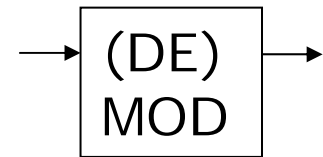
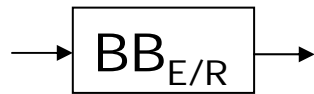


TLC system block scheme

Part of the material in:

O.Andrisano, G.Mazzini, "*Appunti di Sistemi di Telecomunicazione – sistemi di trasmissione digitali passabanda*", soc. ed. Esculapio

O.Andrisano, D.Dardari, "*Appunti di Sistemi di Telecomunicazione – elementi di progetto di sistemi radiomobili*", soc. ed. Esculapio

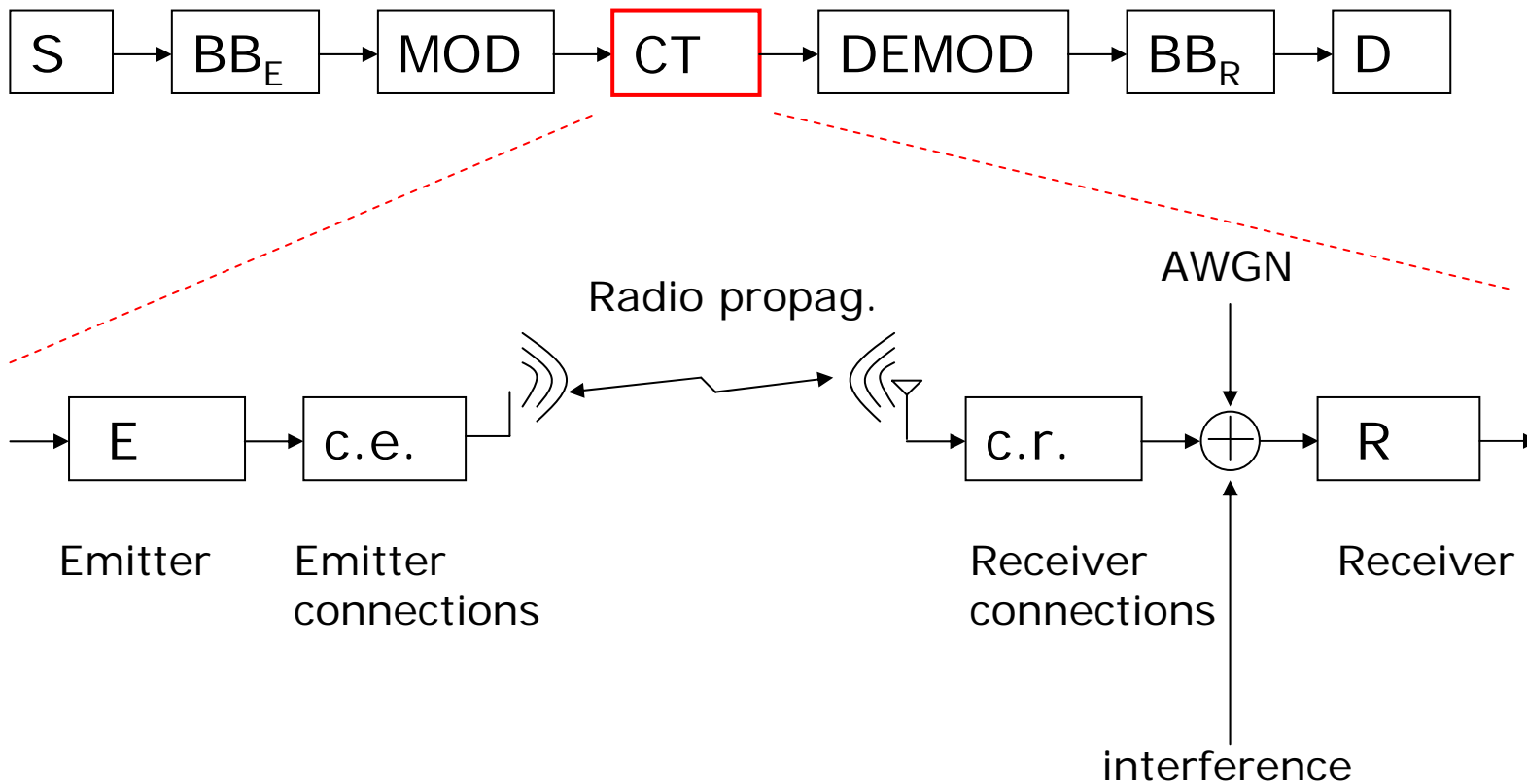


Base-band processing at emitter-receiver sides (e.g., pre/de-emphasis) (e.g., coding, PAM mod, synch recovery, sampling, detection,...)

