BANDPASS CAVITY RESONATORS

S Parameters Measurements and Modelling
Using Bandpass Cavities for Impedance Matching

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INTRODUCTION

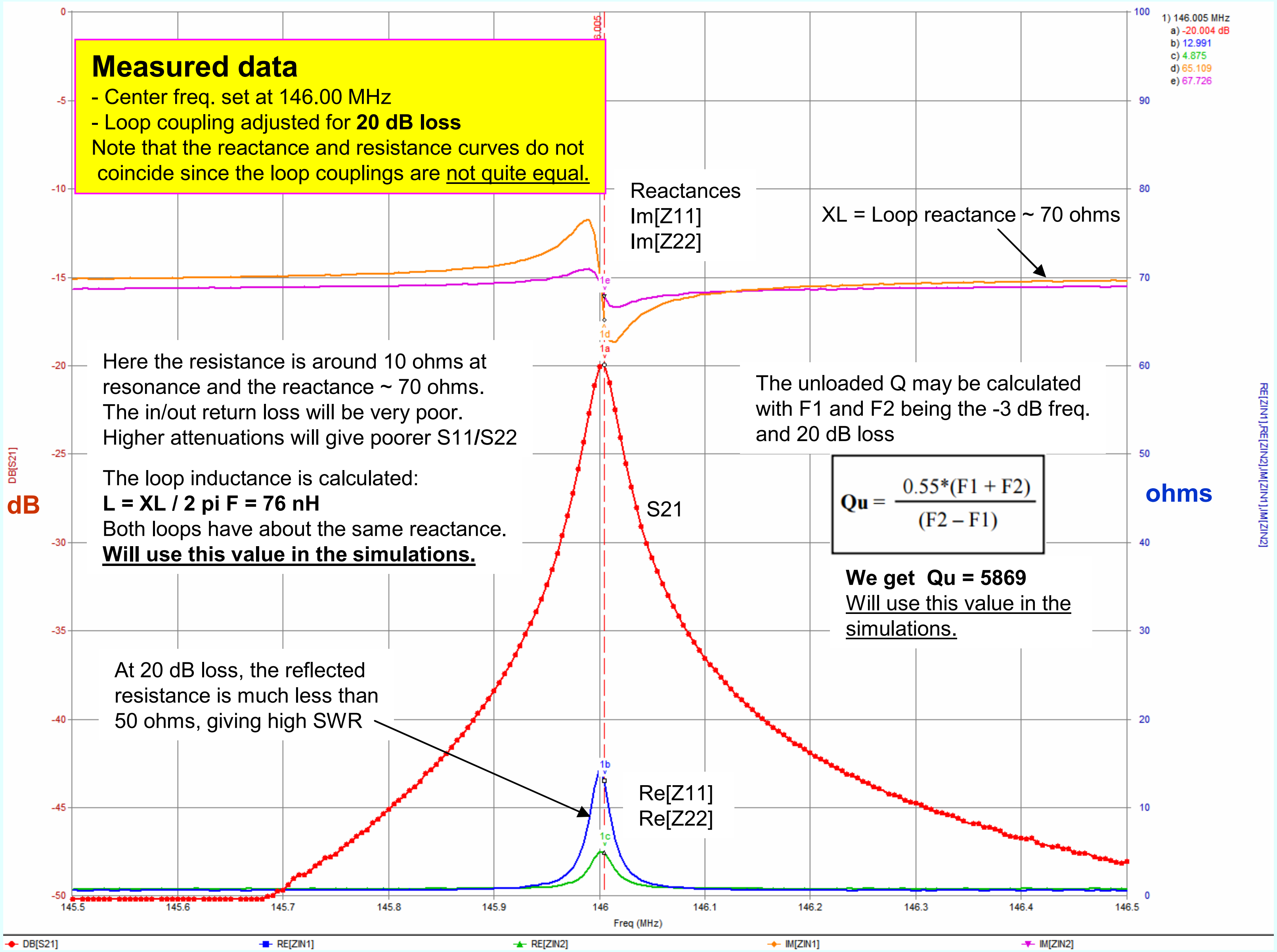
This investigation on the bandpass cavities came after a conversation with Luc Laplante VE2ULU.

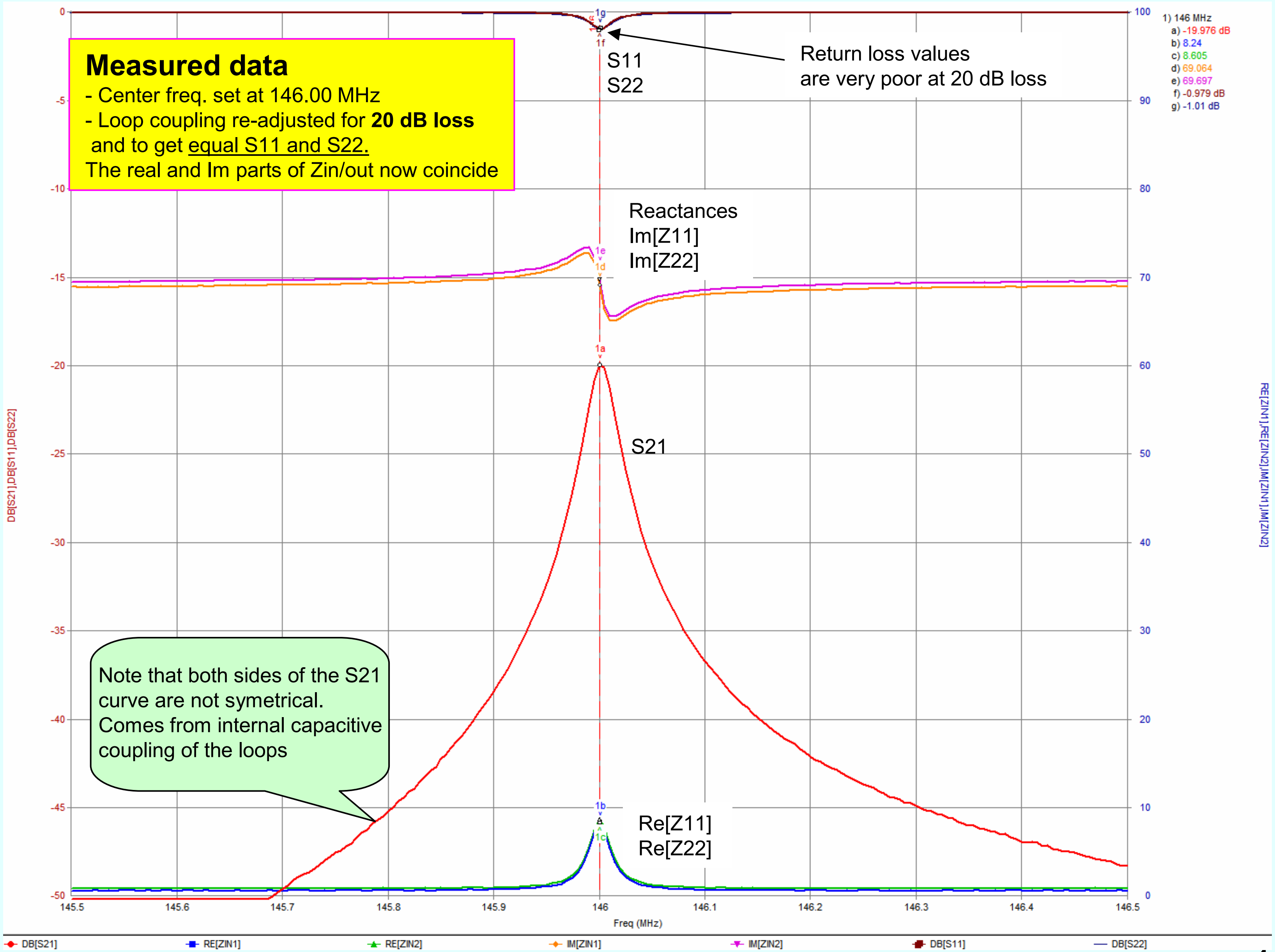
Luc has used bandpass cavities for impedance matching by adjusting the loop couplings.

I was interested to see if this capability would show up in the simulations of the cavity resonators.

This technique also improves RX sensitivity mostly for receivers operating above the 2 meter band, where atmospheric noise levels are lower. It also allows matching 75 ohm heliax antenna cable to the duplexer.

