Further Adventures in openEMS

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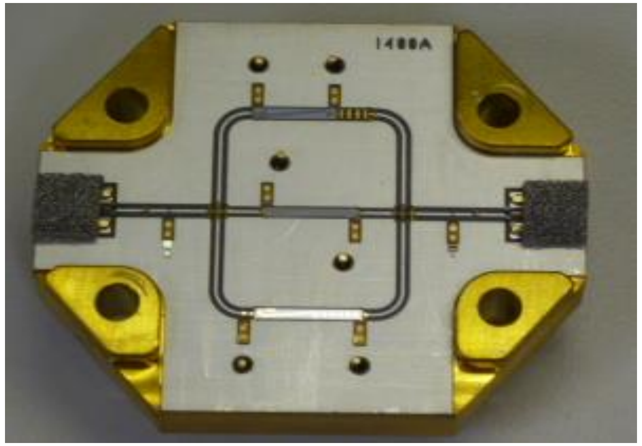
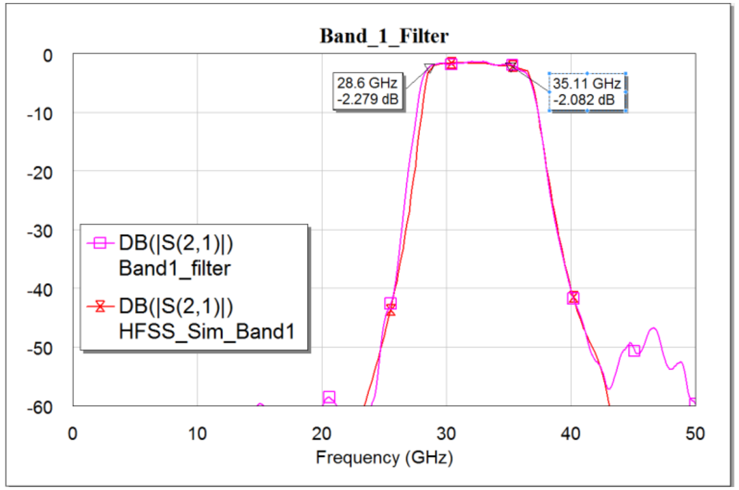
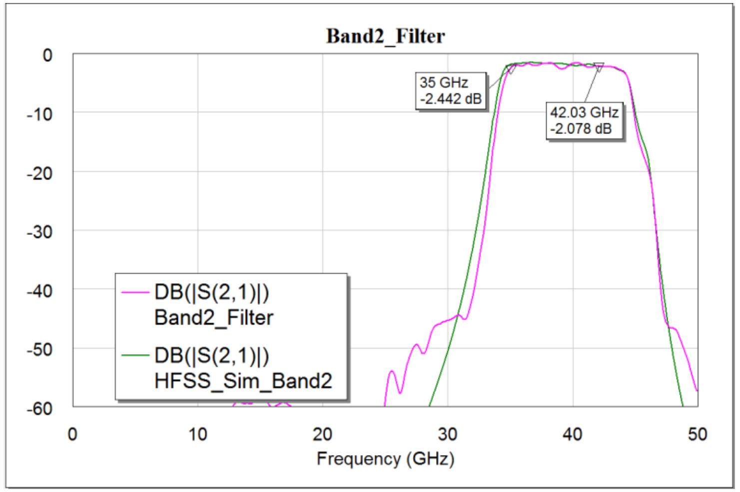
October 8, 2016

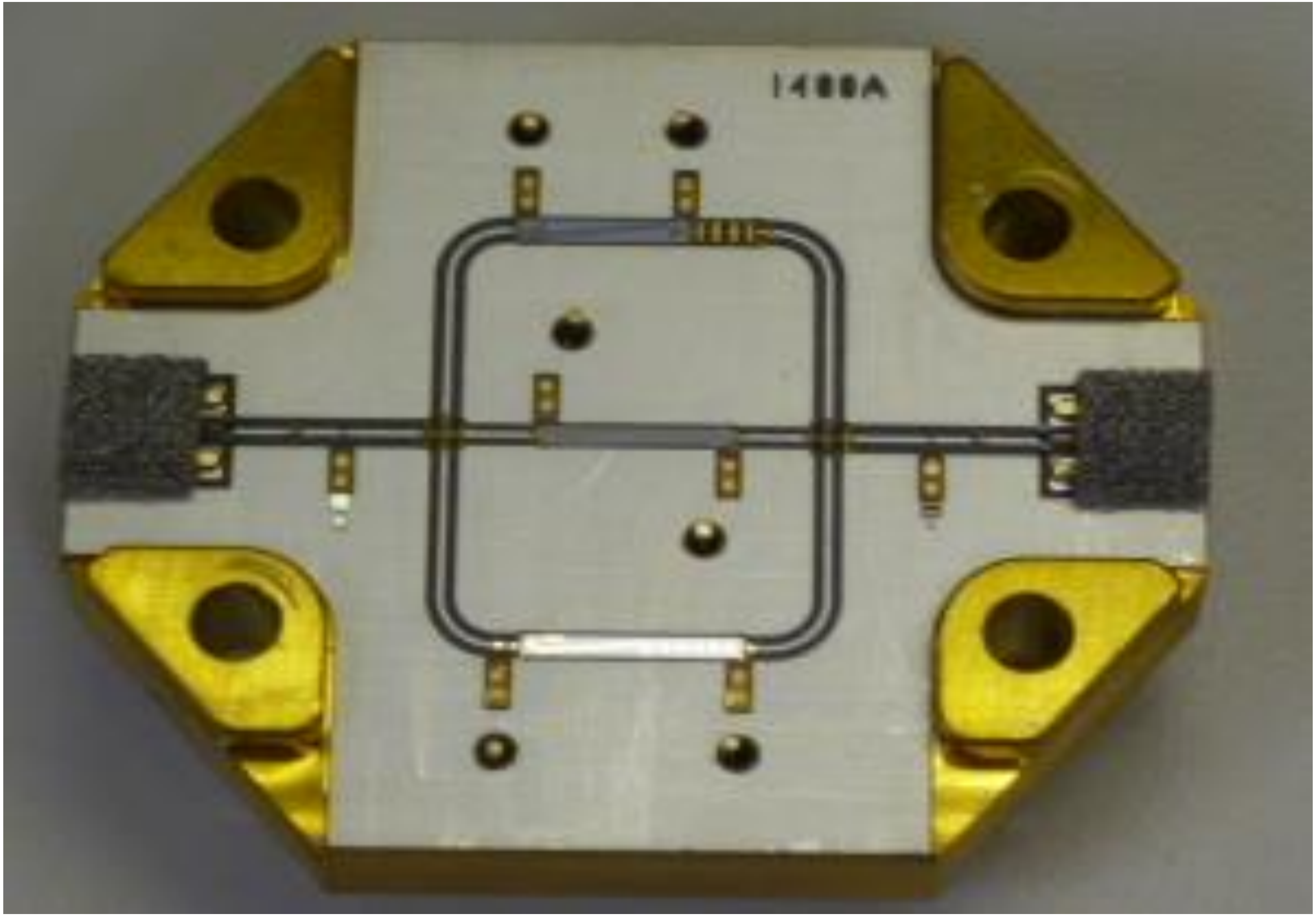
Why Simulation?







