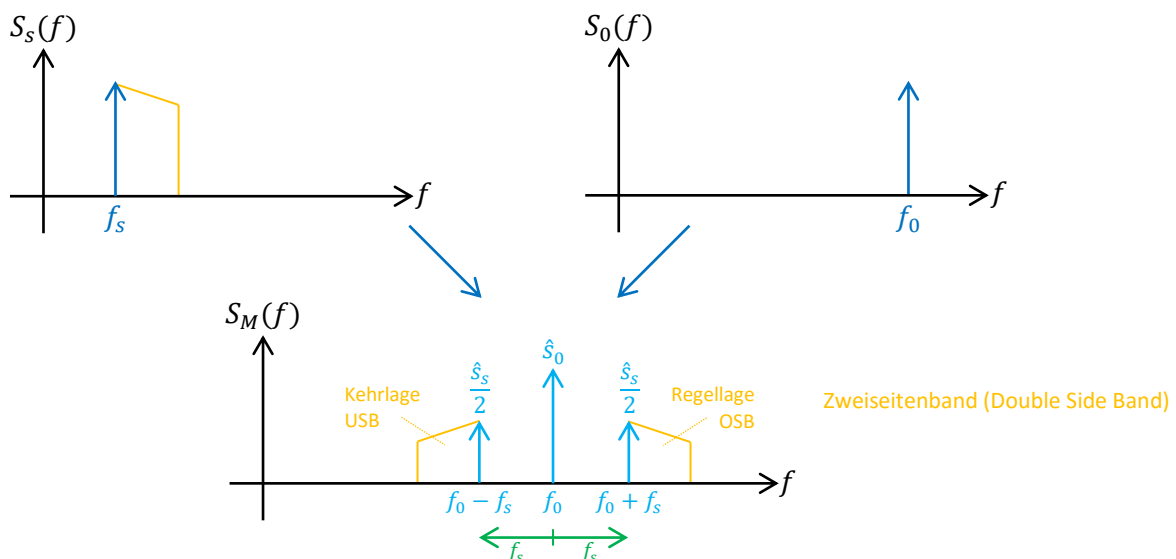
$$\cos\alpha * \cos\beta = \frac{1}{2} * [\cos(\alpha + \beta) + \cos(\alpha - \beta)]$$

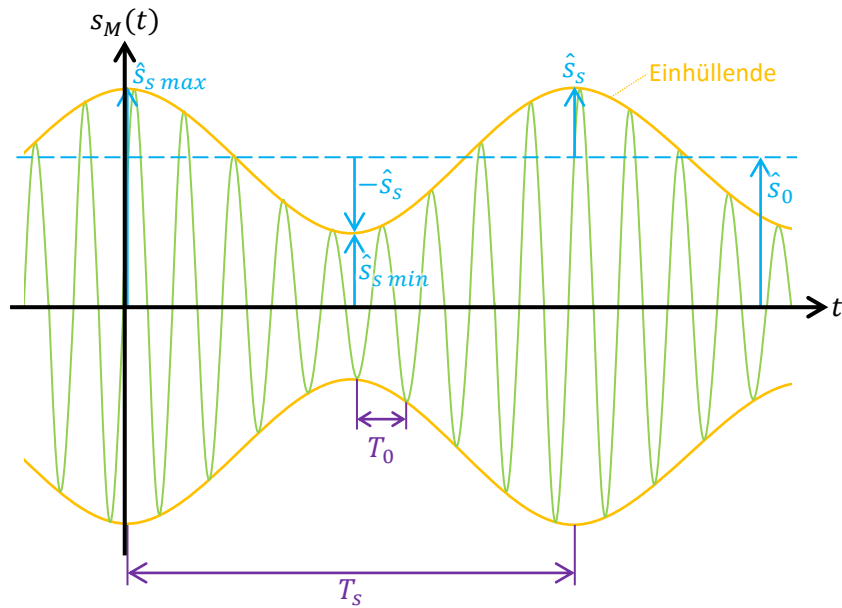
$$s_M(t) = \hat{s}_0 * \cos(\omega_0 t) + \frac{\hat{s}_s}{2} * \cos[(\omega_0 + \omega_s)t] + \frac{\hat{s}_s}{2} * \cos[(\omega_0 - \omega_s)t]$$

$$s_M(t) = \hat{s}_0 * \left\{ \cos(\omega_0 t) + \frac{m}{2} * \cos[(\omega_0 + \omega_s)t] + \frac{m}{2} * \cos[(\omega_0 - \omega_s)t] \right\}$$