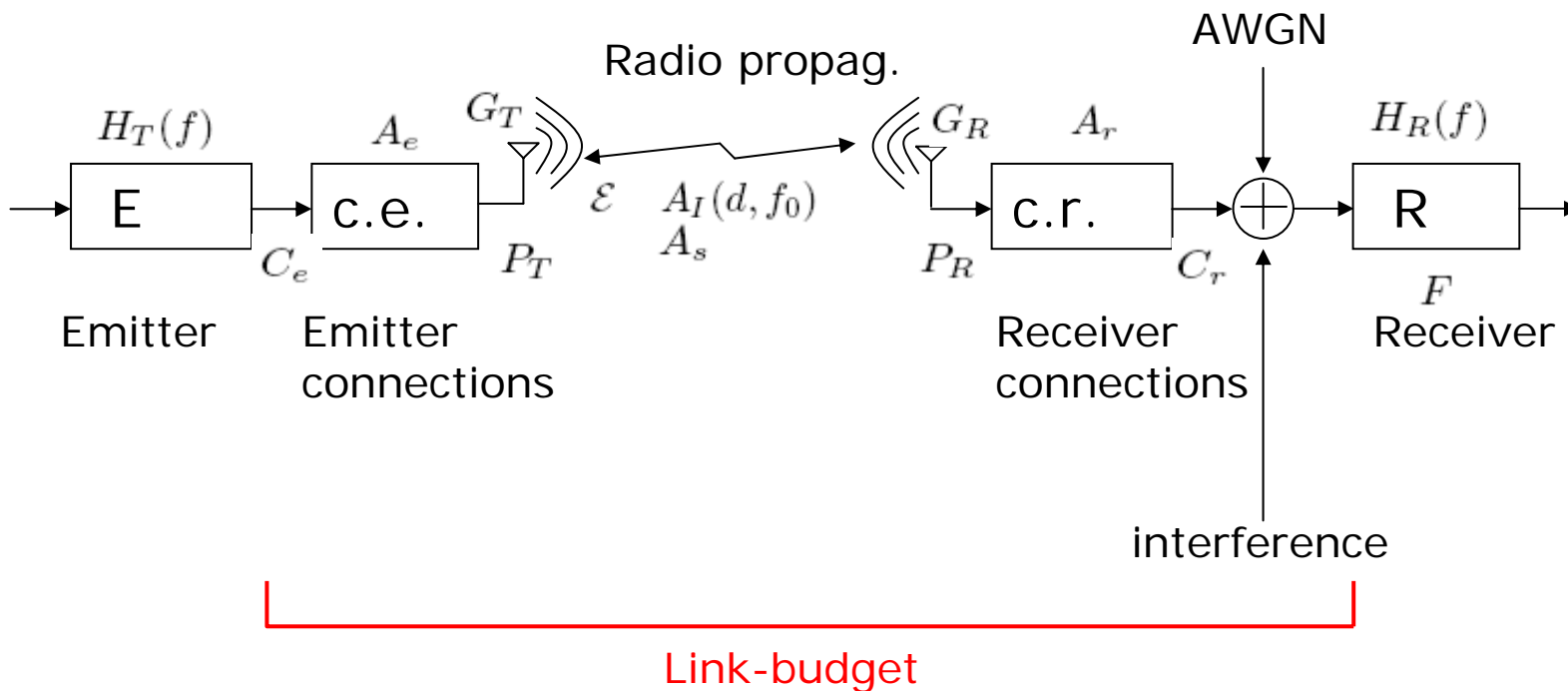
Transmission channel: tx/rx filters (antennas) propagation medium AWGN interference

