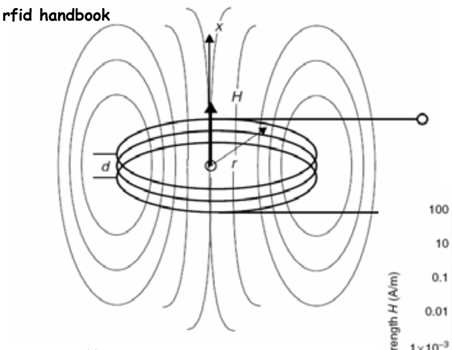
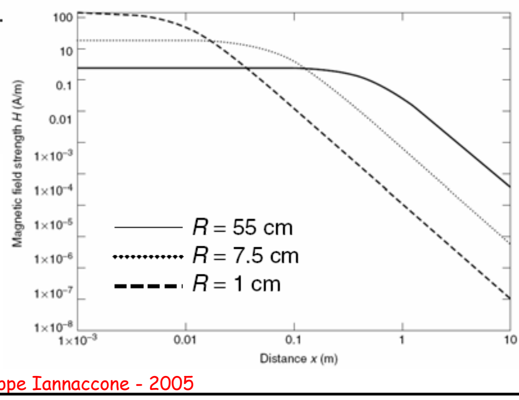
Transponder ad accoppiamento induttivo

Campo magnetico indotto da un avvolgimento con spire circolari

rfid handbook



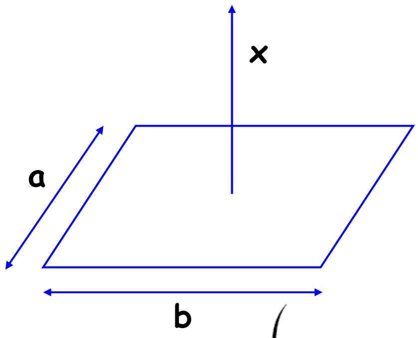
- per x << R: $H = \frac{I \cdot N}{2R}$
- pe x >> R: $H = \frac{I \cdot N \cdot R^2}{2x^3}$



- Sull'asse, se d << R e x < $\lambda/2\pi$.

$$H = \frac{I \cdot N \cdot R^2}{2\sqrt{(R^2 + x^2)^3}}$$

Campo magnetico indotto da un avvolgimento con spire rettangolari



$$H = \frac{N \cdot I \cdot ab}{4\pi\sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2 + x^2}} \cdot \left(\frac{1}{\left(\frac{a}{2}\right)^2 + x^2} + \frac{1}{\left(\frac{b}{2}\right)^2 + x^2} \right)$$

- x >> a/2, b/2 → $H \approx 1/x^3$

Relazione tra portata e dimensione ottimale delle spire

- Nelle espressioni precedenti consideriamo x fissato, e calcoliamo R per cui H(R,x) è massimo
- Caso di spire circolari:

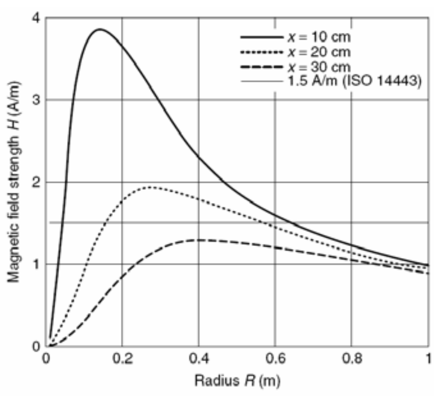
$$\frac{\partial H}{\partial R} = \frac{RNI}{\left(R^2+x^2\right)^{3/2}} - \frac{3INR^2}{4\left(R^2+x^2\right)^{5/2}} 2R =$$

$$NIR \frac{2\left(R^2+x^2\right) - 3R^2}{2\left(R^2+x^2\right)^{5/2}} = NIR \frac{2x^2 - R^2}{2\left(R^2+x^2\right)^{5/2}} = 0$$