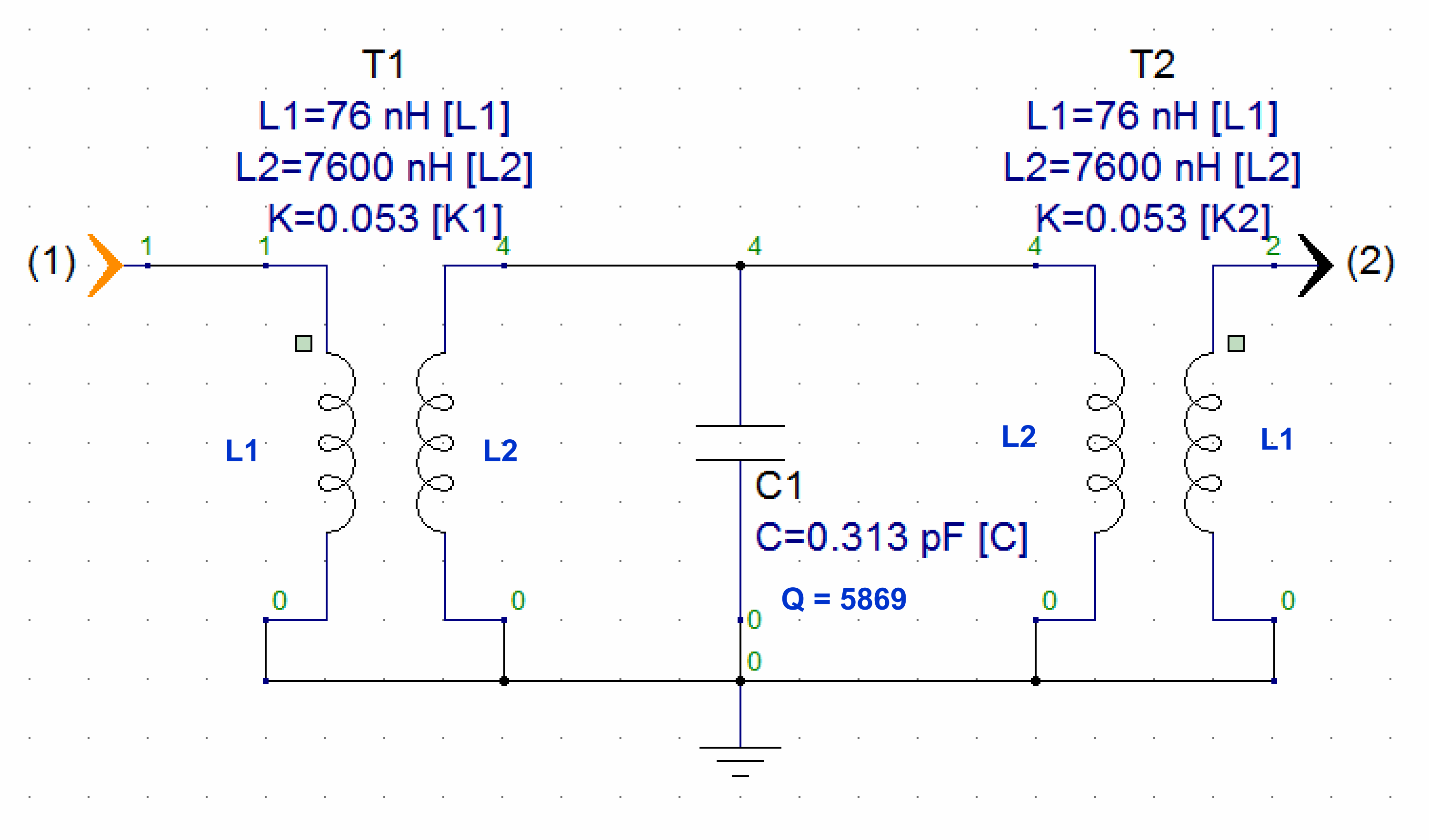
S parameter measurements as well as simulations were done on a bandpass cavity to better understand what is going on.

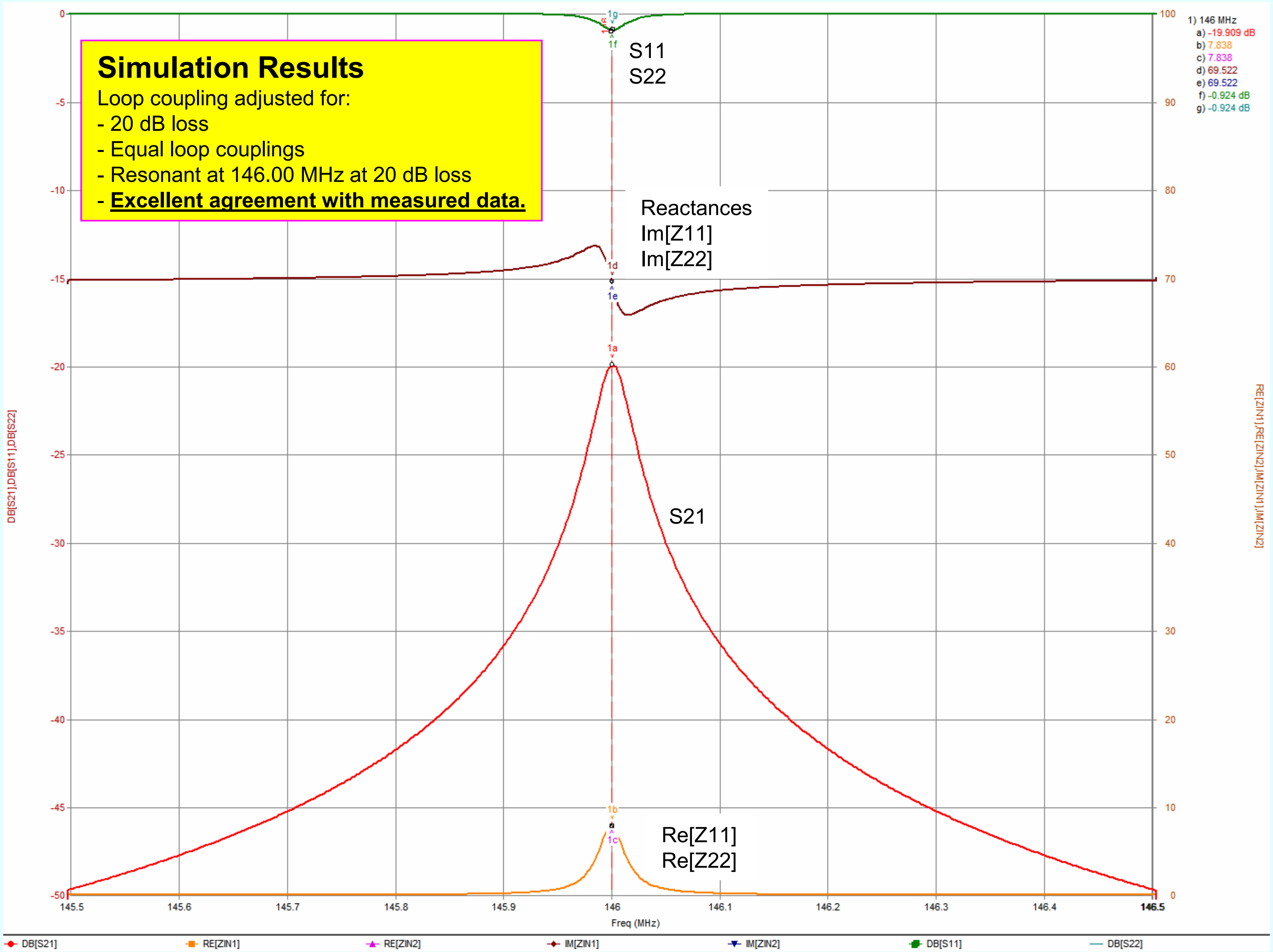

Measured data
- Center freq. set at 146.00 MHz
- Loop coupling adjusted for 20 dB loss
Note that the reactance and resistance curves do not coincide since the loop couplings are not quite equal.
Reactances
Im[Z11]
Im[Z22]
XL = Loop reactance ~ 70 ohms
Here the resistance is around 10 ohms at resonance and the reactance ~ 70 ohms.
The in/out return loss will be very poor.
Higher attenuations will give poorer S11/S22
The loop inductance is calculated:
L = XL / 2 pi F = 76 nH
Both loops have about the same reactance.
Will use this value in the simulations.
The unloaded Q may be calculated with F1 and F2 being the -3 dB freq. and 20 dB loss
Qu = 0.55*(F1 + F2) / (F2 – F1)
We get Qu = 5869
Will use this value in the simulations.
S21
At 20 dB loss, the reflected resistance is much less than 50 ohms, giving high SWR
Re[Z11]
Re[Z22]
dB
ohms
DB[S21]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
1) 146.005 MHz
a) -20.004 dB
b) 12.991
c) 4.875
d) 65.109
e) 67.726
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]