Modulator Demodulator

Wireless Transmission Channel 1/2



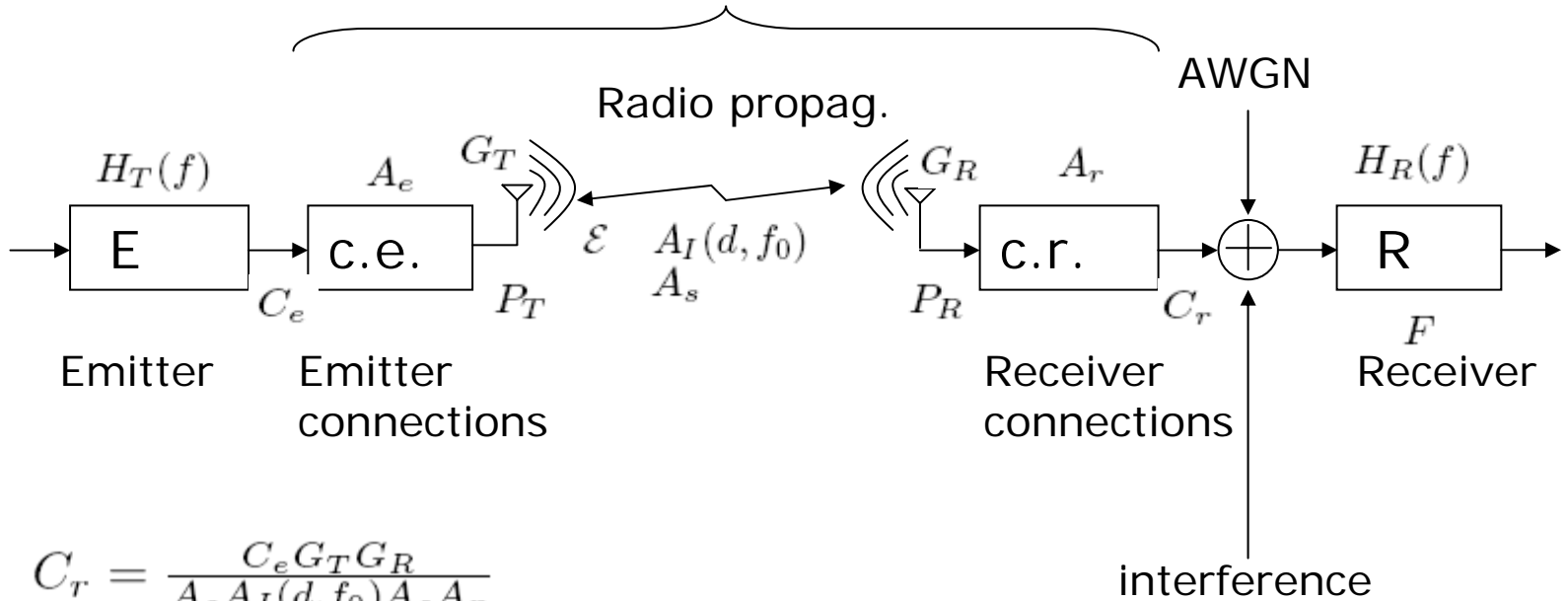
Wireless Transmission Channel 2/2



Link-budget 1/3

Narrow-band characterization

$$H_{MP}(f), \quad |H_{MP}(f_0)|^2 = \frac{1}{A(d, f_0)} = \frac{C_r}{C_e}$$



$$C_r = \frac{C_e G_T G_R}{A_e A_I(d, f_0) A_s A_r}$$

$$C_r(\text{dBm}) = C_e(\text{dBm}) - A_e(\text{dB}) + G_T(\text{dB}) - A_I(\text{dB}) - A_s(\text{dB}) + G_R(\text{dB}) - A_r(\text{dB})$$

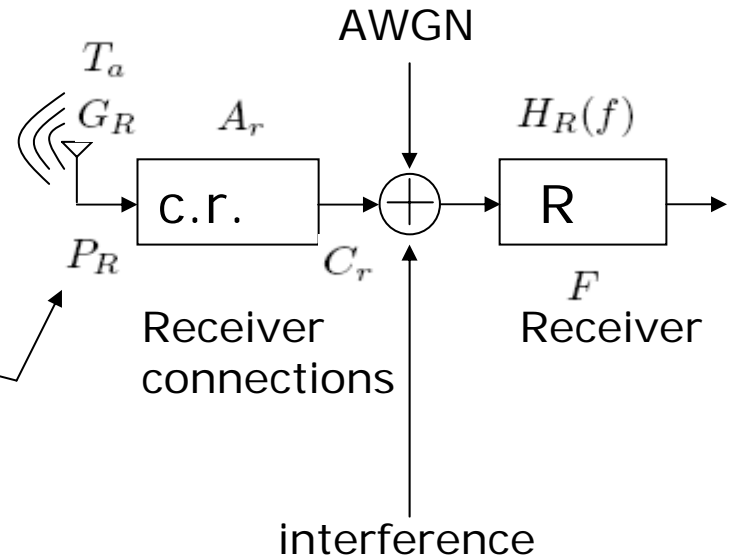
dBW dBW Tx antenna gain Isotropic attenuation margin Rx antenna gain

