Transmission line model of cavity with coupler

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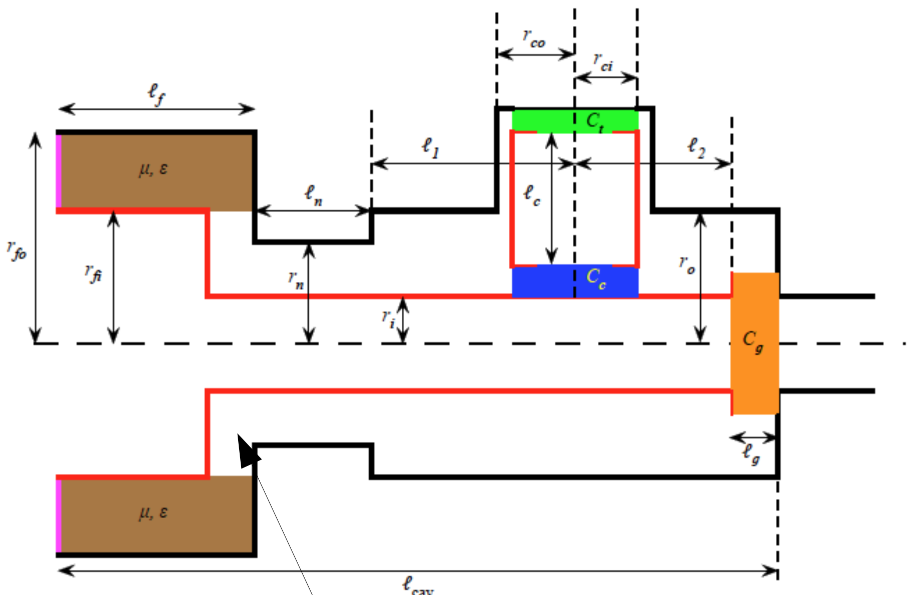
Goal

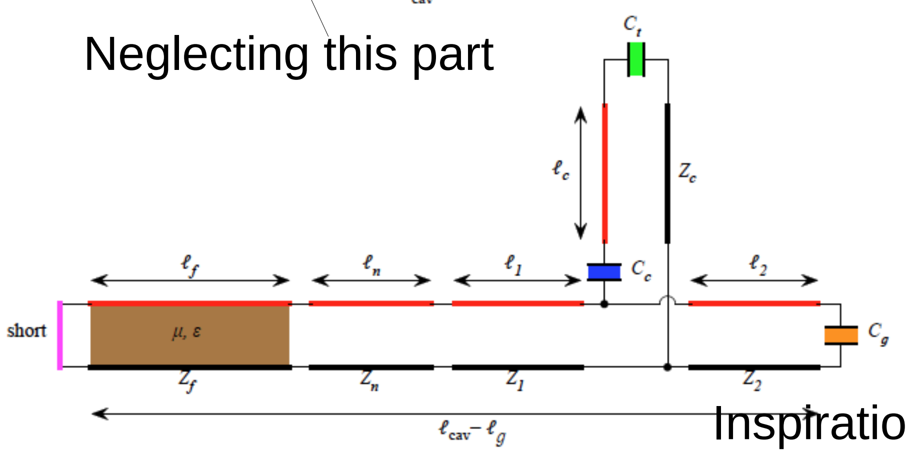
- Create semi-analytic model to see what's going on.
  - Voltage profile along the cavity.
  - How to add coupler.
  - What the reflection coefficient is at the coupler.
  - Does adding a “neck” help with impedance matching or voltage shaping? ← not done yet!
- **Caveat Emptor! Results discussed here are all PRELIMINARY probably not right!**
  - **Subject to change without notice, apologies or regret!!!!**