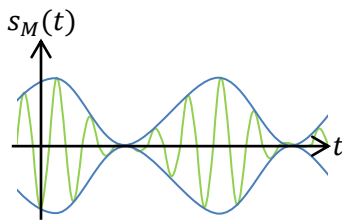
$$m = \frac{\hat{s}_s}{\hat{s}_0} \dots \text{Modulationsfaktor} = \frac{\text{Signalamplitude}}{\text{Trägeramplitude}}$$

Spektrum der Amplitudenmodulation:

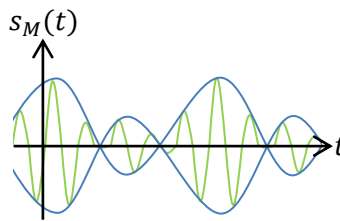


Zeitsignal:

m=1:



m>1:

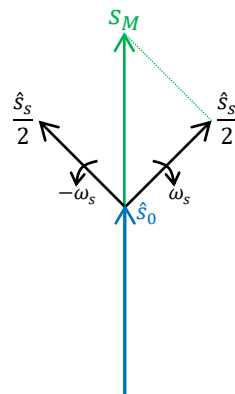


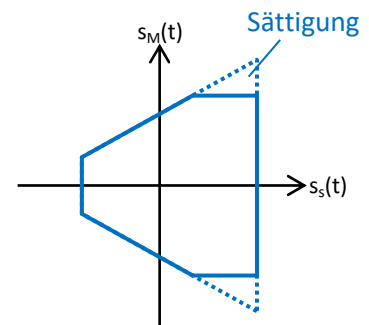
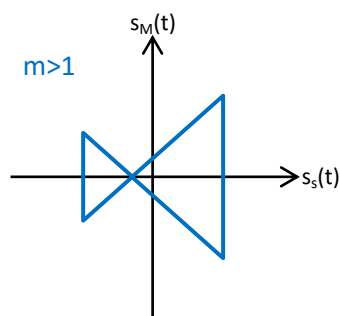
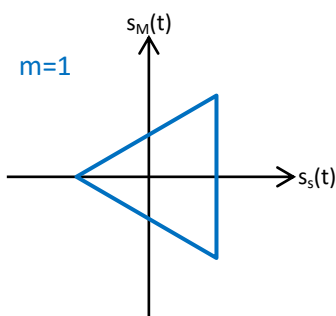
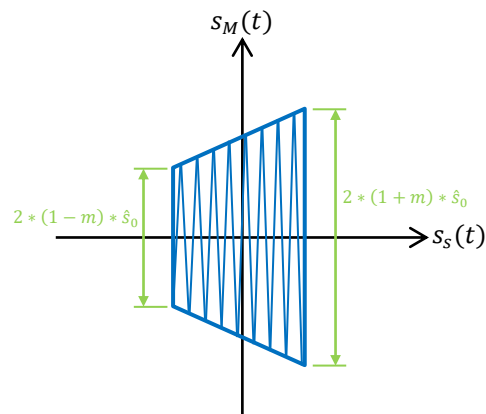
Bei Modulationsfaktor m>1 entstehen Oberwellen

komplexe Schreibweise, Zeigerdiagramm:

$$\underline{s}_M(t) = \underline{s}_T(t) * e^{j\omega_0 t}$$

$$\underline{s}_T(t) = \hat{s}_0 * \left(1 + \frac{m}{2} * e^{j\omega_s t} + \frac{m}{2} * e^{-j\omega_s t} \right)$$



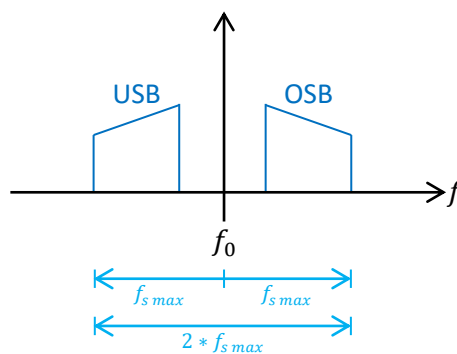
Modulationstrapez:**Leistungsinhalt:**

$$P_{ges} = P_0 + P_{OSB} + P_{USB} = P_0 * \left(1 + \frac{m^2}{2}\right)$$

$$m = 1: P_{ges} = P_0 * \left(1 + \frac{1}{2}\right) = 1,5 * P_0$$

Bandbreite:

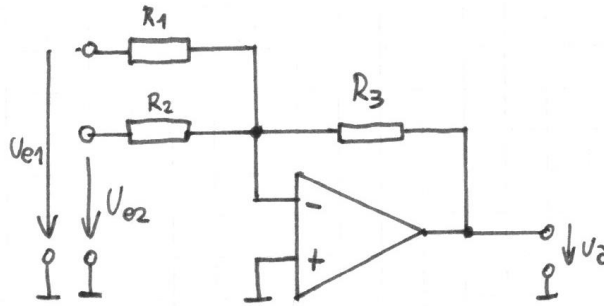
$$B_{HF} = 2 * B_{BB}$$



Modulationsschaltung:

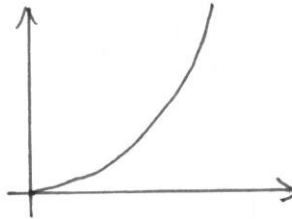
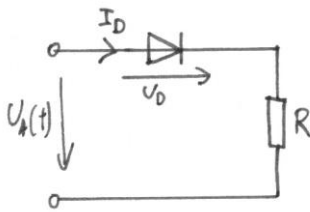
$$s_M(t) = [\hat{s}_0 + \hat{s}_s * \cos(\omega_s t)] * \cos(\omega_0 t)$$

Addition:



$$U_a = -R_3 * \left(\frac{U_{e1}}{R_1} + \frac{U_{e2}}{R_2} \right)$$

Multiplikator:



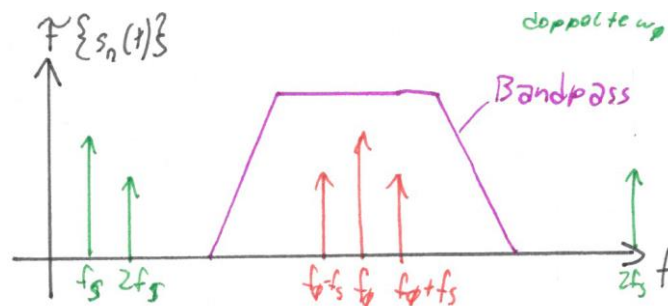
$$I_D = I_S * \left(e^{\frac{U_D}{m * U_T}} - 1 \right)$$

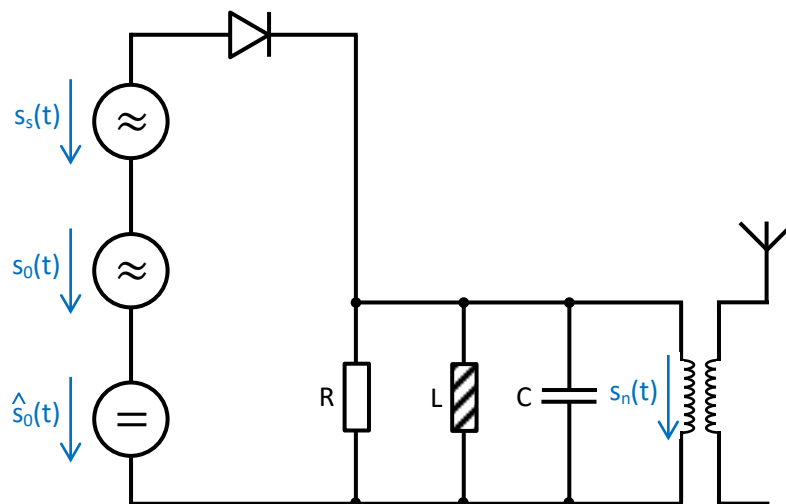
$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