There is a BPF followed by a lowpass filter on all three paths.



Towards a 77 GHz Filter

- Based on OE9PMJ design.
- Current build had some issues:
  - Higher than desired in band losses
  - Second passband ~60 GHz.

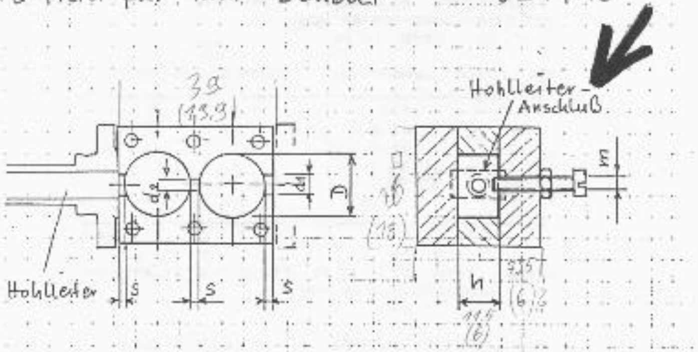
Hubert Krause

micro – mechanik

mechanische komponenten für mikrowellen – funkanlagen und messtechnik

Darmstädter Straße 79 b D-64839 MÜNSTER

High-Q-Filter für mm-Bänder OE9PMJ



f_0 (GHz)	a	h	d_1	d_2	s	m
24,192	13,00	11,50	4,30	3,50	1	M 4
47,088	9,20	6,00	2,20	1,80	0,5	M 3
75,500	5,75	3,70	1,40	1,15	0,3	M 2 (M 2,5)
78,384	5,55	3,60	1,35	1,10	0,3	M 2 (M 2,5)

Auf die Lage (90°) der Hohlleiteranschlüsse achten!

Beim Eindrehen der Abstimmschrauben erhöht sich f_0!

Bei etwa $f_0/2$ kommt es zum Übersprechen durch die E_{01}-Resonanz, diese wird jedoch durch den Hohlleiter-Cutoff eliminiert.

Juni 1989

What about the Spurious Resonance?

- Matthaei, Young and Jones has the equation for a circular cylinder resonator.

5.11-7

$L := .146$ Length of cavity in inches

$D := .222$ Diameter of circular cavity

$n := 1$

a

$$f := \sqrt{\frac{\left[139.3\cdot\left(\frac{1.841}{\pi}\right)^2 + \left(n\cdot\frac{D}{2\cdot L}\right)^2\right]}{D^2}}$$

1.841 is the root for a Bessel function....There are a bunch.

From Mathaei, Young and Jones
page 247 & 248
by Chuck Clark AF8Z

Diameter	Length
0.222	0.146

mode	n	Bessel Function Root	Frequency	Higher order mode frequencies n=2	n=3
TE11n	1	1.841	31.29992	31.85702	32.76448
TE21	1	3.054	51.72461	52.06361	52.62377
TE01	1	3.832	64.84942	65.12014	65.56885
31	1	4.201	71.0774	71.32448	71.73439
41	1	5.318	89.93683	90.13223	90.45695
12	1	5.332	90.17325	90.36814	90.69202
51	1	6.415	108.4644	108.6265	108.8961
22	1	6.706	113.3799	113.5349	113.7929
2	1	7.016	118.6164	118.7646	119.0113
61	1	7.501	126.8095	126.9481	127.1789
32	1	8.016	135.5098	135.6395	135.8555
13	1	8.536	144.2949	144.4167	144.6196
71	1	8.578	145.0045	145.1257	145.3276
42	1	9.283	156.9155	157.0276	157.2142
81	1	9.648	163.0825	163.1903	163.3699
23	1	9.97	168.5229	168.6273	168.8011
3	1	10.174	171.9697	172.072	172.2423
TM01	1	2.405	40.78735	41.21642	41.92177
11	1	3.832	64.84942	65.12014	65.56885
21	1	5.136	86.86343	87.06572	87.40184
2	1	5.52	93.34815	93.53642	93.84936
31	1	6.3	106.522	106.687	106.9615
12	1	7.016	118.6164	118.7646	119.0113
41	1	7.588	128.2792	128.4163	128.6444
22	1	8.417	142.2844	142.408	142.6137
0.3	1	8.654	146.2885	146.4087	146.6088
51	1	8.772	148.2821	148.4007	148.5981
32	1	9.761	164.9917	165.0983	165.2758
61	1	9.936	167.9485	168.0532	168.2276
13		10.174	171.9356	172.072	172.2423

Cavity Resonance

- OE9PMJ didn’t use dominant mode. The dominant mode makes the cavity too small to conventionally machine.
- Like the microstrip filters we need to add second type of filter to reject other modes.