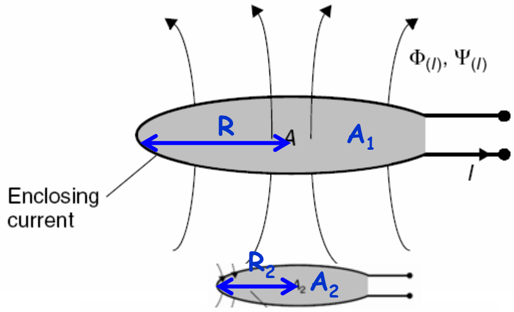
- abbiamo $R = x\sqrt{2}$

$$H = \frac{I \cdot N}{2} \frac{2x^2}{3^{3/2} x^3} = \frac{NI}{x} \cdot \frac{1}{3^{3/2}}$$

- es. ISO 14443 H=1.4 A/m, x=1 m
- → R=1.4 m, N=10, I ~A



Induttanza di un avvolgimento



$$L = \frac{\Psi}{I} = \frac{N \cdot \Phi}{I} = \frac{N \cdot \mu \cdot H \cdot A}{I}$$

- Se d << R, N spire circolari

$$L = N^2 \mu_0 R \cdot \ln\left(\frac{2R}{d}\right)$$

- Mutua

$$M_{21} = \frac{\Psi_{21}(I_1)}{I_1} = \oint_{A2} \frac{B_2(I_1)}{I_1} \cdot dA_2$$

- Nel caso che A_2 <<A, e si possa considerare B uniforme in A_2 (uguale al valore sull'asse):

$$M_{21} = M_{12} = \frac{\mu_0 H_1(x) N_2 A_2}{I_1}$$

- otteniamo

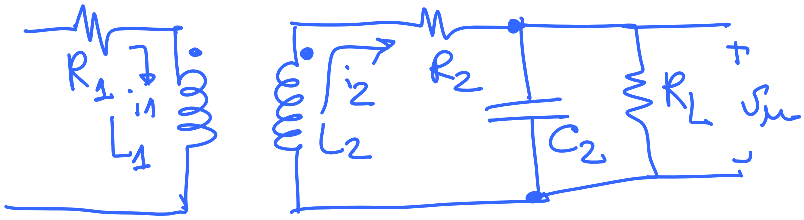
$$M_{12} = \frac{\mu_0 \cdot N_1 \cdot R_1^2 \cdot N_2 \cdot R_2^2 \cdot \pi}{2\sqrt{(R_1^2 + x^2)^3}}$$

- se x >> R_1, $M \approx 1/x^3$,
- se x << R_1, $M \approx 1/R_1$

Coefficiente di accoppiamento

$$k = \frac{M}{\sqrt{L_1 \cdot L_2}}$$

- 0 < k < 1
- Nei casi pratici, in sistemi RFID otteniamo k ≈ 1%
- Se gli assi dei due avvolgimenti formano un angolo θ, $k = k_{max} \cos\theta$

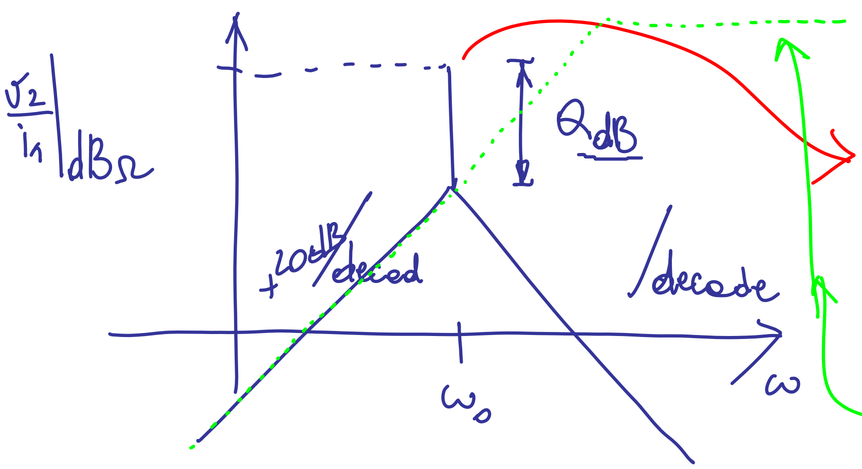


$$i_2 = \frac{j\omega M i_1}{R_2 + j\omega L_2 + \frac{R_L}{j\omega R_L C_2 + 1}} \longrightarrow v_2 = i_2 \frac{R_L}{j\omega R_L C_2 + 1}$$

