BANDPASS CAVITY RESONATORS

S Parameters Measurements and Modelling
Using Bandpass Cavities for Impedance Matching

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With the collaboration of Luc Laplante VE2ULU
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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.

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:
\[ L = \frac{XL}{2 \pi F} = 76 \, \text{nH} \]
Both loops have about the same reactance. **Will use this value in the simulations.**

At 20 dB loss, the reflected resistance is much less than 50 ohms, giving high SWR

The unloaded Q may be calculated with F1 and F2 being the -3 dB freq. and 20 dB loss

\[ Q_u = \frac{0.55(F1 + F2)}{(F2 - F1)} \]

We get \( Q_u = 5869 \)
**Will use this value in the simulations.**
**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

Return loss values are very poor at 20 dB loss

Note that both sides of the S21 curve are not symmetrical. Comes from internal capacitive coupling of the loops
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.

\[ Q = 5869 \]
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.
Measured data
Loop coupling adjusted for:
- 1 dB loss
- Equal S11 and S22 curves
Was resonant at 146.00 MHz at 20 dB loss
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.

Loop inductance = 76 nH
Coupling = 0.053
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.
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
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

Bandwidth 3 dB = 266 KHz
Qloaded = 550
Simulation data
Changing the couplings to match 50Ω to 75Ω at the peak frequency

Here the couplings have been readjusted to get the best S11 and S22, while keeping the peak S21 at 1 dB. Note that the peak freq. dropped 38 KHz compared to equal coupling.

Bandwidth 3 dB = 264 KHz
Q_{\text{loaded}} = 554

\[ Z_{\text{in}} = 53.944 + j 10.989 \]
\[ Z_{\text{out}} = 74.422 + j 16.694 \]
Simulation data
Changing the couplings to match 50Ω to 25Ω at the peak frequency

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. increased 90 KHz compared to equal coupling.

Bandwidth 3 dB = 250 KHz
Qloaded = 585

<table>
<thead>
<tr>
<th>ohms</th>
<th>dB</th>
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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

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.

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

Bandwidth 3 dB = 254 KHz
Qloaded = 575
Simulation data
Adding a coupling cap between the loops (in to out), to simulate parasitic coupling

A small amount of coupling affects the symmetry of the S21 response away from the center frequency.

- No coupling
- 0.1 pF loop coupling
MEASURED WIDEBAND RESPONSE  Red = 1 dB loss  Blue = 3 dB loss

1 dB loss setting

3 dB loss setting provides more selectivity

Response at 3X the fundamental frequency.
Comparison between Measured and Simulated Response Data for 1 dB coupling

Note that the simple circuit of page 5 gives valid simulation results only around the fundamental frequency. It does NOT account for the resonance at 3X the fundamental.

Blue = Simulation results as per page 5
Red = Measurements results
Green = Simulation results as per page 5 with added magnetic coupling in to out

This dip seems to come from magnetic coupling.
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

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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.