Dominate Mode

- Lowest frequency mode of the waveguide or cavity.
- Lowest frequency mode of circular cavity varies with radius to length ratio.
- In a rectangular cavity it is determined by the largest dimension.

$$f_{m,n,p} := \frac{1}{2\cdot\sqrt{\mu_o\cdot\varepsilon_0}}\cdot\sqrt{\left(\frac{n}{b\cdot units}\right)^2+\left(\frac{m}{a\cdot units}\right)^2+\left(\frac{p}{d\cdot units}\right)^2}$$

eqn4.1.1
Laio

Waveguide Cutoff Frequency

- Circular Waveguide TE modes

$$f := \sqrt{\frac{\left[139.3\cdot\left(\frac{1.841}{\pi}\right)^2 + \left(n\cdot\frac{D}{2\cdot L}\right)^2\right]}{D^2}}$$

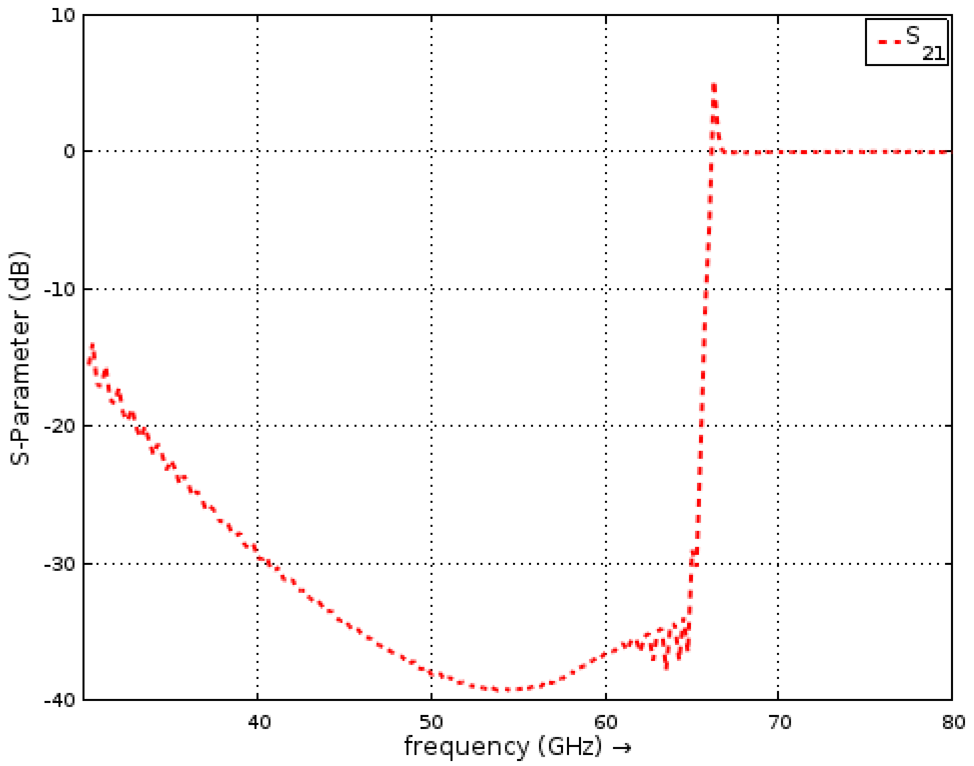
- Rectangular Waveguide
- TE_{nm} modes

$$f_c := \frac{1}{2\cdot\pi\cdot\sqrt{\mu_o\cdot\varepsilon_0}}\cdot\sqrt{\left(\frac{\pi}{a\cdot units}\right)^2}$$