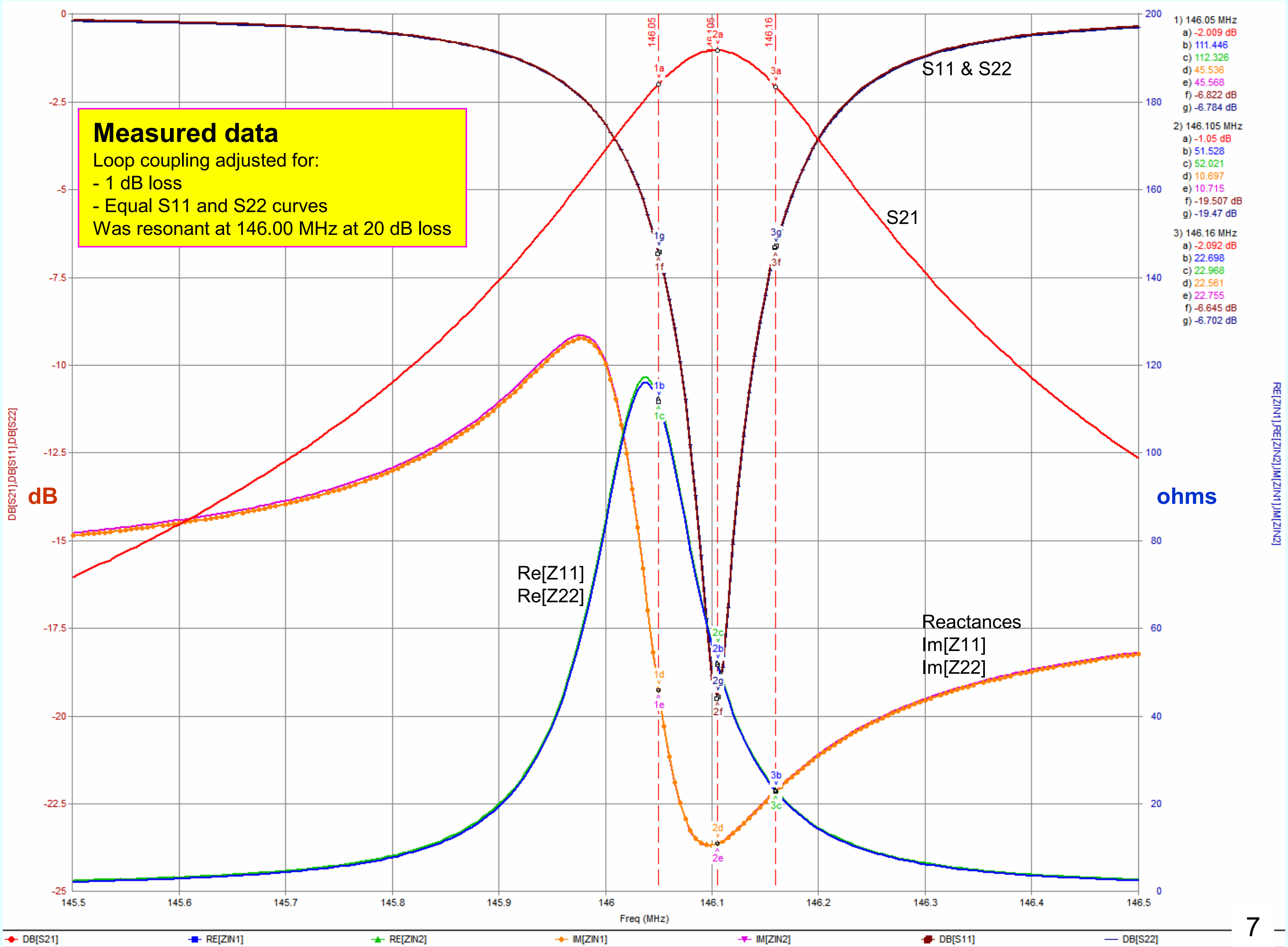

Measured data
- Center freq. set at 146.00 MHz
- Loop coupling re-adjusted for 20 dB loss
and to get equal S11 and S22.
The real and Im parts of Zin/out now coincide
S11
S22
Return loss values
are very poor at 20 dB loss
Reactances
Im[Z11]
Im[Z22]
S21
Note that both sides of the S21 curve are not symetrical.
Comes from internal capacitive coupling of the loops
Re[Z11]
Re[Z22]
1) 146 MHz
a) -19.976 dB
b) 8.24
c) 8.605
d) 69.064
e) 69.697
f) -0.979 dB
g) -1.01 dB
DB[S21],DB[S11],DB[S22]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
145.5
145.6
145.7
145.8
145.9
146
146.1
146.2
146.3
146.4
146.5
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]
DB[S11]
DB[S22]

Circuit used for simulation

Uses mutually coupled inductors with coupling coeff. K, adjusted for desired loss at the resonant freq..
L1 inductors (lossless) are the coupling coils that control attenuation at resonance.
L2 inductors (lossless) sets the resonant freq. at 146 MHz.
L2 is 100 X L1 but **ANY** ratio will give the same results !
C1 is set to resonate at 146 MHz, and sets the Q factor of the cavity.
- Gives equal S11 and S22 curves
- Resonant at 146.00 MHz at 20 dB loss
- A small value capacitor (not shown), connected between in – out, will simulate the loop to loop coupling.



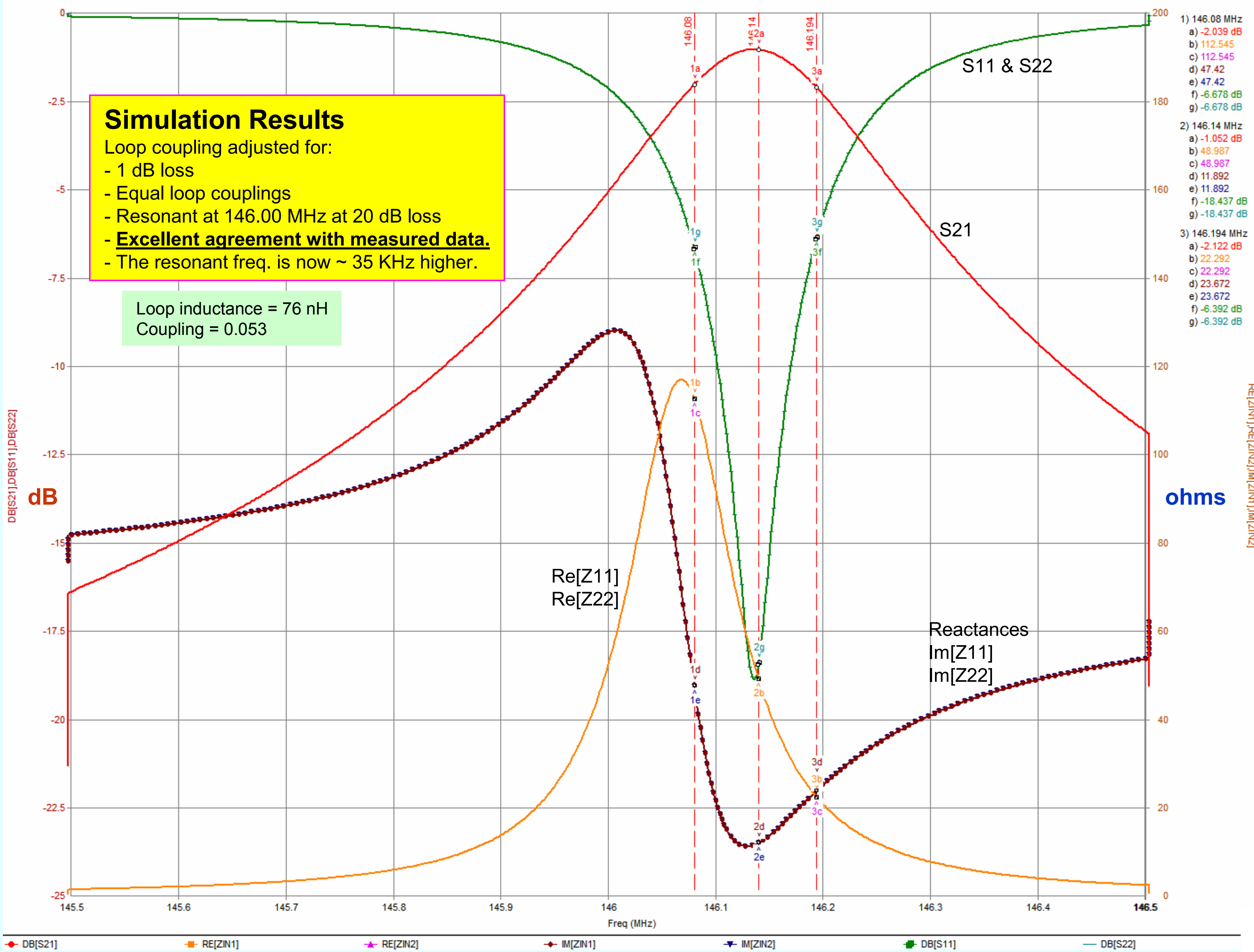

Simulation Results
Loop coupling adjusted for:
- 20 dB loss
- Equal loop couplings
- Resonant at 146.00 MHz at 20 dB loss
- Excellent agreement with measured data.
S11
S22
Reactances
Im[Z11]
Im[Z22]
S21
Re[Z11]
Re[Z22]
1) 146 MHz
a) -19.909 dB
b) 7.838
c) 7.838
d) 69.522
e) 69.522
f) -0.924 dB
g) -0.924 dB
DB[S21],DB[S11],DB[S22]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]
DB[S11]
DB[S22]