$$v_2 = \frac{j\omega M R_L i_1}{(R_2 + j\omega L_2)(1 + j\omega R_L C_2) + R_L} = \frac{j\omega M R_L i_1}{R_2 + R_L + j\omega(L_2 + R_2 R_L C_2) - \omega^2 R_L L_2 C_2}$$

$$\omega_0 = \sqrt{\frac{R_2 + R_L}{R_L L_2 C_2}} \qquad \frac{1}{Q\omega_0} = \left[\frac{L_2 + R_2 R_L C_2}{R_2 + R_L}\right]$$

$$v_2 = \frac{j\omega M \frac{R_L}{R_L + R_2} i_1}{1 + j\frac{\omega}{\omega_0 Q} - \frac{\omega^2}{\omega_0^2}}$$



$$\frac{M \frac{R_L}{R_2 + R_L}}{\frac{L_2 + R_2 R_L C_2}{R_2 + R_L}} = \frac{M R_L}{L_2 + R_2 R_L C_2}$$

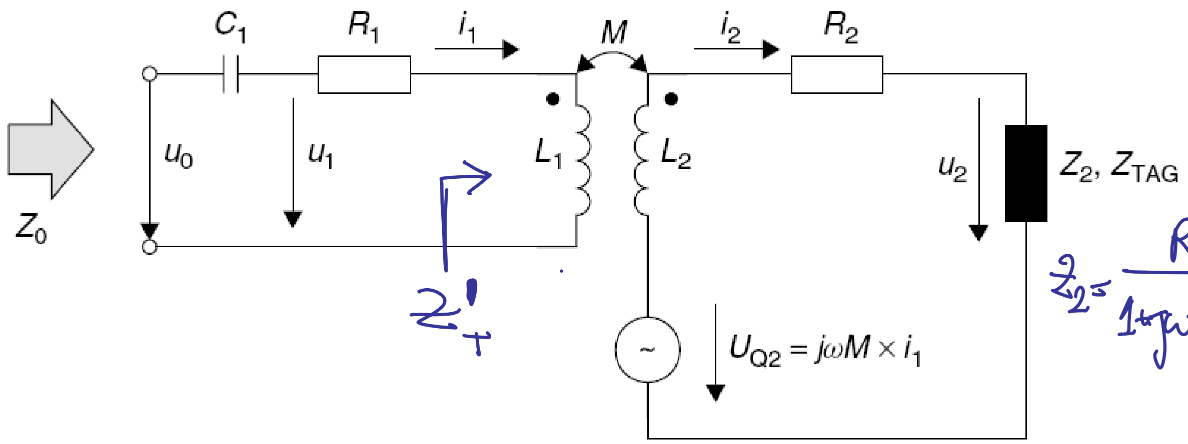
Se non avessimo inserito la capacità C_2