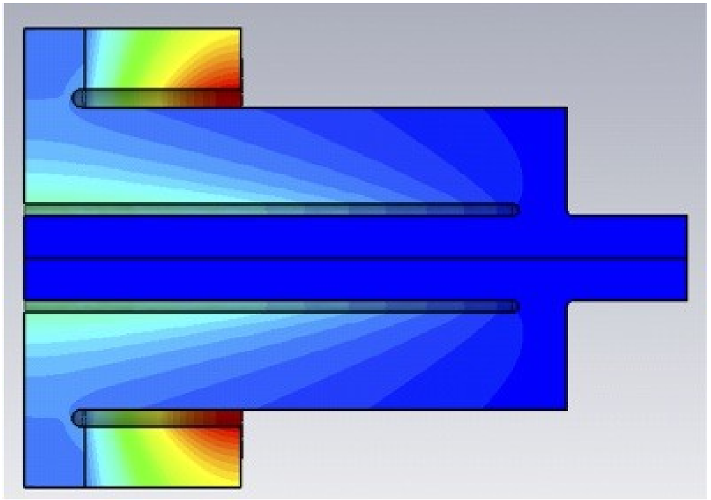
Transmission line model

Too complicated! So work with even simpler model



Neglecting this part





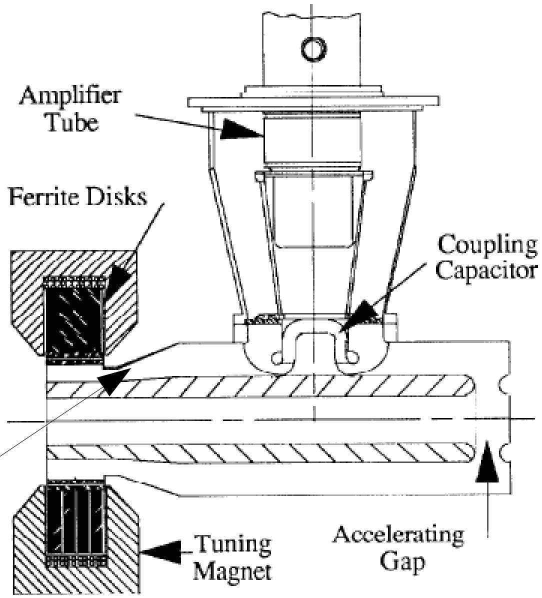
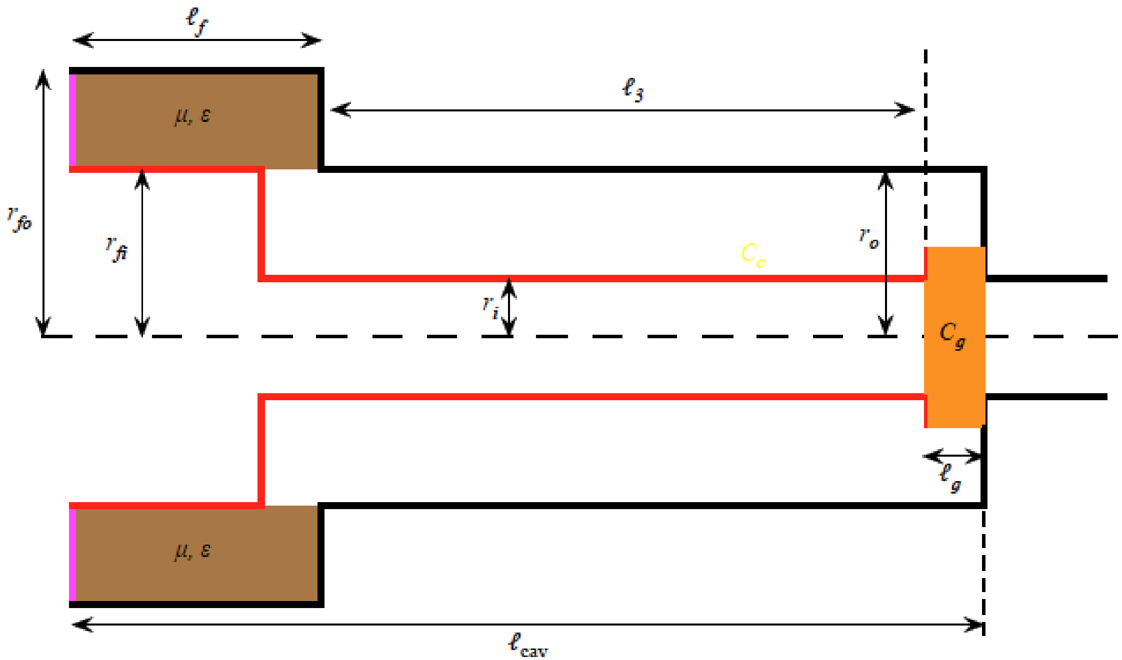