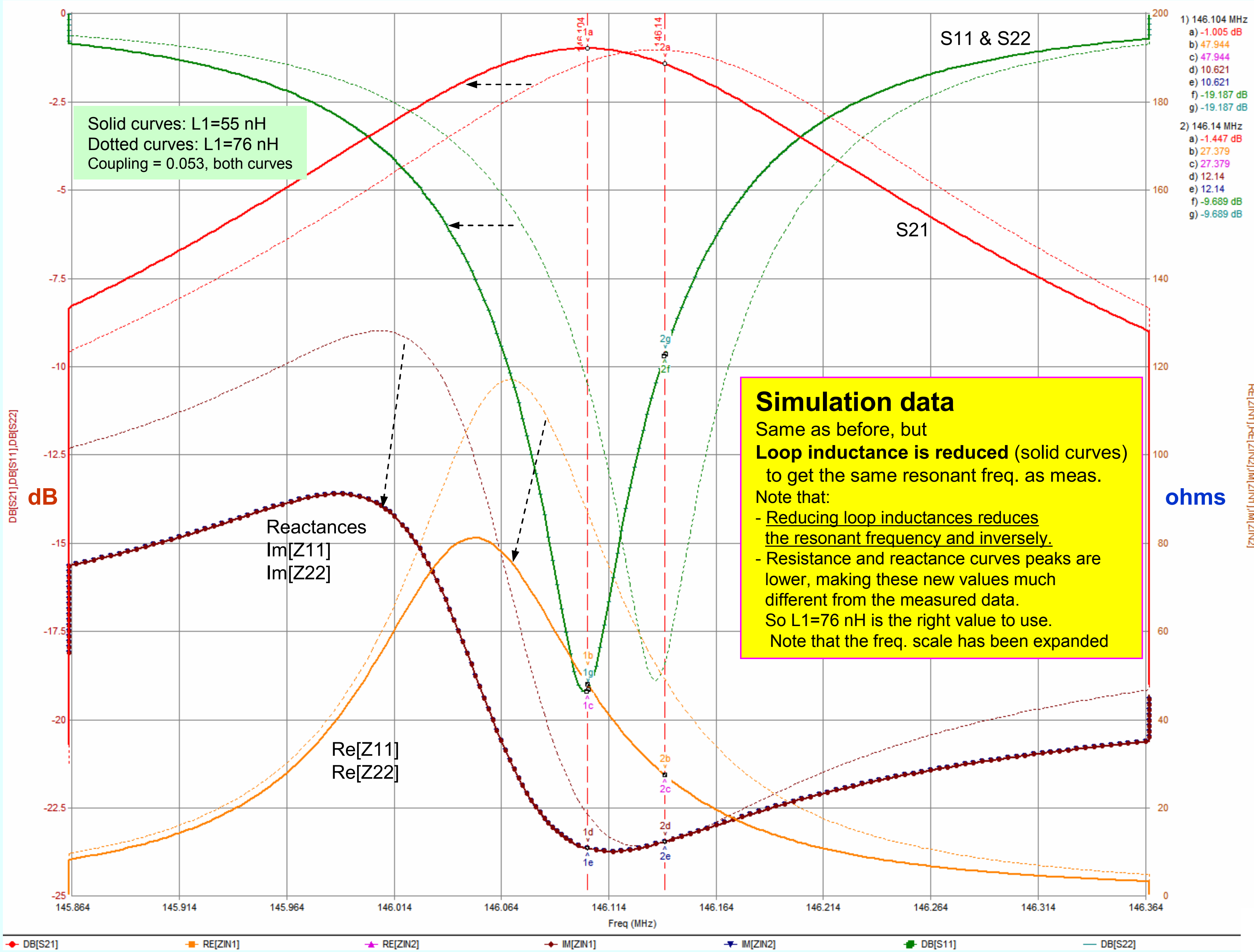

Measured data
Loop coupling adjusted for:
- 1 dB loss
- Equal S11 and S22 curves
Was resonant at 146.00 MHz at 20 dB loss
S11 & S22
S21
Re[Z11]
Re[Z22]
Reactances
Im[Z11]
Im[Z22]
dB
ohms
DB[S21],DB[S11],DB[S22]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
1) 146.05 MHz
a) -2.009 dB
b) 111.446
c) 112.326
d) 45.536
e) 45.568
f) -6.822 dB
g) -6.784 dB
2) 146.105 MHz
a) -1.05 dB
b) 51.528
c) 52.021
d) 10.697
e) 10.715
f) -19.507 dB
g) -19.47 dB
3) 146.16 MHz
a) -2.092 dB
b) 22.698
c) 22.968
d) 22.561
e) 22.755
f) -6.645 dB
g) -6.702 dB
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]
DB[S11]
DB[S22]

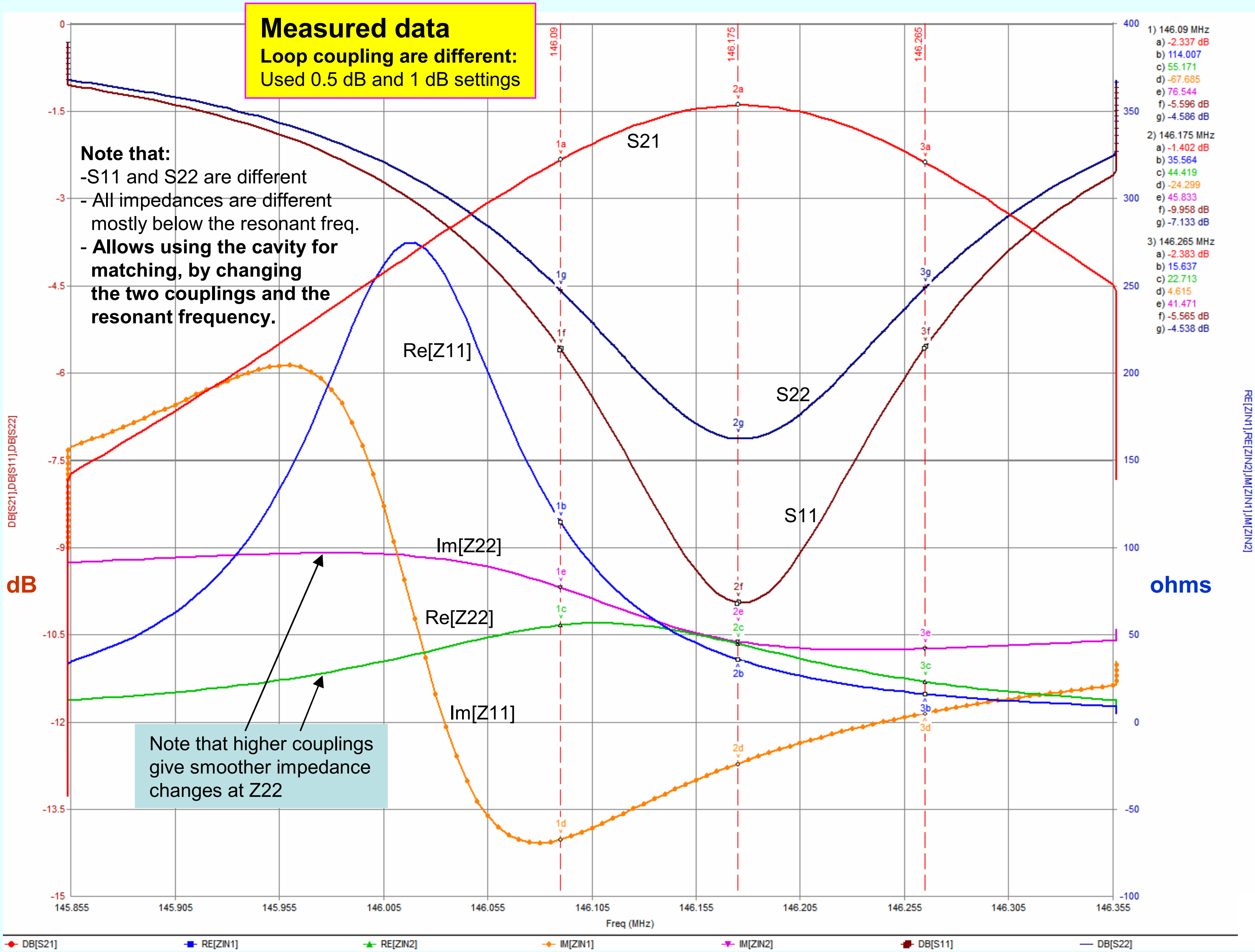
Simulation Results

Loop coupling adjusted for:

- 1 dB loss
- Equal loop couplings
- Resonant at 146.00 MHz at 20 dB loss
- **Excellent agreement with measured data.**
- The resonant freq. is now ~ 35 KHz higher.



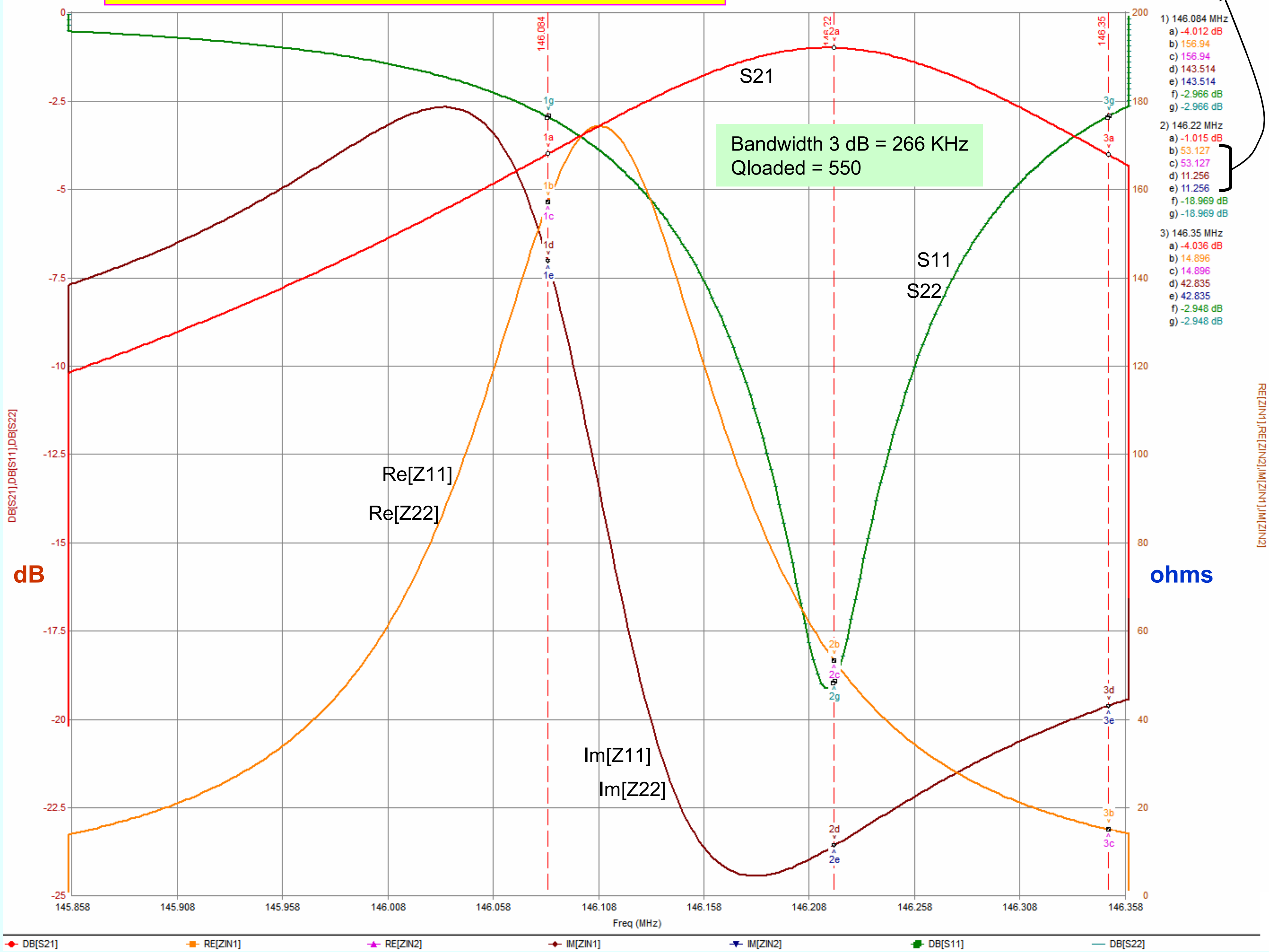

S11 & S22
S21
Solid curves: L1=55 nH
Dotted curves: L1=76 nH
Coupling = 0.053, both curves
Reactances
Im[Z11]
Im[Z22]
Re[Z11]
Re[Z22]
dB
ohms
DB[S21],DB[S11],DB[S22]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
1) 146.104 MHz
a) -1.005 dB
b) 47.944
c) 47.944
d) 10.621
e) 10.621
f) -19.187 dB
g) -19.187 dB
2) 146.14 MHz
a) -1.447 dB
b) 27.379
c) 27.379
d) 12.14
e) 12.14
f) -9.689 dB
g) -9.689 dB
Simulation data
Same as before, but
Loop inductance is reduced (solid curves)
to get the same resonant freq. as meas.
Note that:
- Reducing loop inductances reduces
the resonant frequency and inversely.
- Resistance and reactance curves peaks are
lower, making these new values much
different from the measured data.
So L1=76 nH is the right value to use.
Note that the freq. scale has been expanded
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]
DB[S11]
DB[S22]


Measured data
Loop coupling are different:
Used 0.5 dB and 1 dB settings
Note that:
-S11 and S22 are different
- All impedances are different mostly below the resonant freq.
- Allows using the cavity for matching, by changing the two couplings and the resonant frequency.
Note that higher couplings give smoother impedance changes at Z22
S21
S22
S11
Re[Z11]
Im[Z22]
Re[Z22]
Im[Z11]
dB
ohms
1) 146.09 MHz
a) -2.337 dB
b) 114.007
c) 55.171
d) -67.685
e) 76.544
f) -5.596 dB
g) -4.586 dB
2) 146.175 MHz
a) -1.402 dB
b) 35.564
c) 44.419
d) -24.299
e) 45.833
f) -9.958 dB
g) -7.133 dB
3) 146.265 MHz
a) -2.383 dB
b) 15.637
c) 22.713
d) 4.615
e) 41.471
f) -5.565 dB
g) -4.538 dB
DB[S21],DB[S11],DB[S22]
RE[ZIN1],RE[ZIN2],IM[ZIN1],IM[ZIN2]
Freq (MHz)
DB[S21]
RE[ZIN1]
RE[ZIN2]
IM[ZIN1]
IM[ZIN2]
DB[S11]
DB[S22]

