Università degli Studi dell'Aquila

Ingegneria

Corso di laurea Magistrale in
Ingegneria elettronica

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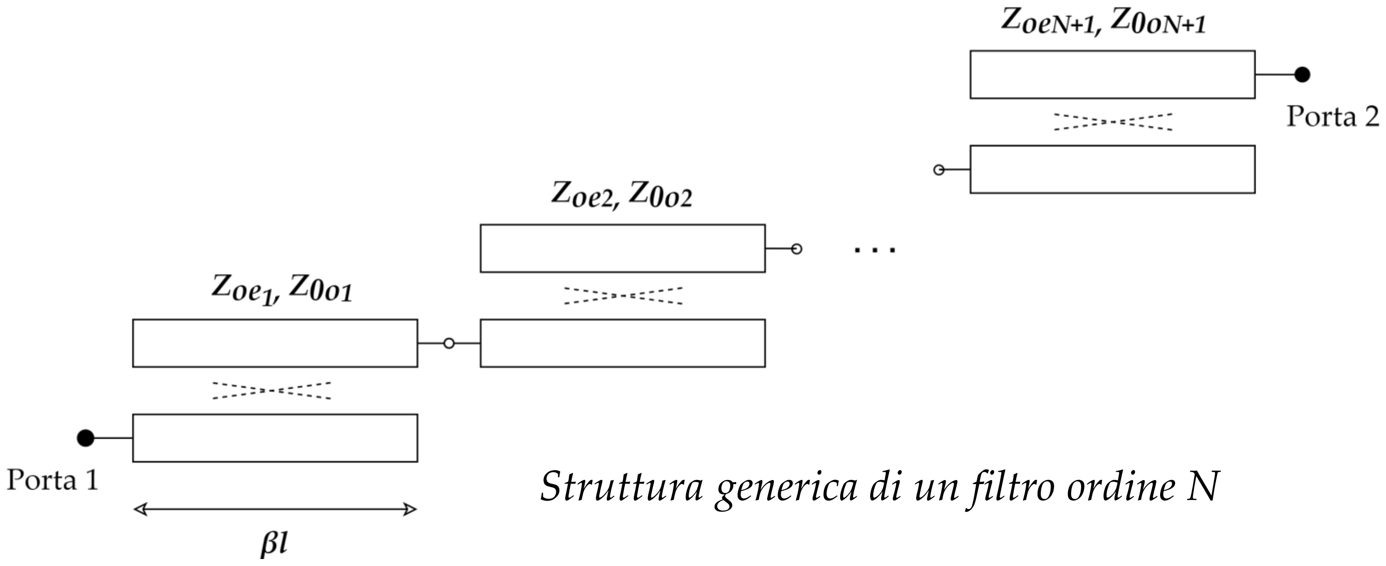
Design, realizzazione e test di un filtro a microstrice accoppiate

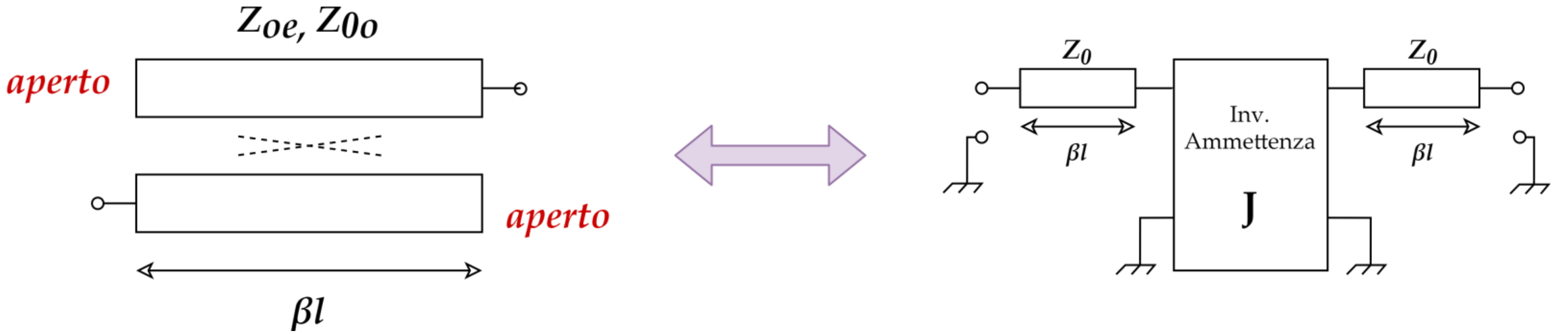
Principio di funzionamento di un filtro a linee accoppiate



Struttura generica di un filtro ordine N

- Ordine N → N+1 linee accoppiate
- Valido per linee generiche

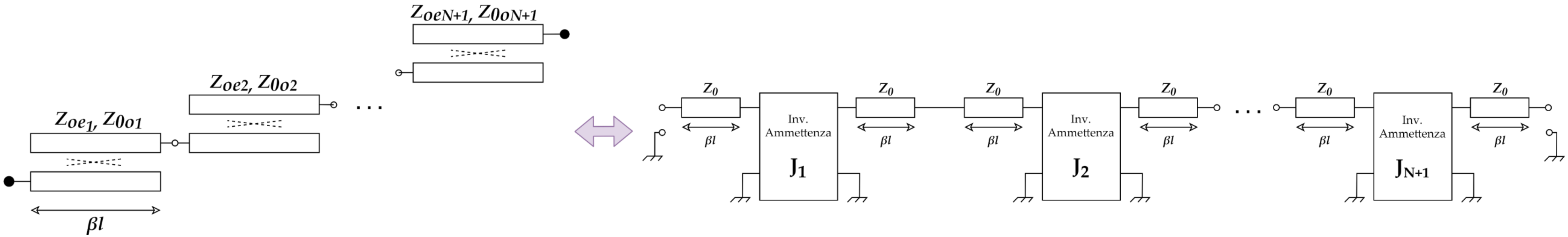
Su quale principio si basa tale struttura?



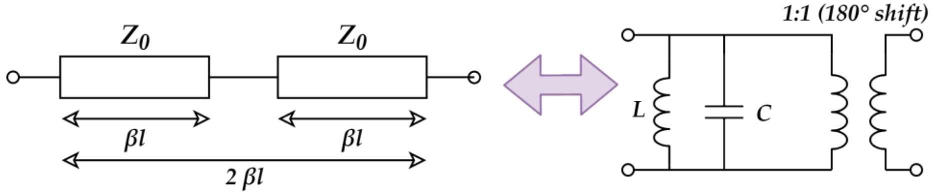
$$Z_{0e} = Z_0\,[\,1 + J\,Z_o + (J\,Z_0)^2]$$

$$Z_{0o} = Z_0\,[\,1 - J\,Z_o + (J\,Z_0)^2]$$

Se $\beta l = \frac{\pi}{2}$ (cioè $l=\lambda/2$) per entrambi i modi even e odd vale l'equivalenza

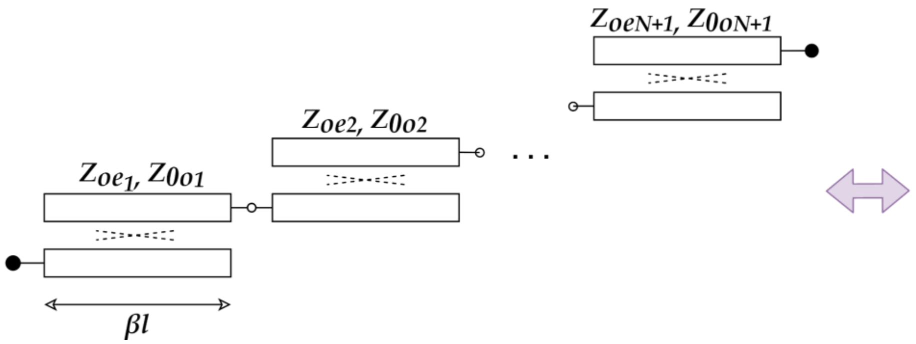


Sempre se $\beta l = \frac{\pi}{2}$ *vale l'equivalenza:*

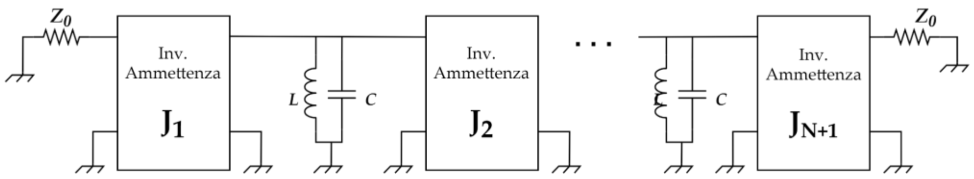


$$L = \frac{2\, Z_0}{\pi\, \omega_0} \qquad C = \frac{\pi}{2\, Z_0\, \omega_0} \qquad \omega_0 = 2\pi f_0\,,$$ freq per cui $l = \lambda/2$

Date le precedenti equivalenze:



<u>N celle LC totali</u>



Per calcolare i Jn:

$$J_1 = \sqrt{\frac{\pi\Delta}{2\, g1}}\, \frac{1}{Z_0}$$

$$J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}\, g_n}}\, \frac{1}{Z_0}$$

$$J_{N+1} = \sqrt{\frac{\pi\Delta}{2\, g_{N+1} g_n}}\, \frac{1}{Z_0}$$

Δ: bw frazionale
g: parametri imp. inv.