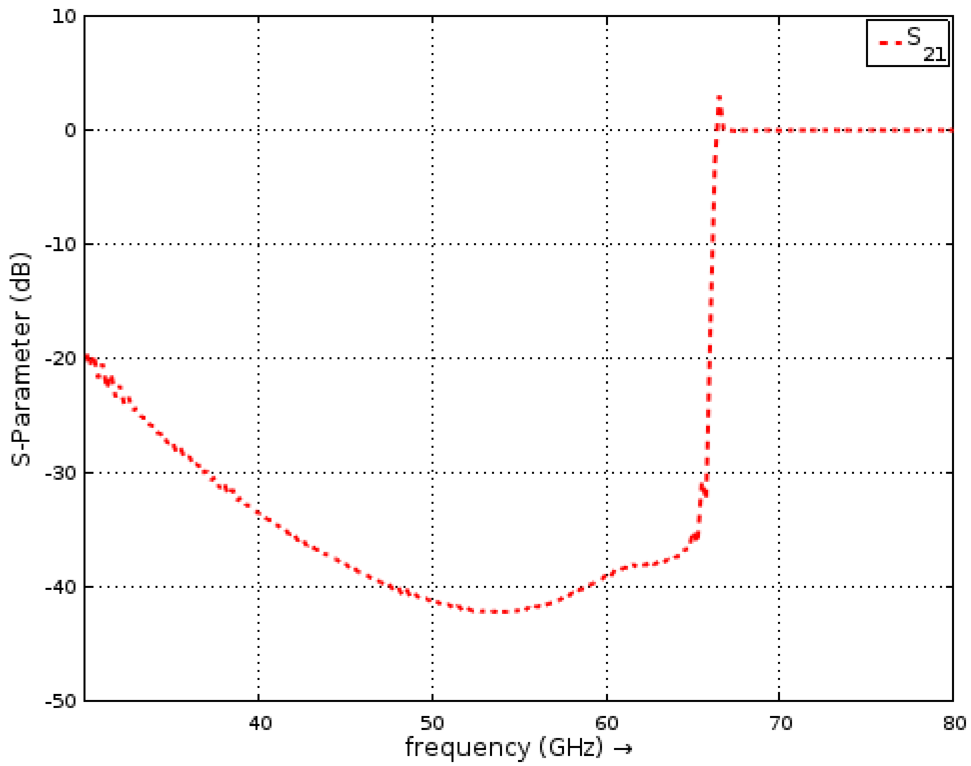
This is for the TE10 mode
Jordan

Circular Guide Simulation

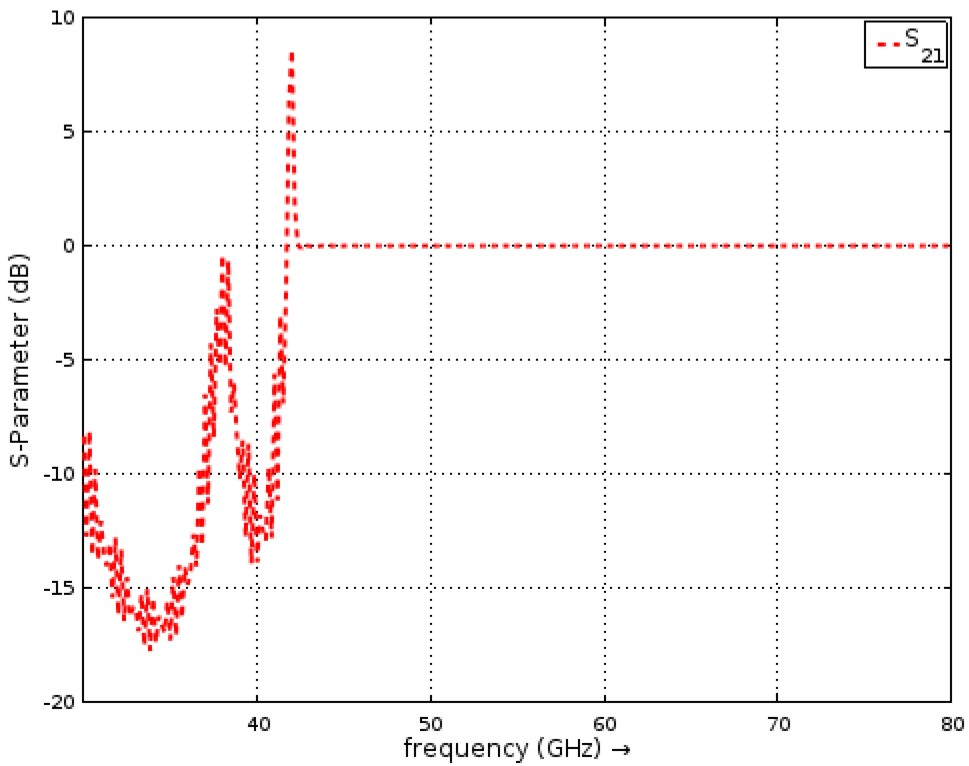
2 m=cm of 1.321 radius guide



3 cm 1.321 radius guide



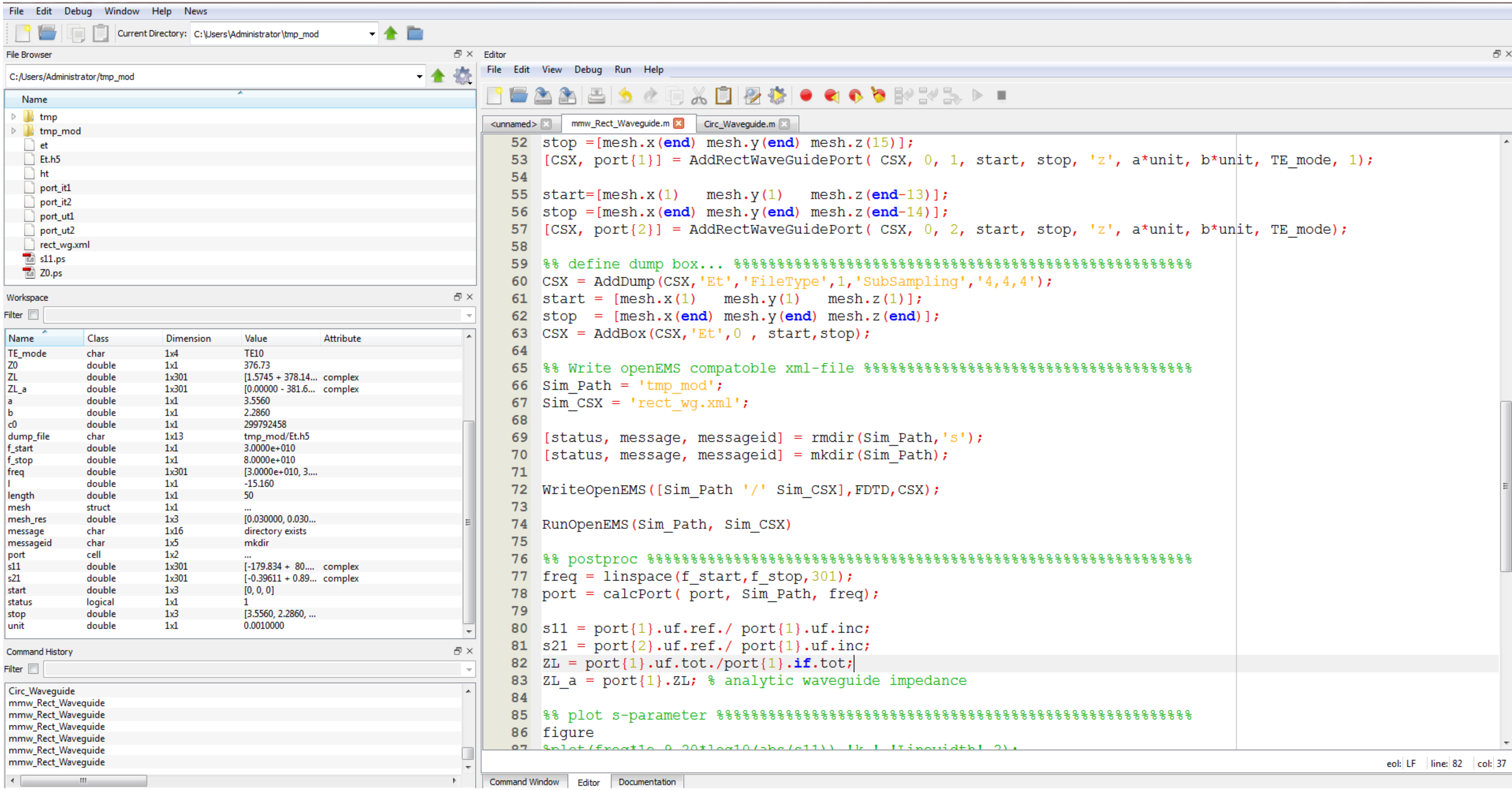
WR10 Simulation



Internal dimensions, .140x0.090 inches
Length 5 cm.

Octave/openEMS Quirks……

- Difficult getting 2 different lines with different axis, which make the interpertation questionable.
- Troubleshooting shows extreme values.
- Turns out openEMS has difficulty below cutoff and the values are wrong! Getting 50 dB S11 in a passive lossless network isn’t happening.



File Edit Debug Window Help News
Current Directory: C:\Users\Administrator\tmp_mod
File Browser
C:/Users/Administrator/tmp_mod
Name
tmp
tmp_mod
et
Et.h5
ht
port_it1
port_it2
port_ut1
port_ut2
rect_wg.xml
s11.ps
Z0.ps
Workspace
Filter
Name Class Dimension Value Attribute
TE_mode char 1x4 TE10
Z0 double 1x1 376.73
ZL double 1x301 [1.5745 + 378.14... complex
ZL_a double 1x301 [0.00000 - 381.6... complex
a double 1x1 3.5560
b double 1x1 2.2860
c0 double 1x1 299792458
dump_file char 1x13 tmp_mod/Et.h5
f_start double 1x1 3.0000e+010
f_stop double 1x1 8.0000e+010
freq double 1x301 [3.0000e+010, 3....
l double 1x1 -15.160
length double 1x1 50
mesh struct 1x1 ...
mesh_res double 1x3 [0.030000, 0.030...
message char 1x16 directory exists
messageid char 1x5 mkdir
port cell 1x2 ...
s11 double 1x301 [-179.834 + 80.... complex
s21 double 1x301 [-0.39611 + 0.89... complex
start double 1x3 [0, 0, 0]