Fig. 1. The Proposed LEB Cavity

Inspiration for neck

Simple garnet loaded cavity



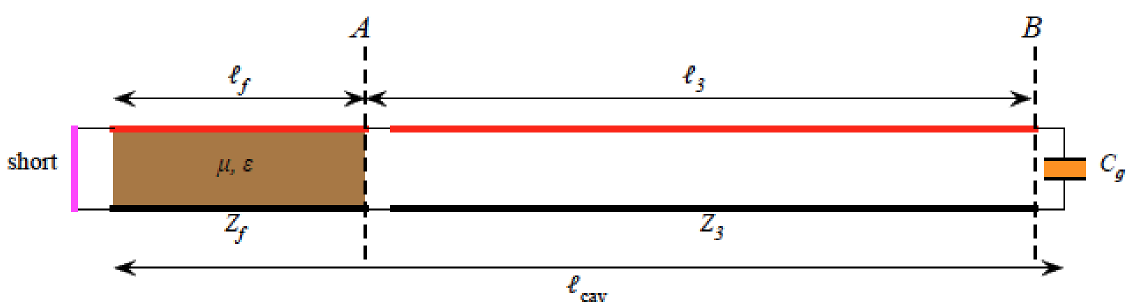
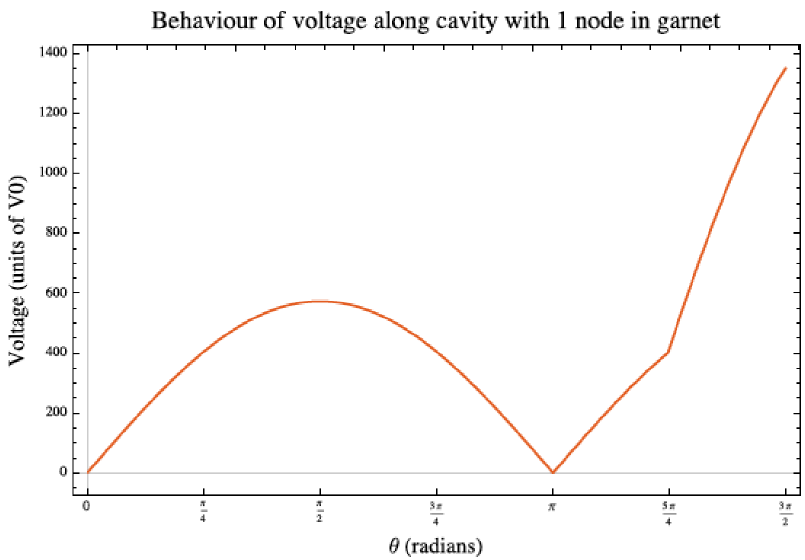
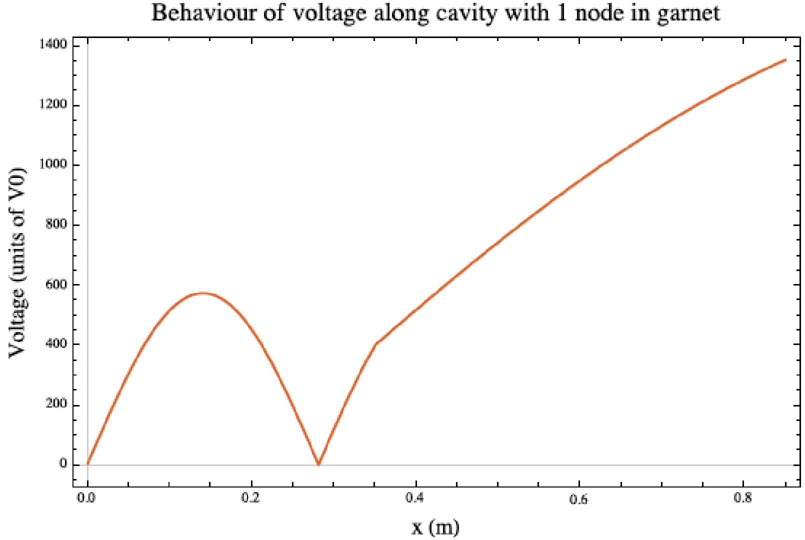


