

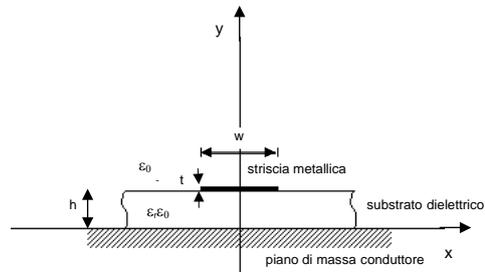
Sistemi e componenti a microonde

parametri principali

Sistemi a RF/microonde

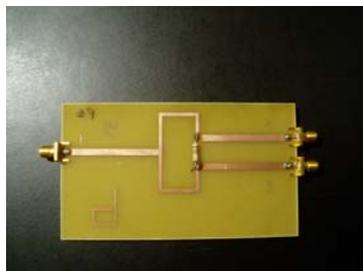
Denominazioni	Intervallo di frequenza GHz (10 ⁹ Hz)
HF	0.003 - 0.030
VHF	0.030 - 0.300
UHF	0.300 - 1.000
Banda L	1.0 - 2.0
Banda S	2.0 - 4.0
Banda C	4.0 - 8.0
Banda X	8.0 - 12.0
Banda Ku	12.0 - 18.0
Banda K	18.0 - 26.5
Banda Ka	26.5 - 40.0
Banda Q	40.0 - 50.0
Banda V	50.0 - 75.00
Millimetrico	40.0 - 300.0
Terahertz	> 300.0

Microstriscia

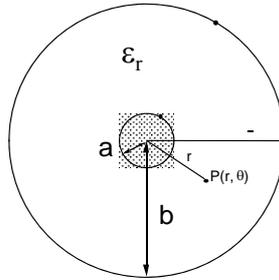


Microstriscia
(circuiti planari, amp., filtri etc.)

Microstriscia

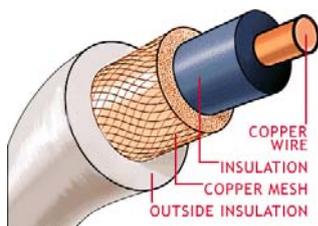


Cavo Coassiale



cavo coassiale
(telecomunicazioni, laboratorio)

Cavo Coassiale



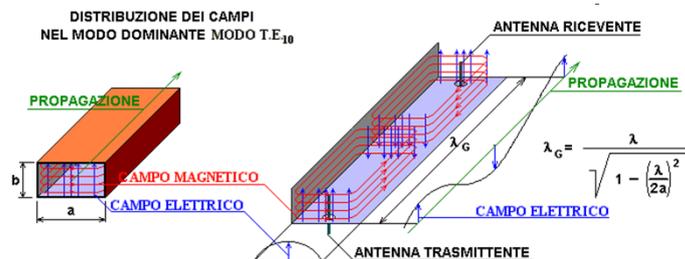
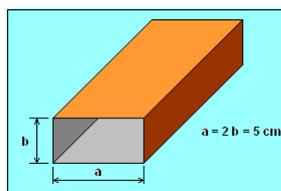
Connettori /Transizioni

TABLE 6.10 Common Coaxial Connectors

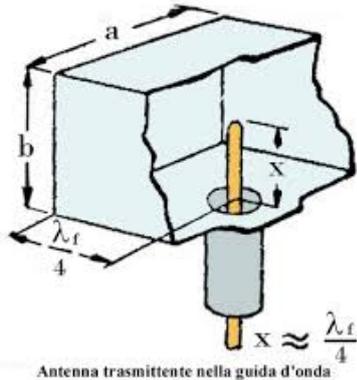
Connector Type	Cutoff Frequency	Mating Torque
BNC	4.0 GHz	N/A
SMB	4 GHz	N/A
SMC	10 GHz	30–50 in-oz
TNC	15 GHz	12–15 in-lbs
Type-N	18 GHz	12–15 in-lbs
7 mm	18 GHz	12–15 in-lbs
SMA	18 GHz	7–10 in-lbs
3.5 mm	26.5 GHz	7–12 in-lbs
2.9 mm	46 GHz	8–10 in-lbs
2.4 mm	50 GHz	8–10 in-lbs



Guida d'onda

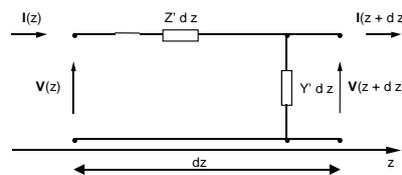
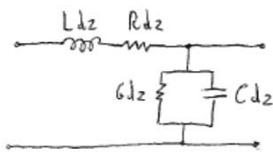