status logical 1x1 1
stop double 1x3 [3.5560, 2.2860, ...
unit double 1x1 0.0010000
Command History
Filter
Circ_Waveguide
mmw_Rect_Waveguide
mmw_Rect_Waveguide
mmw_Rect_Waveguide
mmw_Rect_Waveguide
mmw_Rect_Waveguide
mmw_Rect_Waveguide
Editor
File Edit View Debug Run Help
<unnamed>
mmw_Rect_Waveguide.m
Circ_Waveguide.m
stop =[mesh.x(end) mesh.y(end) mesh.z(15)];
[CSX, port{1}] = AddRectWaveGuidePort(CSX, 0, 1, start, stop, 'z', a*unit, b*unit, TE_mode, 1);
start=[mesh.x(1) mesh.y(1) mesh.z(end-13)];
stop =[mesh.x(end) mesh.y(end) mesh.z(end-14)];
[CSX, port{2}] = AddRectWaveGuidePort(CSX, 0, 2, start, stop, 'z', a*unit, b*unit, TE_mode);
%% define dump box... %%%
CSX = AddDump(CSX,'Et','FileType',1,'SubSampling','4,4,4');
start = [mesh.x(1) mesh.y(1) mesh.z(1)];
stop = [mesh.x(end) mesh.y(end) mesh.z(end)];
CSX = AddBox(CSX,'Et',0 , start,stop);
%% Write openEMS compatoble xml-file %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Sim_Path = 'tmp_mod';
Sim_CSX = 'rect_wg.xml';
[status, message, messageid] = rmdir(Sim_Path,'s');
[status, message, messageid] = mkdir(Sim_Path);
WriteOpenEMS([Sim_Path '/' Sim_CSX],FDTD,CSX);
RunOpenEMS(Sim_Path, Sim_CSX)
%% postproc %%
freq = linspace(f_start,f_stop,301);
port = calcPort(port, Sim_Path, freq);
s11 = port{1}.uf.ref./ port{1}.uf.inc;
s21 = port{2}.uf.ref./ port{1}.uf.inc;
ZL = port{1}.uf.tot./port{1}.if.tot;
ZL_a = port{1}.ZL; % analytic waveguide impedance
%% plot s-parameter %%
figure
eol: LF line: 82 col: 37
Command Window Editor Documentation