Link-budget 2/3

$$p = P_R / A_u$$

$$A_u = \frac{\lambda^2 G_R}{4\pi} [m^2]$$

$$E = \sqrt{2\eta p} [V/m]$$



Parabolic antenna $A_u = \eta_g A_g = \eta_g \pi D^2 / 4$

Vacuum

$$\eta_0 = 377 [\Omega]$$

$$A_I = A_{I0} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$$

$$A_{I0}(\text{dB}) = 32.4 + 20 \log_{10} d_{[Km]} + 20 \log_{10} f_{[MHz]}$$

Equivalent noise system temperature (at the rx input)

$$T_{\text{sist}} = [T_a + (A_r - 1)T_0] / A_r + (F - 1)T_0$$

antenna noise temp

rx noise figure

Ref temperature

Signal-to-Noise ratio(s)

AWGN

$\nu(t)$

$$T_{\text{sist}} \leftrightarrow N_0^{(\text{mon})}$$

$$B_{eq} = \frac{1}{2|H_R(f_0)|^2} \int_{-\infty}^{+\infty} |H_R(f)|^2 df$$

RF SNR at the rx output

$$\rho = \frac{C}{N} = \frac{C_r |H_R(f_0)|^2}{N_0^{(\text{mon})} |H_R(f_0)|^2 B_{eq}} = \frac{C_r}{kT_{\text{sist}} B_{eq}}$$

Conventional RF SNR at the rx input

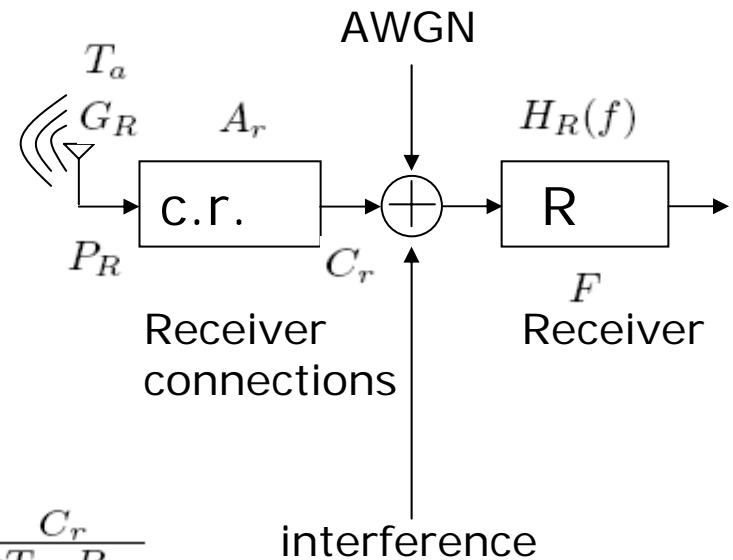
$$\rho_c = \frac{C}{N^*} = \frac{C_r}{kT_{\text{sist}} B^*} \quad \rho_c = \rho B_{eq} / B^*$$

$$B^* = 2 f_M \quad \text{analog}$$

$$B^* = R_b \quad \text{digital}$$

... emphasizing the RF bit-energy for digital systems (under particular conds)

$$\frac{E_b}{N_0^{(\text{mon})}} = \rho_c / F_p^2$$



Performance of digital communication systems in AWGN channel (no ISI)

A posteriori: error-rate (symbol, bit)