Simulation data

Identical couplings to match 50Ω to 50Ω at the peak frequency

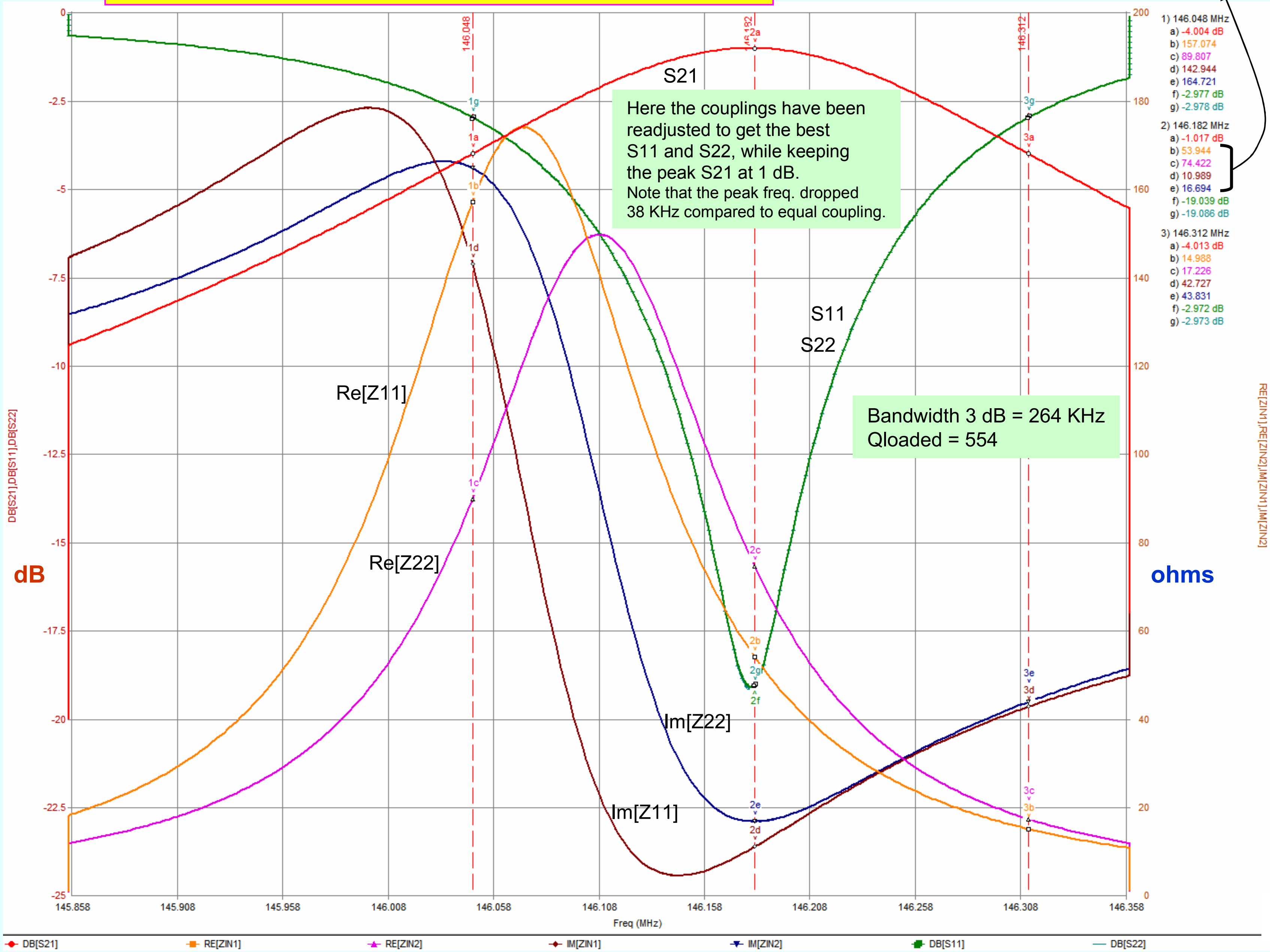
Zin = 53.127 + j 11.256
Zout = 53.127 + j 11.256



Simulation data

Changing the couplings to match 50Ω to 75Ω at the peak frequency

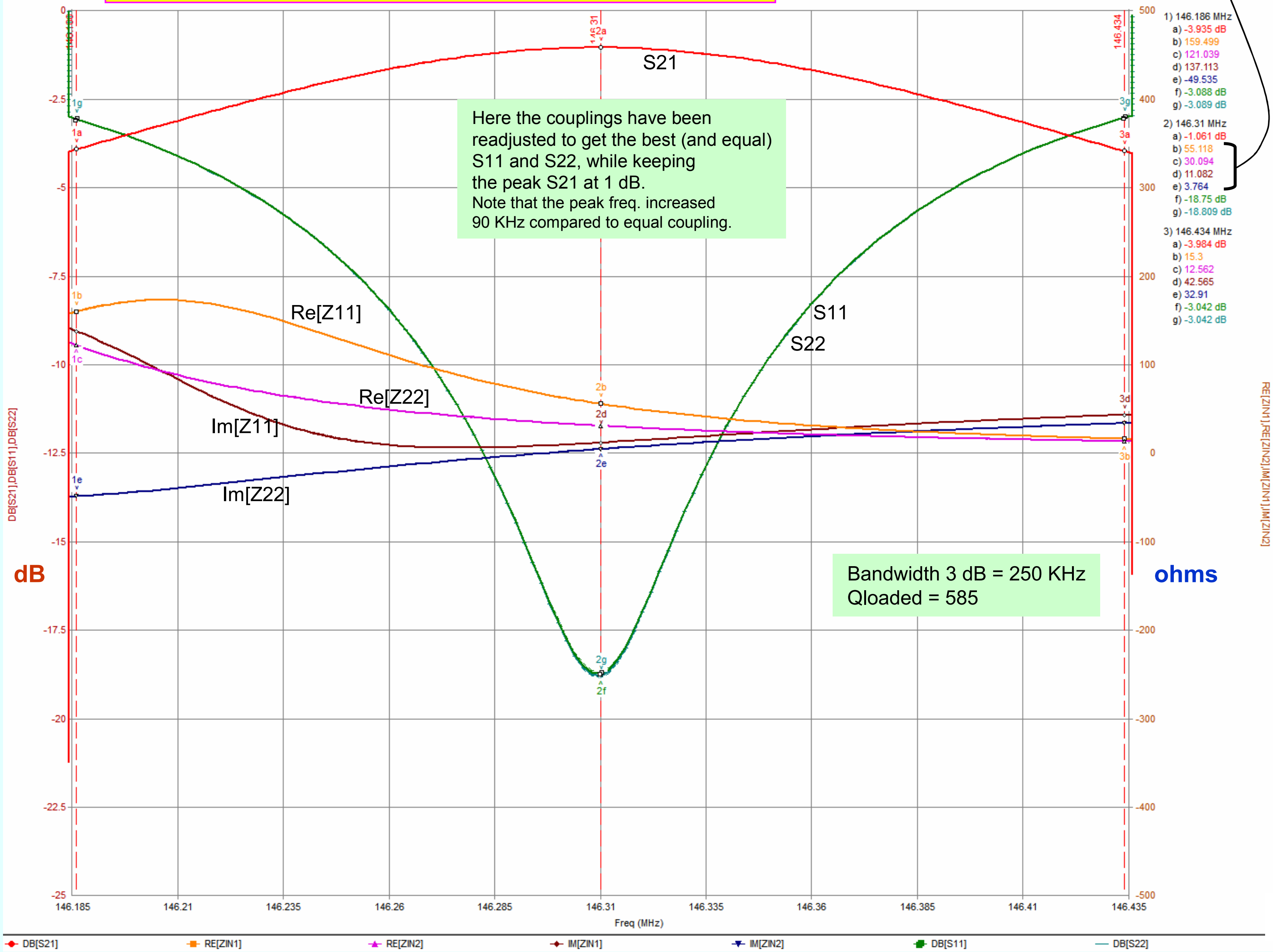
Zin = 53.944 + j 10.989
Zout = 74.422 + j 16.694