Name	Class	Dimension	Value	Attribute
TE_mode	char	1x4	TE10	
Z0	double	1x1	376.73	
ZL	double	1x301	[1.5745 + 378.14...	complex
ZL_a	double	1x301	[0.00000 - 381.6...	complex
a	double	1x1	3.5560	
b	double	1x1	2.2860	
c0	double	1x1	299792458	
dump_file	char	1x13	tmp_mod/Et.h5	
f_start	double	1x1	3.0000e+010	
f_stop	double	1x1	8.0000e+010	
freq	double	1x301	[3.0000e+010, 3....	
l	double	1x1	-15.160	
length	double	1x1	50	
mesh	struct	1x1	...	
mesh_res	double	1x3	[0.030000, 0.030...	
message	char	1x16	directory exists	
messageid	char	1x5	mkdir	
port	cell	1x2	...	
s11	double	1x301	[-179.834 + 80....	complex
s21	double	1x301	[-0.39611 + 0.89...	complex
start	double	1x3	[0, 0, 0]	
status	logical	1x1	1	
stop	double	1x3	[3.5560, 2.2860, ...	
unit	double	1x1	0.0010000	

Quirks cont….

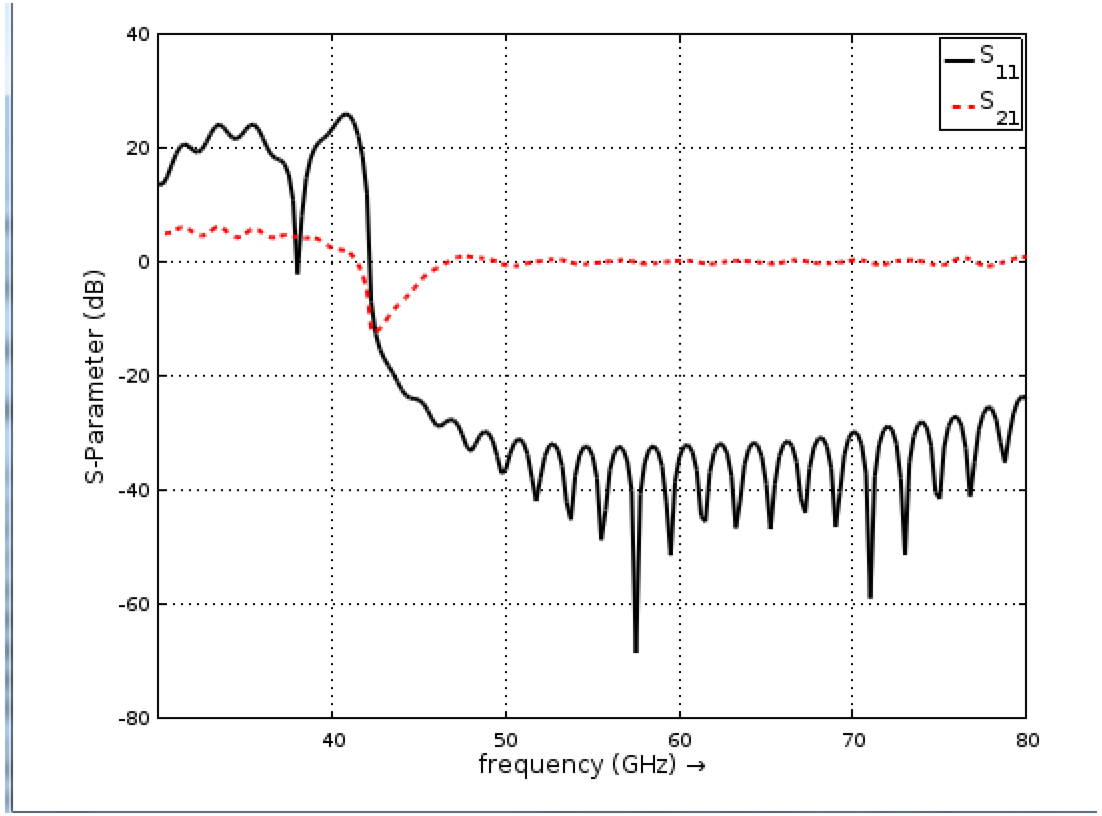
```
s11 = port{1}.uf.ref./ port{1}.uf.inc;
s21 = port{2}.uf.ref./ port{1}.uf.inc;
ZL = port{1}.uf.tot./port{1}.if.tot;
ZL_a = port{1}.ZL; % analytic waveguide impedance

```

The port(1) values can be extreme. This is from frequencies below the cutoff frequency and “The end result is the energy never decays out of the system and the post processing results are garbage”.

Getting the Time step correct changes results and simulation time…good 1 minute 8 seconds…….bad 14 hours +