Ottenuti i Jn ottengo Z_{even} *e* Z_{odd} *delle linee accoppiate → sintesi*

Sviluppo del filtro

Z_0= 50 Ω   Δ = 2.5% f_0= 4 GHz   Tipologia: Butterworth, N=4 ed N=5

Dalle tabelle dei coeffienti g ottengo i parametri desiderati per la risposta Butterworth

TABLE 8.3 Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

Source: Reprinted from G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass., 1980, with permission.

Calcolo le impedenze caratteristiche even e odd delle linee

```
g0=1; g1=0.7654; g2=1.8478;
g3=1.8478; g4=0.7654; g5=1;
D=0.025; Zo=50;

J1= sqrt((pi*D)/(2*g1)) * (1/Zo);
Zoe1= Zo*( 1 + (J1*Zo) + (J1*Zo)^2 );
Zoo1= Zo*( 1 - (J1*Zo) + (J1*Zo)^2 );

J2= ((pi*D)/(2*(sqrt(g1*g2))))*(1/Zo);
Zoe2= Zo*( 1 + (J2*Zo) + (J2*Zo)^2 );
Zoo2= Zo*( 1 - (J2*Zo) + (J2*Zo)^2 );

J3= ((pi*D)/(2*(sqrt(g2*g3))))*(1/Zo);
Zoe3= Zo*( 1 + (J3*Zo) + (J3*Zo)^2 );
Zoo3= Zo*( 1 - (J3*Zo) + (J3*Zo)^2 );

J4= ((pi*D)/(2*(sqrt(g3*g4))))*(1/Zo);
Zoe4= Zo*( 1 + (J4*Zo) + (J4*Zo)^2 );
Zoo4= Zo*( 1 - (J4*Zo) + (J4*Zo)^2 );

J5= sqrt((pi*D)/(2*g5*g4))*(1/Zo);
Zoe5= Zo*( 1 + (J5*Zo) + (J5*Zo)^2 );
Zoo5= Zo*( 1 - (J5*Zo) + (J5*Zo)^2 );
```

N=4

Zoe1	63.8908
Zoe2	51.7056
Zoe3	51.0852
Zoe4	51.7056
Zoe5	63.8908

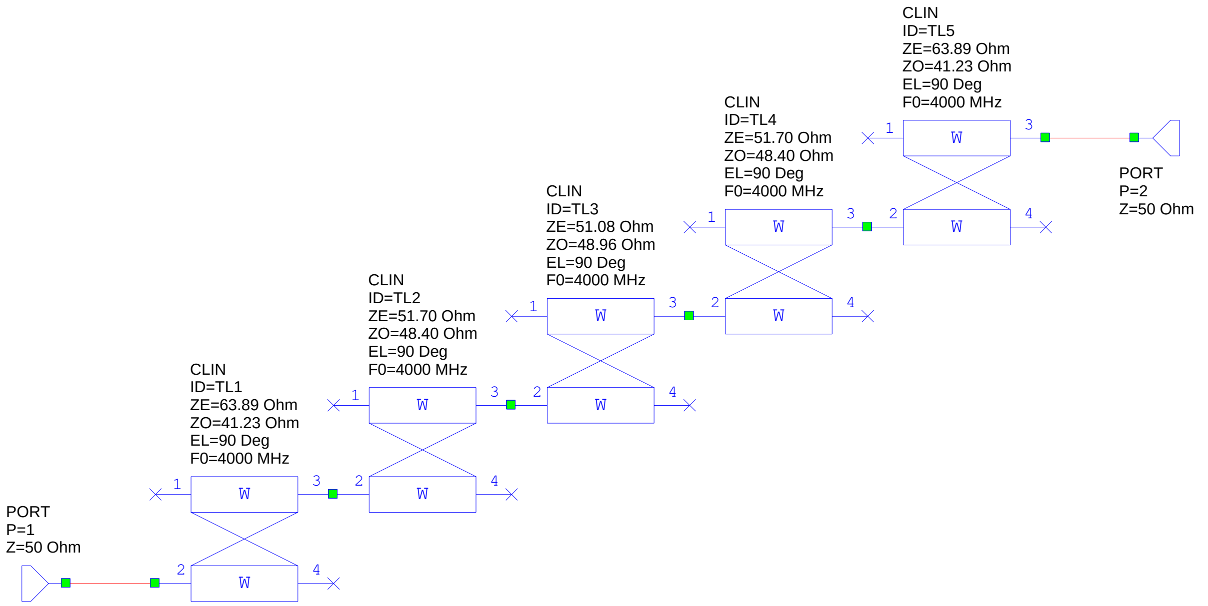
Zoo1	41.2399
Zoo2	48.4035
Zoo3	48.9600
Zoo4	48.4035
Zoo5	41.2399

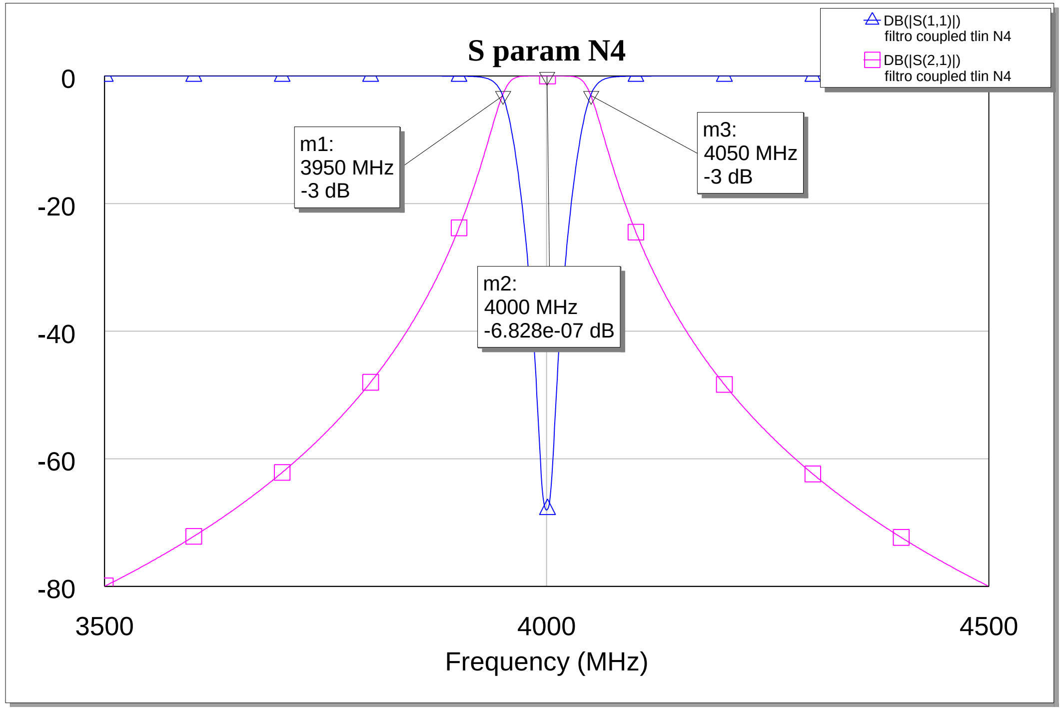
N=5

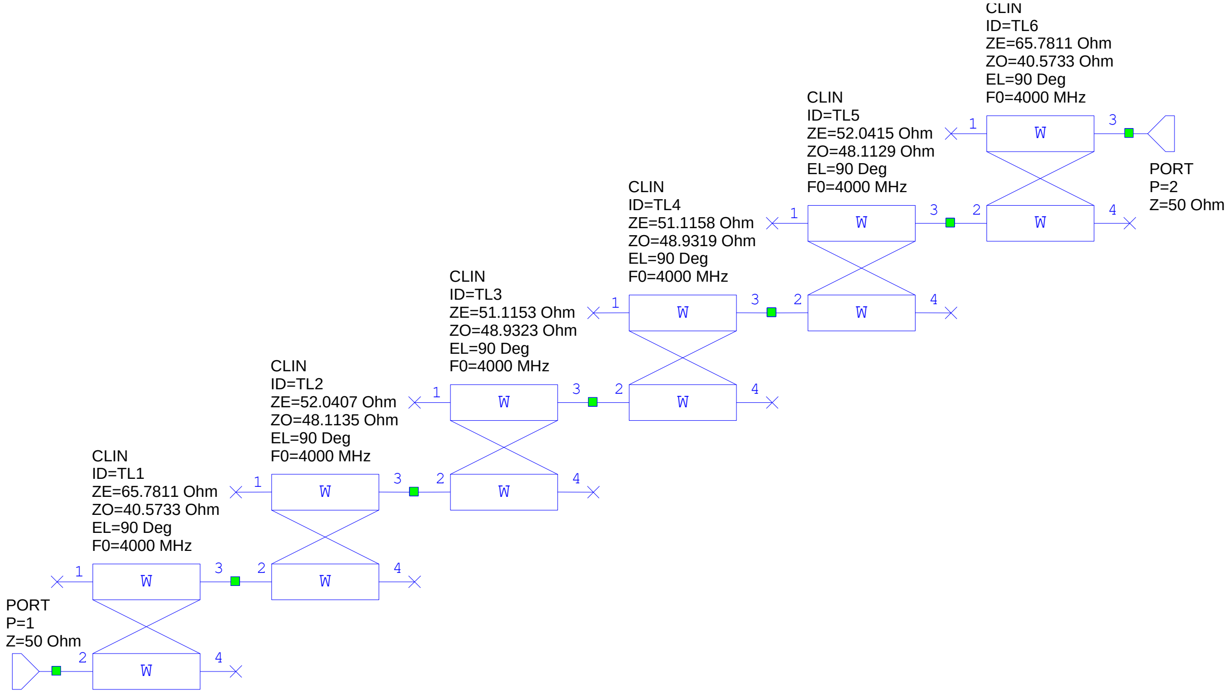
Zoe1	65.7811
Zoe2	52.0407
Zoe3	51.1153
Zoe4	51.1158
Zoe5	52.0415
Zoe6	65.7811