$f \sim 125\,KHz \longrightarrow L_2 \sim 1 \div 10\ mH$

$C_2 \sim 20 \div 200\ pF$

$f \sim 13.56\,MHz \longrightarrow C_2 \sim pF \qquad L \sim 0.1\,mH$

capacità parassite dell'induttore



$$Z_2 = \frac{R_L}{1 + j\omega R_L C_2}$$

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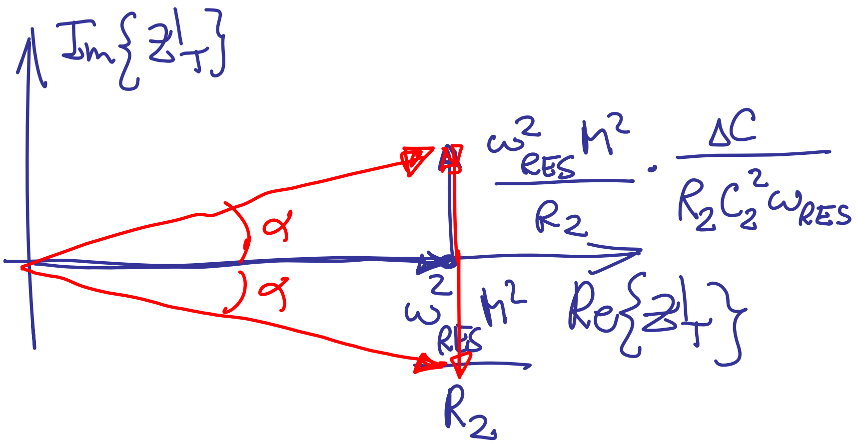
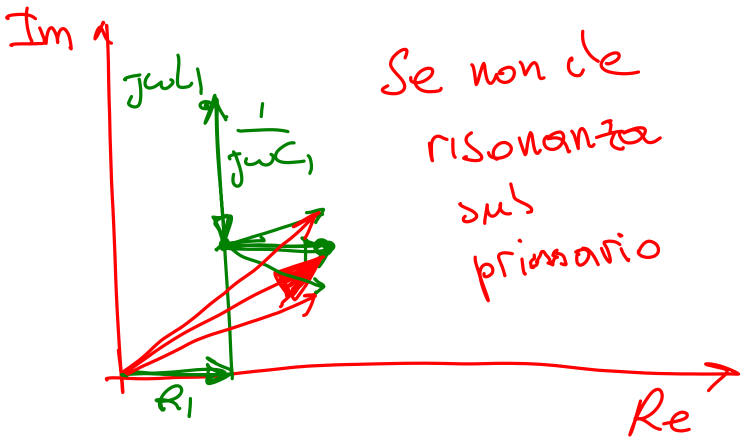
$$i_2 = \frac{-j\omega M i_1}{R_2 + j\omega L_2 + Z_2}$$

$$v_0 = i_1\left(R_1 + \frac{1}{j\omega C_1} + j\omega L_1\right) + j\omega M i_2 = i_1\left[R_1 + \frac{1}{j\omega C_1} + j\omega L_1 + \overbrace{\frac{\omega^2 M^2}{R_2 + j\omega L_2 + Z_2}}^{Z'_T}\right]$$



$$\alpha = \arctan\left(\frac{\Delta C}{R_2 C_2^2 \omega_{RES}}\right) \sim \frac{\Delta C}{R_2 C_2^2 \omega_{RES}}$$

$$\frac{u_0}{i_1} = R_1 + \frac{1}{j\omega C_1} + j\omega L_1 + Z'_T$$



Se non c'e risonanza sul primario

$$Z'_T = \frac{\omega^2 M^2}{R_2 + j\omega L_2 + \frac{1}{j\omega C_2}} \qquad \left[R_2 \gg \left|\frac{1}{j\omega C_2}\right|, |j\omega L_2|, R_2 \right]$$

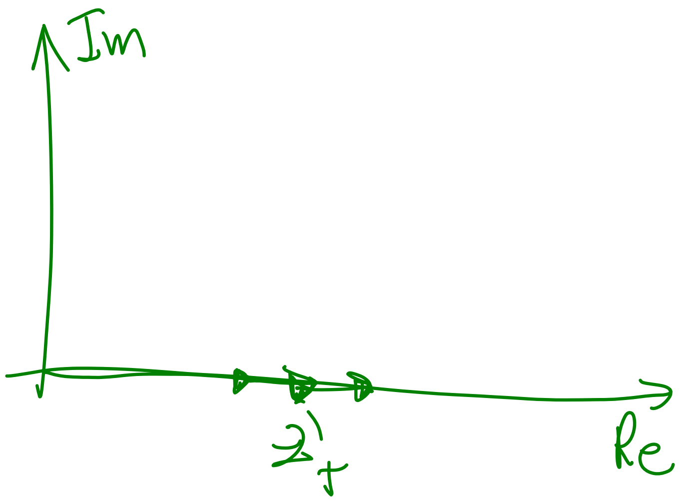
$$\omega_{RES} = \frac{1}{\sqrt{L_2 C_2}}$$

moduliamo $C_2 \longrightarrow C_2 + \Delta C$ $\quad \boxed{\Delta C \ll C_2}$

$$Z'_T = \frac{\omega^2 M^2}{R_2 + j\omega L_2 + \frac{1}{j\omega C_2\left(1 + \frac{\Delta C}{C_2}\right)}} = \frac{\omega^2 M^2}{R_2 + j\omega L_2 + \frac{1}{j\omega C_2}\left(1 - \frac{\Delta C}{C_2}\right)}$$