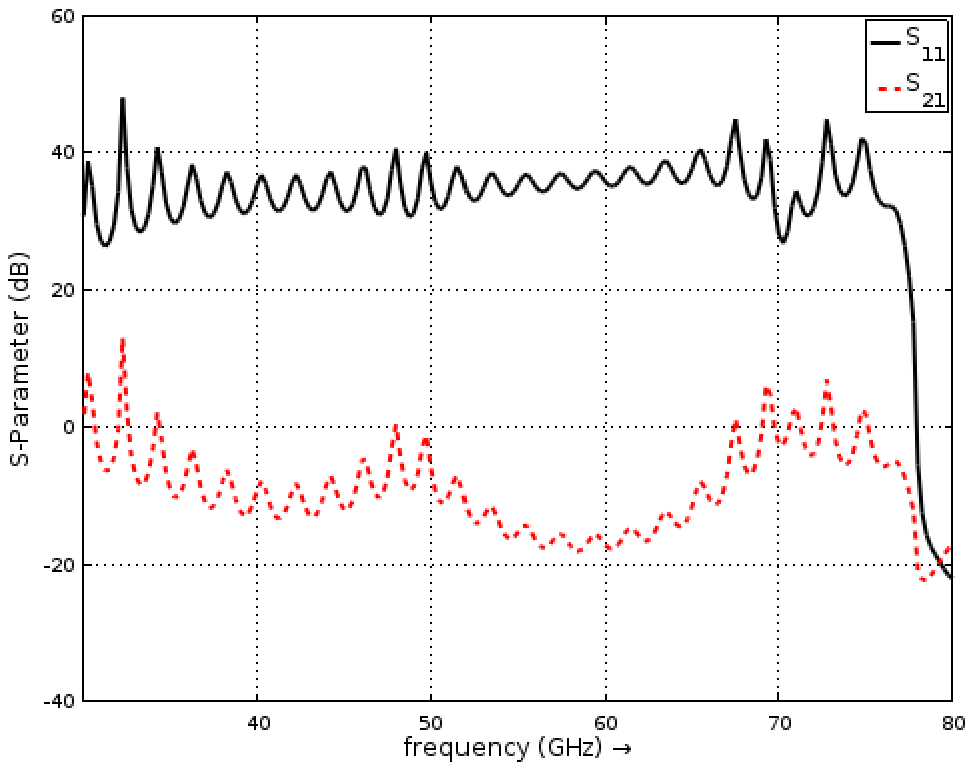
Changed mes_res to fix it.

TE10 WR10



40
20
0
-20
-40
-60
-80
40
50
60
70
80
S-Parameter (dB)
frequency (GHz) →
S11
S21

