Facoltà d' Ingegneria
Dipartimento di Elettronica e Telecomunicazioni

Radar

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RADAR: RAdio **D**etection **A**nd **R**anging

1904 Hulsmeyer brevetta un rivelatore di ostacoli a onde elettromagnetiche

1922 Marconi ipotizza l'impiego del radar in una conferenza negli Stati Uniti

1925 Breit e Tuve (USA) misurano l'altezza della ionosfera con una tecnica radar

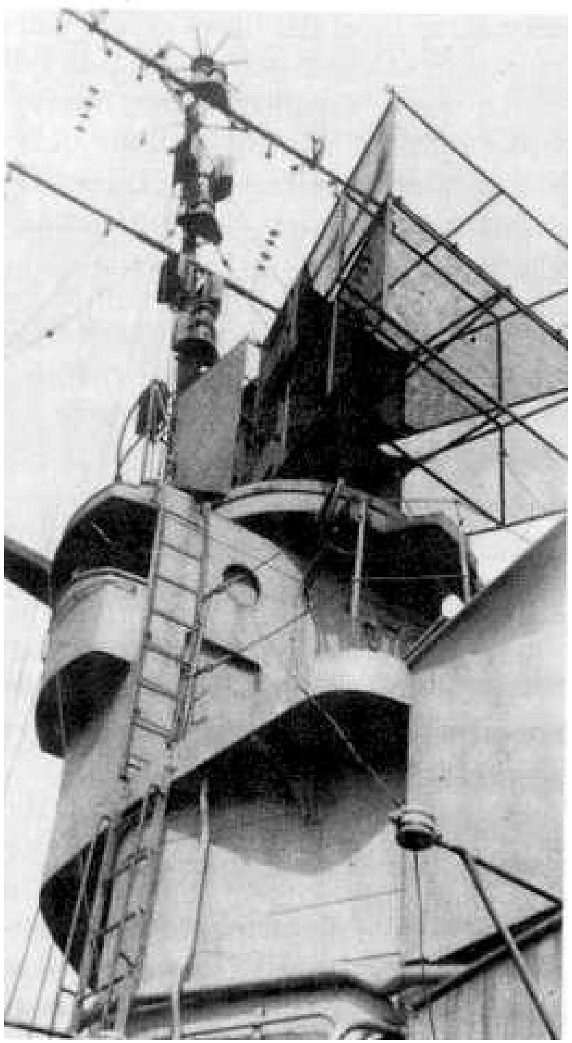
1934 in Germania Kuhnold realizza il primo radar (600 MHz, 7 miglia)

1936 in USA il Naval Research Lab realizza un radar (200 MHz)

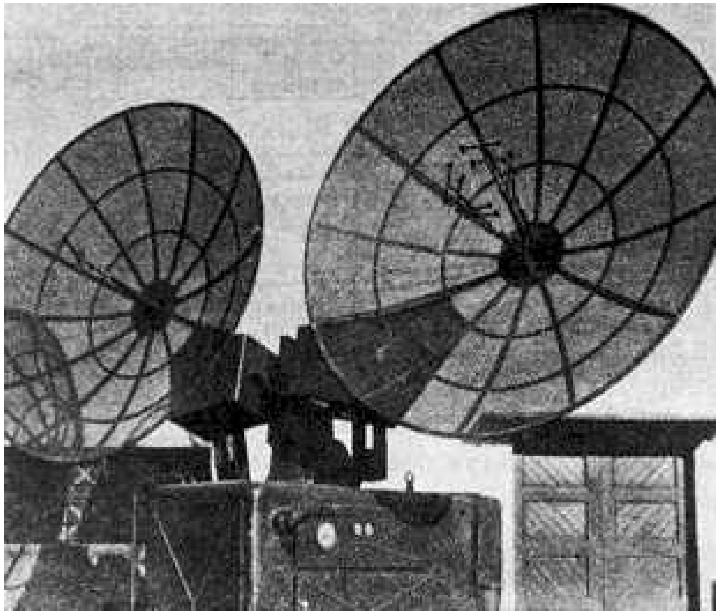
1935 prof. Tiberio propone alla Marina Italiana il Radio-Detector Telemetro

1941 il *Gufo* (400-750 Mhz, fino a 200 Km)

Entro l'8 settembre 1943 furono consegnati complessivamente
13 "Gufo"
4 "Folaga"