Componenti in guida d'onda



Teoria delle Linee di trasmissione

(esempi cavo coassiale)



PARAMETRI PRIMARI

- C' = Capacità parallela per unità di lunghezza (F/m)
- L' = Induttanza serie per unità di lunghezza (H/m)
- G' = Conduttanza parallela per unità di lunghezza (S/m)
- R' = Resistenza serie per unità di lunghezza (Ω/m)
- $Z' = R' + j\omega L'$ Impedenza per unità di lunghezza (Ω/m)
- $Y' = G' + j\omega C'$ Ammettenza per unità di lunghezza (S/m)

$$C' = \frac{Q'}{V_0} = \frac{2\pi\epsilon'}{\ln \frac{b}{a}} \quad L' = \frac{\Psi'}{I_0} = \frac{\mu}{2\pi} \ln \frac{b}{a}$$

$$R_s = \sqrt{\frac{\omega\mu}{2g}} \quad \tan \delta = \epsilon''/\epsilon'$$

$$G' = \frac{I'_c}{V_0} = \omega C' \tan \delta = \frac{2\pi\omega\epsilon''}{\ln \frac{b}{a}}$$

$$\frac{1}{2} R' I_0^2 = \frac{R_s}{2} \int_{r_1}^{r_2} |\mathbf{h}_t(r, \theta)|^2 dl$$

$$R' = R_s \frac{\int_{r_1}^{r_2} |\mathbf{h}_t(r, \theta)|^2 dl}{\left(\int_{r_1}^{r_2} |\mathbf{h}_t(r, \theta)| dl \right)^2} = \frac{R_s}{2\pi} \frac{b+a}{ab}$$

Equazioni dei telegrafisti

$$\frac{dV(z)}{dz} = -Z' I(z)$$

$$\frac{dI(z)}{dz} = -Y' V(z)$$

$$V(z) = V^+ e^{-\gamma z} + V^- e^{+\gamma z} \quad I(z) = \left(\frac{1}{Z_0}\right) (V^+ e^{-\gamma z} - V^- e^{+\gamma z})$$

Onda diretta e riflessa di tensione

Onda diretta e riflessa di corrente

Parametri secondari della linea

$$\gamma = \alpha + j\beta = \sqrt{Z' Y'} = \sqrt{(R' + j\omega L')(G' + j\omega C')} \quad \text{Costante di propagazione (attenuazione e fase)}$$

$$Z_0 = Z_{0r} + jZ_{0j} = \sqrt{\frac{Z'}{Y'}} = \sqrt{\frac{R' + j\omega L'}{G' + j\omega C'}} \quad \text{Impedenza caratteristica}$$

Cavo Coassiale

basse perdite $\gamma \approx \frac{1}{2} \left(\frac{R'}{Z_0} + G' Z_0 \right) + j\omega \sqrt{L' C'}$

$$\beta \approx \omega \sqrt{L' C'} = \omega \sqrt{\varepsilon_0 \mu_0} \sqrt{\varepsilon_r} = \frac{\omega}{c_0} \sqrt{\varepsilon_r}$$

$$v = \frac{\omega}{\beta} = \frac{c_0}{\sqrt{\varepsilon_r}} = \frac{3 \cdot 10^8}{\sqrt{\varepsilon_r}} \text{ m/s} \quad \text{(velocità di fase)}$$

$$Z_0 = \sqrt{\frac{L'}{C'}} = \frac{1}{2\pi} \sqrt{\frac{\mu}{\varepsilon}} \ln\left(\frac{b}{a}\right) = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{b}{a}\right) \Omega$$

Valore tipico per cavi e microstrisce $Z_0 = 50 \Omega$

Parametri caratteristici

$$A_{dB} = 10 \log \frac{P_{IN}}{P_{OUT}} = 10 \log \frac{P_{IN}}{P_{IN} e^{-2\alpha l}} = 8.686 \alpha l \text{ dB} \quad \text{attenuazione}$$