TABLE I. Equivalent circuit parameters

Part	Parameter	Value	Units	Description
	r_i	0.035	m	radius of the beam tube.
	ℓ_f	0.195	m	length of the garnet.
	ℓ_g	0.04	m	length of the gap.
z_f		17.17	Ω	characteristic impedance of the garnet.
	μ_r	3.5		relative permeability of garnet at 76 MHz.
	ϵ_r	14		relative permeability of garnet.
	ℓ_f	0.195	m	length of the garnet.
	r_{fo}	0.195	m	outer radius of the garnet
	r_{fi}	0.110	m	inner radius of the garnet
z_n		tbd[2]	Ω	characteristic impedance of the neck.
	ℓ_n	tbd	m	length of the neck.
	r_n	tbd	m	outer radius of the neck
$z_{1,2}$		62.9	Ω	characteristic impedance of the non-ferrite part.
	$\ell_{1,2}$	0.25	m	length of transmission line 1.
	r_o	0.10	m	outer radius of transmission line 1.
z_3		62.9	Ω	characteristic impedance of the non-ferrite part.
	ℓ_3	0.5	m	length of transmission line 1.
	r_o	0.10	m	outer radius of transmission line 1.
z_c		40.6[3]	Ω	characteristic impedance of the coupler.
	ℓ_c	tbd	m	length of the coupler.
	r_{co}	0.25[A]	m	outer radius of the coupler.
	r_{ci}	0.127[A]	m	inner radius of the coupler.
C_t		56	pF	tube capacitance from anode to screen.
C_c		8	pF	coupling capacitance.
C_g		18.76[4]	pF	gap capacitance.

Results



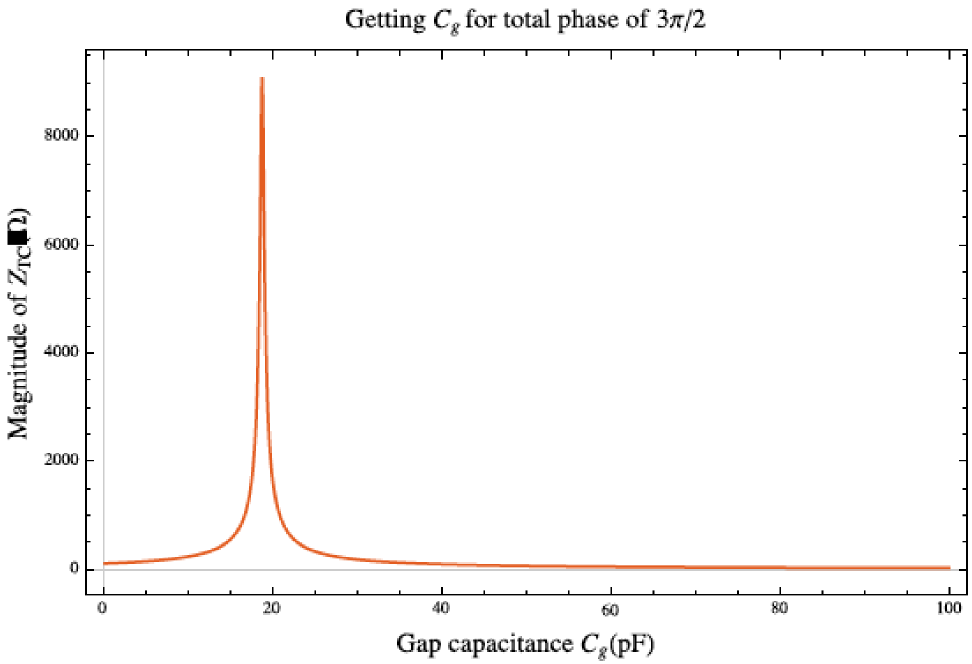


I force the length of the garnet+non-garnet part = 3π/2 or 3λ/4 and find that:

Length of garnet =0.35 m

Length of non-garnet = 0.5 m

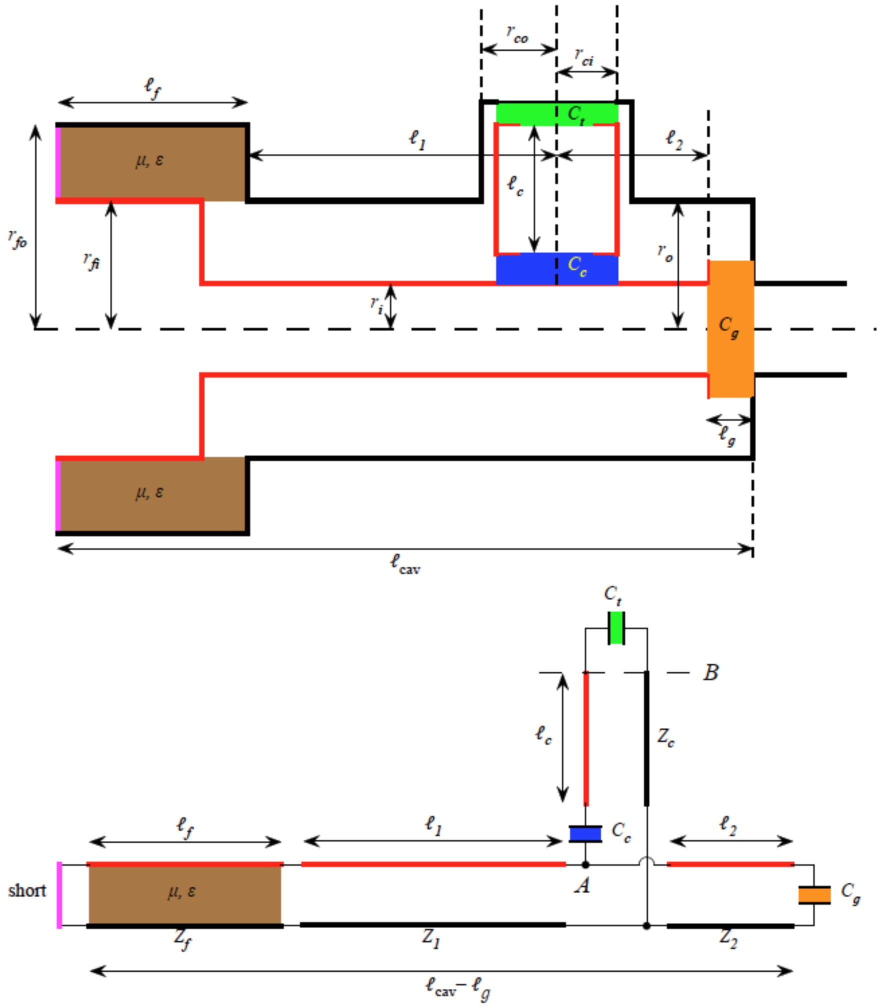
Gap capacitance = 18.76 pF



Results (cont'd)

- The cavity must be at least 3λ/4 because the garnet length even in MWS has more than π/2 phase change in it.
- The cavity can be any length that we want depending on the gap capacitance.
  - I found the gap capacitance to be ~20 pF, expect ~1 pF at 76 MHz
    - Source of the problem is that z_f = 60*Sqrt[μ_r/ε_r]Log[r_o/r_i] and for μ_r=3.5 and ε_r=14, Sqrt[3.5/14] = 0.5 < 1. And so for the same β*l*, the inductance is smaller (Z = *i* z_0 Tan[β*l*] for shorted coaxial line). From the geometry of the model z_f = 17.17Ω and *z*=62.9Ω.
    - I need to understand this! Is this a problem of the way I've set up my model?
  - There is a reduction in length, in general, from the resonant length of a shorted transmission line (λ/4 or 3λ/4) due to the gap capacitor.
  - The length will affect Rs, so have to be careful. Q=π/4*(z/Rs) where z is the characteristic impedance.

Coupler



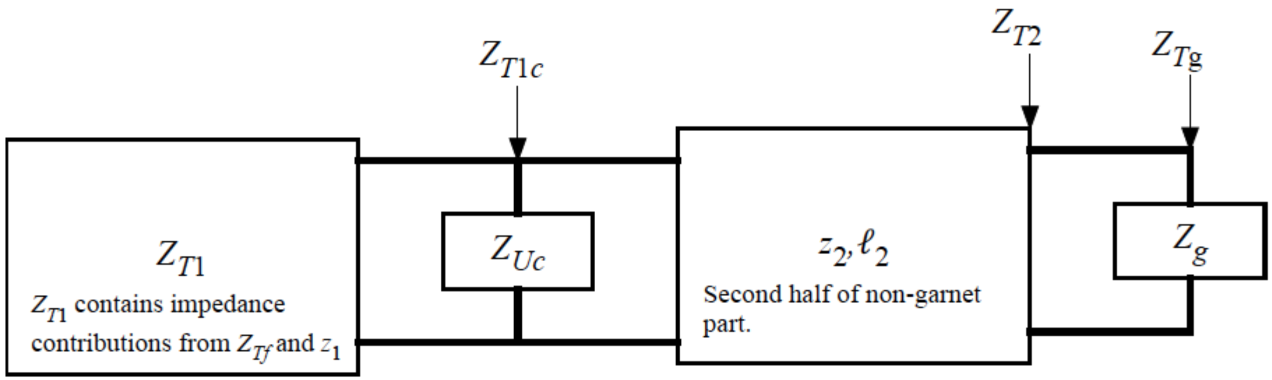
Location of coupler will be in the middle of the non-garnet part.
The centre conductor has radius 5” because of the tube anode constraints.