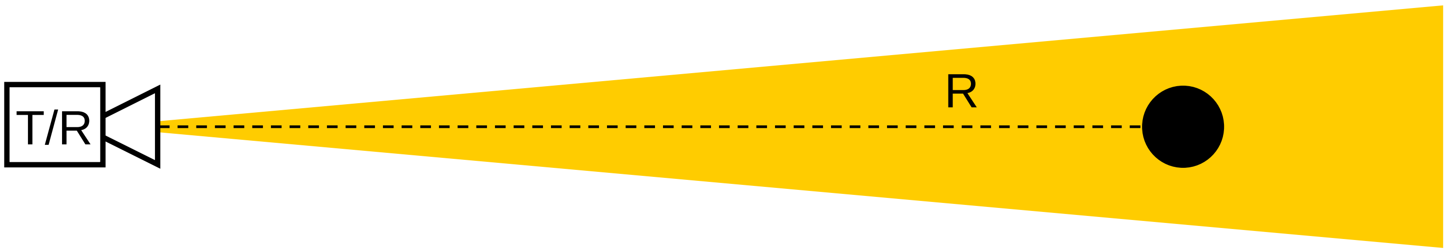


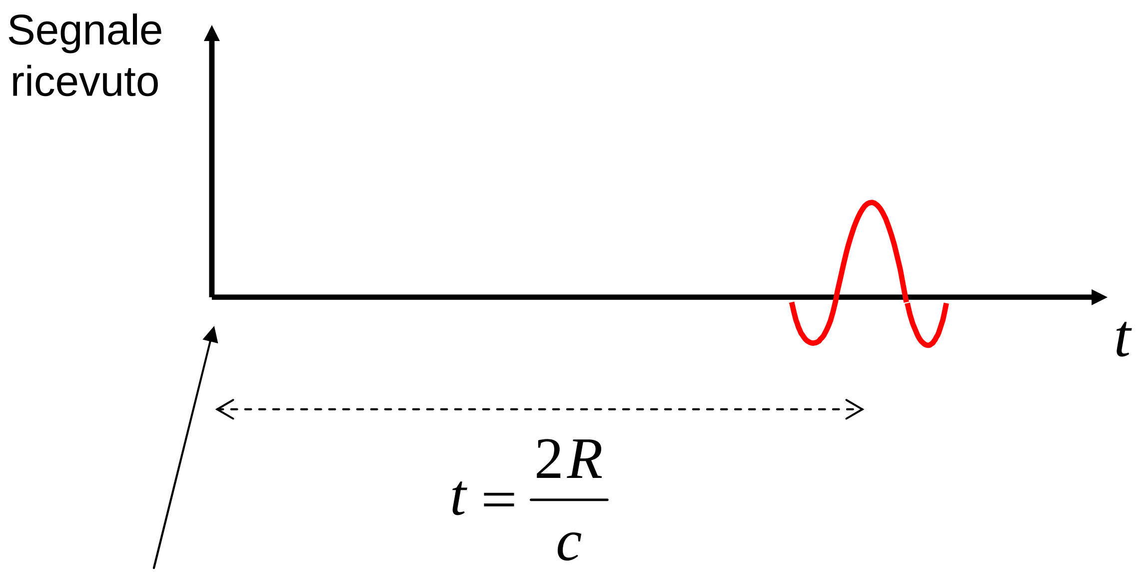
Gufo



Folaga

Principio di funzionamento





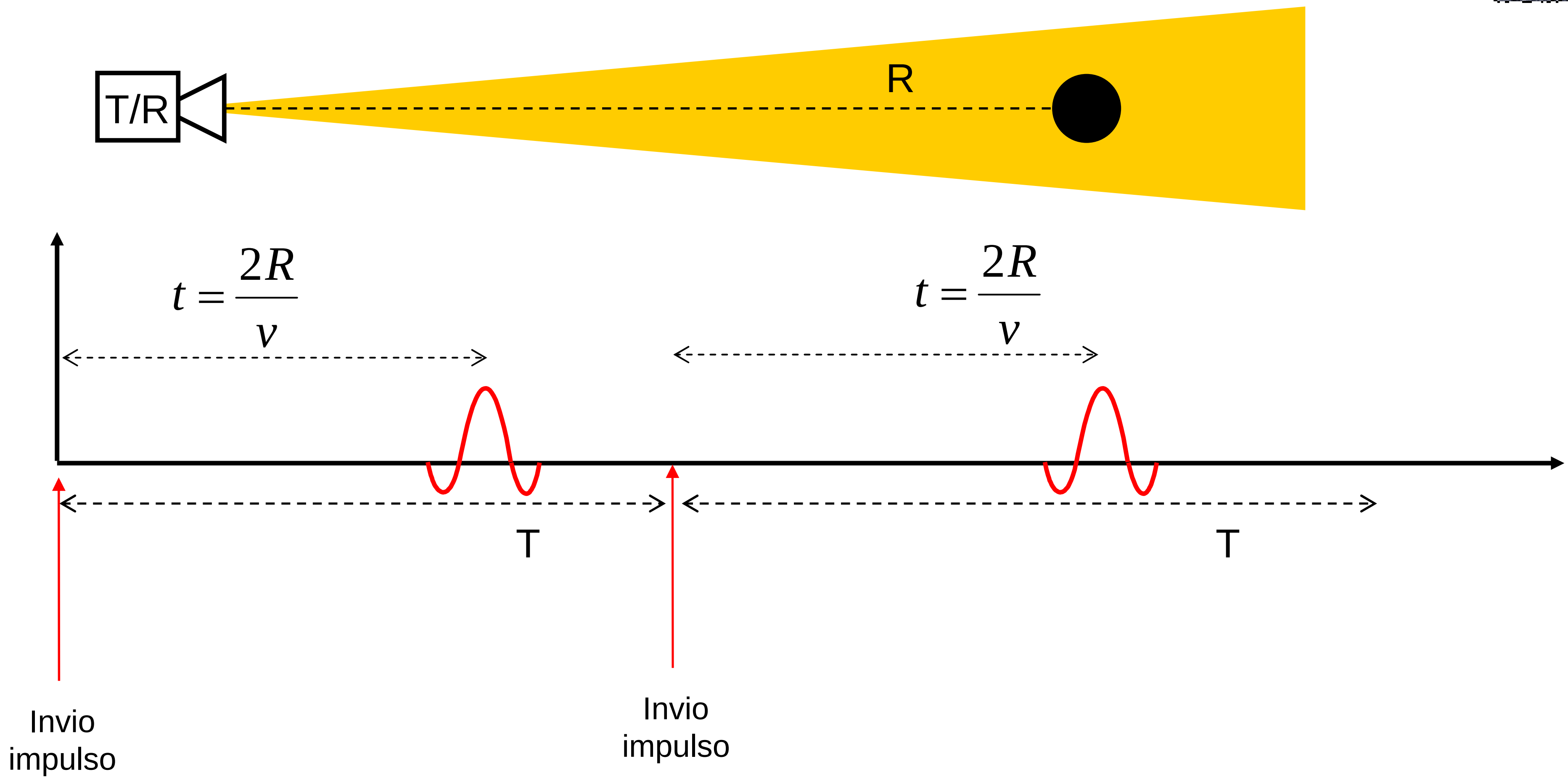
$$t = \frac{2R}{c}$$

Invio dell’impulso
$t = 0$

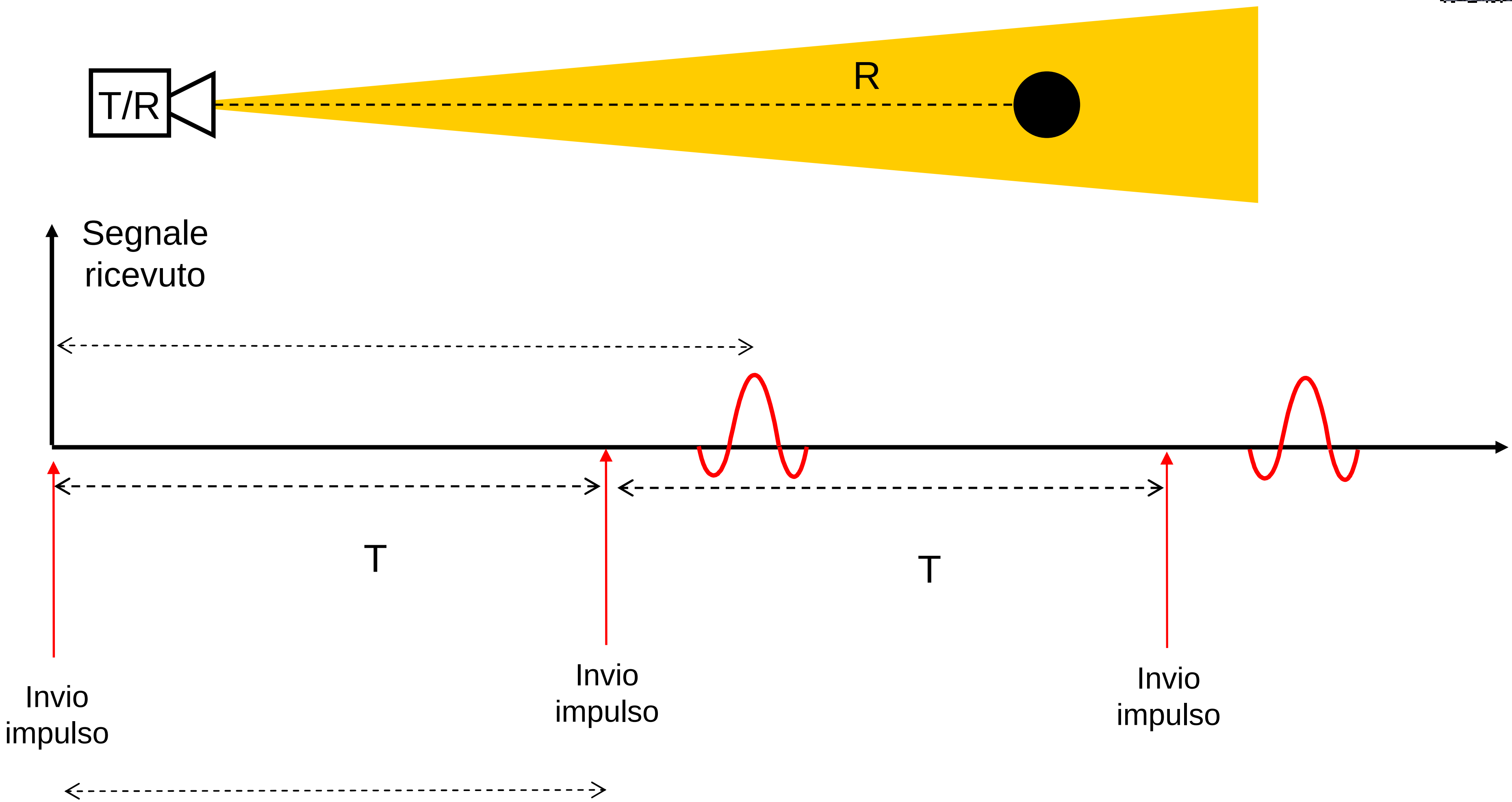
Direttività

Capacità di misurare la distanza

Principio di funzionamento

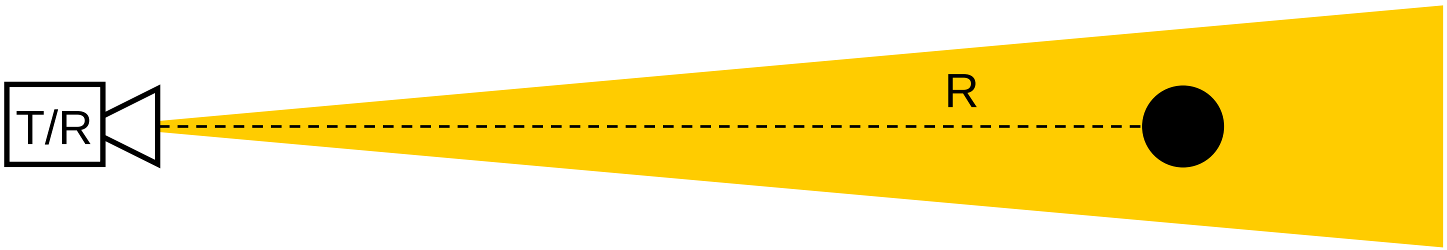


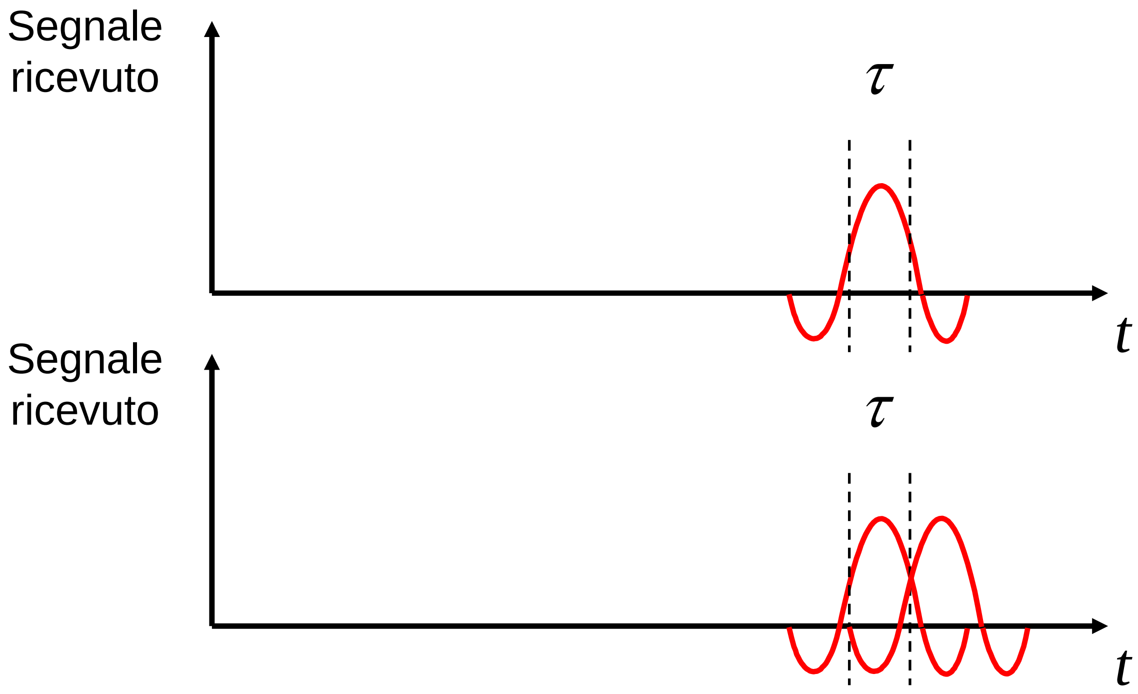
Principio di funzionamento



Range non ambiguo: $\boxed{R_U = \frac{vT}{2}}$

Principio di funzionamento



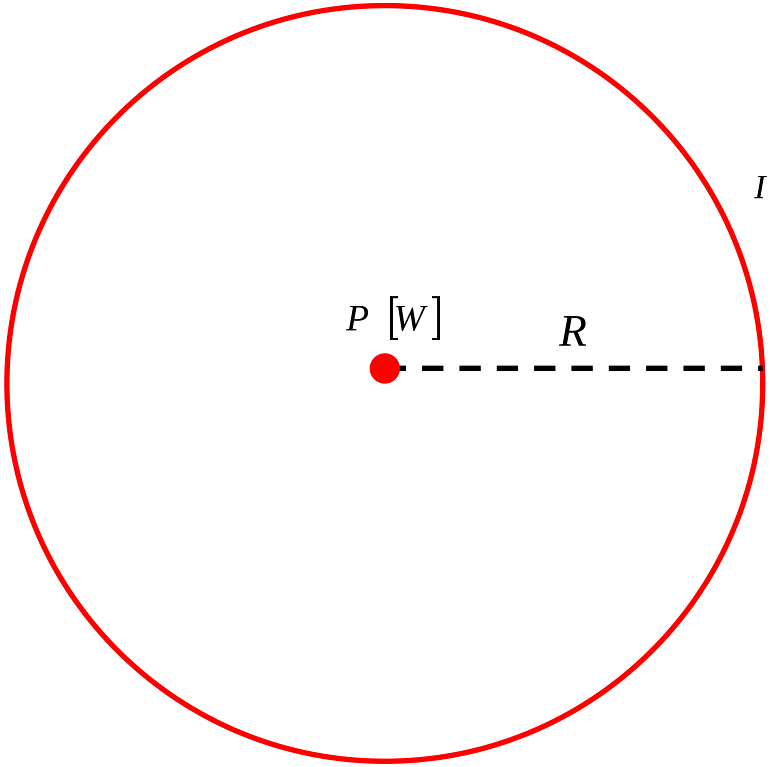


$$\boxed{\tau = \frac{1}{B}}$$

Risoluzione in range: $\Delta R = \dfrac{v\tau}{2}$

$$\boxed{\Delta R = \frac{c}{2B}}$$

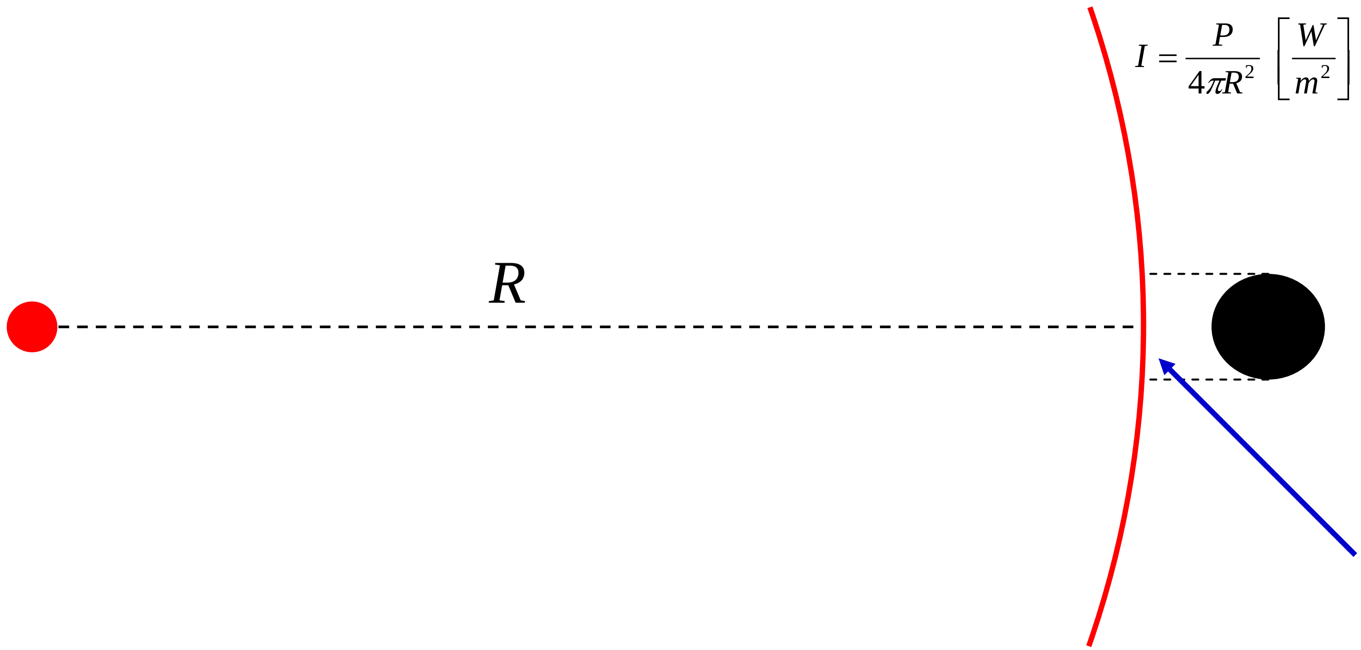
Attenuazione geometrica



$$I = \frac{P}{4\pi R^2}\ \left[\frac{W}{m^2}\right]$$

RCS

$$I = \frac{P}{4\pi R^2} \left[\frac{W}{m^2}\right]$$



Potenza intercettata dal bersaglio $P_i = I\sigma$

Potenza intercettata dal bersaglio e diffusa $P_{scatt} = I\sigma\alpha$