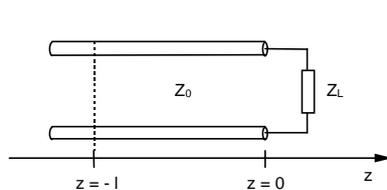
$$Z(z) = \frac{V(z)}{I(z)} = Z_0 \frac{V^+ e^{-\gamma z} + V^- e^{+\gamma z}}{V^+ e^{-\gamma z} - V^- e^{+\gamma z}} \quad \text{Impedenza lungo la linea}$$

$$\Gamma(z) = \frac{V^- e^{+\gamma z}}{V^+ e^{-\gamma z}} = \frac{V^-}{V^+} e^{2\gamma z} \quad \text{coefficiente di riflessione lungo la linea}$$

$$\Gamma(z) = \frac{Z(z) - Z_0}{Z(z) + Z_0}$$

$$Z(z) = Z_0 \frac{1 + \Gamma(z)}{1 - \Gamma(z)}$$

Linee di trasmissione chiuse su carichi



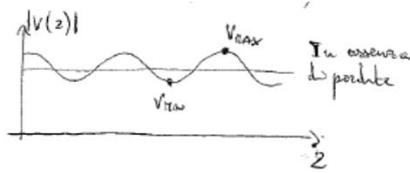
$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \rho e^{j\varphi}$$

$$Z_L = Z_0 \frac{1 + \Gamma_L}{1 - \Gamma_L}$$

$$Z(-l) = Z_0 \frac{Z_L \cos(\beta l) + j Z_0 \sin(\beta l)}{Z_0 \cos(\beta l) + j Z_L \sin(\beta l)}$$

$$\Gamma(-l) = \Gamma_L e^{-2j\beta l} = \rho e^{-2j\beta l + j\varphi}$$

ROS e vari casi



rapporto d'onda stazionaria
(ROS o SWR)

$$\text{ROS} = \frac{V_{\text{MAX}}}{V_{\text{MIN}}} = \frac{1+\rho}{1-\rho} \quad \rho = \frac{\text{ROS} - 1}{\text{ROS} + 1}$$

Carico adattato $Z_L = Z_0$ $\rho = 0$ $\text{ROS} = 1$

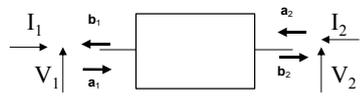
Corto circuito $Z_L = 0$ $\rho = 1$ $\text{ROS} = \infty$

Circuito aperto $Z_L = \infty$ $\rho = 1$ $\text{ROS} = \infty$

Per approfondimenti dispensa nel sito

Circuiti lineari

matrice scattering 1/2



(onde di tensione)

$$V_1 = a_1 + b_1$$

$$V_2 = a_2 + b_2$$

$$I_1 = \frac{a_1 - b_1}{Z_0}$$

$$I_2 = \frac{a_2 - b_2}{Z_0}$$

$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

$$[b] = [S] [a]$$

$$S_{ij} = \left(\frac{b_i}{a_j} \right)_{a_k=0 \text{ con } k \neq j}$$

Nell'ipotesi che tutte le impedenze caratteristiche delle linee di accesso Z_{0i} siano uguali, valgono le seguenti proprietà:

per componenti reciproci $S_{ij} = S_{ji}$ che, in forma matriciale diventa: $[S] = [S]^T$
 per componenti privi di perdite $[S] [S]^* = [1]$
 simmetria porte $i, j \Rightarrow S_{ij} = S_{ji}$

matrice scattering 2/2



$$P_1 = P_E = \frac{1}{2} \text{Re}(V_1 I_1^*) = \frac{1}{2} \text{Re} \left\{ (a_1 + b_1) \left(\frac{a_1 - b_1}{Z_0} \right)^* \right\} = \frac{1}{2Z_0} |a_1|^2 - \frac{1}{2Z_0} |b_1|^2$$

$$P_1 = P_E = P_i - P_R = P_i \left(1 - \frac{P_R}{P_i} \right) = P_i (1 - |\Gamma_i|^2)$$

$$P_2 = \frac{1}{2} \text{Re}(V_2 (-I_2)^*) = \frac{1}{2} \text{Re} \left\{ (a_2 + b_2) \left(\frac{b_2 - a_2}{Z_0} \right)^* \right\} = -\frac{1}{2Z_0} |a_2|^2 + \frac{1}{2Z_0} |b_2|^2$$

$$\text{se } a_2 = 0 \longrightarrow P_2 = P_o = \frac{1}{2Z_0} |b_2|^2 = \frac{1}{2Z_0} |S_{21}|^2 |a_1|^2 = P_i |S_{21}|^2 \longrightarrow |S_{21}|^2 = \frac{P_o}{P_i}$$

$$\text{se } a_2 = 0 \longrightarrow |\Gamma_i| = |S_{11}| \longrightarrow |S_{11}|^2 = \frac{P_R}{P_i}$$

i moduli quadrati dei parametri di scattering sono rapporti tra potenze

Parametri sistemi lineari 1/5



$$A_{dB} = 10 \log_{10} \frac{P_I}{P_O} = 10 \log_{10} \frac{P_I}{P_E} + 10 \log_{10} \frac{P_E}{P_O} = A_{RdB} + A_{DdB}$$