A priori (statistical characterization of random process):
error-probability (symbol, bit)

$$P_b \gtrsim \frac{P_e}{\log_2 L}$$

$$L\text{-ASK } P_e = \frac{L-1}{L} \operatorname{erfc} \left\{ \sqrt{\rho \frac{\cos^2(\Delta)}{(L-1)^2}} \right\}$$

$$P_b \gtrsim \frac{P_e}{\log_2 \sqrt{M}}$$

$$M\text{-QASK } P_e = \frac{\sqrt{M}-1}{\sqrt{M}} \operatorname{erfc} \left\{ \sqrt{\rho \frac{\cos^2(\Delta)}{2(\sqrt{M}-1)^2}} \right\}$$

$$P_b \gtrsim \frac{P_e}{\log_2 L}$$

$$L\text{-PSK, } L \geq 8, P_e = \frac{1}{2} \operatorname{erfc} \left\{ \sqrt{\rho \sin^2(\pi/L - \Delta)} \right\} + \frac{1}{2} \operatorname{erfc} \left\{ \sqrt{\rho \sin^2(\pi/L + \Delta)} \right\}$$

$$2\text{-DPSK, } P_b = P_e = \frac{e^{-\rho}}{2}$$

Gaussian-Q function

$$Q(x) = \frac{1}{2} \operatorname{erfc} \left\{ \frac{x}{\sqrt{2}} \right\}$$

Performance of analog communication systems in AWGN channel

$Q = SNR$ (mean power ratio) at the final user

$$Q = \frac{S_U}{N_U} = m_q \rho_c$$

$$Q = m_p m_q \rho_c$$

processing margin

generic
sinusoidal

$$m_q = 2 m_{a_{eff}}^2$$
$$m_q = \hat{m}_a^2$$

AM

$$m_q = 6 \Delta f_{eff}^2 / f_M^2$$
$$m_q = 3 \hat{\Delta f}^2 / f_M^2$$

FM

$$m_q = 2 \alpha_{eff}^2$$
$$m_q = \hat{\alpha}^2$$

PM

Video-FM:

$$m_q = 3 \hat{\Delta f}_{pp}^2 / f_M^2$$

Spectral efficiency of digital communication systems

$$\eta_s = \frac{R_b}{B} \quad [\text{bit/s/Hz}]$$

Spectral efficiency of analog communication systems

$$\eta_s = \frac{f_M}{B}$$

$$\text{AM} \quad \eta_s = 1/2$$

$$\text{FM, PM} \quad \eta_s = \frac{1}{2(1 + \widehat{\Delta f}/f_M)}$$

System Design 1/2

Minimum cost solution is adopted among those satisfying QoS requirements

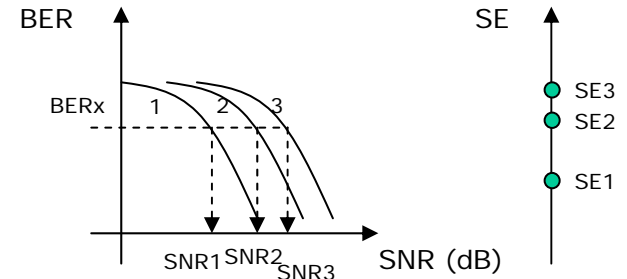
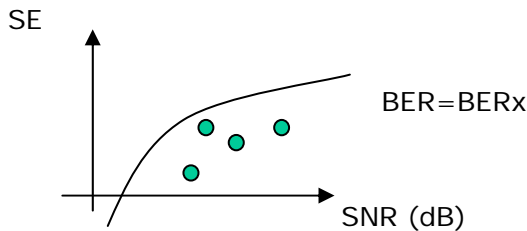
MOS

QoS (subjective)
I like yes-no, a lot, a few...



QoS (objective)
BER, SNR

Trade-off bandwidth-power



Link-budget 3/3

$$C_r = \frac{C_e G_T G_R}{A_e A_I(d, f_0) A_s A_r}$$

$$C_r(\text{dBm}) = C_e(\text{dBm}) - A_e(\text{dB}) + G_T(\text{dB}) - A_I(\text{dB}) - A_s(\text{dB}) + G_R(\text{dB}) - A_r(\text{dB})$$

System figure

$$\mathcal{I} = \mathcal{E} \mathcal{R} \mathcal{M}$$

ERP [W]

Rx figure [1/K]

