The SAFARI FDM Crosstalk
a) Carrier Leakage

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Overview

- Possible causes of crosstalk
- Previous work

  - SAFARI
  - X-IFU
- Work in process
  - Modeling
  - Measurement
- Open Issues
  - Length of harness
  - Frequency Spacing
  - X-IFU simulator for SAFARI?
- Future Plan
- References

Possible Causes of Crosstalk [1,2]

Mechansim	Dependence	Mitigation
Thermal Leakage	Interpixel distance on sensor array	Thermalization layer De-focussing
Carrier Leakage	In TES bias circuit, depends on L_{flt}, R_n , Δf	Increase Δf
Common Impedance	In readout circuit, depends on Δf, L_{com}, f , L_{flt}	Increase Δf Lower L_{com}
Non linear amplification	Mostly in SQUID depends on Gain- BW, Dynamic Range (DR)	Higher GBW More DR
Coupling between wires and circuits	Mutual L'_s and leakage C'_s	Shielding the circuits
Else?		

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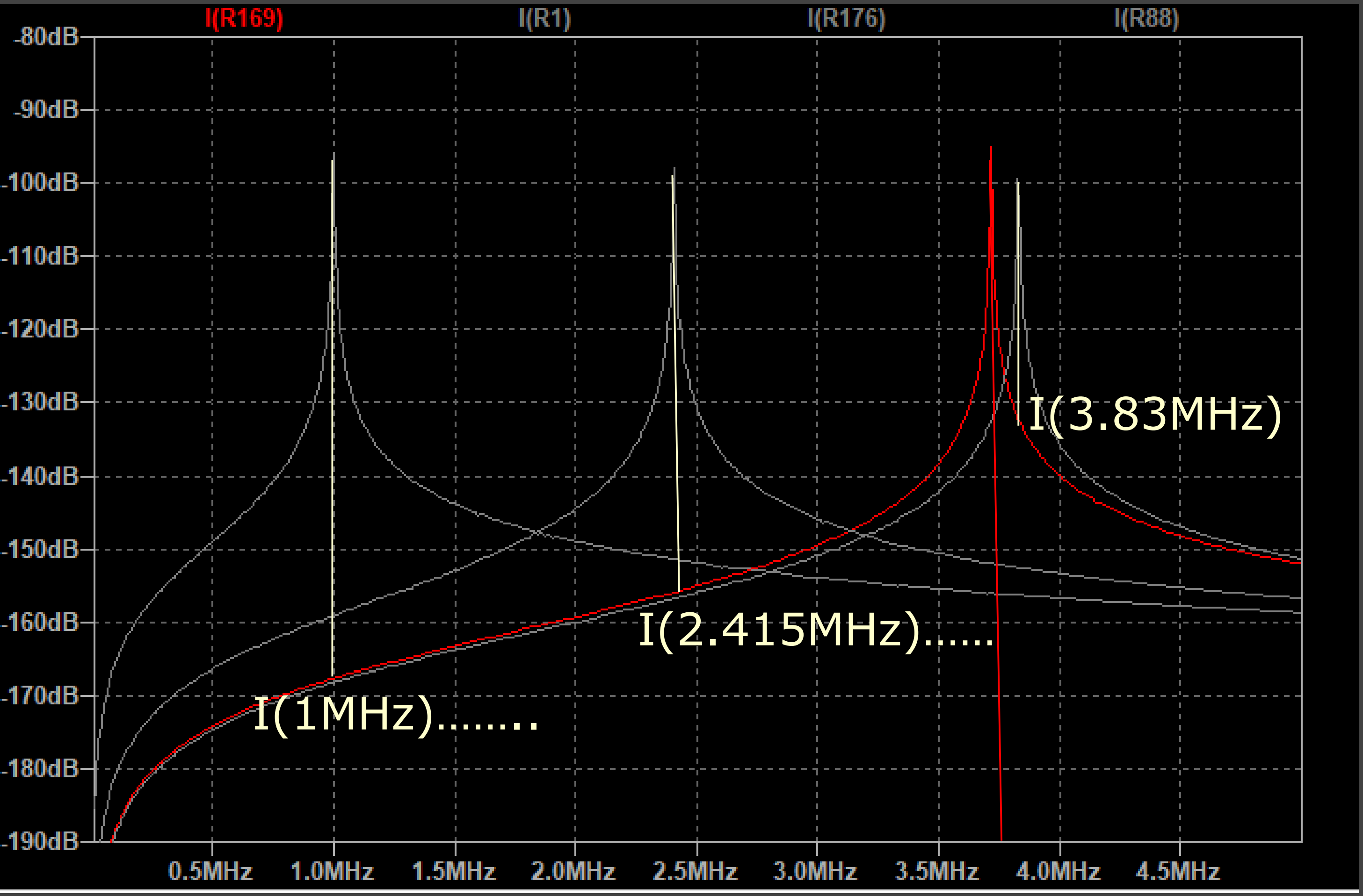
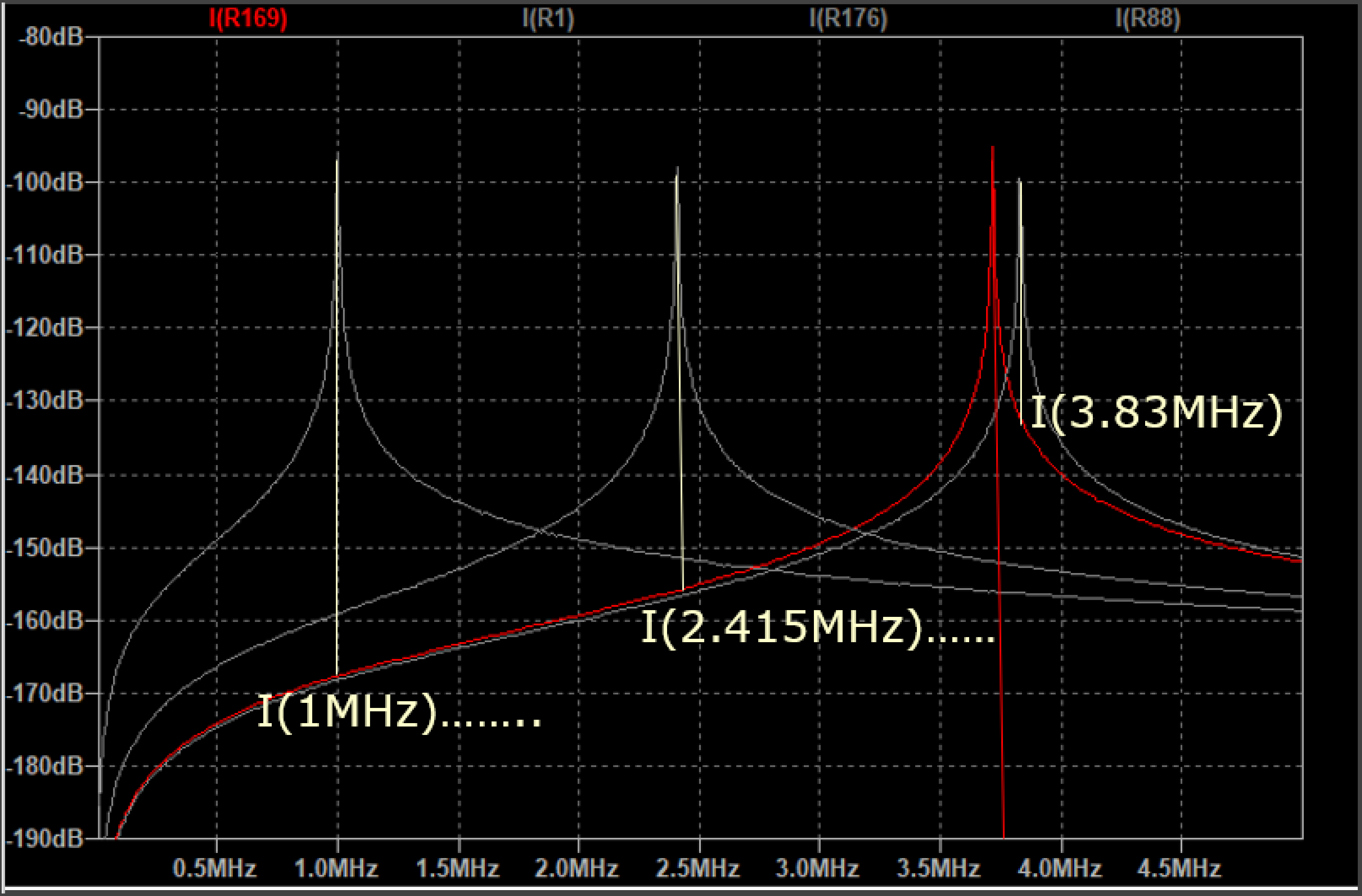
Leakage Currents I(f1,f2,....,f176)