< 1

Radar Cross Section $\sigma_{RCS} = \alpha\sigma$

$$P_{scatt} = I\sigma_{RCS}$$

RCS di una sfera riflettente

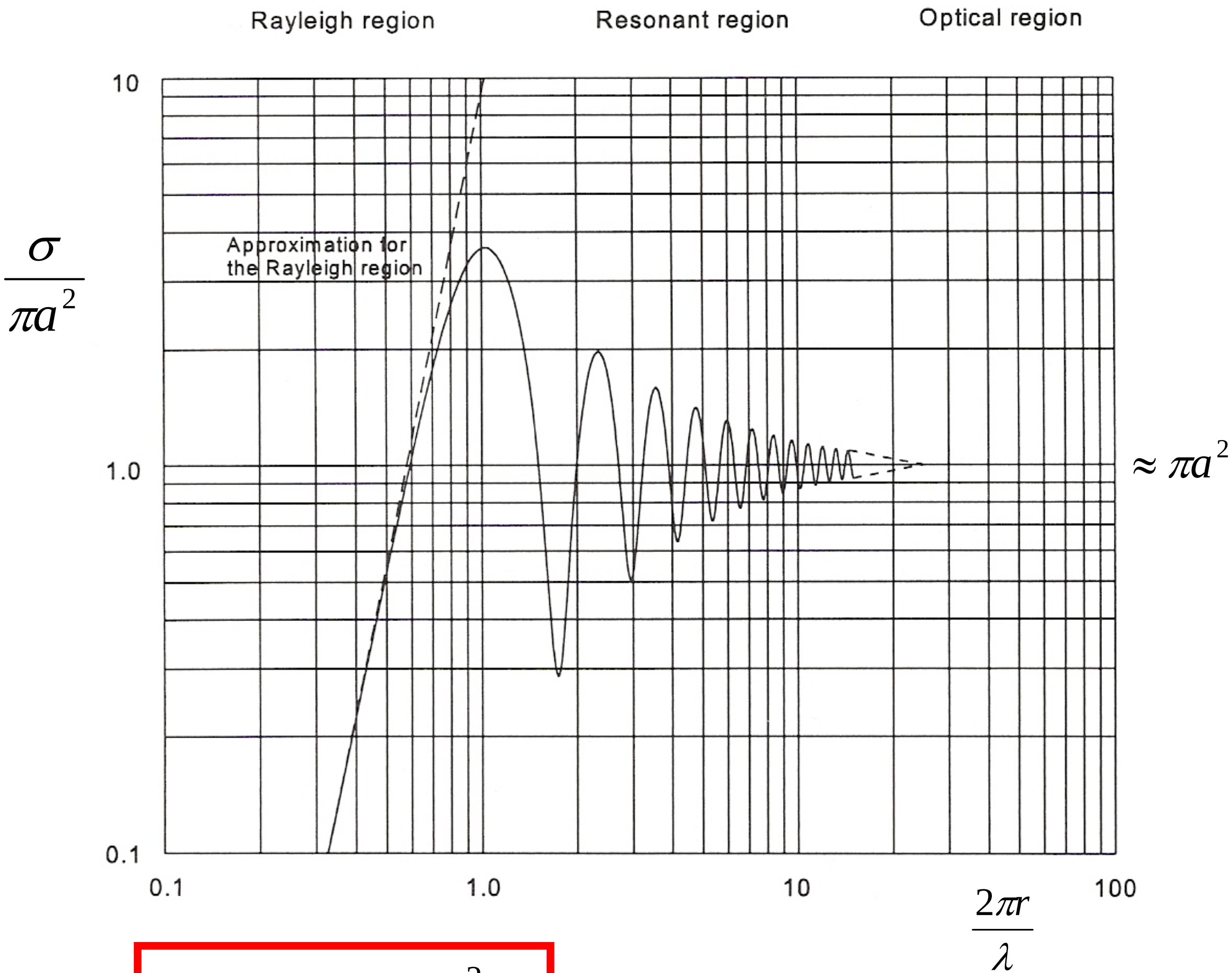
Teoria di Mie

$$\sigma = \pi\left(\left|\sum_{n=1}(-1)^n(2n+1)(a_n(r)+b_n(r))\right|\right)^2$$

$$a_n(r) = \frac{j_n(r)}{j_n(r)-y_n(r)}$$

$$a_n(r) = \frac{-\frac{d}{dr}[rj_n(r)]}{\frac{d}{dr}[rj_n(r)-jry_n(r)]}$$

Teoria di Mie



$$\boxed{\sigma \approx 9\pi \left(\frac{2\pi a}{\lambda}\right)^2 a^2}$$

Tecnologia Stealth

1) Vernici e rivestimenti assorbenti

2) Materiali non metallici

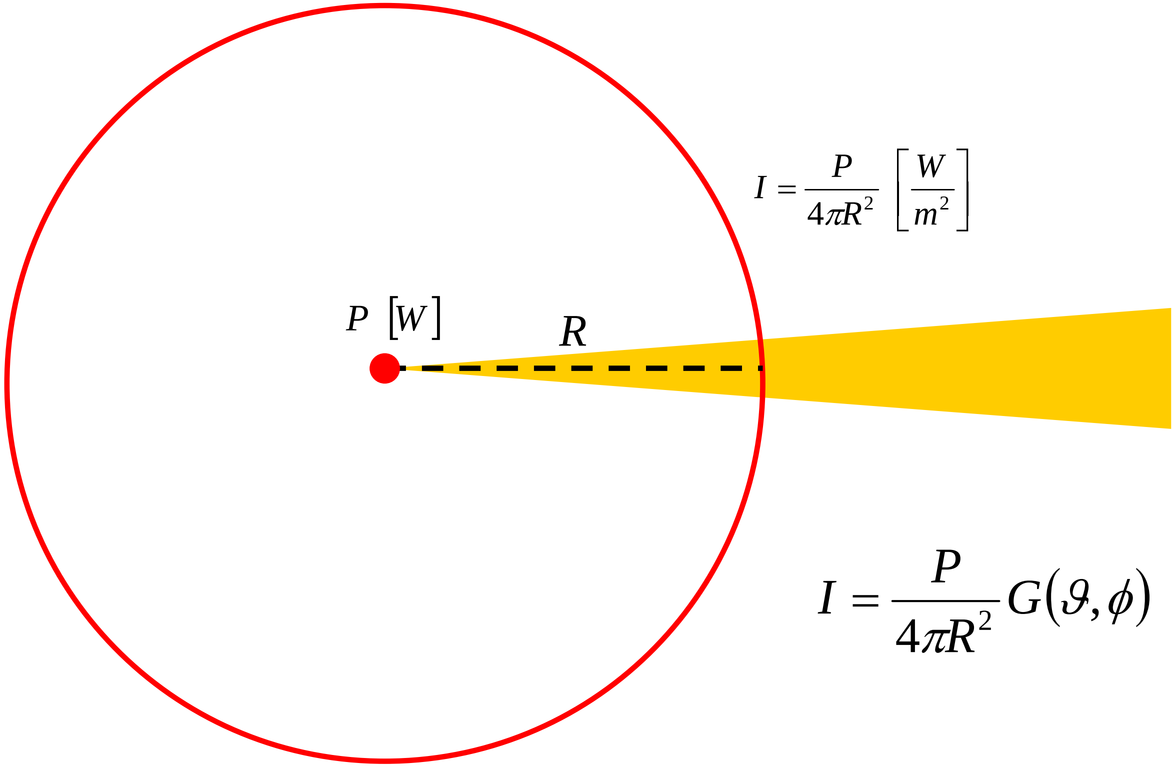
3) Superfici studiate in modo da minimizzare l'energia diffusa nella stessa direzione di incidenza

4) Forme studiate per produrre interferenza distruttiva alla frequenza dei radar

F-117

B-2

Direttività

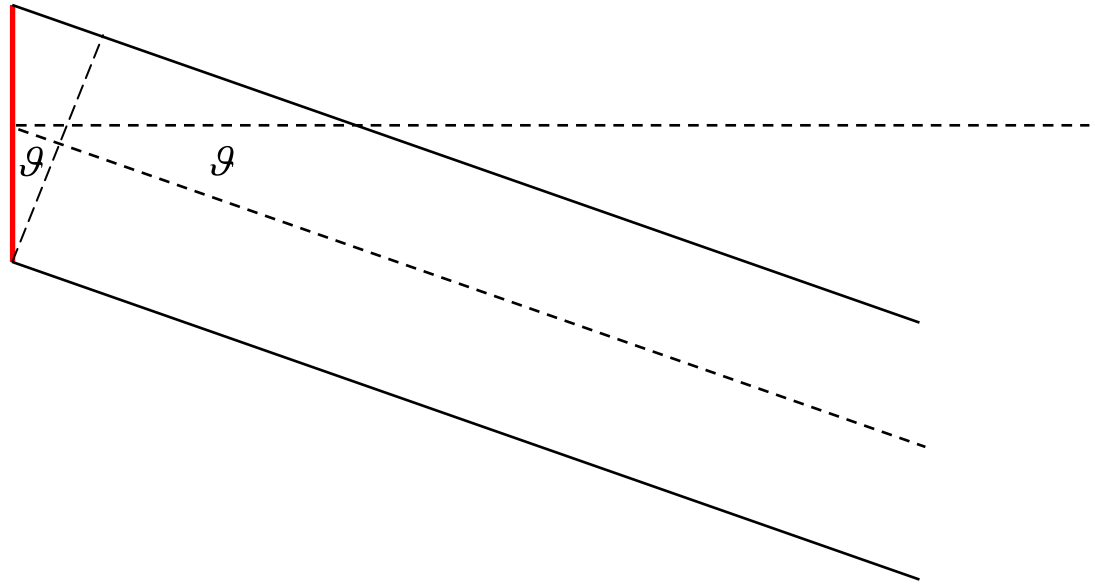


$$I = \frac{P}{4\pi R^2} \left[\frac{W}{m^2} \right]$$

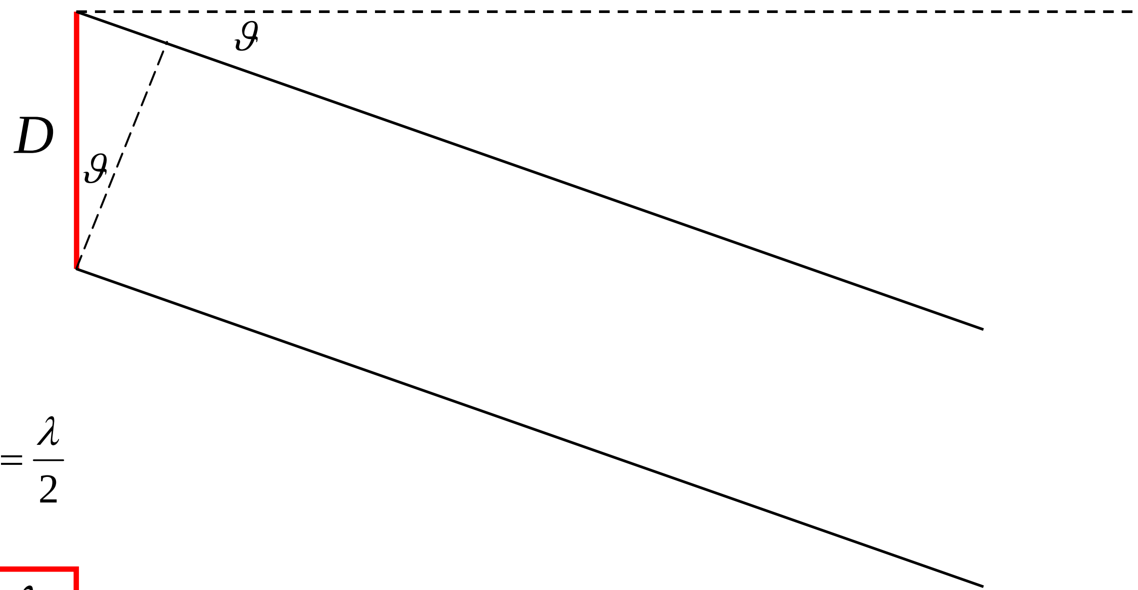
$$I = \frac{P}{4\pi R^2} G(\vartheta, \phi)$$