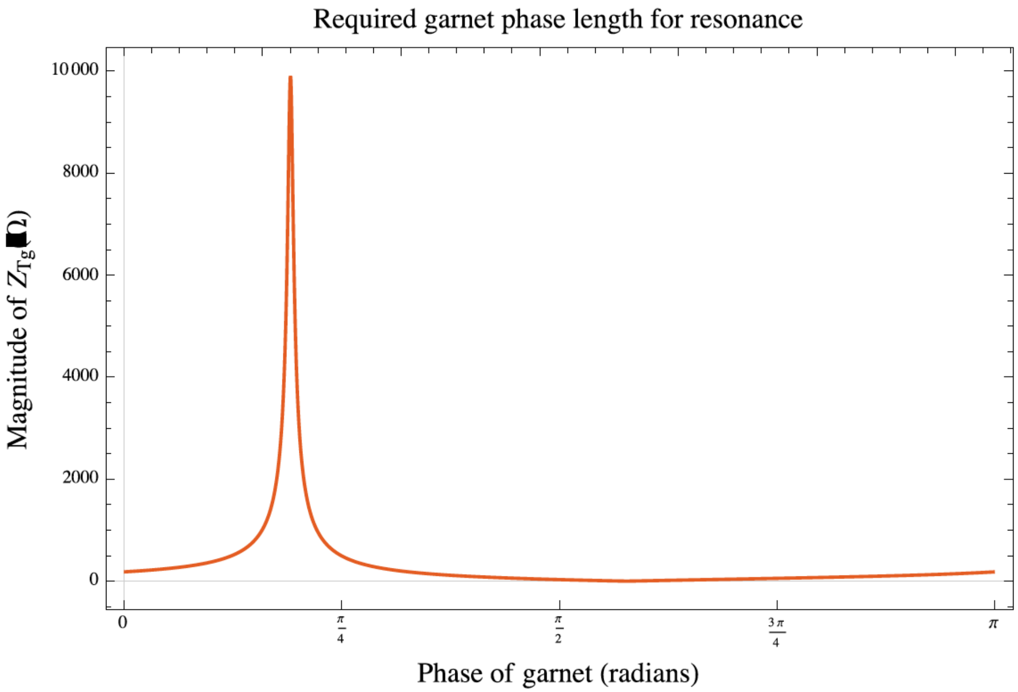
r_{ci} = 5”=0.127 m, r_{co}=0.25 m and so z_c=40.6Ω.

I chose the length of the coupler transmission line = 20 cm (← not the right way to do this, according to Joe)

C_c = 8 pF, C_t = 56 pF.