$$I_{\text{rms-leakage}} = \sqrt{(\Sigma(I_n)^2)}$$

Career Leakage CT@TES$_{_169}$= 11.92%

To be seen at TES$_{_169}$


I(R169)
I(R1)
I(R176)
I(R88)
-80dB
-90dB
-100dB
-110dB
-120dB
-130dB
-140dB
-150dB
-160dB
-170dB
-180dB
-190dB
0.5MHz
1.0MHz
1.5MHz
2.0MHz
2.5MHz
3.0MHz
3.5MHz
4.0MHz
4.5MHz
I(3.83MHz)
I(2.415MHz)......
I(1MHz)........

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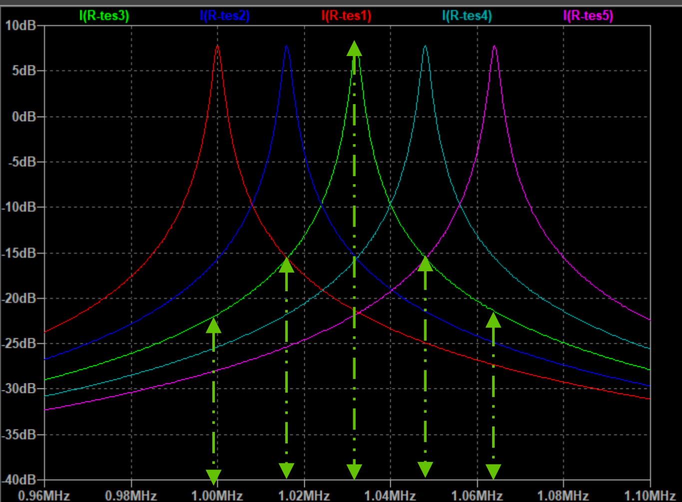
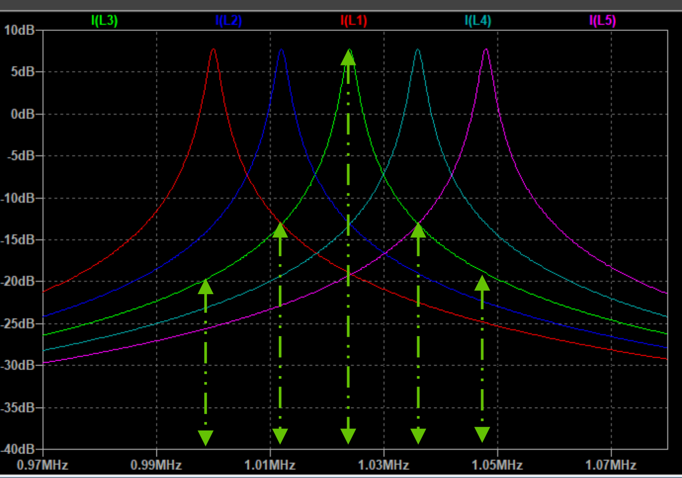
Career Leakage at a fixed TES – Nearby Channels:



- 5 LCs
- L's 3uH
- $R_{\_TES}$ 40mOhm
- 1-1.064 MHz
- 16kHz spacing
- Total current leakage/$I_{\_TES}$

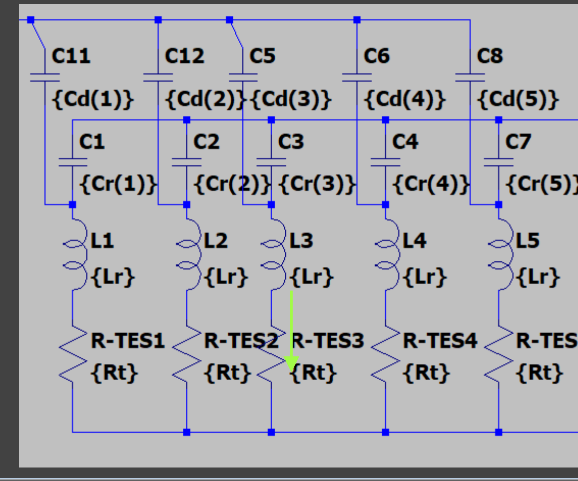
10.7 %

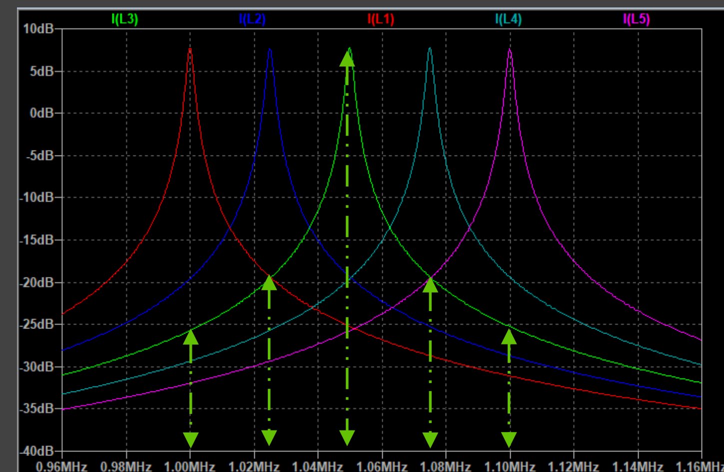


- Same RLC's
- 1-1.048 MHz
- 12kHz spacing

Total current leakage/$I_{\_TES}$

14.3%





- Same RLC's
- 25kHz spacing
- 1-1.10 MHz
- Total current leakage/$I_{\_TES}$

%6.9

Total current leakage/$I_{\_TES}$ changes linearly by inverse of frequency spacing

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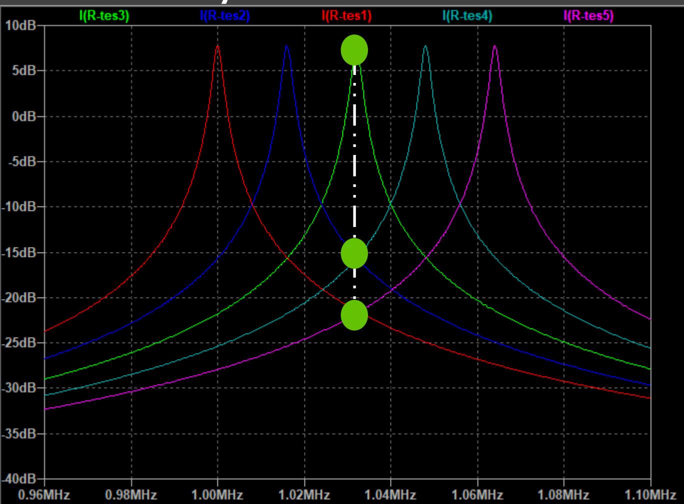
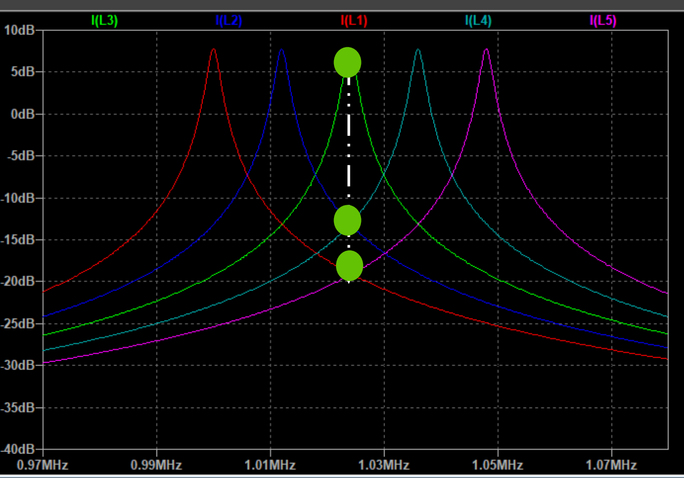
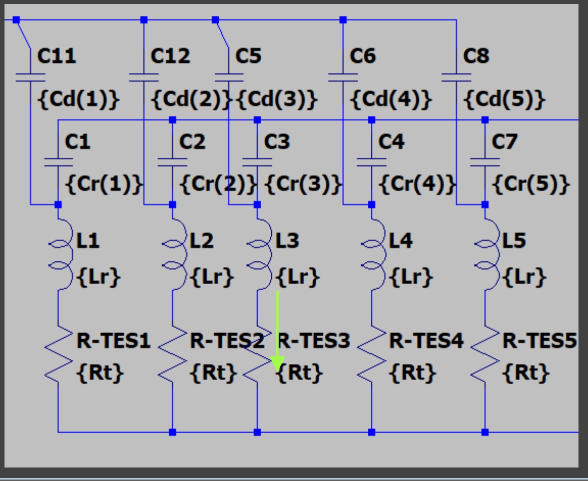
Career Leakage at a fixed resonance frequency – nearby channels:

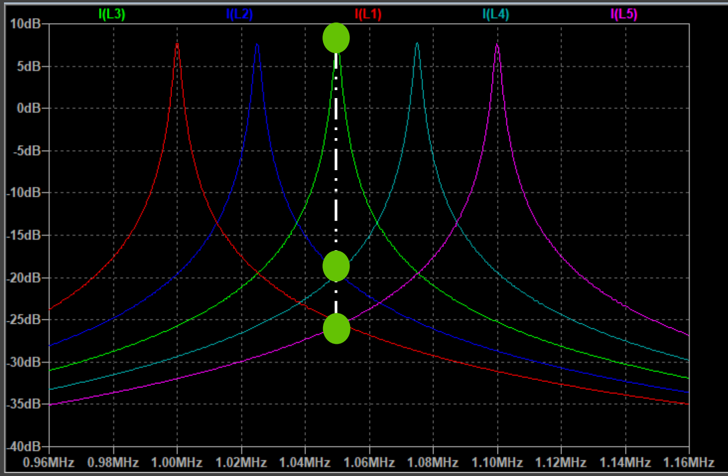


- 5 LCs
- L's 3uH
- R_{TES} 40mOhm
- 1-1.064 MHz
- 16kHz spacing
- 22dB above 1st nearby channels
- 29dB above 2nd nearby channels
- Total current leakage/I_{TES} 1.15%



- Same RLC's
- 1-1.048 MHz
- 12kHz spacing
- 20dB above 1st nearby channels
- 26 dB above 2nd nearby channels
- Total current leakage/I_{TES} 2.05%





- 1-1.10 MHz, Same RLC's
- 25kHz spacing
- 27dB above 1st nearby channels
- 33dB above 2nd nearby channels
- Total current leakage/I_{TES} 0.51 %