Signal processing figure [K/W]

$$\mathcal{E} = P_T G_T$$

$$\mathcal{R} = \frac{G_R}{A_r T_{\text{sis}}}$$

$$\mathcal{M} = \frac{m}{2k f_M}$$

$$m = m_p m_q \quad \text{analog}$$

$$m = \rho_c^{(\text{ref})} / \rho_c \quad \text{digital (ref=antipodal)}$$



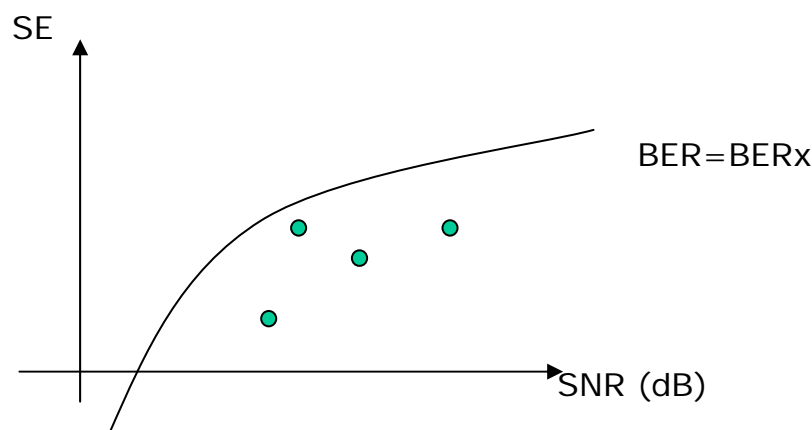
analog	$\mathcal{I} = Q_x A_I A_s$
digital	$\mathcal{I} = \rho_{cx} A_I A_s$

$$P_{bx} = \frac{1}{2} \text{erfc} \sqrt{\rho_c^{(\text{ref})}}$$

System design 2/2

From performance and spectral efficiency requirements possible solutions and required SNRs are obtained. Thus, the link-budget provides required power levels

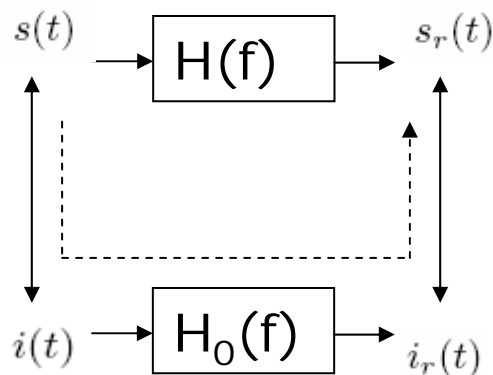
Research on new modulation & coding techniques (OFDM, turbo-codes, LDPC,...), as well as diversity techniques is toward the enhancement of the trade-off SE-SNR



The performance evaluation requires a careful characterization of the transmission channel as well as disturbances (i.e., noise, interference).

Low-pass equivalent signal and system 1/2

Mathematical methodology useful to evaluate signals transformation through the channel



$$h_0(t) = h_+(t) \exp[-j2\pi f_0 t]$$

$$H_0(f) = H_+(f + f_0) = H_-^*(-f - f_0)$$

$$s(t) = \Re \{ i(t) \exp[j2\pi f_0 t] \}$$

$$i(t) = 2s_+(t) \exp[-j2\pi f_0 t]$$

$$i_r(t) = i(t) * h_0(t)$$

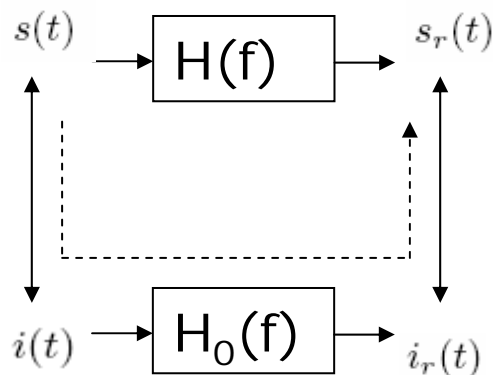
$$I_r(f) = I(f)H_0(f)$$

$$s_r(t) = \Re \{ i_r(t) \exp[j2\pi f_0 t] \}$$

$$s(t) = V_0[1 + m(t)] \cos(2\pi f_0 t + \alpha(t) + \varphi_0)$$

Low-pass equivalent signal and system 2/2

$H_0(f)$ can be implemented (not only mathematics) iff the channel is symmetric $H_0(-f) = H_0^*(f)$ (i.e., hermitian around f_0) → it is called **base-band equivalent system**



$$h_0(t) = h_+(t) \exp[-j2\pi f_0 t]$$

$$H_0(f) = H_+(f + f_0) = H_-^*(-f - f_0)$$

example: equalization + matched filter

$$H_{T0}(f) = \sqrt{CR_\alpha(f)/G(f)}$$

$$H_{R0}(f) = \sqrt{CR_\alpha(f)}$$