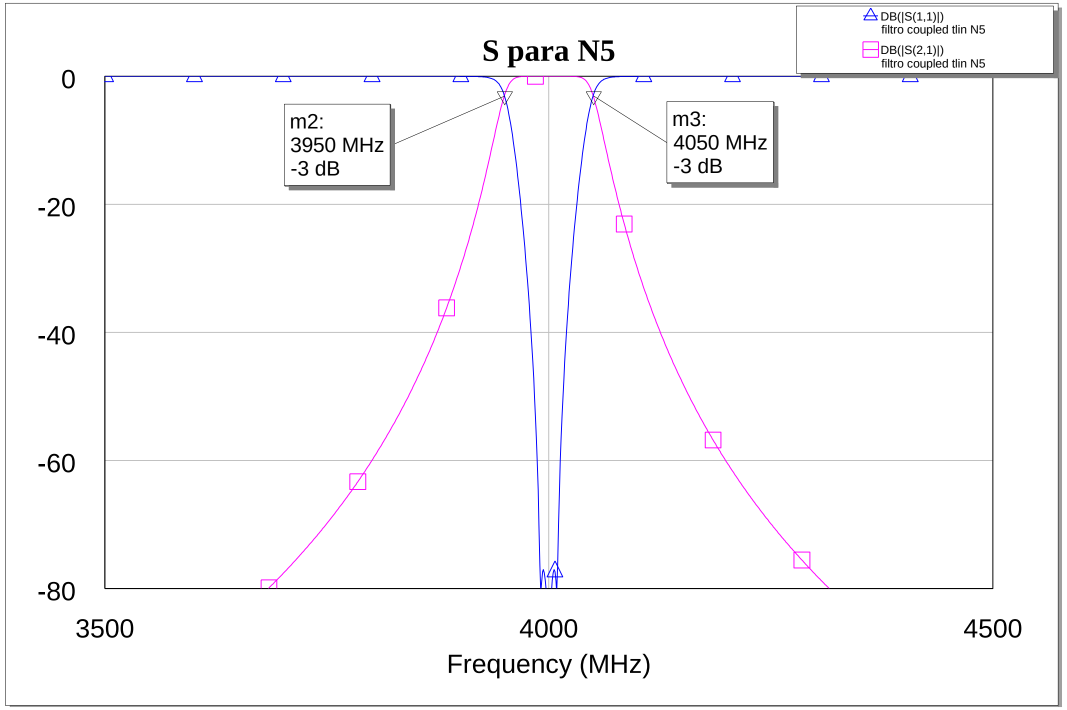
Zoo1	40.5733
Zoo2	48.1135
Zoo3	48.9323
Zoo4	48.9319
Zoo5	48.1129
Zoo6	40.5733

Simulazione filtro prototipo a linee accoppiate generiche

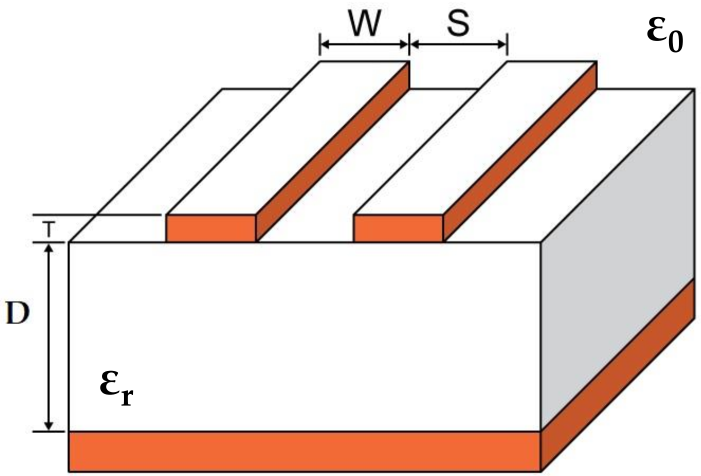








Passaggio a linee a microstrisce

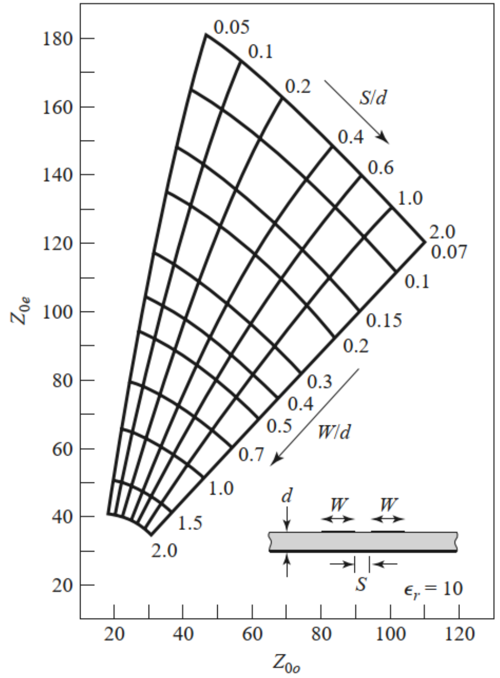


Come passare da linee generiche a microstrisce?

*Le impedenze even e odd dipendono dai parametri delle microstrisce accoppiate → posso trovarli dal grafico o tramite il **sintetizzatore** di AWR*

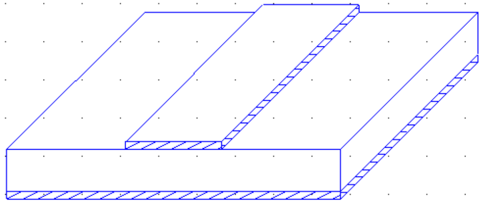
Synthesize	Name	Value	Unit	Description
☐	Freq	4000	MHz	Evaluation Frequency
☑	W	1.74144	mm	Conductor Width
☑	S	0.292865	mm	Gap Width
☑	L	12.6566	mm	Conductor length
☐	Er	2.55		Relative dielectric constant
☐	H	0.76	mm	Substrate thickness
☐	T	0.035	mm	Conductor thickness
☐	Rho	0		Metal resistivity normalized to gold
☐	Tand	0		Loss tangent of dielectric

Target	Name	Value	Unit	Description
☑	Z0 re (even)	63.8908	Ohms	Characteristic Impedance (real)
☐	Z0 im (even)	0	Ohms	Characteristic Impedance (imag)
☐	Alpha (even)	0	dB/m	Attenuation Constant
☐	Loss (even)	0	dB	Loss
☐	Beta (even)	7160.29	deg/m	Phase Constant
☑	EL (even)	90	deg	Electrical Length
☑	Z0 re (odd)	41.2399	Ohms	Characteristic Impedance (real)
☐	Z0 im (odd)	0	Ohms	Characteristic Impedance (imag)
☐	Alpha (odd)	0	dB/m	Attenuation Constant
☐	Loss (odd)	0	dB	Loss
☐	Beta (odd)	6625.09	deg/m	Phase Constant
☑	EL (odd)	90	deg	Electrical Length



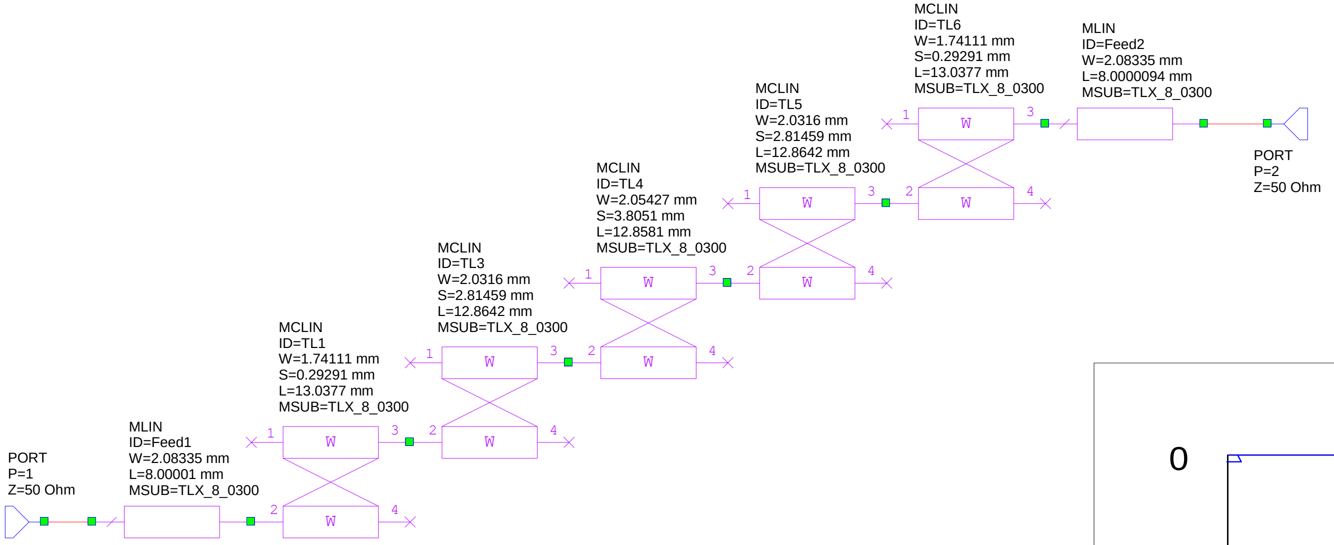
***Discontinuità** di dielettrico: $\boldsymbol{\beta_{even}}$ e $\boldsymbol{\beta_{odd}}$ sono diversi in linee a microstrisce*