$\omega = \omega_{RES}$

$$Z'_T = \frac{\omega_{RES}^2 M^2}{R_2 - \frac{1}{j\omega_{RES} C_2}\left(\frac{\Delta C}{C_2}\right)} = \frac{\omega_{RES}^2 M^2}{R_2\left[1 - \frac{\Delta C}{j\omega_{RES} R C_2^2}\right]} = \frac{\omega_{RES}^2 M^2}{R_2}\left(1 - \frac{j\Delta C}{\omega_{RES} R C_2^2}\right)$$

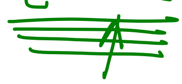


impedenza vista dal primario

$$R_1 + j\omega L_1 + \frac{1}{j\omega C_1} + Z'_T$$

in condizioni di risonanza $\longrightarrow$ $\underline{\underline{R_1 + Z'_T}}$ $\quad$ modulata in ampiezza

Modulazione di ampiezza delle Z'_T



$$Z'_T = R_2 + j\omega L_2 + \frac{R_L}{j\omega R_L C_2 + 1}$$

$\omega = \omega_{RES} \rightarrow Z'_T$ è resistiva

$$R_2 + \frac{R_L}{1+\omega^2 R_L^2 C_2^2}$$

supponiamo che $R_L \gg R_2$

$$\omega_{RES}^2 \simeq \frac{1}{L_2 C_2}$$

$$Z'_T = \underbrace{R_2 + \frac{R_L}{1+\frac{R_L^2 C_2}{L_2}}}$$

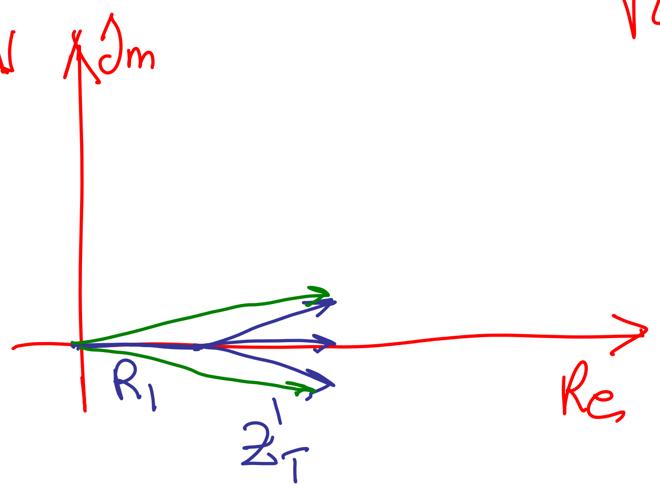
$R_L \rightarrow \Delta R_L + R_L$

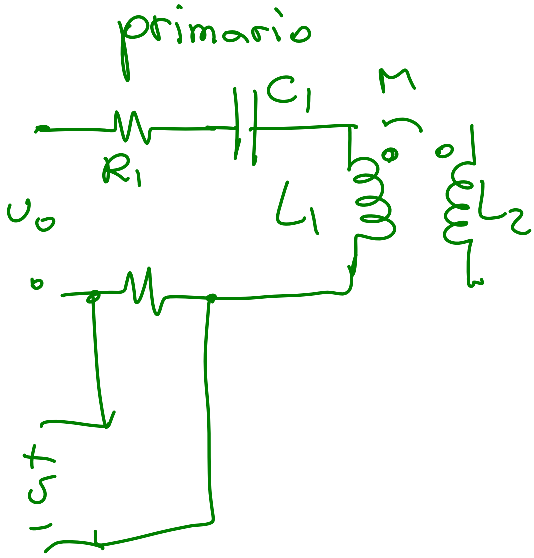
$Z'_T \rightarrow Z'_T + \Delta Z'_T$

variazione reale

$$\frac{v_0}{i_1} = R_1 + \underbrace{j\omega L_1 + \frac{1}{j\omega C_1}} + Z'_T$$