$$U_D = U_A * [\cos(\omega_s t) + \cos(\omega_0 t)]$$

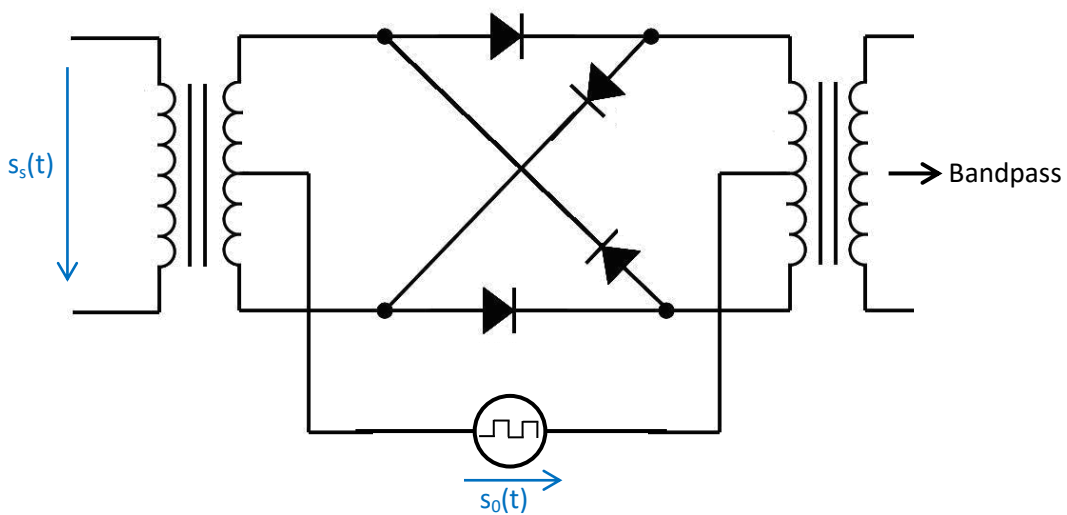
$$U_D^2 = U_A^2 * [\cos^2(\omega_s t) + 2 * \cos(\omega_s t) * \cos(\omega_0 t) + \cos^2(\omega_0 t)]$$

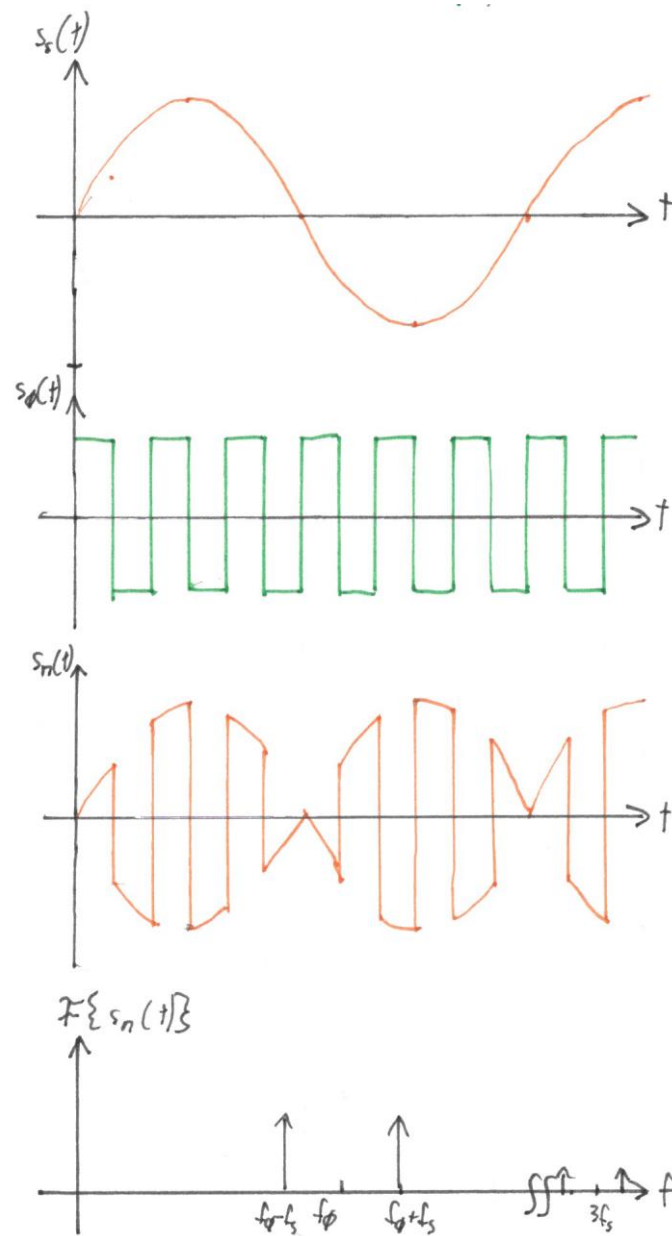
$$U_D^2 = U_A^2 * \left\{ \frac{1}{2} * [\cos(2\omega_s t) + 1] + \frac{2}{2} * [\cos((\omega_s + \omega_0) * t) + \cos((\omega_s - \omega_0) * t)] + \frac{1}{2} * [\cos(2\omega_0 t) + 1] \right\}$$