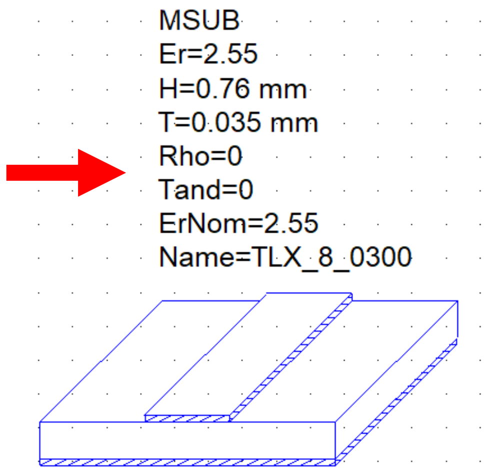
MSUB
Er=2.55
H=0.76 mm
T=0.035 mm
Rho=0.7118
Tand=0.0019
ErNom=2.55
Name=TLX_8_01

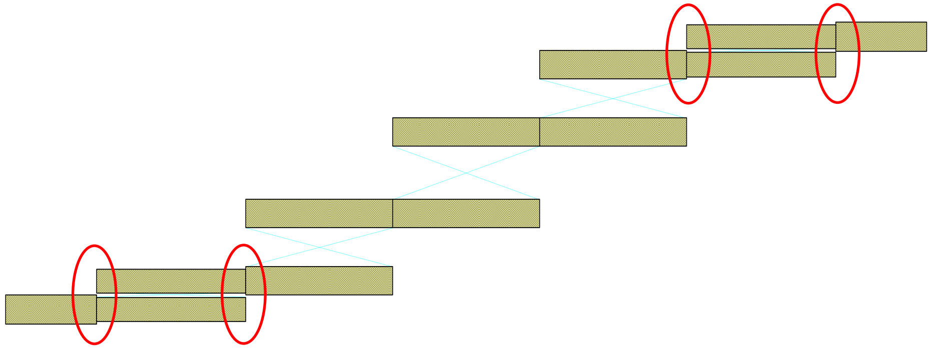


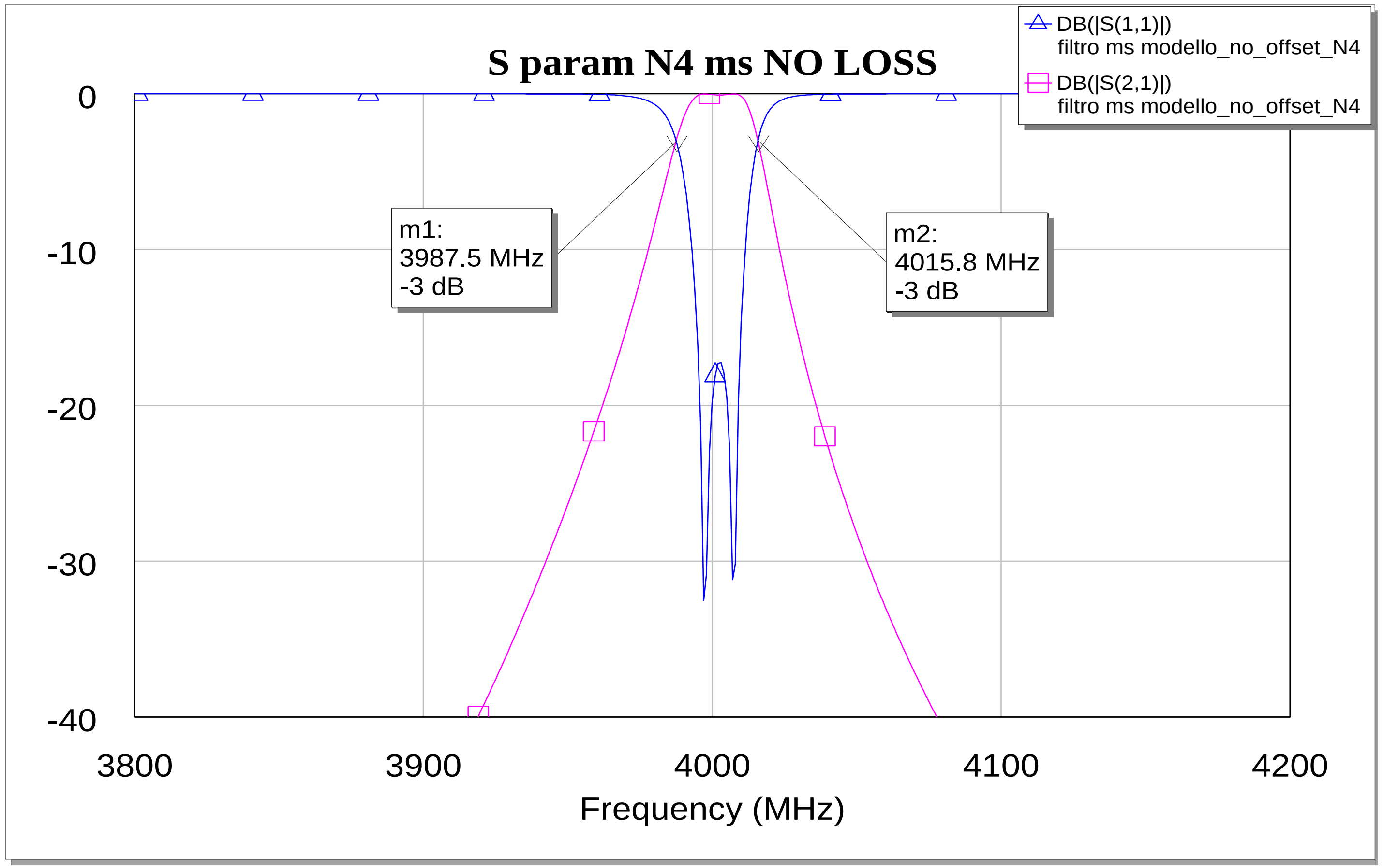
Per questo lavoro è stato usato il substrato TLX_8 0300 di Taconic.