$$\int G(\vartheta, \phi) d\Omega = 4\pi$$

Direttività



Direttività



$$D\sin\vartheta = \frac{\lambda}{2}$$

$$\boxed{\vartheta \approx \frac{\lambda}{2D}}$$

$$\Delta\Omega \approx \pi\vartheta^2$$

$$G = \frac{4\pi}{\Delta\Omega}$$

$$\boxed{\Delta\Omega = \frac{4\pi}{G}}$$

$$\vartheta \approx \frac{\lambda}{2D} \qquad \Delta\Omega \approx \pi\vartheta^2 \qquad G = \frac{4\pi}{\Delta\Omega}$$

$$G = \frac{4\pi}{\Delta\Omega} = \frac{16D^2}{\lambda^2}$$

$$A = \pi\left(\frac{D}{2}\right)^2 \frac{1}{2}$$

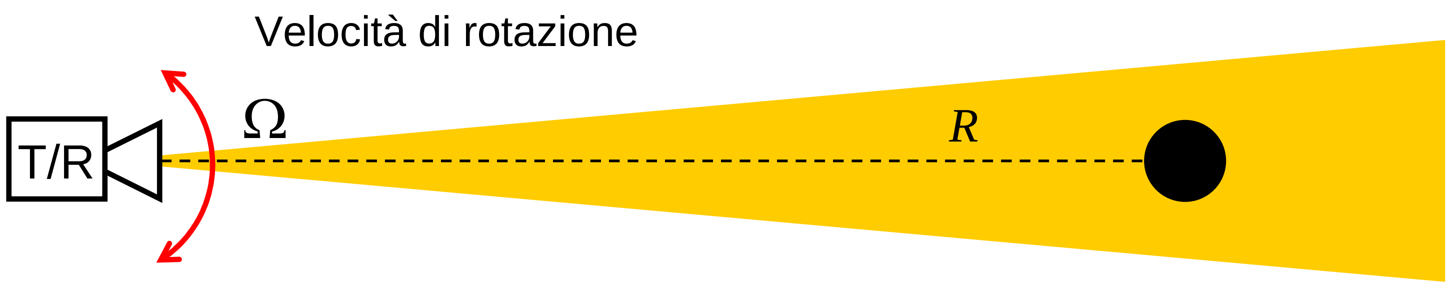
Anche nel migliore dei casi (adattamento di impedenza perfetto) il 50% della potenza incidente su un'antenna è riflessa

$$\frac{A}{G} = \frac{\lambda^2}{10.2}$$

$$\frac{A}{G} = \frac{\lambda^2}{4\pi}$$

$$\boxed{A = \frac{\lambda^2}{4\pi} G}$$

Scansione meccanica



$$\Delta\Omega = \frac{4\pi}{G}$$

$$T_{\max} = \frac{2R_{\max}}{c}$$

$$\pi\vartheta^2 = \frac{4\pi}{G}$$

$$\Omega T < \vartheta$$

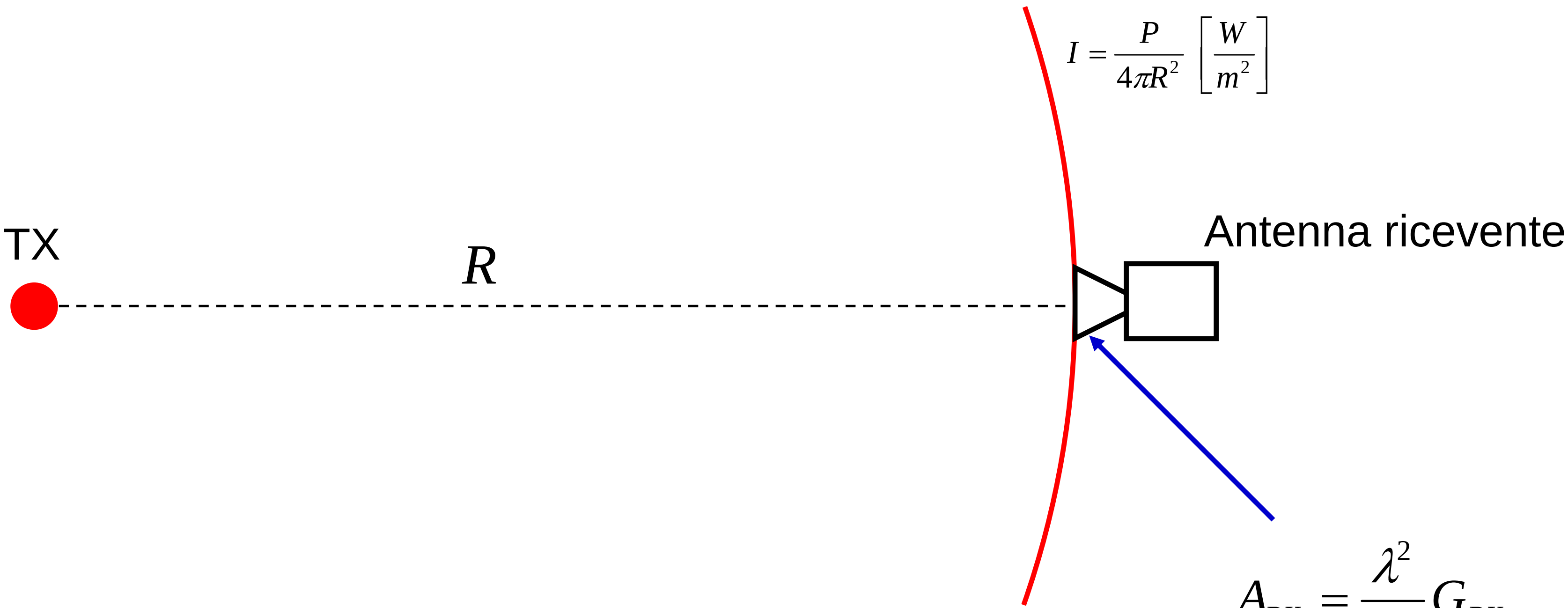
$$\vartheta = \frac{2}{\sqrt{G}}$$

$$\boxed{\Omega < \frac{c}{R_{\max}\sqrt{G}}}$$

Esempio: R_{max}=100 Km, G=40dB → 5 giri/sec

Area efficace di un'antenna

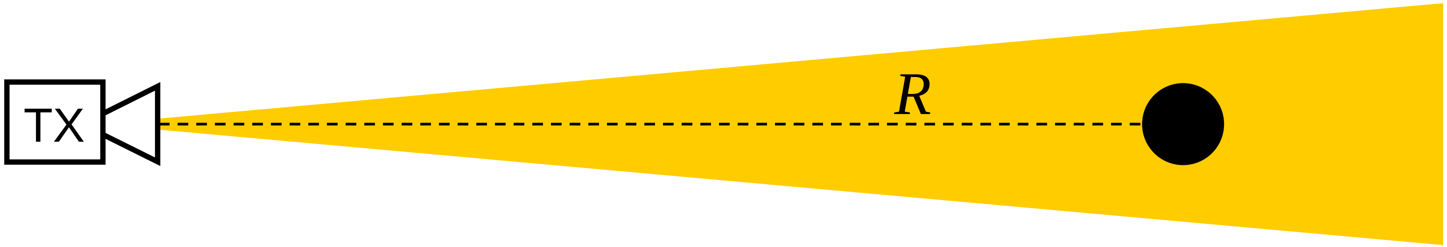
$$I = \frac{P}{4\pi R^2} \left[\frac{W}{m^2}\right]$$



$$A_{RX} = \frac{\lambda^2}{4\pi} G_{RX}$$

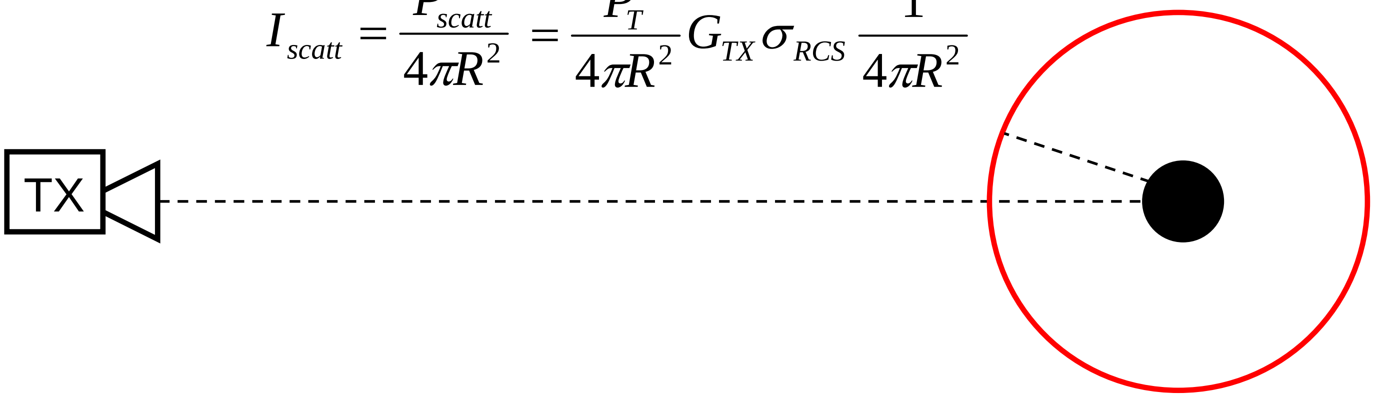
$$P_{RX} = I A_{RX}$$

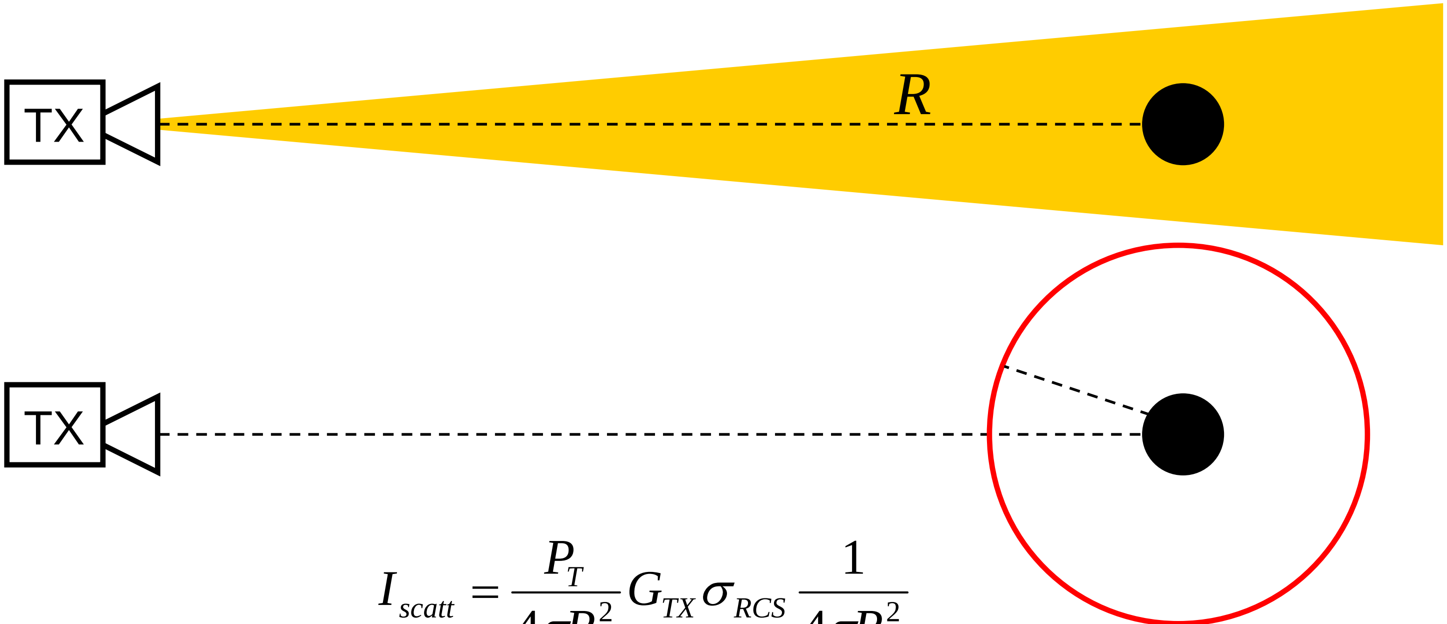
Equazione radar



$$P_{scatt} = I\sigma_{scatt} = \frac{P_T}{4\pi R^2} G_{TX}\,\sigma_{RCS}$$

$$I_{scatt} = \frac{P_{scatt}}{4\pi R^2} = \frac{P_T}{4\pi R^2} G_{TX}\sigma_{RCS}\,\frac{1}{4\pi R^2}$$





$$I_{scatt} = \frac{P_T}{4\pi R^2} G_{TX} \sigma_{RCS} \frac{1}{4\pi R^2}$$

$$A_R = \frac{\lambda^2}{4\pi} G_{RX}$$

$$P_{RX} = I_{scatt} A_R$$

$$P_{RX} = \frac{P_T}{4\pi R^2} G_{TX} \sigma_{RCS} \frac{1}{4\pi R^2} \frac{\lambda^2}{4\pi} G_{RX}$$

$$P_{RX} = \frac{P_T}{4\pi R^2} G_{TX} \sigma_{RCS} \frac{1}{4\pi R^2} \frac{\lambda^2}{4\pi} G_{RX}$$