A_{dB} = Attenuazione

A_{RdB} = Attenuazione per riflessione

A_{DdB} = Attenuazione per dissipazione

$$L_{RdB} = 10 \log_{10} \frac{P_I}{P_R} \quad L_{RdB} = \text{Perdita di Riflessione}$$

Parametri sistemi lineari 2/5

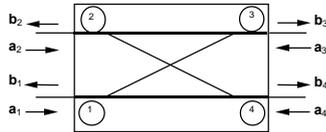
$$A_{RdB} = 10 \log_{10} \frac{P_I}{P_E} = 10 \log_{10} \left[\frac{\frac{1}{2Z_0} |a_1|^2}{\frac{1}{2Z_0} |a_1|^2 (1 - |S_{11}|^2)} \right] = 10 \log_{10} \frac{1}{1 - |S_{11}|^2}$$

$$A_{DdB} = 10 \log_{10} \frac{P_E}{P_O} = 10 \log_{10} \left[\frac{\frac{1}{2Z_0} |a_1|^2 (1 - |S_{11}|^2)}{\frac{1}{2Z_0} |a_1|^2 |S_{21}|^2} \right] = 10 \log_{10} \frac{1 - |S_{11}|^2}{|S_{21}|^2}$$

$$A_{dB} = A_{RdB} + A_{DdB} = 10 \log_{10} \frac{1}{|S_{21}|^2}$$

$$L_{RdB} = 10 \log_{10} \frac{P_I}{P_R} = 10 \log_{10} \left[\frac{\frac{1}{2Z_0} |a_1|^2}{\frac{1}{2Z_0} |a_1|^2 |S_{11}|^2} \right] = 10 \log_{10} \frac{1}{|S_{11}|^2}$$

Parametri sistemi lineari 3/5



Accoppiamento	$C_{dB} = 10 \log \frac{P_1}{P_{31}}$
Direttività	$D_{dB} = 10 \log \frac{P_{31}}{P_{21}}$
Isolamento	$I_{dB} = 10 \log \frac{P_1}{P_{21}}$

Con le porte chiuse su carichi adattati: $a_2 = 0$, $a_3 = 0$, $a_4 = 0$
e la porta 1 alimentata con un generatore adattato

$$P_{31} = P_1 |S_{31}|^2 \quad P_{21} = P_1 |S_{21}|^2$$

$$C_{dB} = 10 \log_{10} \frac{1}{|S_{31}|^2} \quad D_{dB} = 10 \log_{10} \frac{|S_{31}|^2}{|S_{21}|^2} \quad I_{dB} = 10 \log_{10} \frac{1}{|S_{21}|^2}$$

Parametri sistemi lineari 4/5



Guadagno di trasduzione

$$G_T = \frac{\text{potenza erogata dalla rete due porte al carico}}{\text{potenza disponibile del generatore}} = \frac{P_2}{P_{AVS}}$$

se carico $Z_L = Z_0 \longrightarrow a_2 = 0$; generatore $Z_G = Z_0$

$$P_2 = P_1 |S_{21}|^2 \quad P_{AVS} = \frac{1}{2Z_0} |a_1|^2 = \frac{1}{2Z_0} \left| \frac{V_s}{2} \right|^2 = \frac{|V_s|^2}{8Z_0} = P_1$$

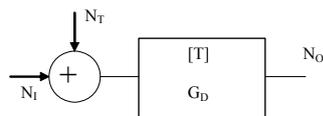
$$G_T = \frac{P_2}{P_1} = |S_{21}|^2 \longrightarrow G_{TdB} = 10 \log_{10} |S_{21}|^2$$

$$G_P = \frac{P_L}{P_S} = \frac{P_O}{P_E} = \frac{P_1 |S_{21}|^2}{P_1 (1 - |\Gamma_1|^2)} = \frac{|S_{21}|^2}{(1 - |S_{11}|^2)} \quad G_D = \frac{P_{AVL}}{P_{AVSS}} = \frac{|S_{21}|^2}{(1 - |S_{22}|^2)}$$

Parametri sistemi lineari 5/5



Fattore di rumore $F = \frac{S_i/N_i}{S_o/N_o}$ Figura di rumore $F_{dB} = 10 \log_{10} F$



N_T = potenza disponibile di rumore dell'amplif. ricondotta in ingresso

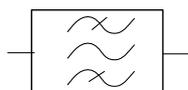
N_i = potenza disponibile di rumore del generatore