Modello 1: modello MCLIN AWR – no perdite

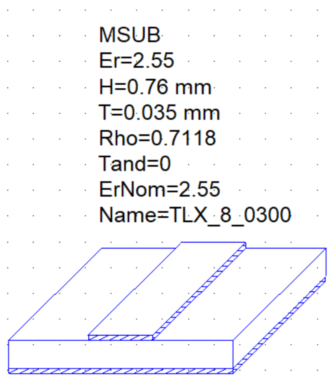


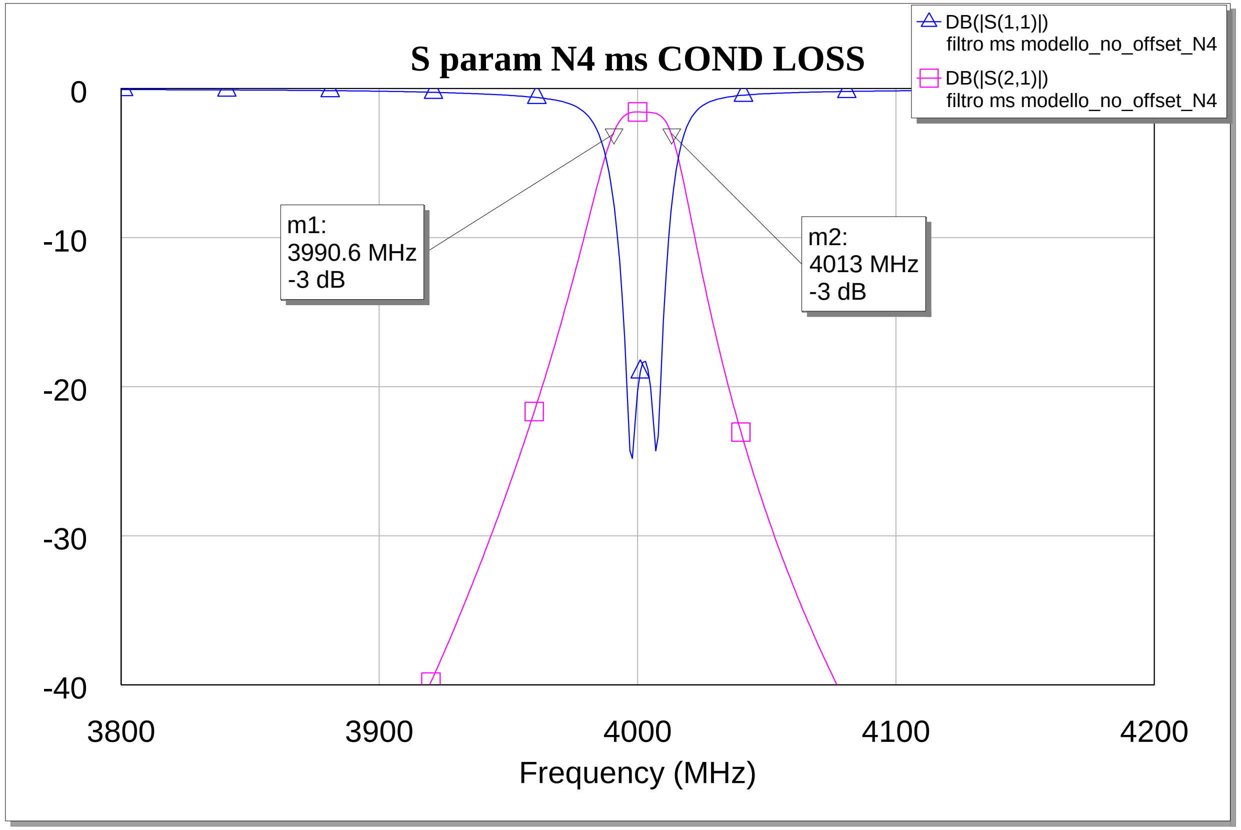




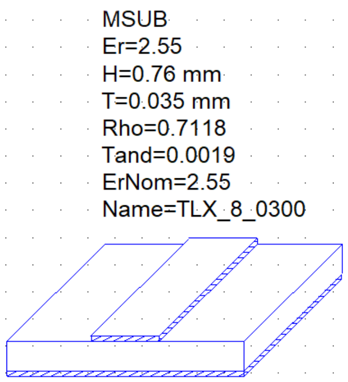


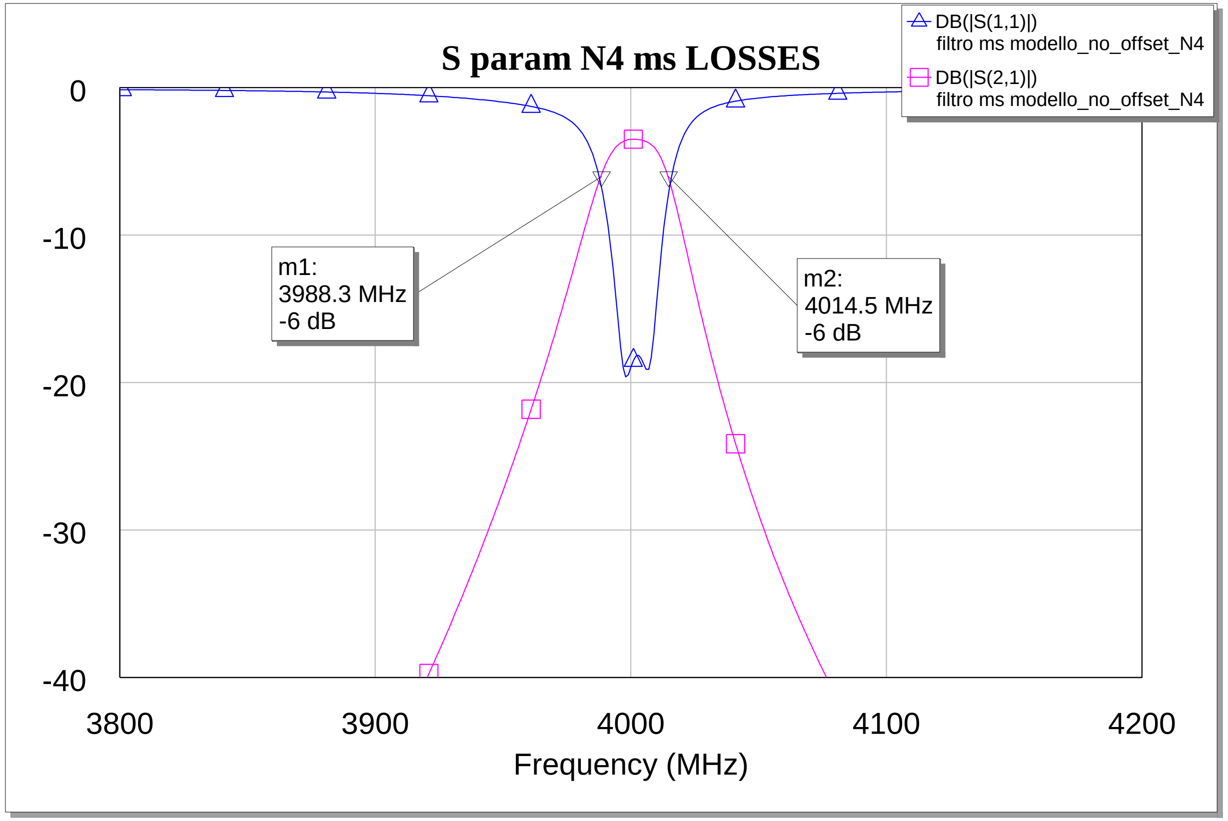
Solo perdite rame

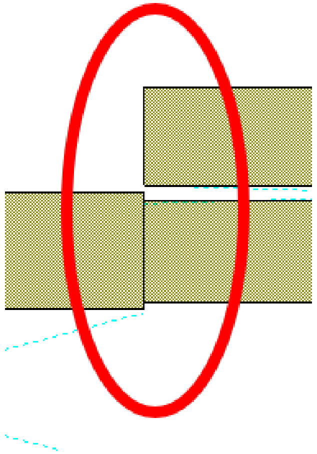




Perdite rame + dielettrico

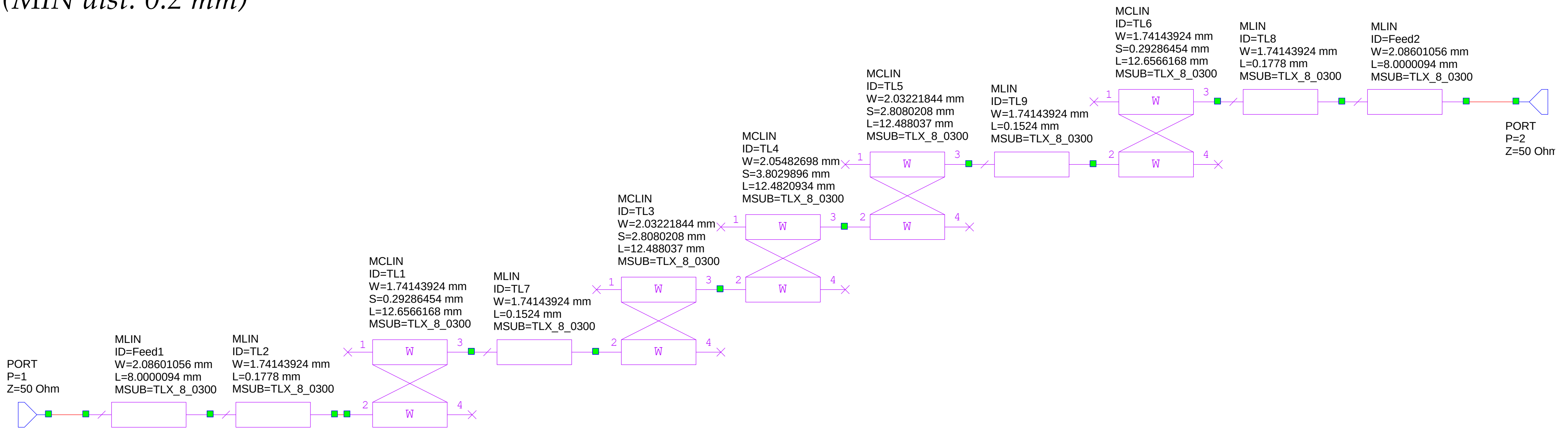


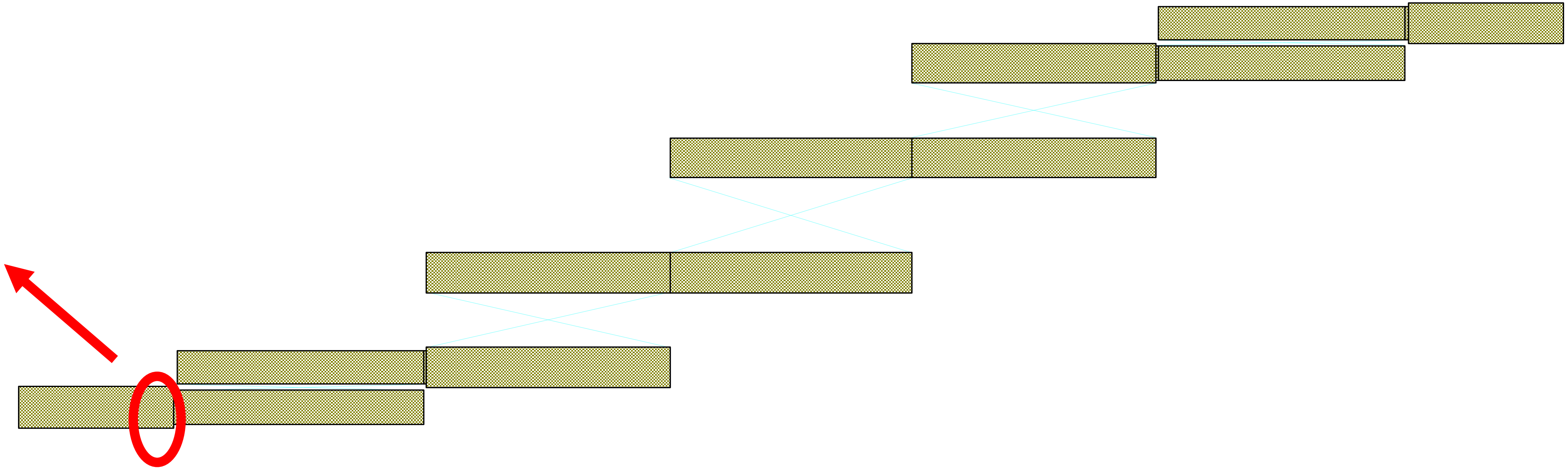


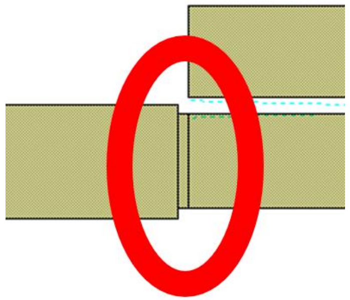


PROBLEMA: *distanza minima di fresatura non rispettata (MIN dist: 0.2 mm)*

Si estendono alcuni punti cercando di modificare la lunghezza delle linee il meno possibile