~~se~~ $=0$ se $\omega_{RES} = \frac{1}{\sqrt{L_1 C_1}}$





$$Z'_T = \frac{\omega^2 M^2}{\underbrace{R_2 + j\omega L_2 + \frac{R_L}{1+j\omega R_L C_2}}} = \frac{\omega^2 M^2 (1+j\omega R_L C_2)}{(R_2+j\omega L_2)(1+j\omega R_L C_2)+R_L} =$$

$$\rightarrow j\omega L_2 + \frac{R_L(1-j\omega R_L C_2)}{1+\omega^2 R_L^2 C_2^2}$$

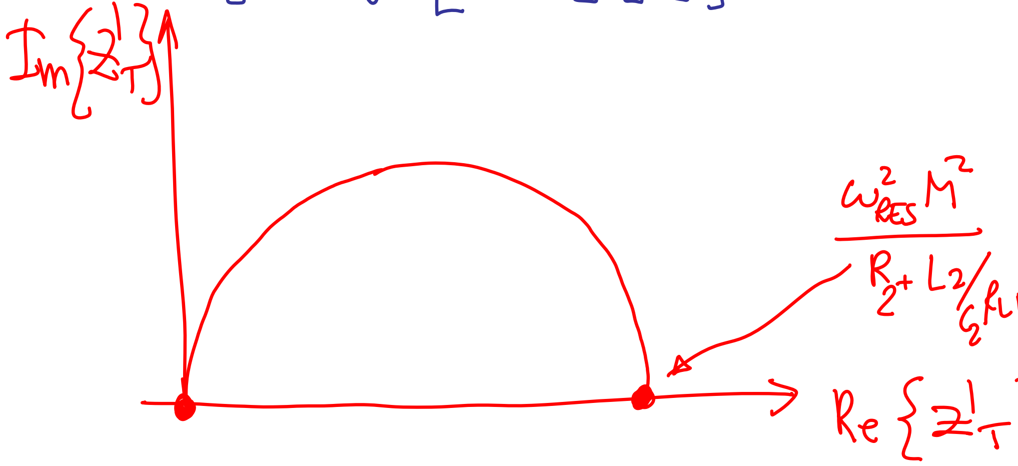
$$Z'_T = \frac{\omega^2 M^2 (1+j\omega R_L C_2)}{R_L + R_2 + j\omega\left[L_2 + R_2 R_L C_2\right] - \omega^2 R_L L_2 C_2}$$

$$\mathrm{Im}(\;) = 0$$

$$\cancel{\omega} L_2 - \frac{R_L \cancel{\omega} R_L C_2}{1+\omega^2 R_L^2 C_2^2} = 0$$