Equazione radar

$$\boxed{P_R = P_T G_T G_R \frac{\lambda^2}{(4\pi)^3 R^4} \sigma_{RCS}}$$

Equazione radar

$$P_R = P_T G_T G_R \frac{\lambda^2}{(4\pi)^3 R^4} \sigma_{RCS}$$

$$\frac{P_R}{P_T} = G_T G_R \frac{1}{(4\pi)^3 \left(\frac{R}{\lambda}\right)^4} \frac{\sigma_{RCS}}{\lambda^2}$$

$$20\log_{10}\left(\frac{P_R}{P_T}\right) = 20\log_{10} G_T + 20\log_{10} G_R \boxed{-20\log_{10}\left((4\pi)^3\left(\frac{R}{\lambda}\right)^4\right)} + 20\log_{10}\left(\frac{\sigma_{RCS}}{\lambda^2}\right)$$

Attenuazione
geometrica

Equazione radar

$$20\log_{10}\left(\frac{P_R}{P_T}\right) = 20\log_{10} G_T + 20\log_{10} G_R - 20\log_{10}\left((4\pi)^3\left(\frac{R}{\lambda}\right)^4\right) + 20\log_{10}\left(\frac{\sigma_{RCS}}{\lambda^2}\right)$$

Attenuazione geometrica

Esempio:

$$20\log_{10} G_{TX} = 20\mathrm{dB}$$

$$20\log_{10} G_{RX} = 20\mathrm{dB}$$

3GHz $\longrightarrow$ $\lambda = 0.1\mathrm{m}$

$R = 10000\mathrm{m}$

$\longrightarrow$ $A = 466\mathrm{dB}$

3GHz $\longrightarrow$ $\lambda = 0.1\mathrm{m}$

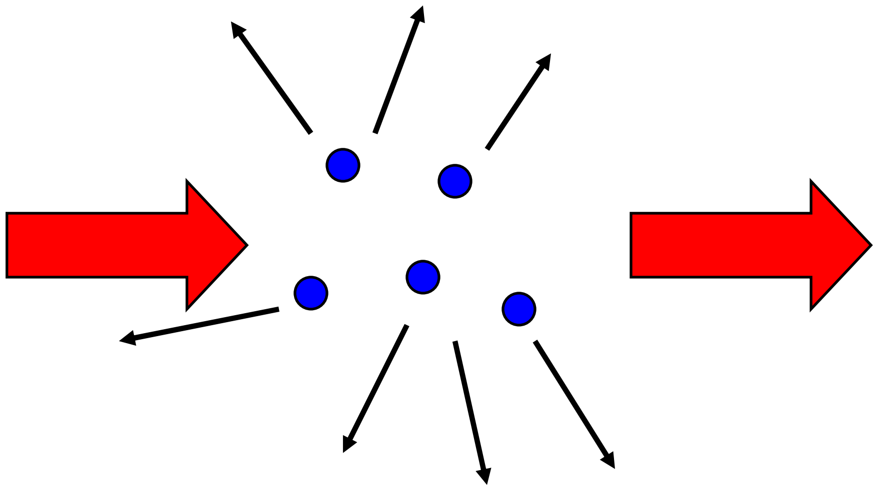
$\sigma_{RCS} = 100\,\mathrm{m}^2$

$\longrightarrow$ $RCS = 60\,\mathrm{dB}$

40-466+60 = -366dB

Dinamica = 366dB

Diffusione su gocce d'acqua



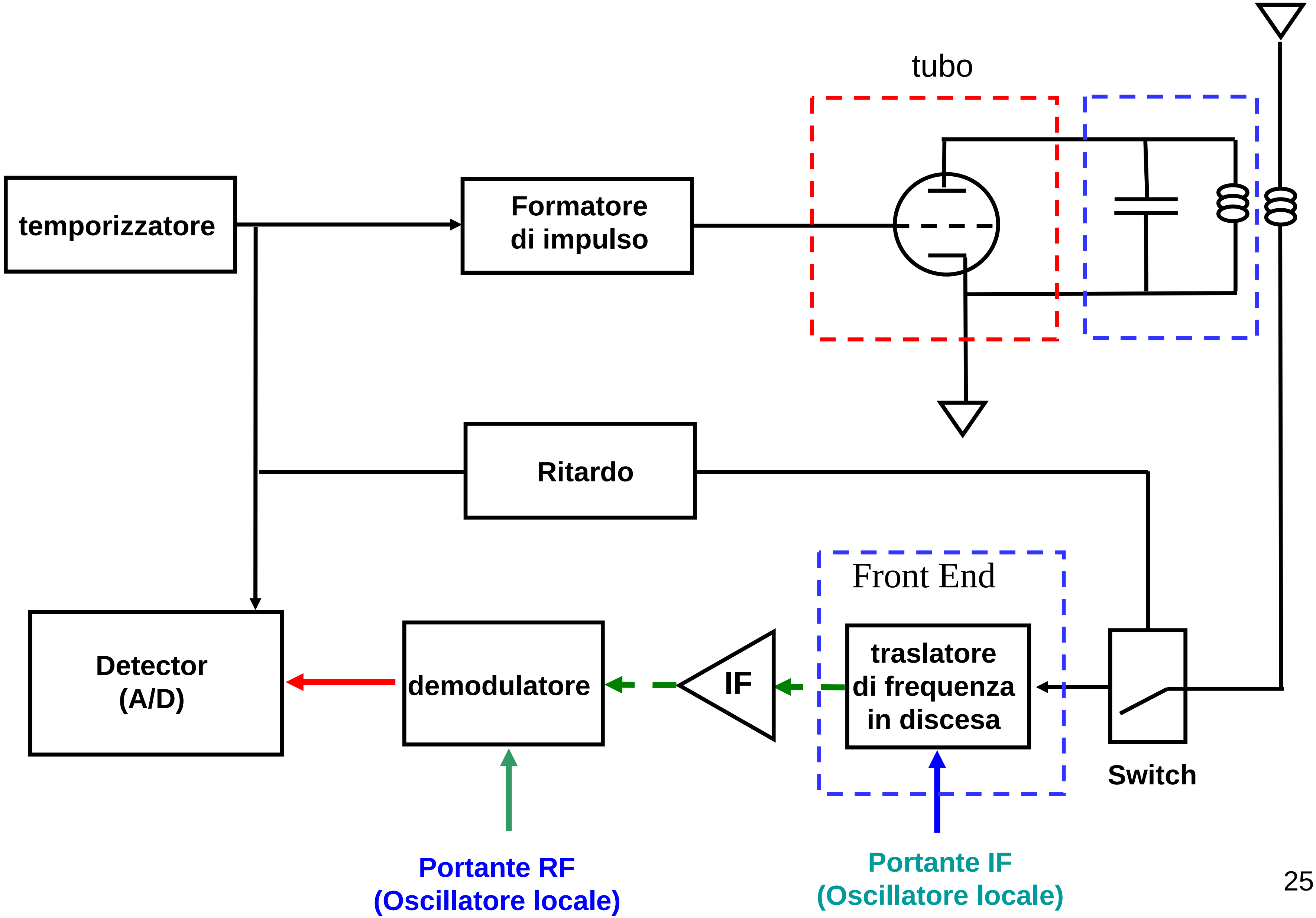
$$\sigma \approx 9\pi\left(\frac{2\pi a}{\lambda}\right)^2 a^2$$

$a = 1\text{mm} \longrightarrow \pi a^2 = 3.14\times10^{-6}$

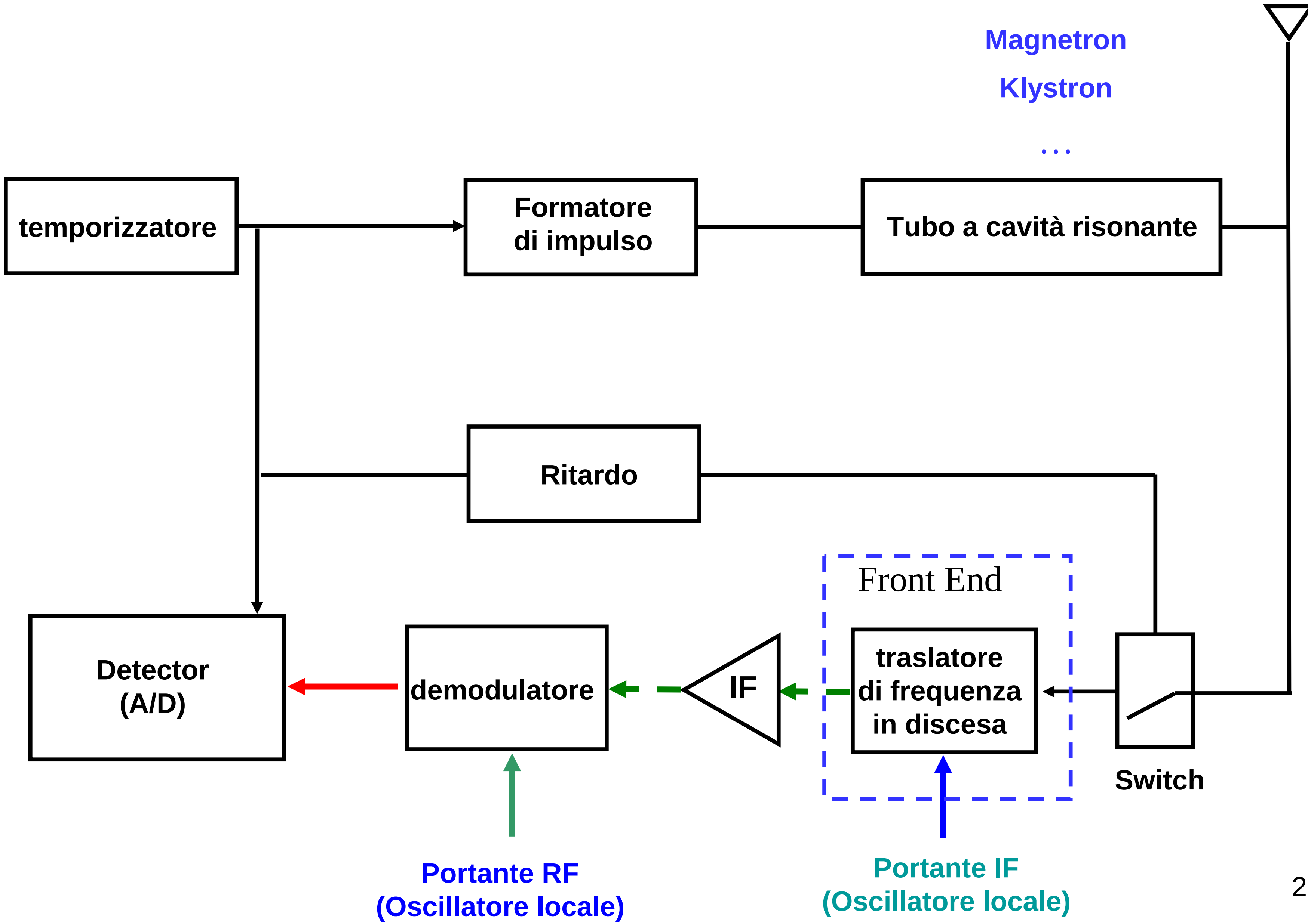
$a = 1\text{mm} \longrightarrow \sigma = 1.12\times10^{-7}$