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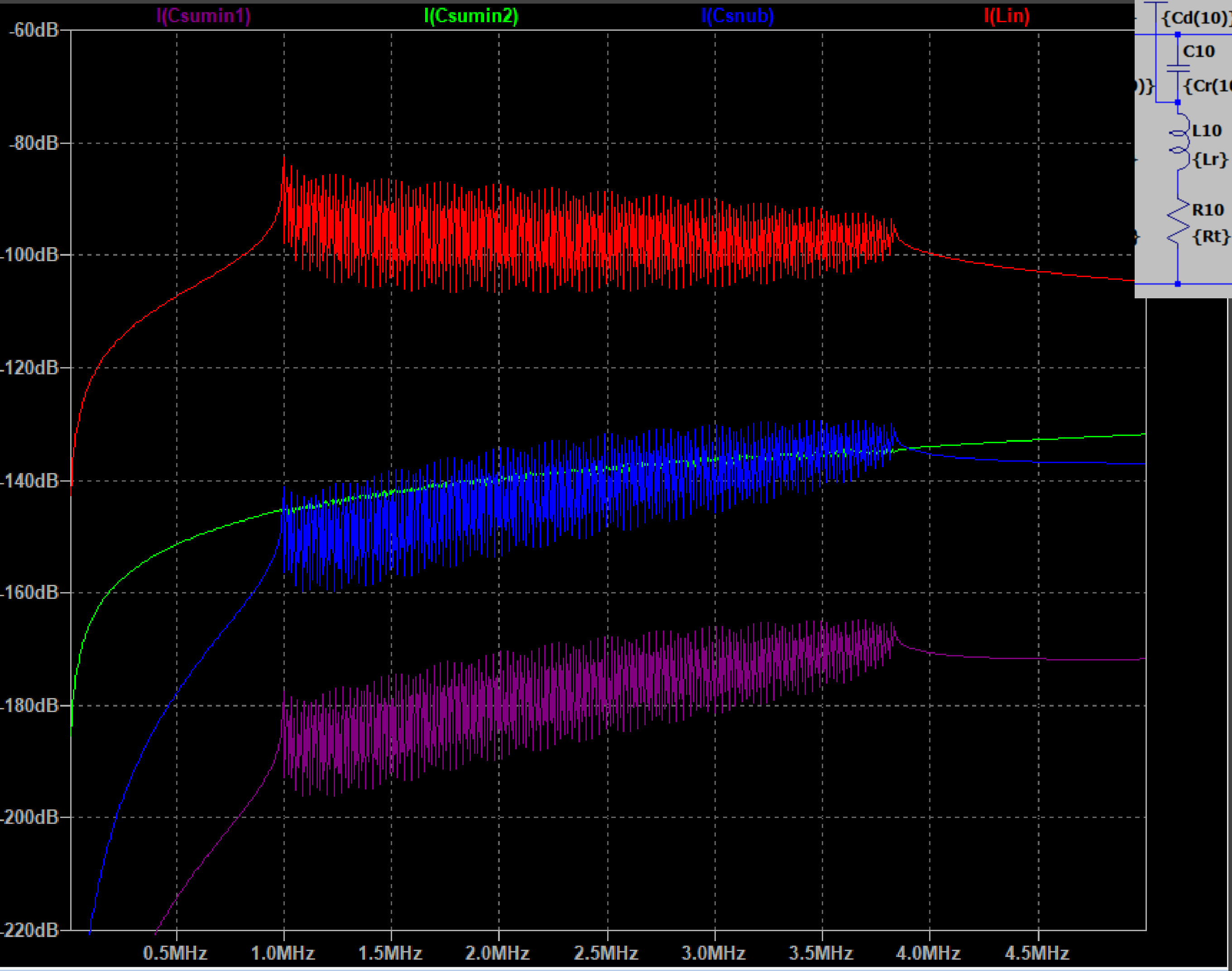
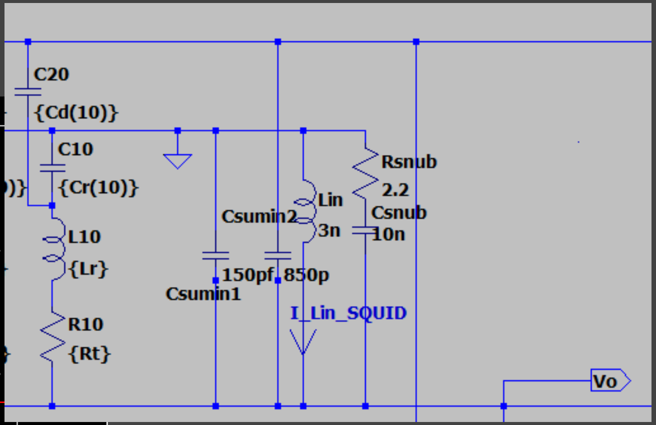
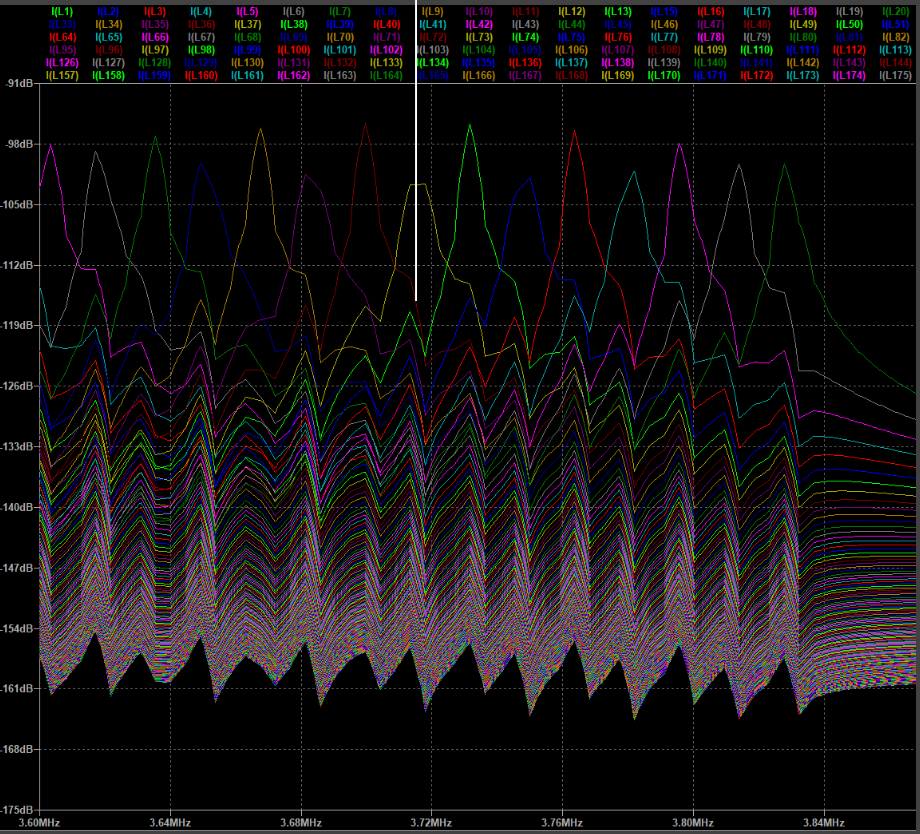
Current Levels at the input of SQUID (176LC's)





- Analysis @ 3.716 MHz, IL_169



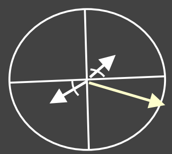
TES Currents(Amp) of Ch.169 and 2 nearby channels

I(L170):mag: 1.2153e-006 phase: 20.6459°

I(L169):mag: 1.53425e-005 phase: -29.3549°

I(L168):mag: 1.34702e-006 phase: -151.64°

Leakage currents in this channel are around 20deg and -150deg. (diagram is not to the scale)

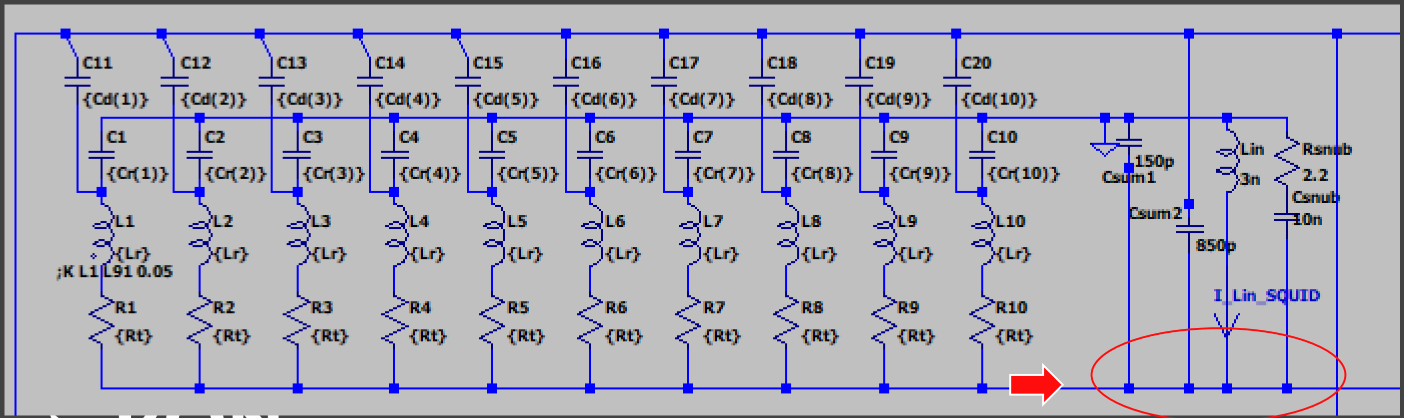


I(L169):