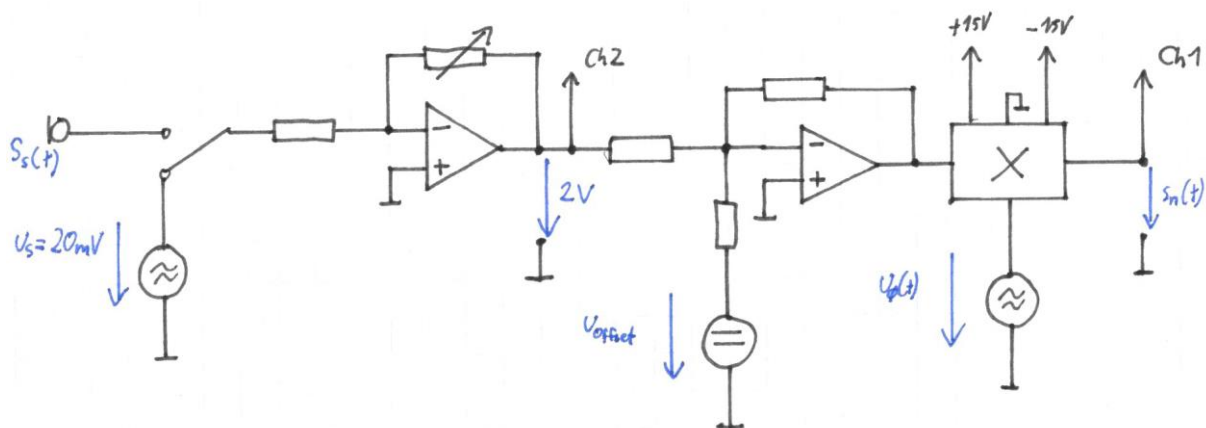
Diodenmodulator:**Ringmodulator:**

AM mit unterdrücktem Träger



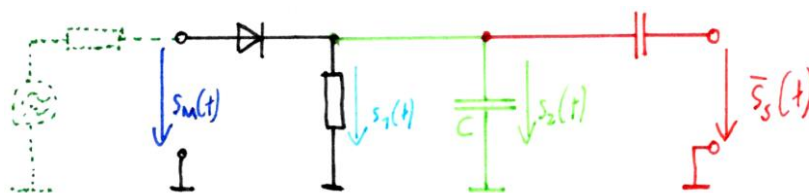


Amplitudenmodulator



Demodulator

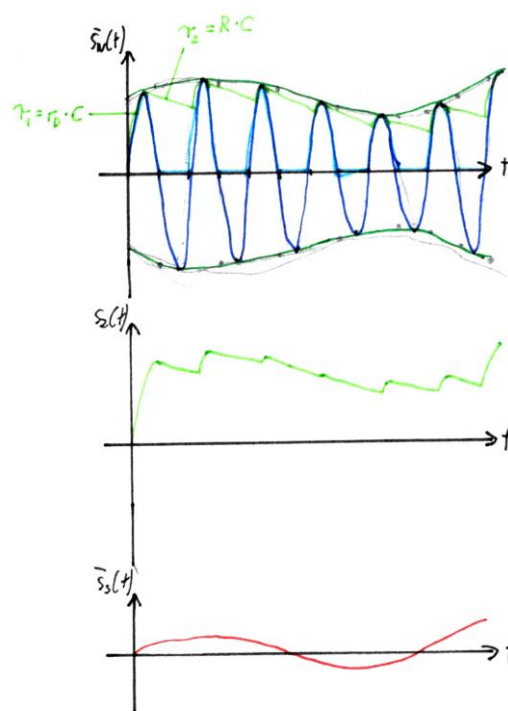
Hüllkurvendemodulator:

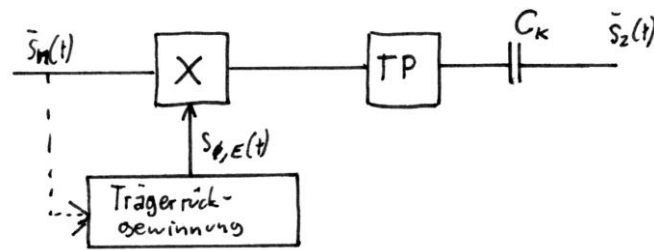


$$f_g = \frac{1}{2\pi \cdot R \cdot C}$$

$$f_s \ll f_g \ll f_0$$

$$\frac{10}{\omega_0} \leq R \cdot C \leq \frac{\sqrt{1-m^2}}{m \cdot \omega_{s \max}}$$



Köhrearter Demodulator:

$$s_n(t) = [\hat{s}_0 + s_s(t)] * \cos(\omega_0 t + \varphi_0)$$

$$s_{0,E}(t) = \hat{s}_{0,E} * \cos(\omega_{0,E} t + \varphi_{0,E})$$

$$s_n(t) * s_{0,E}(t) = [\hat{s}_0 + s_s(t)] * \hat{s}_{0,E} * \cos(\omega_0 t + \varphi_0) * \cos(\omega_{0,E} t + \varphi_{0,E})$$

$$s_n(t) * s_{0,E}(t) = [\hat{s}_0 + s_s(t)] * \hat{s}_{0,E} * \frac{1}{2} \left\{ \underbrace{\cos[(\omega_0 + \omega_{0,E}) * t + \varphi_0 + \varphi_{0,E}]}_{2 * \omega_0 \text{ mit TP wegfiltern}} + \underbrace{\cos[(\omega_0 - \omega_{0,E}) * t + \varphi_0 - \varphi_{0,E}]}_0 \right\}$$

Frequenzgleichheit: $\omega_0 = \omega_{0,E}$

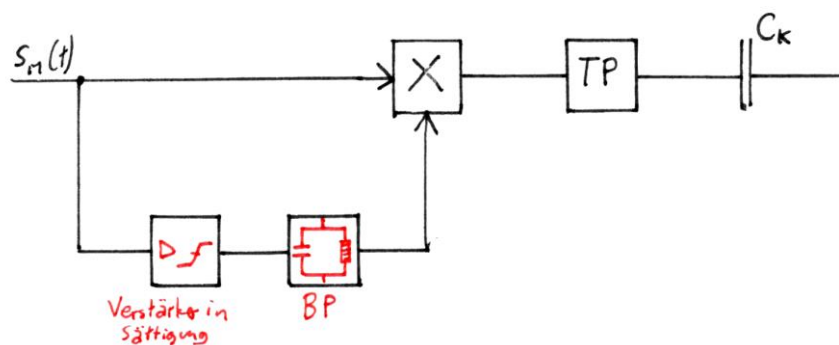
Nach TP: $[\hat{s}_0 + s_s(t)] * \frac{\hat{s}_{0,E}}{2} * \cos(\varphi_0 - \varphi_{0,E})$

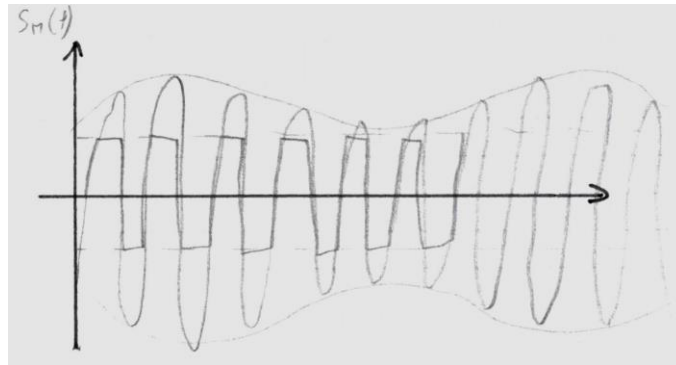
Nach C_k (Koppelkondensator):

$$s_s(t) * \frac{\hat{s}_{0,E}}{2} * \cos(\varphi_0 - \varphi_{0,E}) \rightarrow s_s(t)$$