Simulation data

Changing the couplings to match 50Ω to 25Ω at the peak frequency

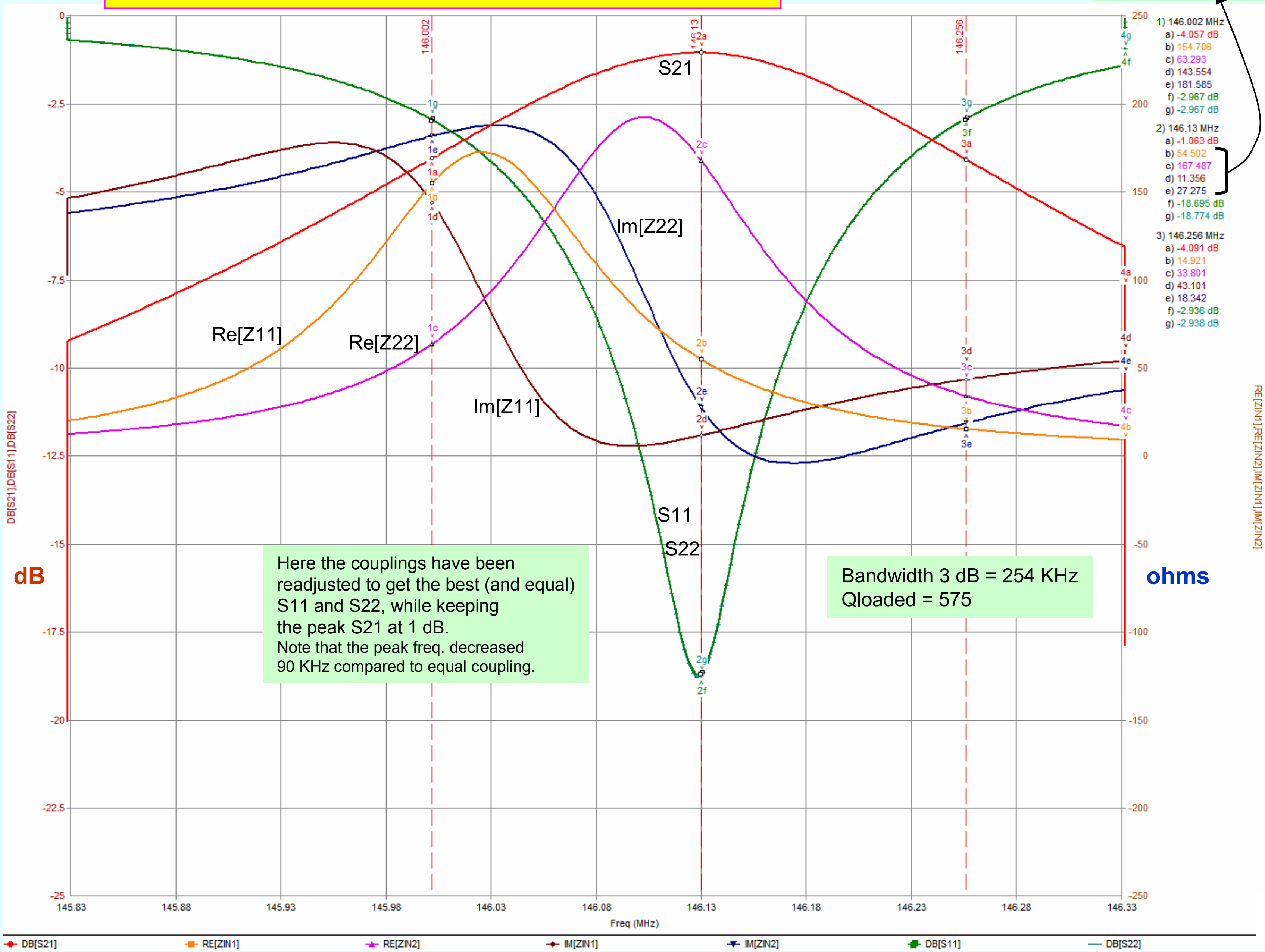
Zin = 55.118 + j 11.082
Zout = 30.094 + j 3.764



Simulation data

Changing the couplings to match 50Ω to 200Ω at the peak frequency

Zin = 54.502 + j 11.356
Zout = 167.487 + j 27.275

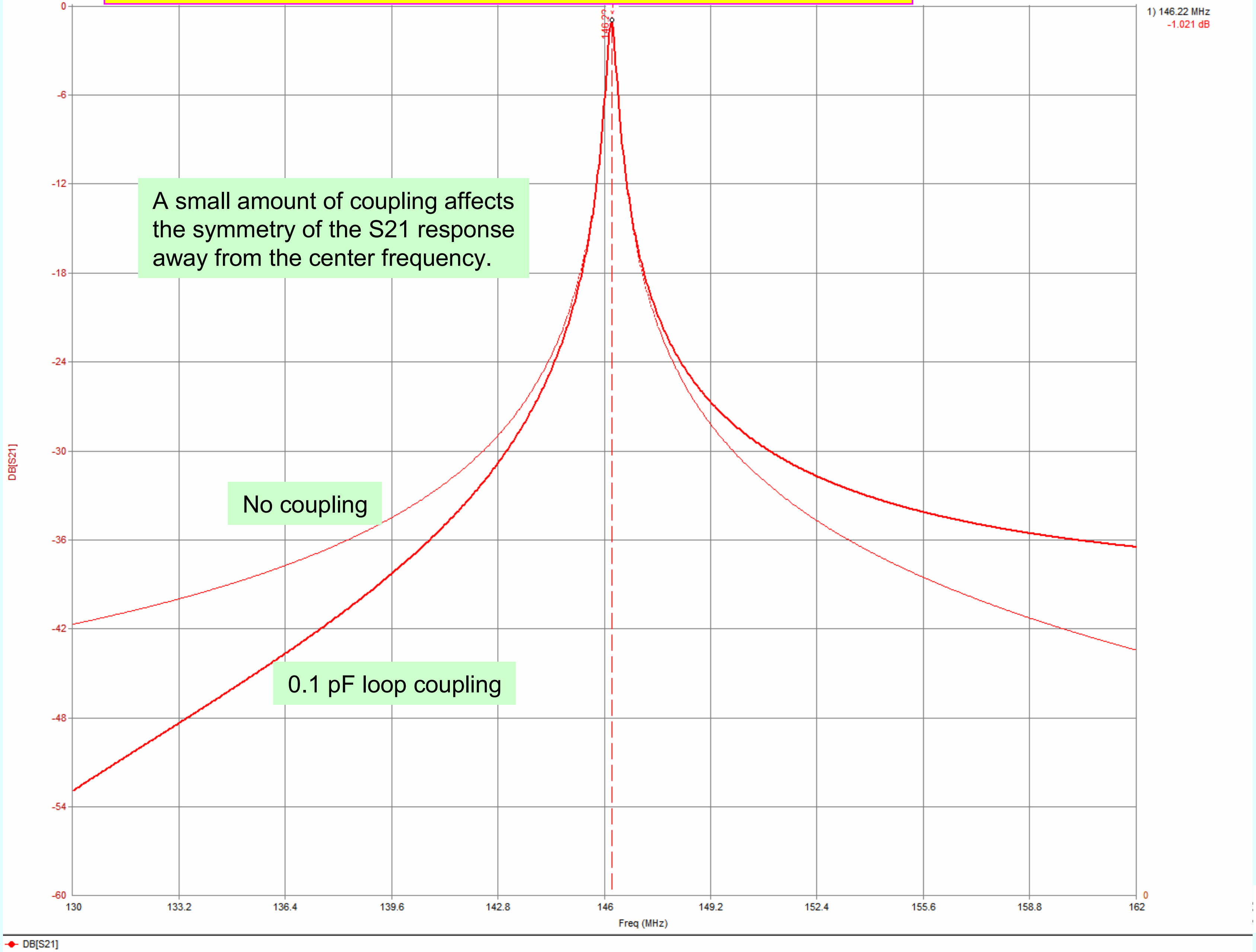


Here the couplings have been readjusted to get the best (and equal) S11 and S22, while keeping the peak S21 at 1 dB.
Note that the peak freq. decreased 90 KHz compared to equal coupling.