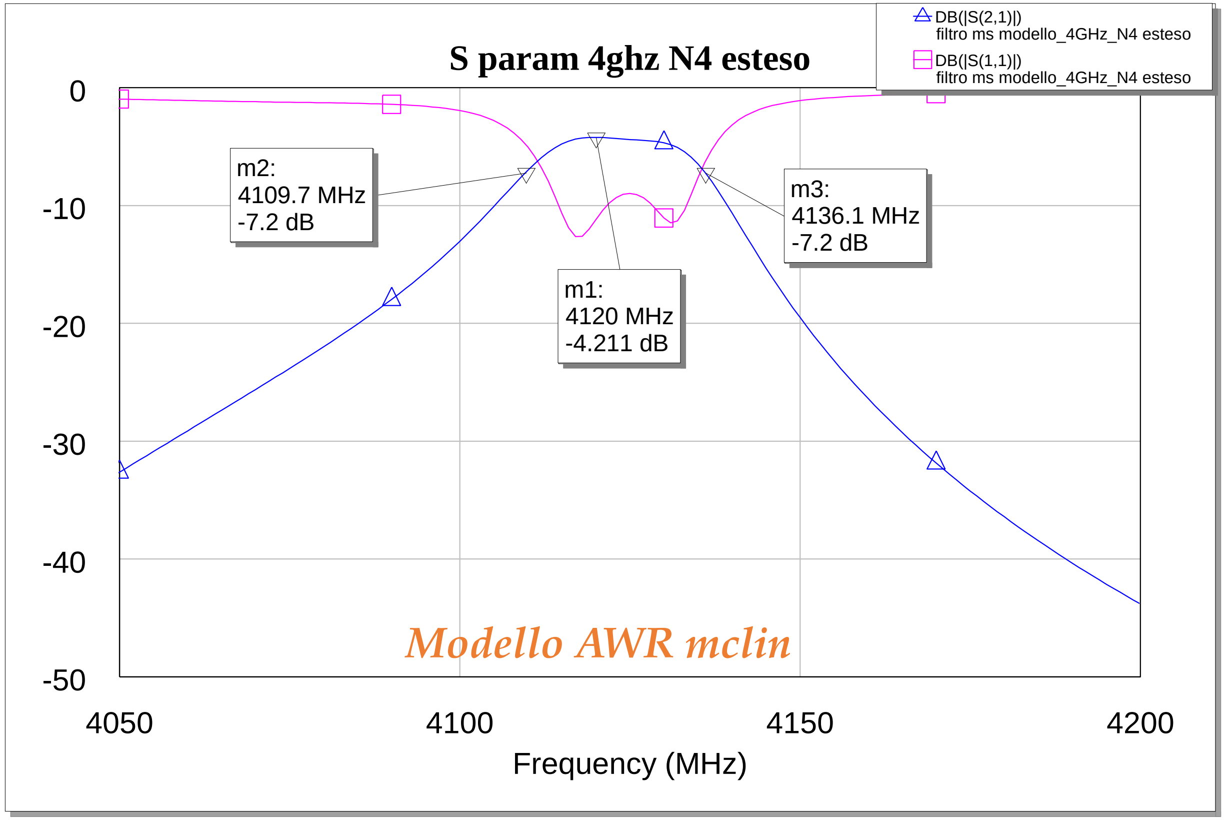


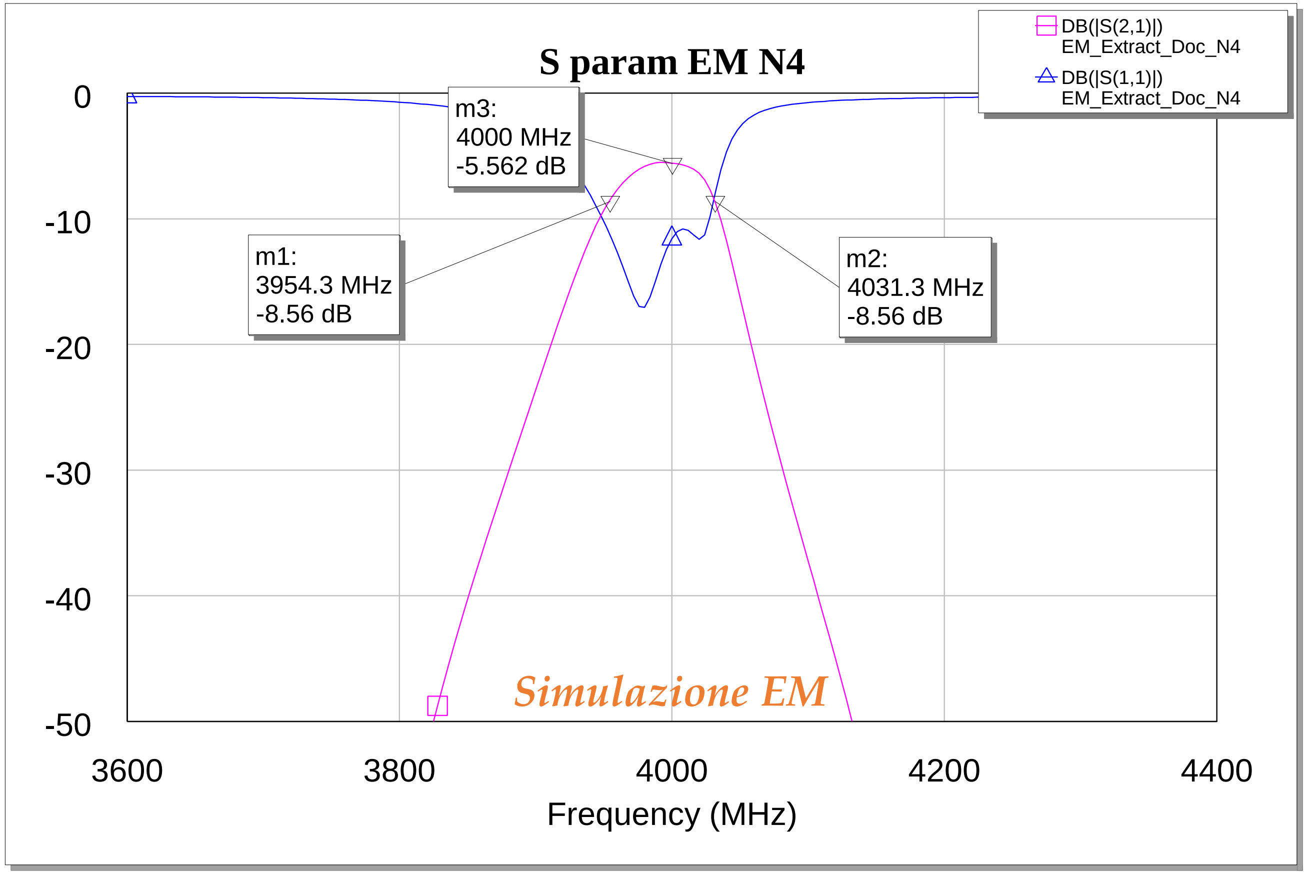




Distanza OK

__PROBLEMA:__ la simulazione EM e la simulazione modello AWR producono risultati con offset in frequenza di circa 100 MHz



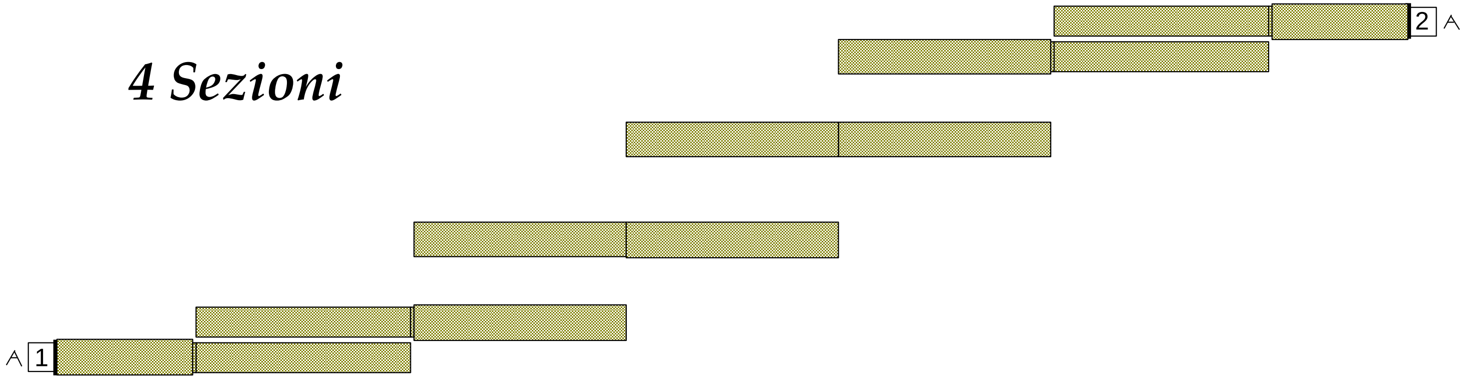


La simulazione EM produce risposta con centrobanda a 4 GHz dimensionando le linee con freq. 4.12 GHz