1.53e-005 amp∠ -29.3°

Total leakage currents of other channels at 3.716MHz:

4.79e-06 amp ∠ -152.40 °

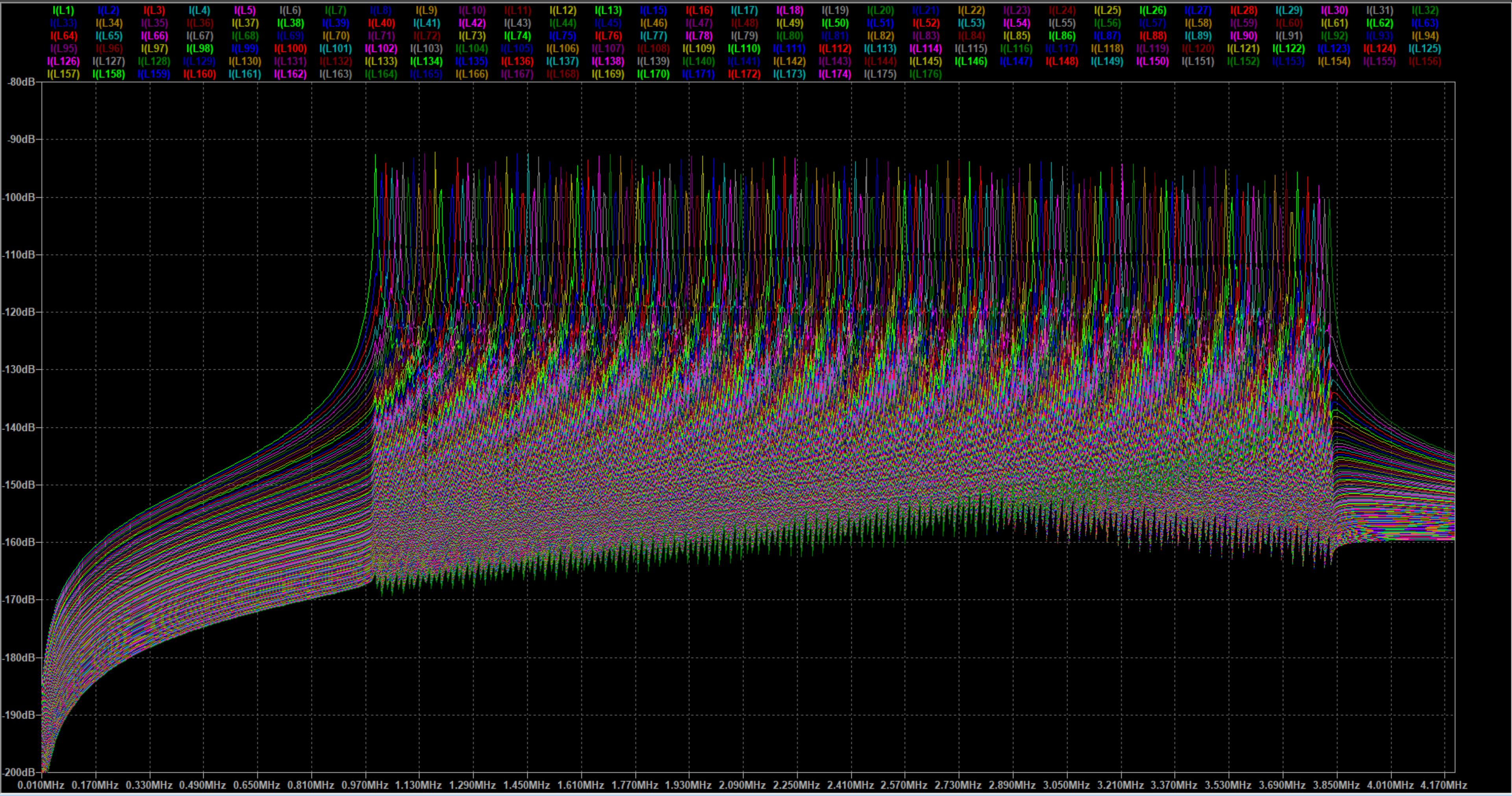


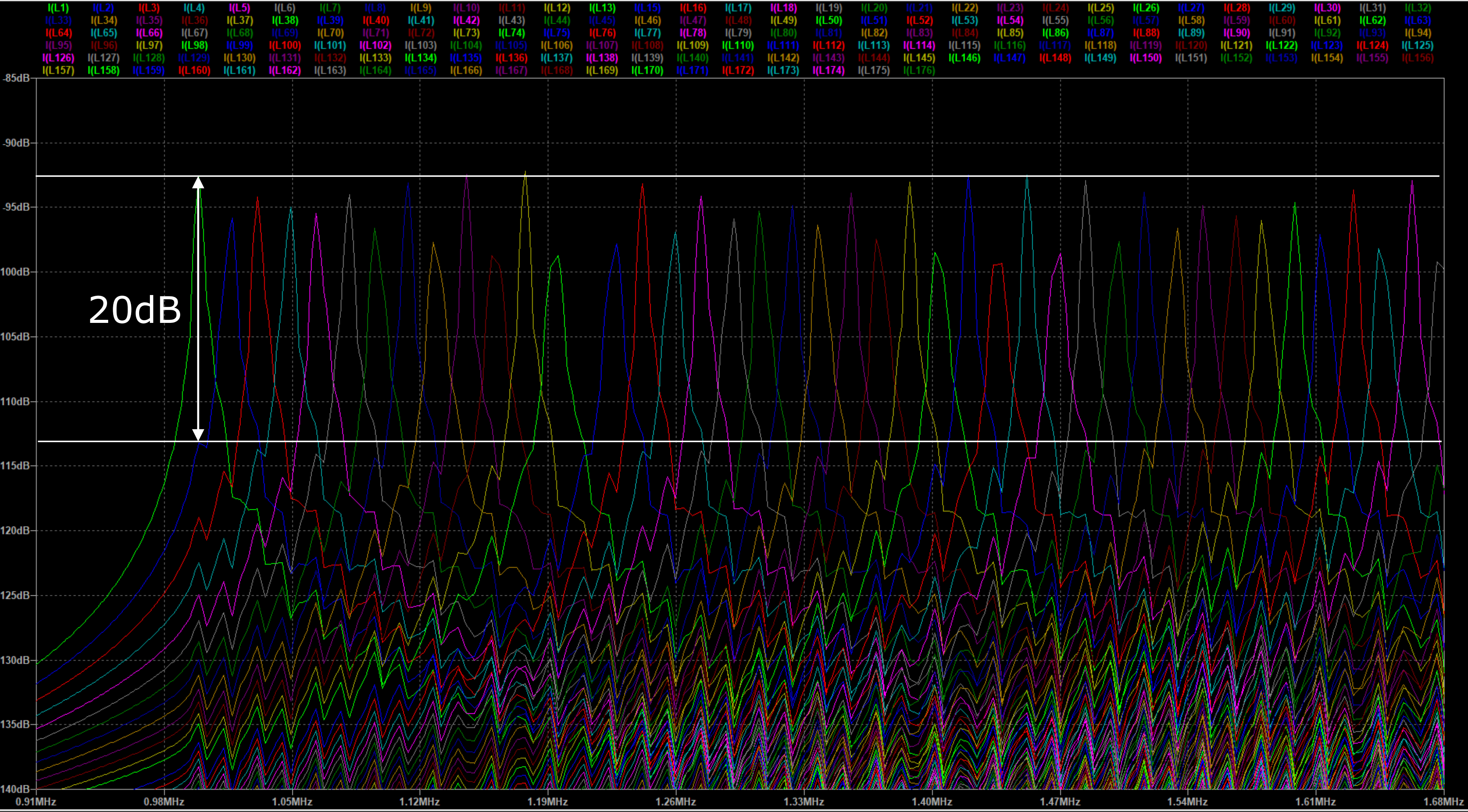
CrossTalk_leakage current@16kHz~31%