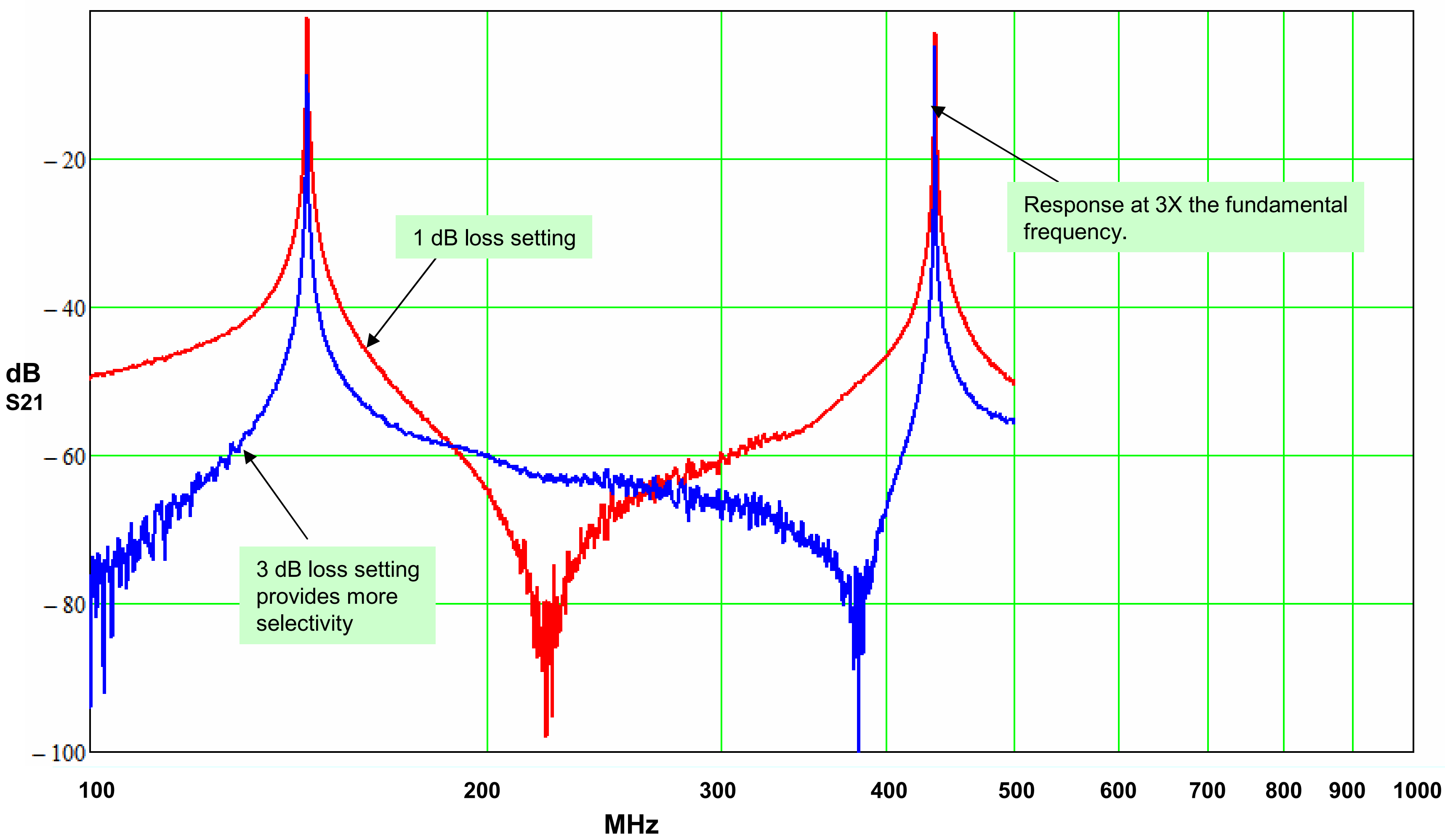
Bandwidth 3 dB = 254 KHz
Qloaded = 575

Simulation data

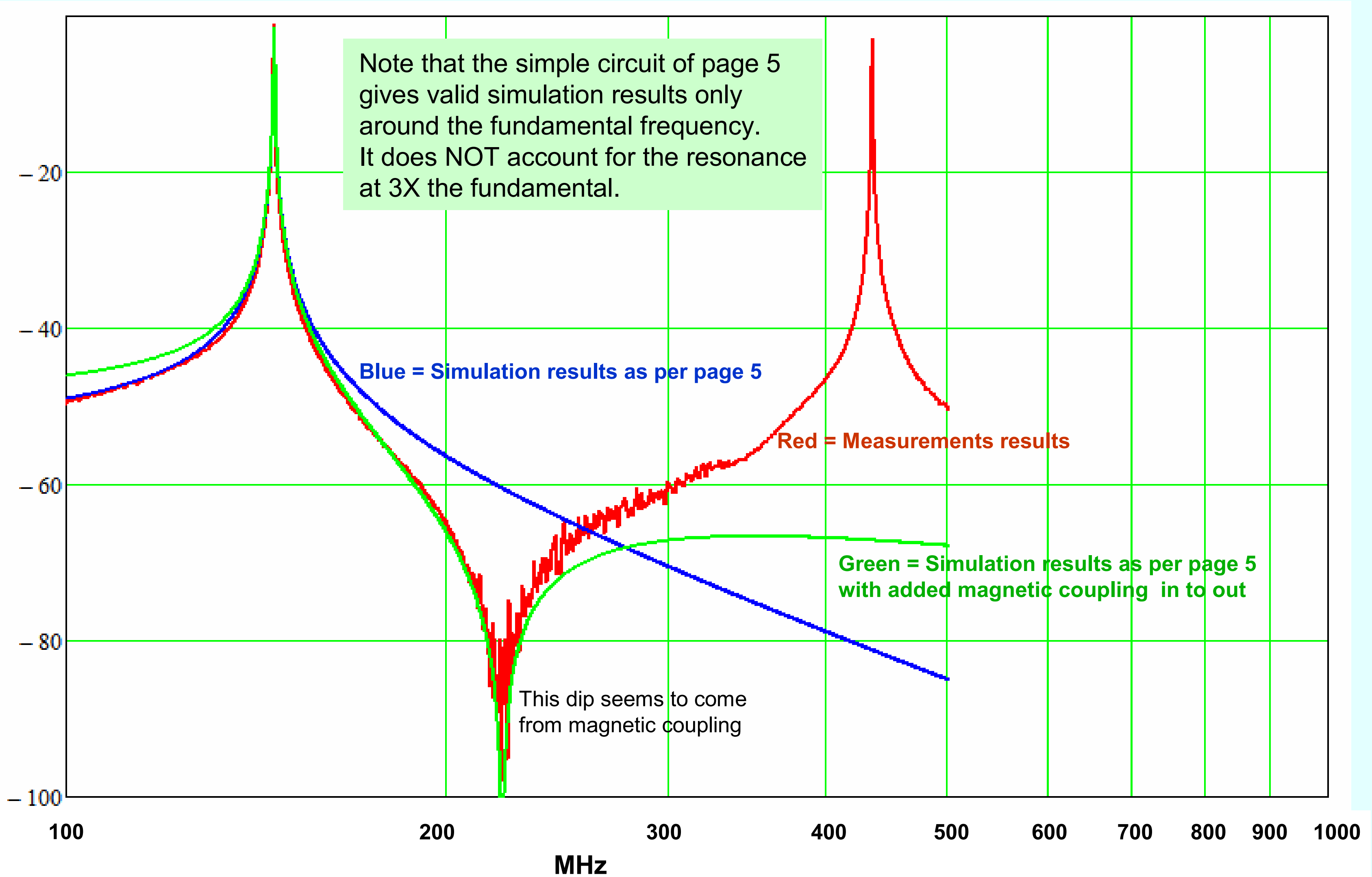
Adding a coupling cap between the loops (in to out), to simulate parasitic coupling



MEASURED WIDEBAND RESPONSE Red = 1 dB loss Blue = 3 dB loss



Comparison between Measured and Simulated Response Data for 1 dB coupling



SUMMARY

Simulations of the bandpass cavity.

An L-C circuit with dual coupling loops is a good model to use around the resonant frequency, in the region where the S21 response is above - 50 dB.
The L-C resonant tank circuit may have any L/C values, as long as it resonates at the desired frequency.
The loop coupling is adjusted to obtain the desired insertion loss. The resonant C sets the Q factor.
A similar circuit may be used for Notch-Bandpass cavities, as done in: http://ve2azx.net/technical/ve2azx-duplexerinfo.pdf
The unequal attenuation on both sides of the passband peak comes from capacitive stray coupling between the two loops.
It may be simulated with a small value capacitor connected between input and output. Measure the attenuation at +/- 10% above and below the center frequency and record the S21. In the simulator place a negative capacitor across the in – out.
Adjust its value until the attenuations are the same at +/- 10% above and below the center frequency.
This is the + value of the capacitor to use in the model.

Increasing the loop coupling…

Decreases the insertion loss at the resonant frequency.
The resonant frequency also moves upward somewhat.
The impedance matching is improved at the same time. (On a cavity with equal loop couplings)
The return loss and rate of change of the impedances decreases.
A symmetrical cavity has equal return loss at both in/out ports. This is obtained by adjusting the in/out couplings.

The bandpass cavity may be used for impedance matching, by setting different couplings and by changing the resonant frequency slightly to set the peak response (and best return loss) at the desired frequency.

Loop inductance…

Increasing loop inductance moves the resonant frequency upwards slightly.
The rate of change of the impedances increases.
The return loss is improved.
Is easily measured by adjusting for a very low coupling (like 20 dB loss) and measuring the complex S11 or S22.
Another method is detailed on page 56 of my document: http://ve2azx.net/technical/ve2azx-duplexerinfo.pdf
Is not critical. It should provide a reactance in the 50 to 100 ohms region at the operating frequency.

Using different loop couplings…

Allows using the bandpass cavity for impedance matching, thus increasing the RX sensitivity.
Allows matching the antenna to the preamp input impedance and/or the preamp to the RX.
Allows matching 75 ohm heliax antenna cable to the duplexer.
The center of the bandpass frequency changes when loop couplings are adjusted and with changing load impedances.
Readjusting may be necessary. Adjust for best return loss at the 50 ohm port.
The bandwidth and return loss are not affected, as long as the insertion loss S21 is kept constant at the peak frequency.