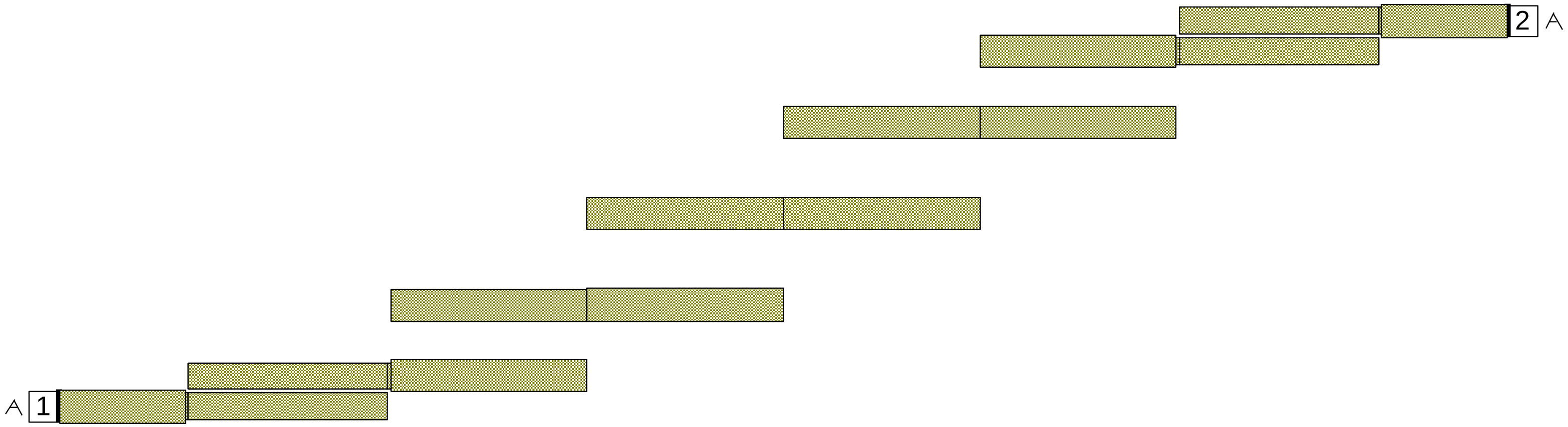
Quale delle due è più affidabile?