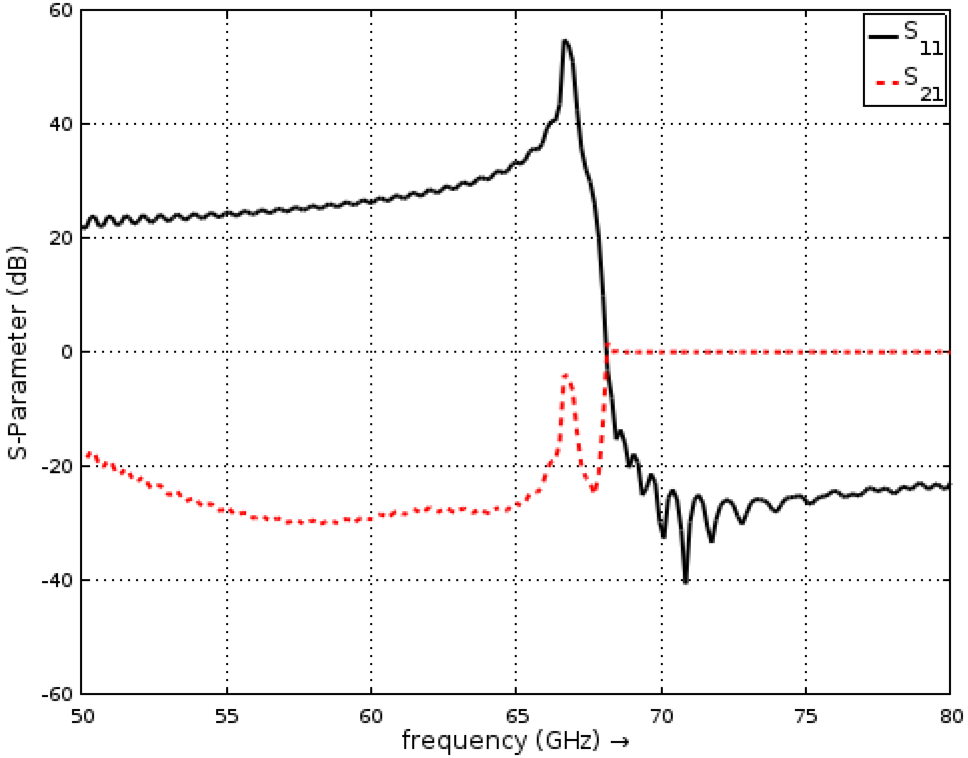
TE01 WR10

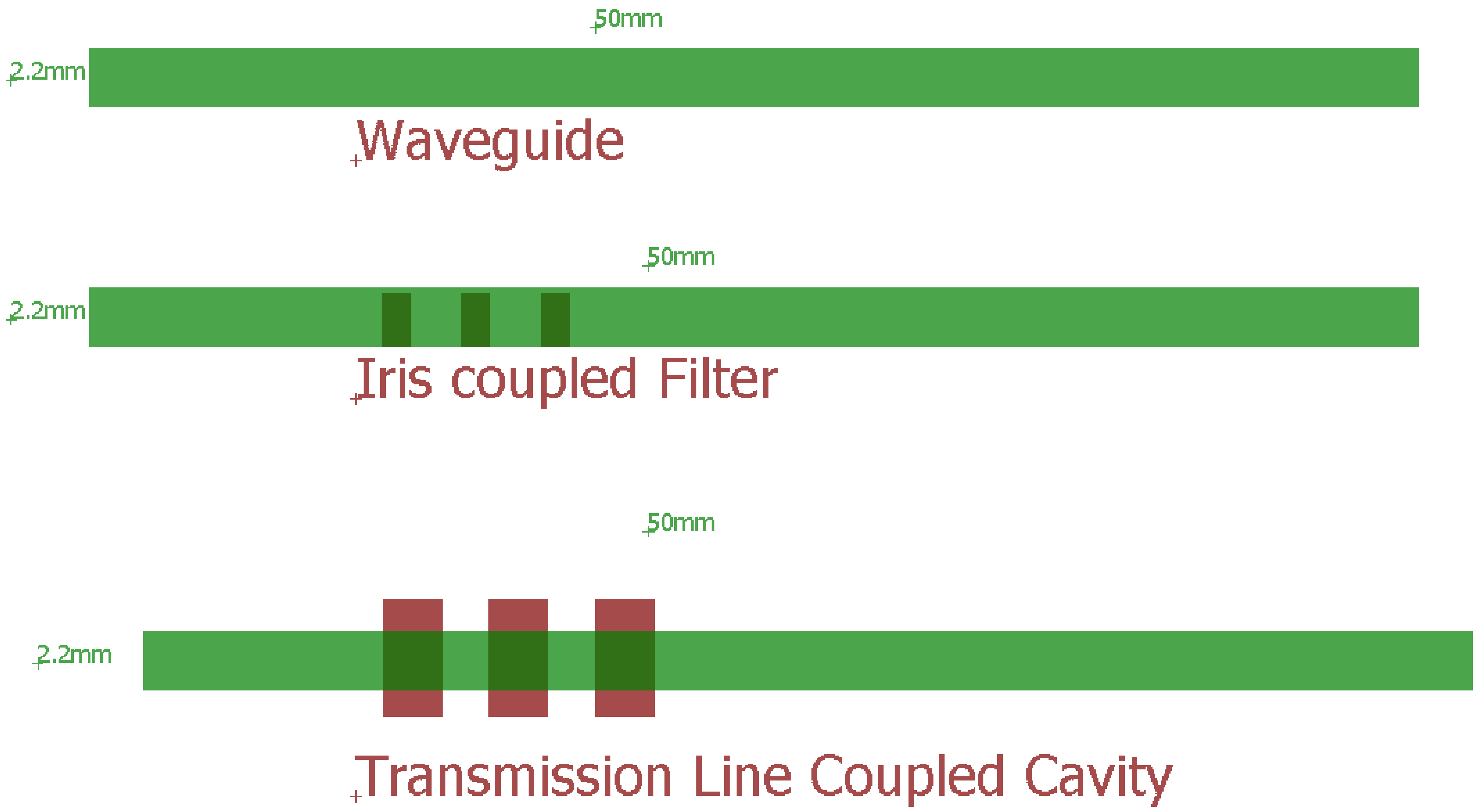


60
40
20
0
-20
-40
40
50
60
70
80
S-Parameter (dB)
frequency (GHz) →
S11
S21

Rectangular Waveguide for 77 GHz

- 2.2 x 1.1 mm
- Bad data in stopband




50mm
2.2mm
Waveguide
50mm
2.2mm
Iris coupled Filter
50mm
2.2mm
Transmission Line Coupled Cavity

Over-moded Rectangular Cavity

a=2.2mm
b=1.2mm
d=1.2mm

$$f_c = \begin{pmatrix} 0 \times 10^0 & 124.914 \times 10^9 & 249.827 \times 10^9 & 374.741 \times 10^9 \\ 68.135 \times 10^9 & 142.287 \times 10^9 & 258.952 \times 10^9 & 380.884 \times 10^9 \\ 136.269 \times 10^9 & 184.859 \times 10^9 & 284.575 \times 10^9 & 398.748 \times 10^9 \\ 204.404 \times 10^9 & 239.55 \times 10^9 & 322.792 \times 10^9 & 426.862 \times 10^9 \end{pmatrix}$$

Larger Cavity, higher mode…

Overmoded Cavity

$m := 0, 1..3$ mode numbers

$n := 0, 1..3$

$p := 0$

$b := 1.2$ depth of cavity

$d := 2.2$ length of cavity

$a := 3.85$ width of cavity

$$f_c = \begin{pmatrix} 0 \times 10^{0} & 124.914 \times 10^{9} & 249.827 \times 10^{9} & 374.741 \times 10^{9} \\ 38.934 \times 10^{9} & 130.841 \times 10^{9} & 252.843 \times 10^{9} & 376.758 \times 10^{9} \\ 77.868 \times 10^{9} & 147.197 \times 10^{9} & 261.681 \times 10^{9} & 382.745 \times 10^{9} \\ 116.802 \times 10^{9} & 171.015 \times 10^{9} & 275.783 \times 10^{9} & 392.522 \times 10^{9} \end{pmatrix}$$

$m := 0, 1..3$ mode numbers

$n := 0, 1..3$

$p := 0$

$b := 1.2$ depth of cavity

$d := 2.2$ length of cavity

$a := 5.85$ width of cavity

$$f_c = \begin{pmatrix} 0 \times 10^{0} & 124.914 \times 10^{9} & 249.827 \times 10^{9} & 374.741 \times 10^{9} \\ 25.623 \times 10^{9} & 127.514 \times 10^{9} & 251.138 \times 10^{9} & 375.616 \times 10^{9} \\ 51.247 \times 10^{9} & 135.017 \times 10^{9} & 255.029 \times 10^{9} & 378.228 \times 10^{9} \\ 76.87 \times 10^{9} & 146.671 \times 10^{9} & 261.386 \times 10^{9} & 382.543 \times 10^{9} \end{pmatrix}$$

How to couple cavities

- A thin aperture very difficult to machine….think 1 mil of wall thickness.
- Use 90 degrees of line to get impedance inverter.
  - Use an impedance inverter to couple like resonance resonators to get additional attenuation.
    - At HF often use top coupled parallel LC resonators.
    - In crystal filters often use shunt coupled series crystals.
    - 90^o in air at 77 GHz….0.974mm, 38.3 mils!
- Get more that you need/want to know about coupling from Matthaei, Young and Jones, Microwave Filters, Impedance Matching Networks and Coupling Structures.