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i/N_i}{S_i G_D / (N_i + N_T) G_D} = 1 + \frac{N_T}{N_i}$$

$$N = \frac{\langle V^2 \rangle}{4R} = \frac{4KTBR}{4R} = KTB \longrightarrow F = 1 + \frac{T_T}{T_i} = 1 + \frac{T_T}{290K}$$

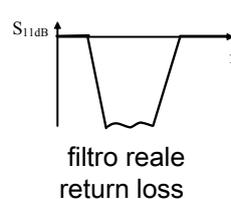
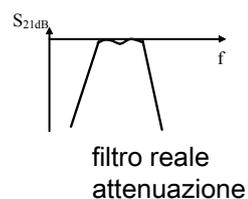
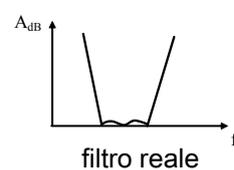
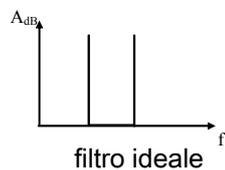
Circuiti lineari FILTRI

Sono essenzialmente degli attenuatori per riflessione

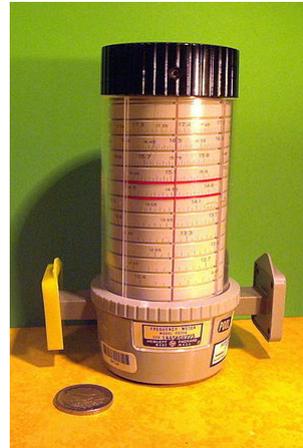
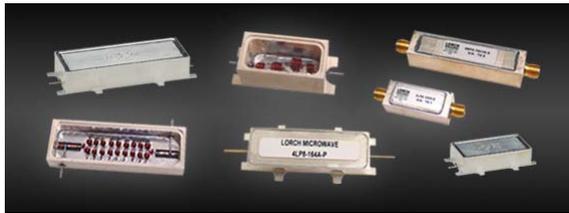


Sono realizzati con:

- Cavità risonanti
- Risonatori dielettrici o ceramici
- Microstriscia o stripline



FILTRI



ondametro

Circuiti lineari

ATTENUATORI

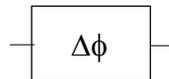
attenuano
per dissipazione



Sono realizzati con:

- Slab dissipative
- Diodi PIN

SFASATORI



Sono realizzati con:

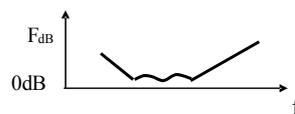
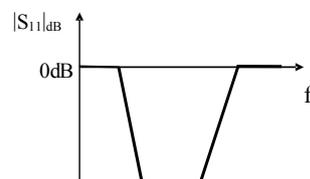
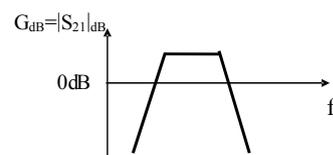
- Slab dielettriche
- Diodi PIN
- MEMS

$$S_{21} = \left(\frac{b_2}{a_1} \right)_{a_2=0} = \frac{V_1 e^{-j\Delta\phi}}{V_1} = e^{-j\Delta\phi} \longrightarrow \Delta\phi = \angle S_{21}$$

Attenuatori



Circuiti lineari AMPLIFICATORI



Sono realizzati con:

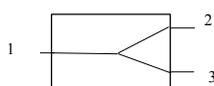
- Stato solido (BJT, Mesfet..)
- Tubi a vuoto (TWT, KLYSTRON)

Amplificatori



Circuiti lineari

DIVISORI



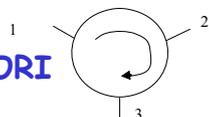
Sono realizzati con:

- Guide rettangolari
- Microstriscia, stripline

Matrici S ideali

$$\underline{S} = \begin{pmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & 0 & 0 \end{pmatrix}$$

CIRCOLATORI

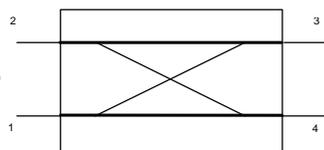


Sono realizzati con ferriti:

- In guida d'onda
- In microstriscia

$$\underline{S} = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

AD



Sono realizzati con:

- guida d'onda
- microstriscia

$$\underline{S} = \begin{pmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & 0 \\ S_{14} & S_{24} & 0 & 0 \end{pmatrix}$$

Accoppiatori direzionali e Circolatori