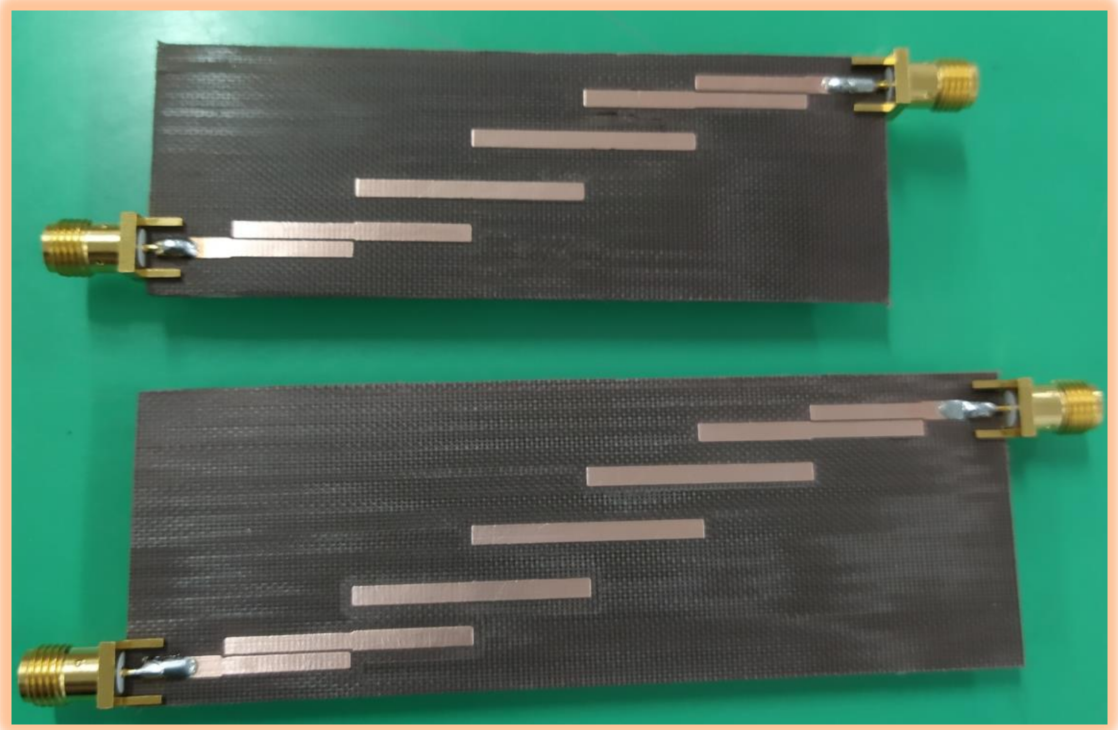
E' stata data «fiducia» al modello EM

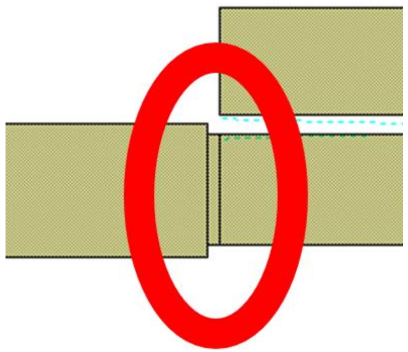
4 Sezioni

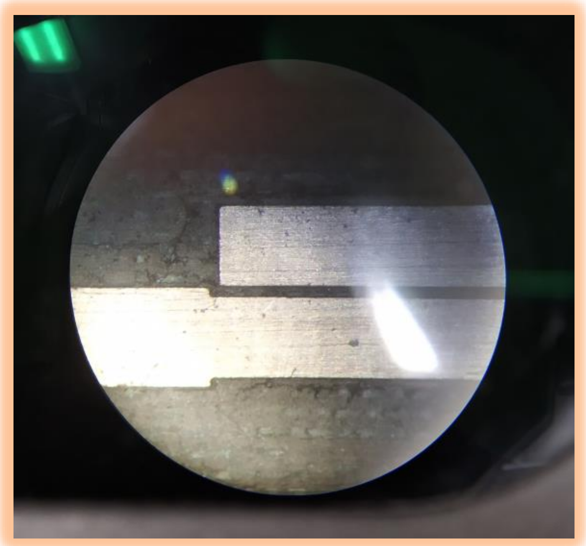


5 Sezioni

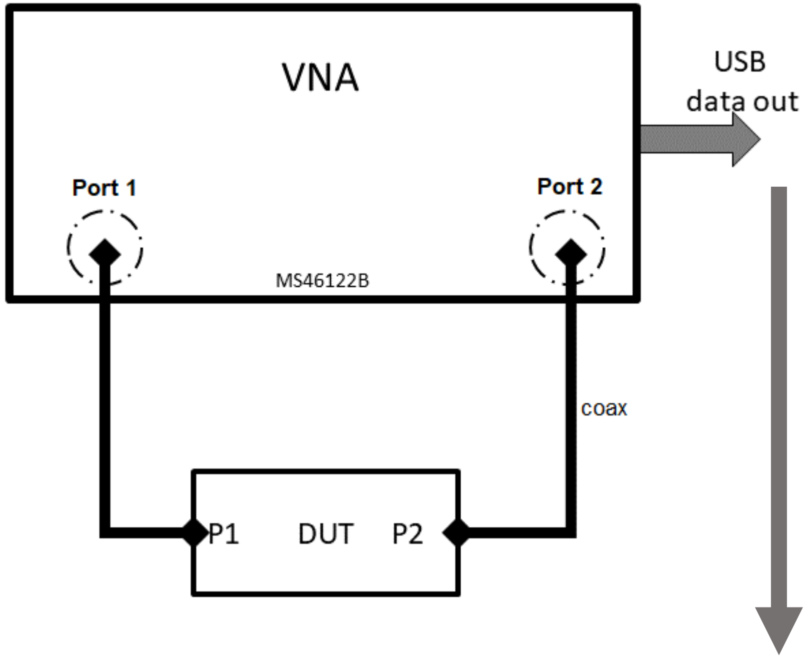


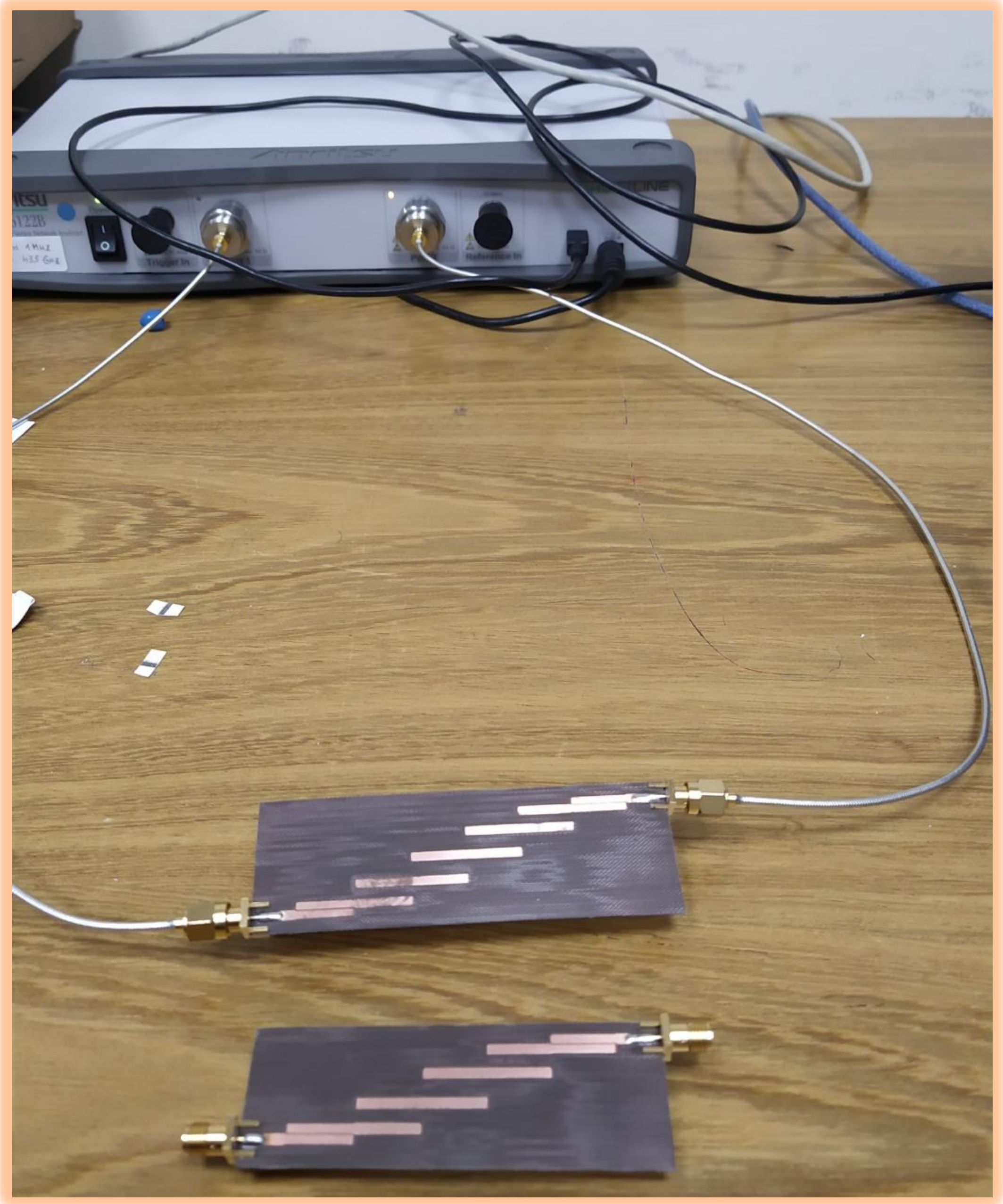






Misure

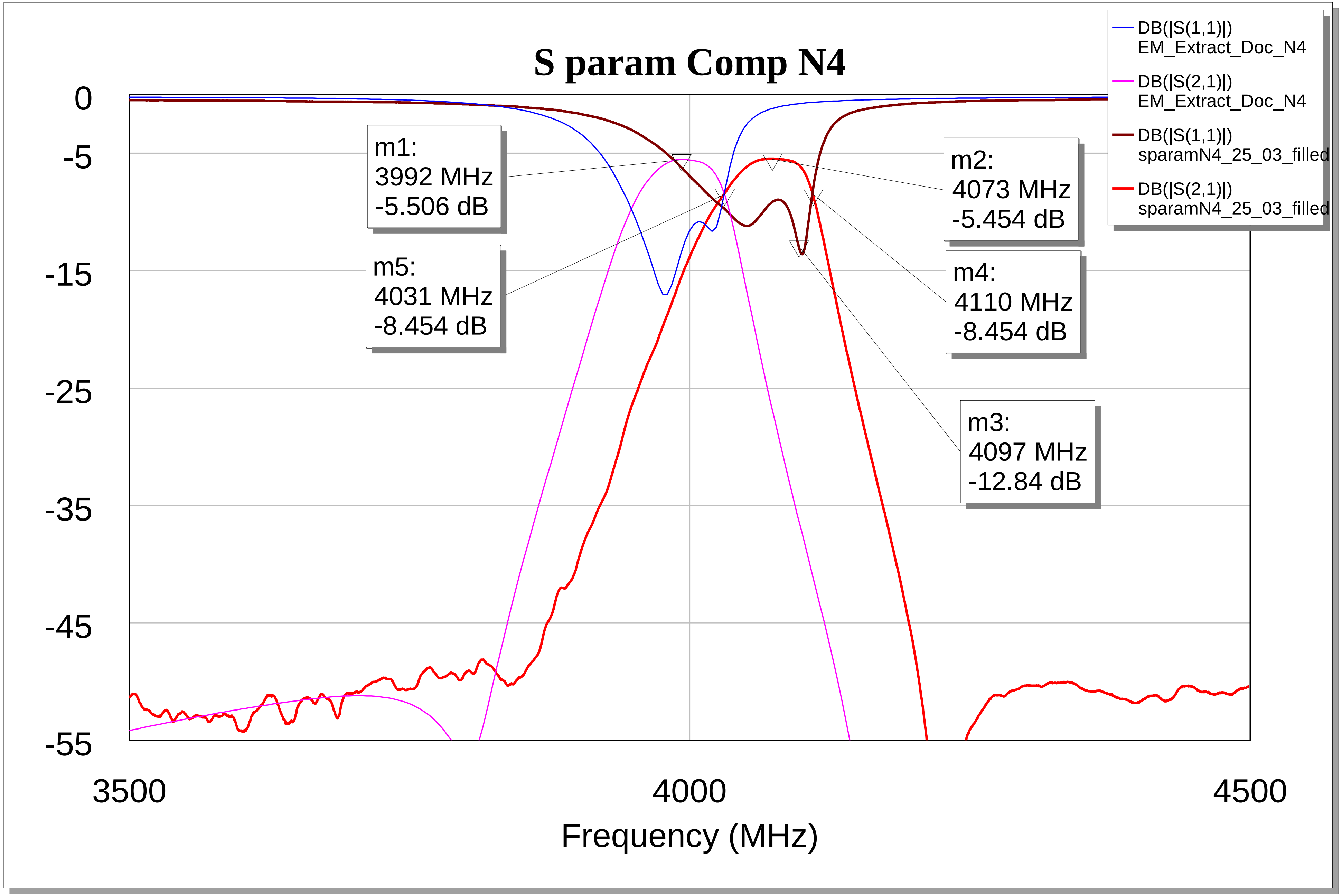




***Output:** .s2p file*

```
! 3/25/2021 4:59:21 PM
! C:\USERS\MATTI\DOCUMENTS\UNIVERSITA\METODI DI PROGETTAZIONE ELETTROMAGNETICA\TESINA FILTRO\4GHZN4\SPARAMN4_25_03_FILLED.S2P
! CHANNEL.1
! TR.MEASUREMENT
! CORRECTED.DATA
# GHZ S RI R 50.0
! FREQ.GHZ        S11RE         S11IM         S21RE         S21IM         S12RE         S12IM         S22RE         S22IM
!; PortSelection: Port_12
  2.000000000    -0.8961431    0.4219566    0.0012121    0.0015205    0.0011156    0.0017113    -0.8947470    0.4160532
  2.000400000    -0.8958023    0.4226803    0.0012170    0.0015208    0.0011290    0.0017072    -0.8942813    0.4167988
  2.000800000    -0.8948580    0.4245912    0.0012213    0.0015307    0.0011261    0.0017031    -0.8939692    0.4175499
  2.001200000    -0.8957133    0.4229515    0.0012316    0.0015303    0.0011374    0.0017126    -0.8936117    0.4182037
  2.001600000    -0.8947821    0.4248238    0.0012367    0.0015327    0.0011387    0.0017162    -0.8934842    0.4188855
  2.002000000    -0.8944988    0.4254482 |  0.0012412    0.0015285    0.0011428    0.0017180    -0.8927935    0.4199751
  2.002400000    -0.8942976    0.4260643    0.0012507    0.0015307    0.0011503    0.0017158    -0.8930171    0.4199895
  2.002800000    -0.8938575    0.4268279    0.0012489    0.0015285    0.0011523    0.0017218    -0.8923733    0.4210781
  2.003200000    -0.8941478    0.4264507    0.0012610    0.0015324    0.0011574    0.0017223    -0.8916491    0.4221396
  2.003600000    -0.8932333    0.4282369    0.0012603    0.0015293    0.0011708    0.0017220    -0.8920567    0.4220450
  2.004000000    -0.8929275    0.4288519    0.0012646    0.0015301    0.0011672    0.0017275    -0.8916045    0.4229805
  2.004400000    -0.8923500    0.4295441    0.0012693    0.0015277    0.0011784    0.0017245    -0.8913860    0.4233768
  2.004800000    -0.8914553    0.4313065    0.0012676    0.0015265    0.0011825    0.0017285    -0.8909621    0.4243078
  2.005200000    -0.8923281    0.4297595    0.0012706    0.0015260    0.0011867    0.0017260    -0.8905634    0.4250216
  2.005600000    -0.8913345    0.4316021    0.0012711    0.0015272    0.0011959    0.0017293    -0.8904660    0.4253288
  2.006000000    -0.8910637    0.4322005    0.0012673    0.0015309    0.0011953    0.0017361    -0.8897797    0.4265786
  2.006400000    -0.8913137    0.4317921    0.0012727    0.0015287    0.0012037    0.0017365    -0.8895956    0.4269475
  2.006800000    -0.8896632    0.4346969    0.0012698    0.0015334    0.0011966    0.0017411    -0.8893471    0.4276288
  2.007200000    -0.8906217    0.4330955    0.0012761    0.0015385    0.0012059    0.0017393    -0.8890819    0.4283139
```

Simulato VS Misurato



Simulato VS Misurato