Getting the resonance

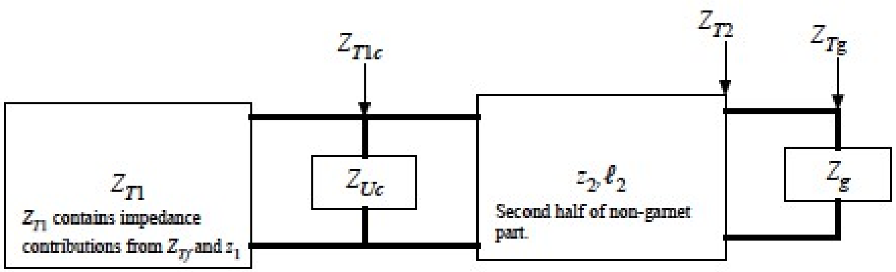


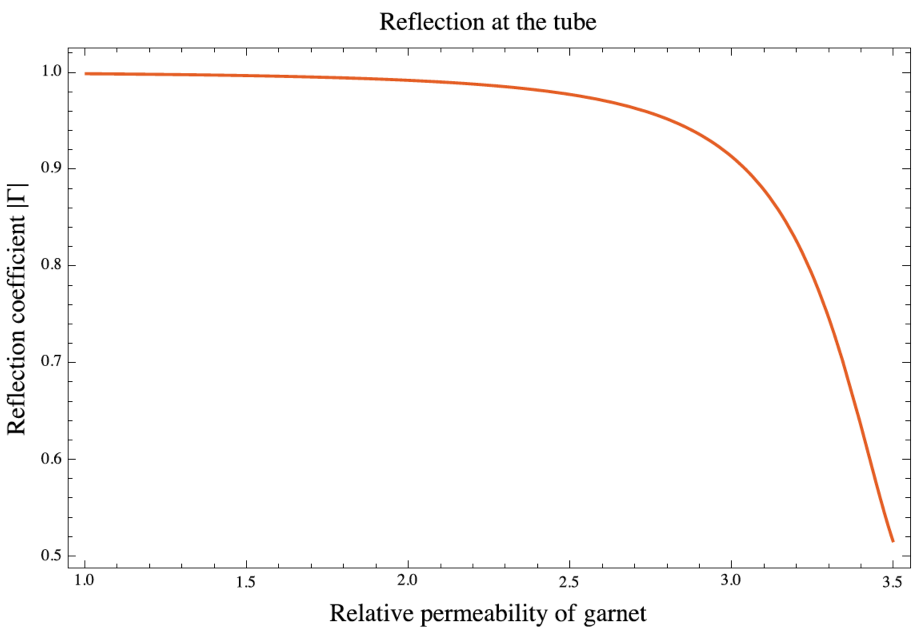


Found l_f to be a little shorter compared to without coupler.

L_f = 0.335 m compared to 0.35 m previously.

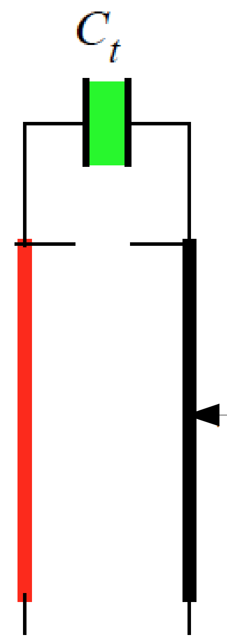
Reflection coefficient





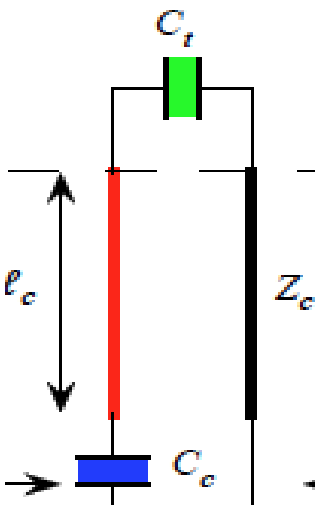
Doesn't work. Too much reflection for the entire range!

Talked to Joe Dey, he suggests that I need to find the point on the line that cancels the cavity impedance.



In[87]:= $ZUnoCc[\theta\_] := \dfrac{zc - i\, Zt\, Cot[\theta]}{Zt / zc - i\, Cot[\theta]}$

Stupidly connecting coupler introduces more problems



Do the simplest case where the cavity imaginary part of the impedance is zero at the coupling point. Then, I find that

```
In[93]:= FindRoot[Im[ZUnoCc[βc L] + 1/(i ω0 8 × 10^-12)] == 0, {L, 0.1}]

Out[93]= {L → 3.32884}
```

Ooops! Coupler length is 3 m!!!!

Let' s try it again with the 1000 pF coupling capacitor

```
In[94]:= FindRoot[Im[ZUnoCc[βc L] + 1/(i ω0 1000 × 10^-12)] == 0, {L, 0.1}]

Out[94]= {L → 0.499349}
```

Much more reasonable. So it is not sufficient to randomly select coupling point to be at the centre of the cavity!

Fine tune length of cavity so that at the coupling point, the imaginary part of the cavity impedance nearly cancels Zc. This could be the trick!

Clearly more work needs to be done!

- Figure out why Cg is so large. Model problems?
- Figure out the location of the coupler so that the impedance at the coupling point mostly cancels the impedance of the coupling capacitor.
- Make sure that the entire device does resonate with the coupler added
  - Make sure that the reflection coefficient is ok.
- Perhaps Ding's HFSS? Model will give a better result.