$$1+\omega^2 R_L^2 C_2^2 = \frac{R_L^2 C_2}{L_2}$$

$$\boxed{\omega_{RES} = \sqrt{\frac{R_L^2 C_2 - L_2}{R_L^2 L_2 C_2^2}}}$$



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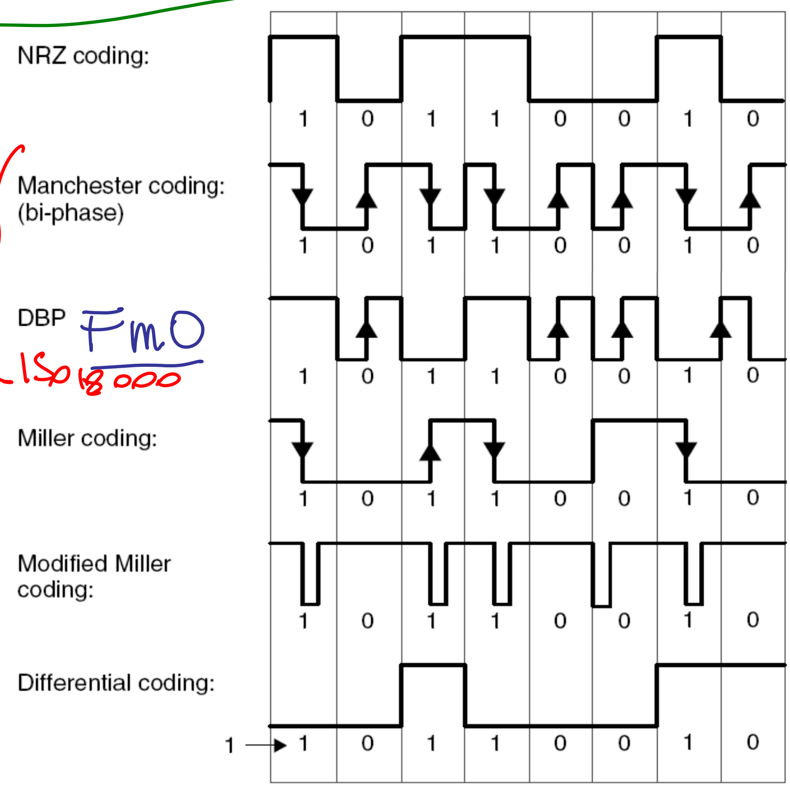

Differential Biphase Space

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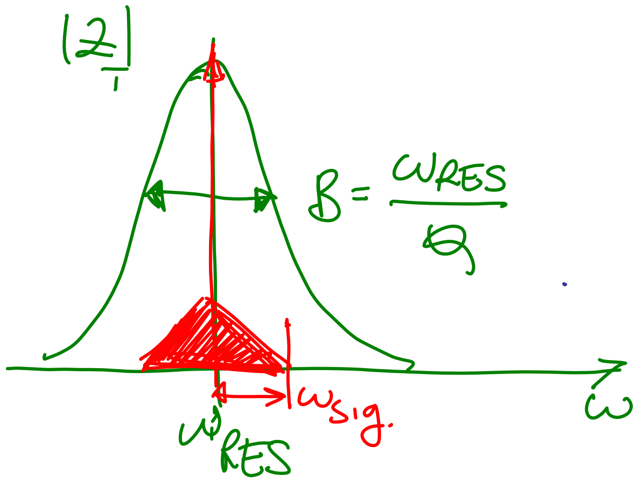
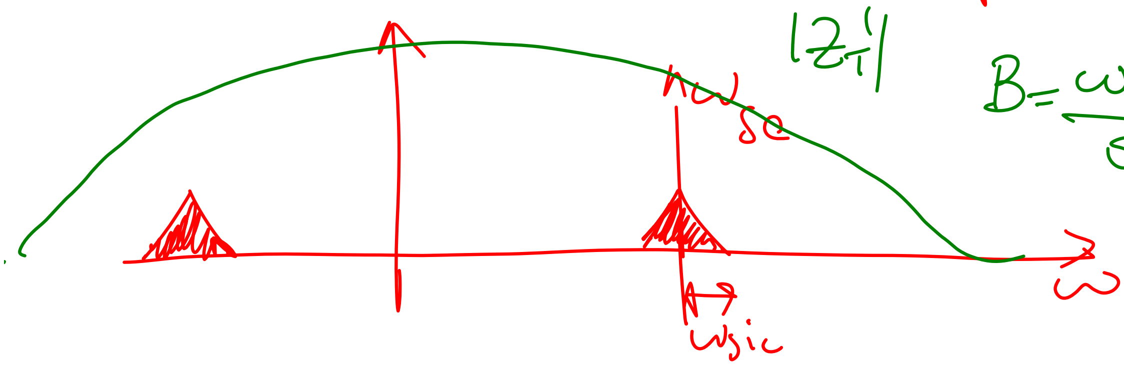


$$B = \frac{\omega_{RES}}{Q}$$

$$B > \omega_{sig}$$

$$\Rightarrow Q < \frac{\omega_{RES}}{\omega_{sig}}$$

Particolarmente importante nel caso di modulazione con sottoportante



$$B = \frac{\omega_{RES}}{Q} > \omega_{SC}$$

$$\boxed{Q < \frac{\omega_{RES}}{\omega_{SC}}}$$