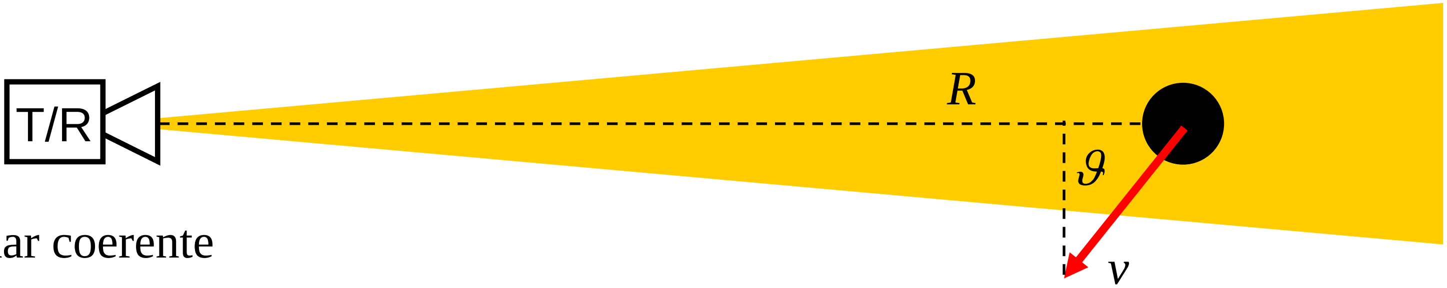
$\lambda = 0.1\text{m}$

Radar non coerente



Radar non coerente



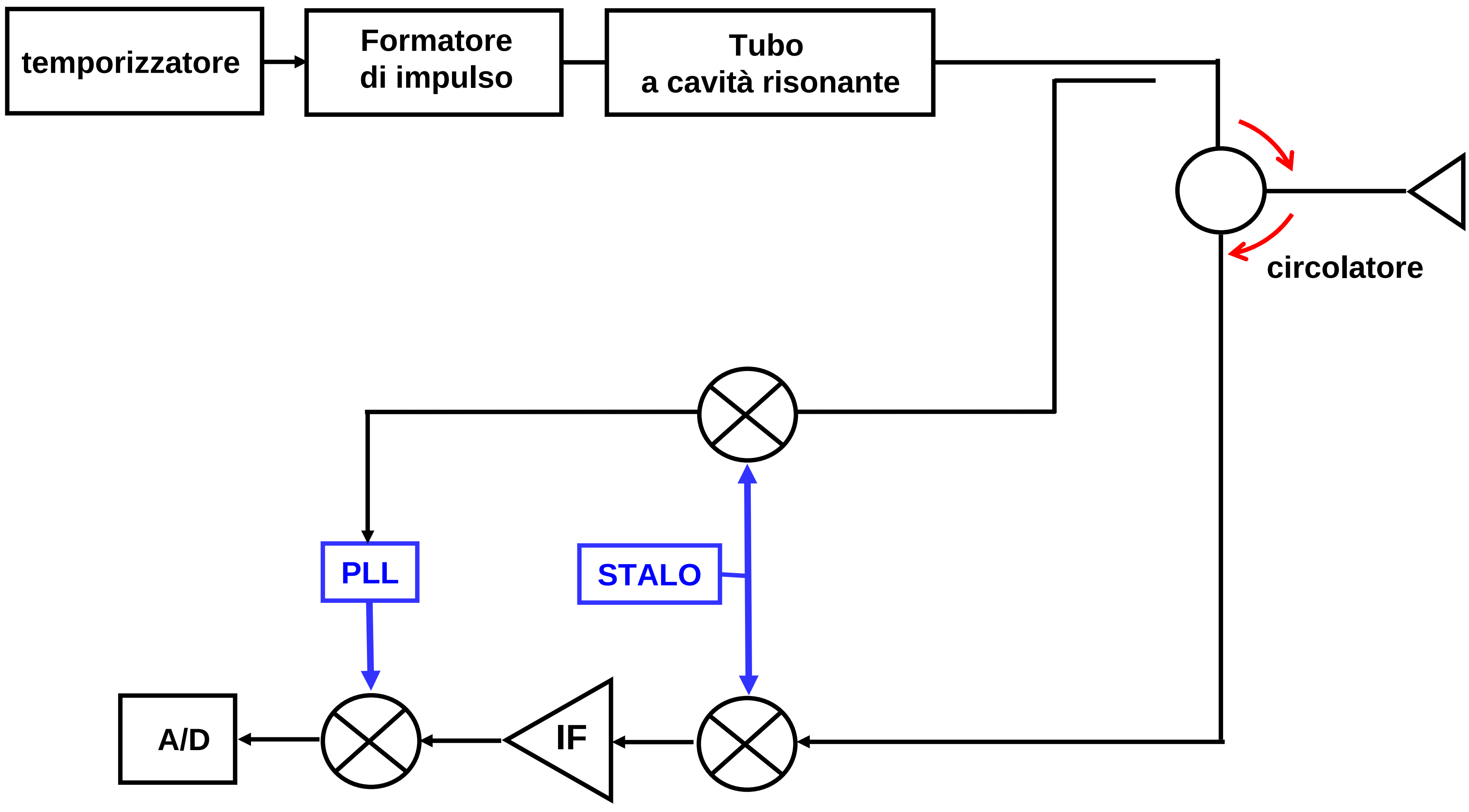


Radar coerente

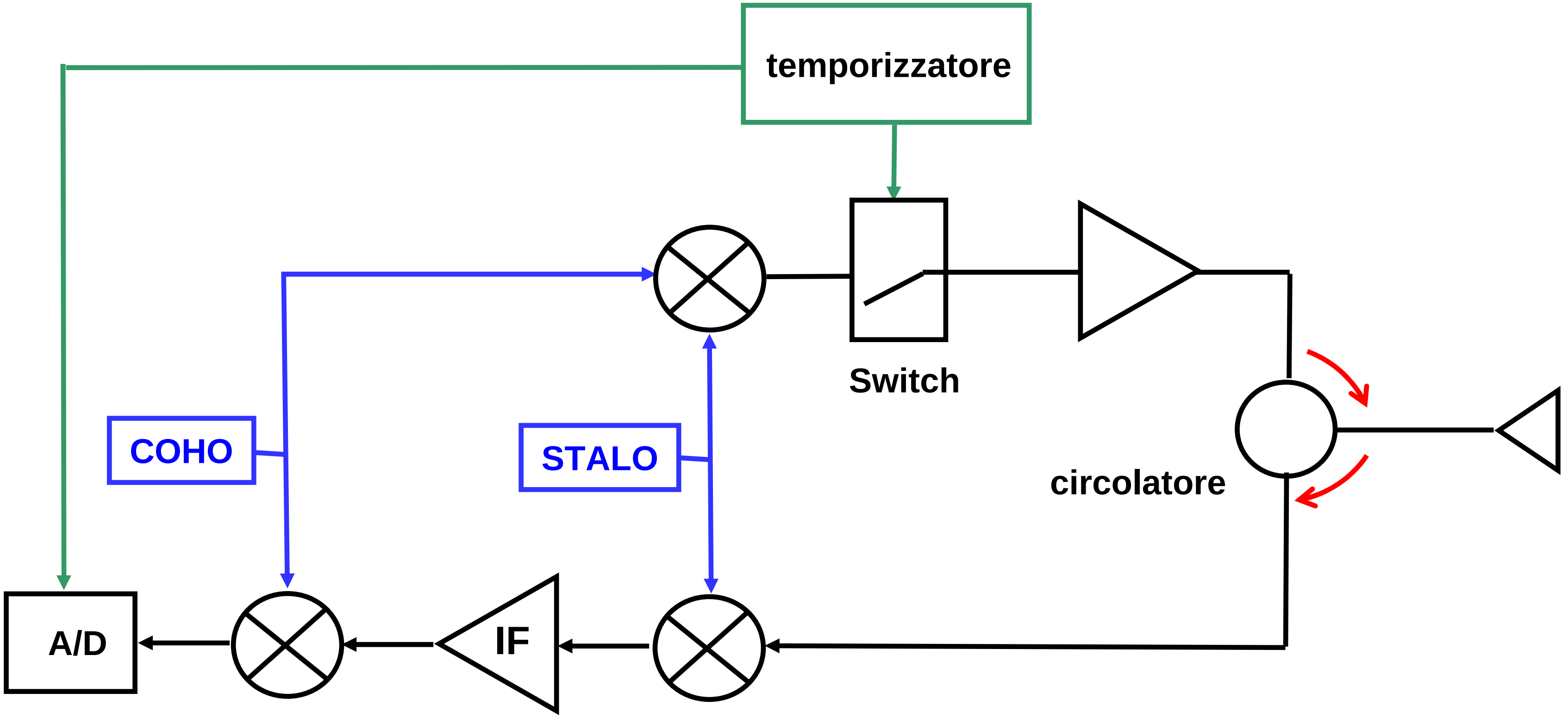
$$\varphi(t) = 2\pi \frac{2v\cos(\vartheta)t}{\lambda}$$