To be seen at the summing point

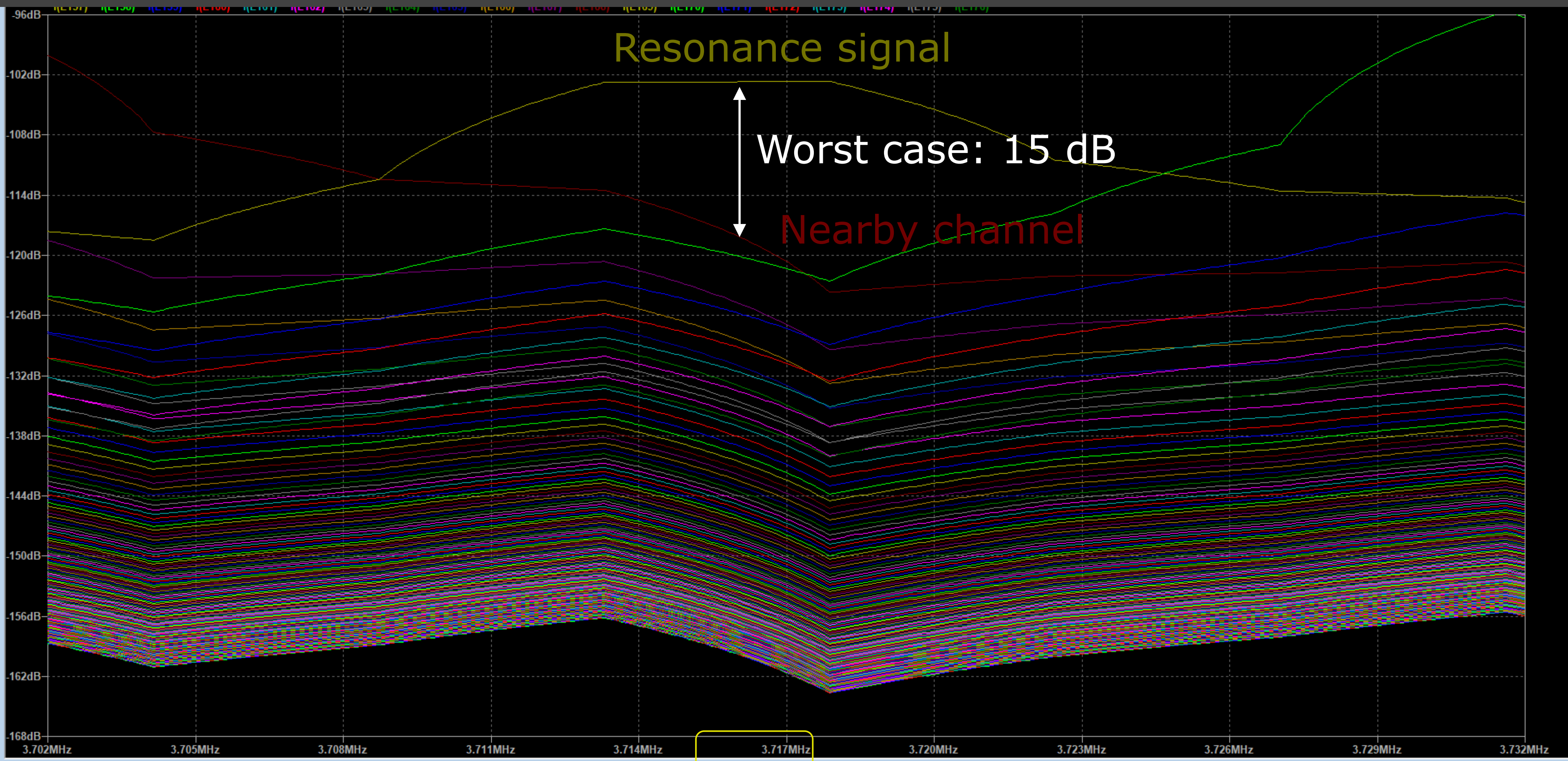
- R_{bias}
  - 5k+5k
- Input loom
- Snubber
- 176 LCs
- L's 3u
- Lin 3n
- 1-3.83 MHz
- R_{TES} 40mOhm
- 16kHz spacing