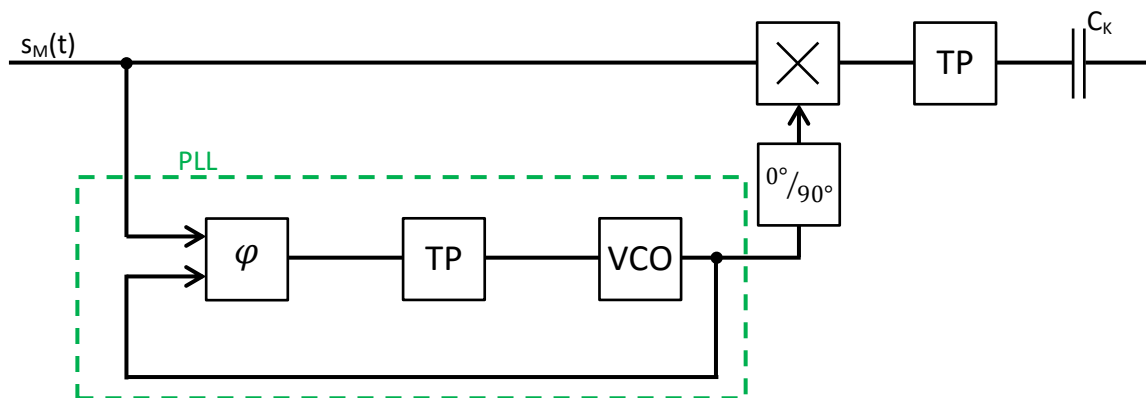
Phasengleichheit:
 $\varphi_0 = \varphi_{0,E}$

$\varphi_0 - \varphi_{0,E} = 90^\circ \rightarrow 0$ (kein Signal bei 90° Phasenverschiebung)

AM-Produktmodulator mit Trägerrückgewinnung:



Kohärenter Demodulator mit PLL (Phase-Locked-Loop / Phasenregelschleife):

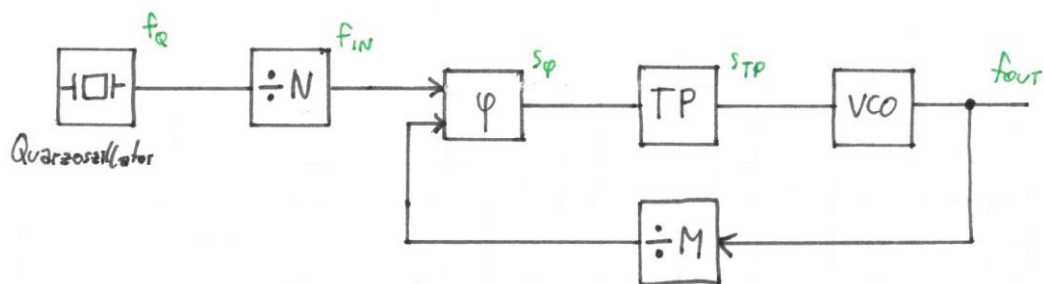


φ Phasendiskriminator

TP Schleifenfilter

VCO Voltage Controlled Oscillator

Takterzeugung mit PLL:



Quarzoszillator: Vorteil: hohe Güte, hohe Frequenzgenauigkeit

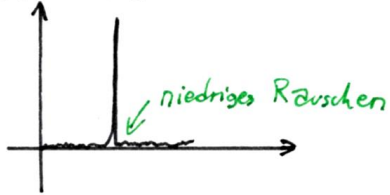
Nachteil: Frequenz nicht veränderbar

VCO, LC-Oszillator: Vorteil: Frequenz veränderbar

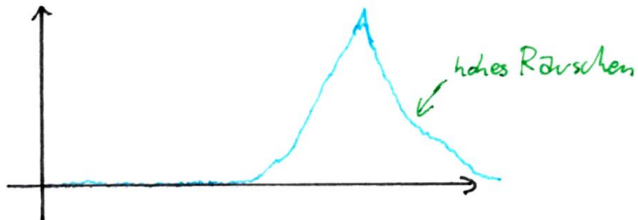
Nachteil: Frequenz ungenau

PLL

Spektrum Quarzosz.



Spektrum VCO unregelt



Spektrum VCO geregelt, PLL