$$\omega_{doppler} = 2\pi \frac{2v\cos(\vartheta)}{\lambda}$$

Radar coerente



Radar coerente



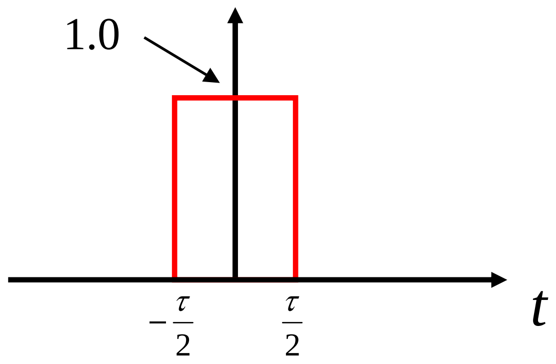
MTI: Moving Target Indicator

Sottrazione dell'impulso

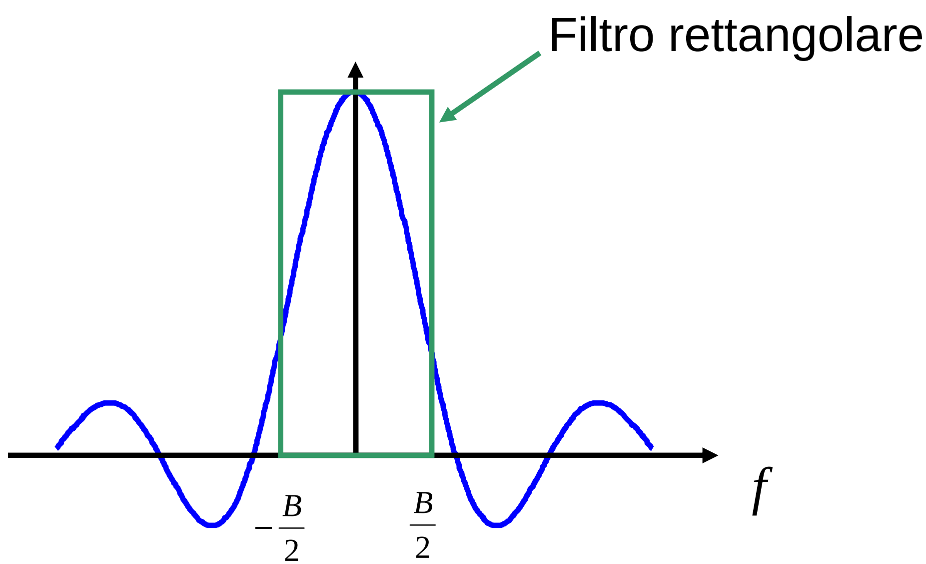
Velocità cieca e ambiguità

Stagger

Filtro adattato



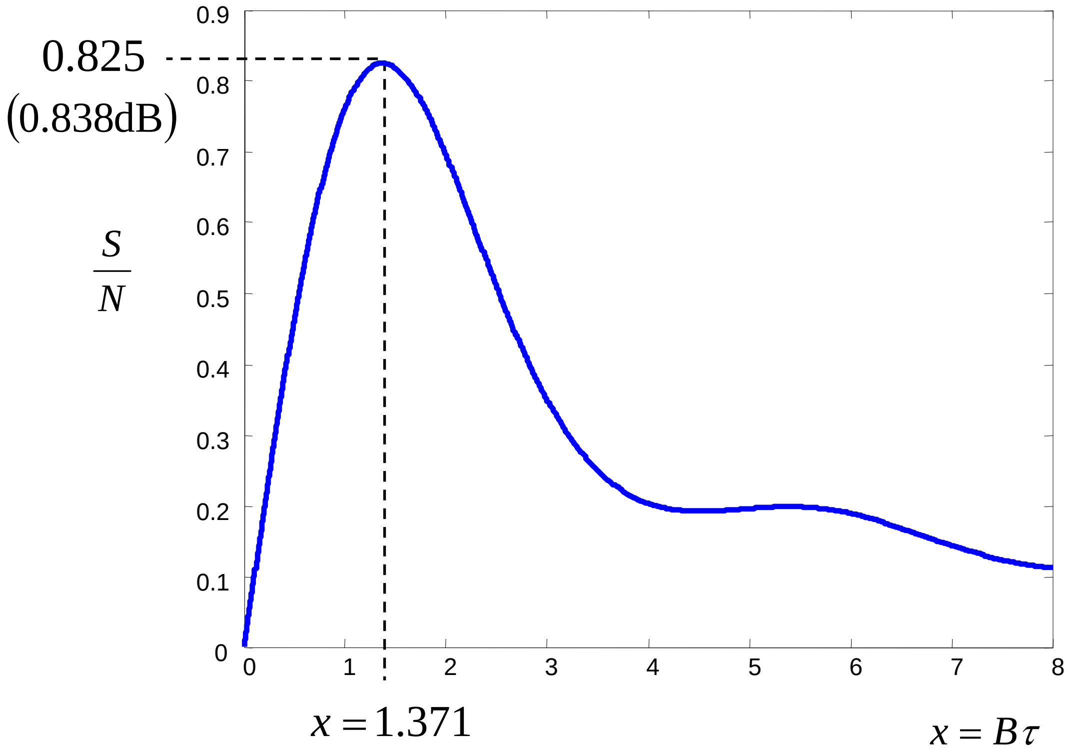
$$S(f)=\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} e^{-j2\pi ft}\,dt = .. = \frac{\sin(\pi f\tau)}{\pi f\tau}$$



$$\frac{S}{N}=\frac{\left[\int_{-\frac{B}{2}}^{\frac{B}{2}} \frac{\sin(\pi f\tau)}{\pi f\tau}\,df\right]^2}{\int_{-\frac{B}{2}}^{\frac{B}{2}} n^2(f)\,df}$$

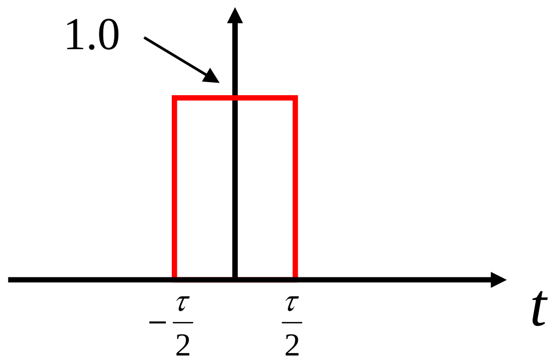
Filtro adattato

$$\frac{S}{N}=\frac{\left[\displaystyle\int_{-\frac{B}{2}}^{\frac{B}{2}}\frac{\sin(\pi f\tau)}{\pi f\tau}df\right]^2}{\displaystyle\int_{-\frac{B}{2}}^{\frac{B}{2}}n^2(f)df}=\frac{\left[\displaystyle\int_{-\frac{B}{2}}^{\frac{B}{2}}\frac{\sin(\pi f\tau)}{\pi f\tau}df\right]^2}{kTB}=\frac{\left[\displaystyle\int_{-\frac{B\tau}{2}}^{\frac{B\tau}{2}}\frac{\sin(\pi f\tau)}{\pi f\tau}df\tau\right]^2}{kTB\tau}=\frac{1}{KT}\frac{\left[\displaystyle\int_{-\frac{x}{2}}^{\frac{x}{2}}\frac{\sin(\pi u)}{\pi u}du\right]^2}{x}$$

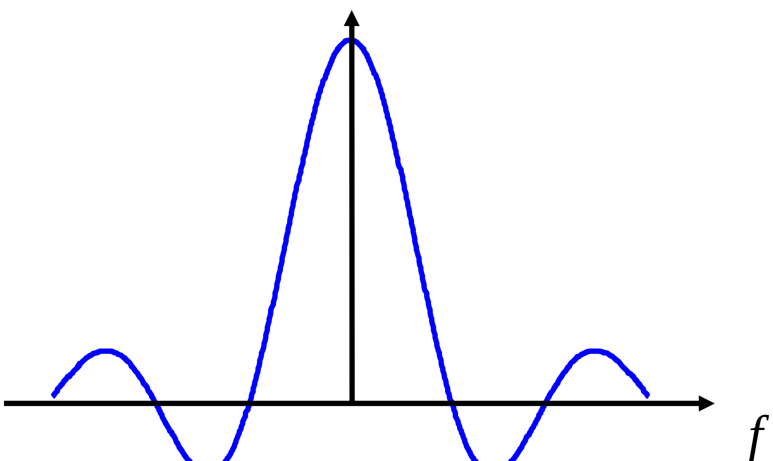


$$B\tau = 1.371$$

$$\boxed{B=\frac{1.371}{\tau}}$$



$$S(f)=\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} e^{-j2\pi ft}dt = .. = \frac{\sin(\pi f\tau)}{\pi f\tau}$$

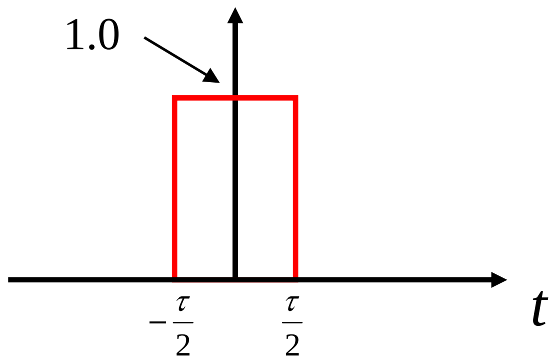


$$\frac{S}{N}=\frac{\left[\int_{-\infty}^{\infty}\frac{\sin(\pi f\tau)}{\pi f\tau}\frac{\sin(\pi f\tau)}{\pi f\tau}df\right]^2}{\int_{-\infty}^{\infty}\left[n(f)\frac{\sin(\pi f\tau)}{\pi f\tau}\right]^2 df}$$

$$\frac{S}{N} = \frac{\left[\int_{-\infty}^{\infty}\left(\frac{\sin(\pi f \tau)}{\pi f \tau}\right)^2 df\right]^2}{\int_{-\infty}^{\infty}\left[n(f)\frac{\sin(\pi f \tau)}{\pi f \tau}\right]^2 df} = \frac{\left[\int_{-\infty}^{\infty}\left(\frac{\sin(\pi f \tau)}{\pi f \tau}\right)^2 df\right]^2}{kT\int_{-\infty}^{\infty}\left(\frac{\sin(\pi f \tau)}{\pi f \tau}\right)^2 df} = \frac{1}{kT}\int_{-\infty}^{\infty}\left(\frac{\sin(\pi u)}{\pi u}\right)^2 du = \frac{1}{kT}$$

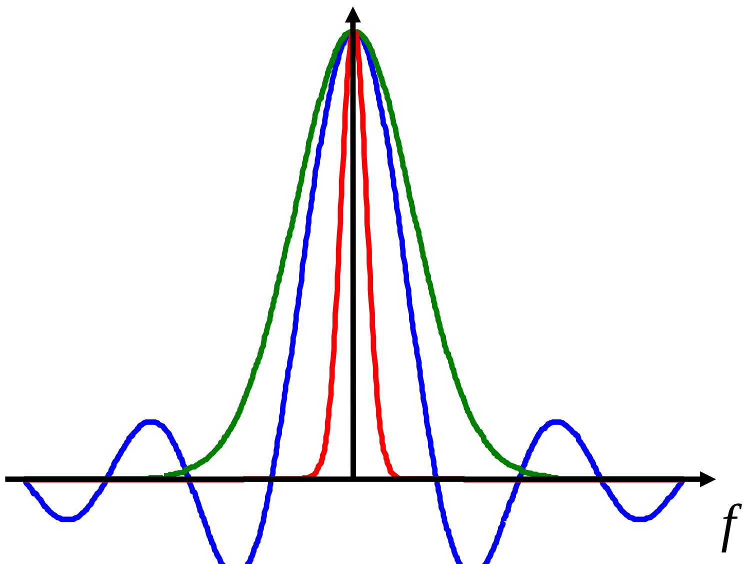
In generale S/N è massimo se uso come filtro lo spettro del segnale trasmesso

Filtro adattato



$$S(f)=\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} e^{-j2\pi ft}dt=..=\frac{\sin(\pi f\tau)}{\pi f\tau}$$

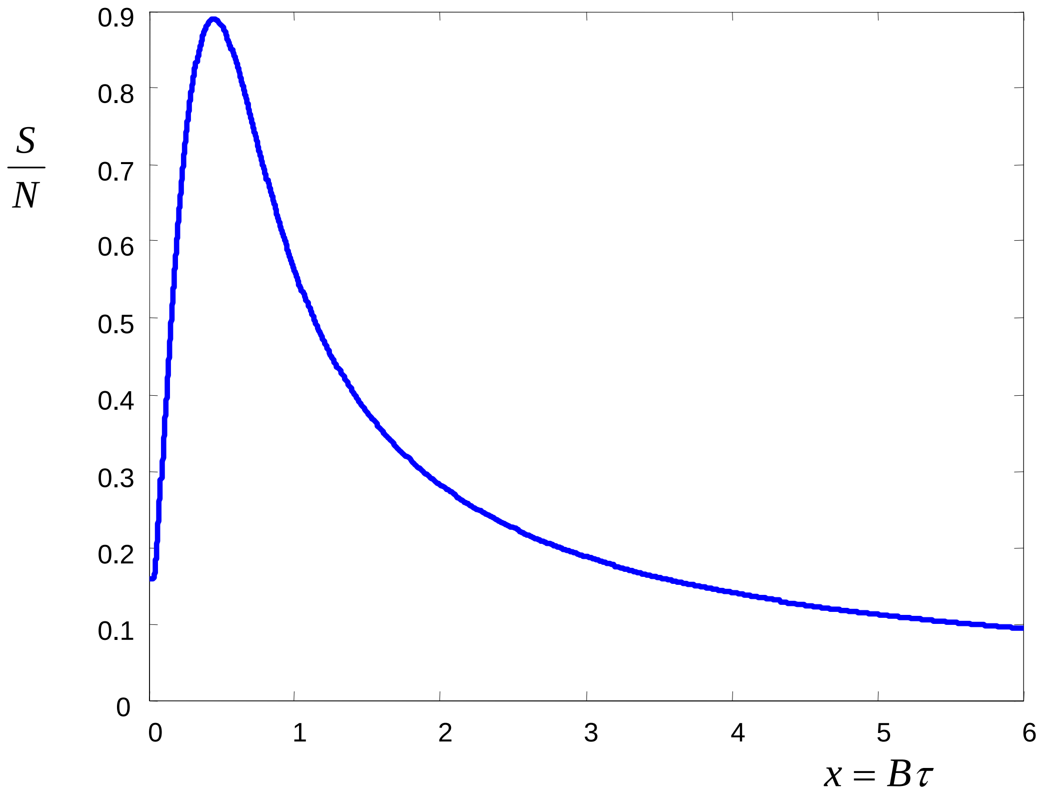
$$F(f)=e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}$$ Filtro gaussiano



$$\frac{S}{N}=\frac{\left[\int_{-\infty}^{\infty}\frac{\sin(\pi f\tau)}{\pi f\tau}e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}df\right]}{\int_{-\infty}^{\infty}n^2(f)e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}df}$$

Filtro adattato

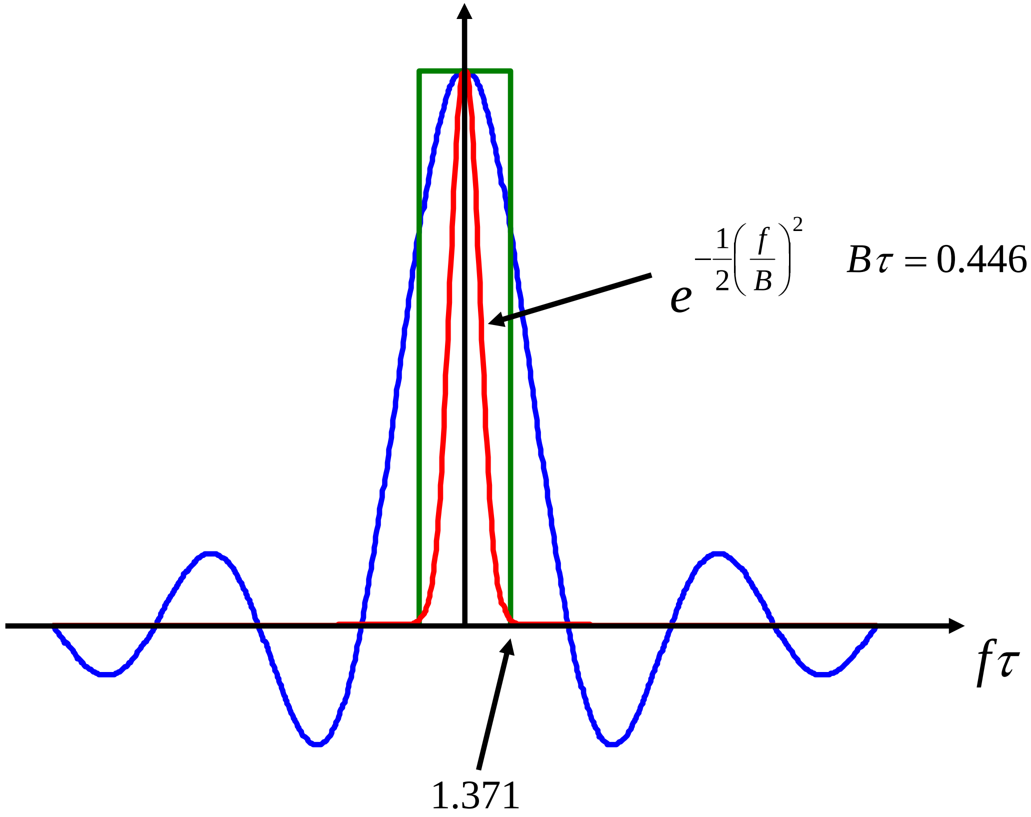
$$\frac{S}{N}=\frac{\left[\displaystyle\int_{-\infty}^{\infty}\frac{\sin(\pi f\tau)}{\pi f\tau}e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}df\right]^2}{\displaystyle\int_{-\infty}^{\infty}\left[n(f)e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}\right]^2df}=\frac{\left[\displaystyle\int_{-\infty}^{\infty}\frac{\sin(\pi f\tau)}{\pi f\tau}e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}df\right]^2}{kT\displaystyle\int_{-\frac{B}{2}}^{\frac{B}{2}}\left[e^{-\frac{1}{2}\left(\frac{f}{B}\right)^2}\right]^2df}=\frac{\left[\displaystyle\int_{-\infty}^{\infty}\frac{\sin(\pi u)}{\pi u}e^{-\frac{1}{2}\left(\frac{u}{B\tau}\right)^2}du\right]^2}{kT\displaystyle\int_{-\infty}^{\infty}\left[e^{-\frac{1}{2}\left(\frac{u}{B\tau}\right)^2}\right]^2du}$$



$$\left(\frac{S}{N}\right)_{\max}=0.890 \quad (-0.506\text{dB})$$

$$B\tau = 0.446$$

Filtro adattato



Filtro adattato

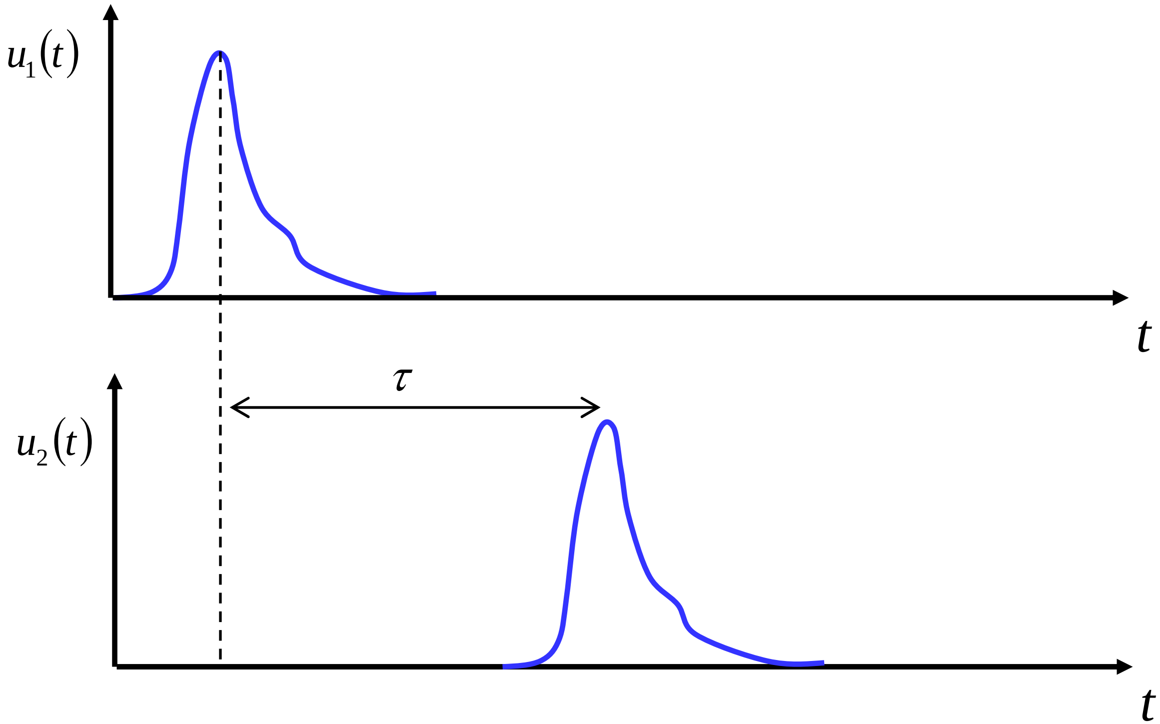
Segnali coerenti

$s(t)$ Segnale inviato

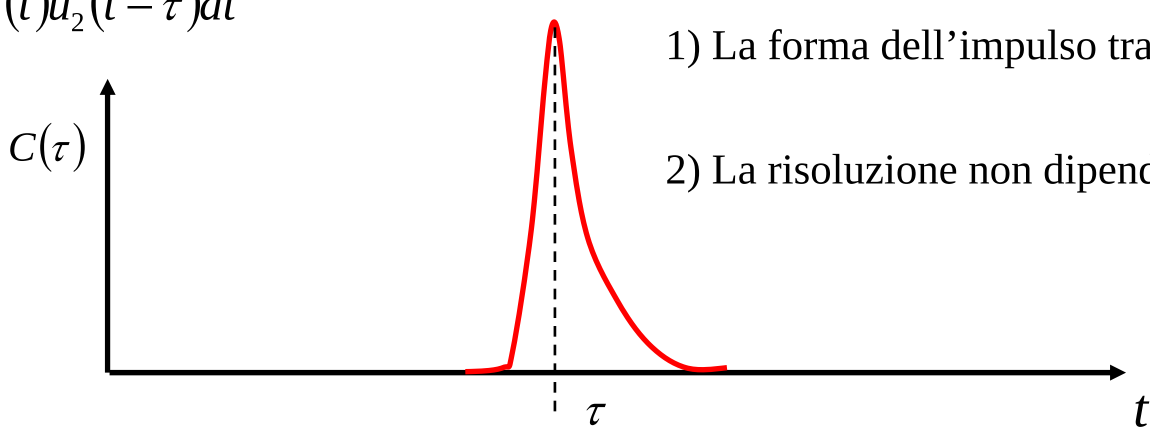
$\tilde{s}(\omega)$ Trasformata di Fourier del segnale

$$\frac{S}{N}=\frac{\left[\int_{-\infty}^{\infty}\tilde{s}(f)a(f)df\right]^2}{kT\int_{-\infty}^{\infty}\left|a(f)\right|^2 df}=\frac{1}{kT}$$

$\boxed{a(f)=\tilde{s}^*(f)}$ **Filtro adattato**



$$C(\tau) = \int u_1(t) u_2(t-\tau)\, dt$$



1) La forma dell'impulso trasmesso agisce da filtro

2) La risoluzione non dipende dalla durata dell'impulso

Compressione di impulso

$$\boxed{C(\tau) = \int_0^T u_{TX}(t)\,u_{RX}(t-\tau)\,dt}$$

$$\tilde{C}(f) = \left|\tilde{u}(f)\right|^2$$

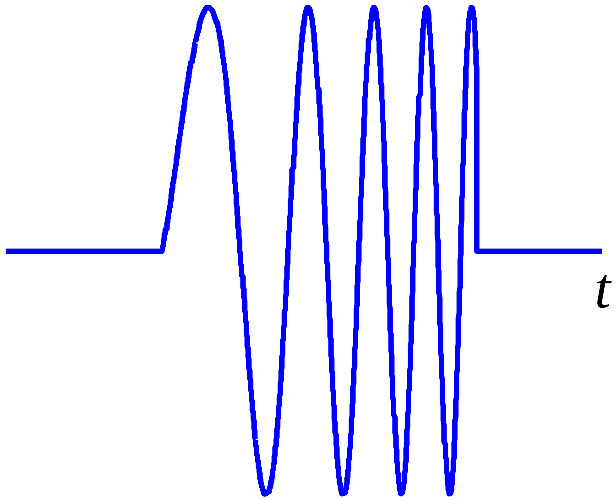
$$\Delta\tau = \frac{1}{B}$$

Separa la durata dell'impulso dalla risoluzione:
la risoluzione non dipende dalla durata dell'impulso, ma dal contenuto spettrale (banda) della modulazione dell'impulso

L'ampiezza del segnale compresso C(τ) dipende non dall'ampiezza assoluta del segnale trasmesso, ma dal suo integrale: quindi a parità di ampiezza del segnale trasmesso, l'ampiezza del segnale compresso aumenta all'aumentare della durata dell'impulso

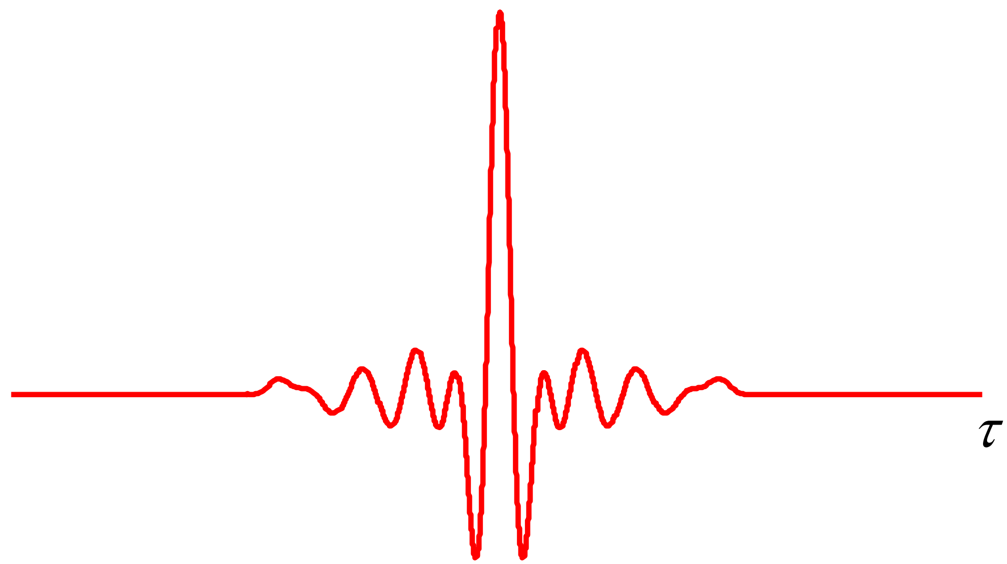
Nota: la compressione di impulso realizza un filtro adattato

Compressione di impulso



$$s(t) = \sin(2\pi(f_0 + kt)t) = \sin\left(2\pi\left(f_0 t + kt^2\right)\right)$$

$$C(\tau) = \int_0^T s(t)s(t-\tau)dt$$



Segnali coerenti

$$\boxed{C(\tau) = \int_0^T u_{TX}(t)\,u_{RX}^*(t-\tau)\,dt}$$