- Current leakage of 176 channels
- 16 kHz Spacing




I(L1) I(L2) I(L3) I(L4) I(L5) I(L6) I(L7) I(L8) I(L9) I(L10) I(L11) I(L12) I(L13) I(L14) I(L15) I(L16) I(L17) I(L18) I(L19) I(L20) I(L21) I(L22) I(L23) I(L24) I(L25) I(L26) I(L27) I(L28) I(L29) I(L30) I(L31) I(L32)
I(L33) I(L34) I(L35) I(L36) I(L37) I(L38) I(L39) I(L40) I(L41) I(L42) I(L43) I(L44) I(L45) I(L46) I(L47) I(L48) I(L49) I(L50) I(L51) I(L52) I(L53) I(L54) I(L55) I(L56) I(L57) I(L58) I(L59) I(L60) I(L61) I(L62) I(L63)
I(L64) I(L65) I(L66) I(L67) I(L68) I(L69) I(L70) I(L71) I(L72) I(L73) I(L74) I(L75) I(L76) I(L77) I(L78) I(L79) I(L80) I(L81) I(L82) I(L83) I(L84) I(L85) I(L86) I(L87) I(L88) I(L89) I(L90) I(L91) I(L92) I(L93) I(L94)
I(L95) I(L96) I(L97) I(L98) I(L99) I(L100) I(L101) I(L102) I(L103) I(L104) I(L105) I(L106) I(L107) I(L108) I(L109) I(L110) I(L111) I(L112) I(L113) I(L114) I(L115) I(L116) I(L117) I(L118) I(L119) I(L120) I(L121) I(L122) I(L123) I(L124) I(L125)
I(L126) I(L127) I(L128) I(L129) I(L130) I(L131) I(L132) I(L133) I(L134) I(L135) I(L136) I(L137) I(L138) I(L139) I(L140) I(L141) I(L142) I(L143) I(L144) I(L145) I(L146) I(L147) I(L148) I(L149) I(L150) I(L151) I(L152) I(L153) I(L154) I(L155) I(L156)
I(L157) I(L158) I(L159) I(L160) I(L161) I(L162) I(L163) I(L164) I(L165) I(L166) I(L167) I(L168) I(L169) I(L170) I(L171) I(L172) I(L173) I(L174) I(L175) I(L176)
-85dB
-90dB
-95dB
100dB
105dB
110dB
115dB
120dB
125dB
130dB
135dB
140dB
20dB
0.91MHz 0.98MHz 1.05MHz 1.12MHz 1.19MHz 1.26MHz 1.33MHz 1.40MHz 1.47MHz 1.54MHz 1.61MHz 1.68MHz

- Currents are calculated at the peak of resonance
- Resonance current is at least 15dB above the leakage currents for all pixels
- Result is shown for 3.716 MHz, IL_$_{169}$



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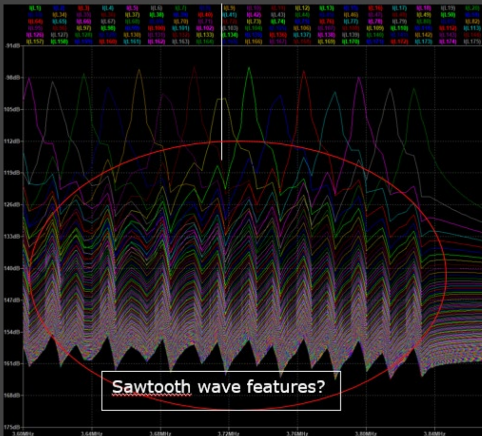
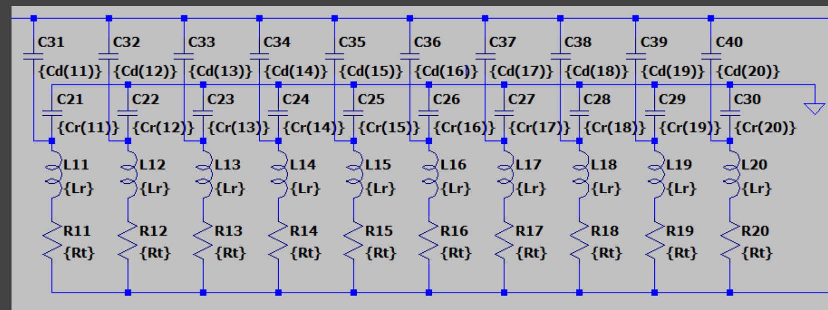
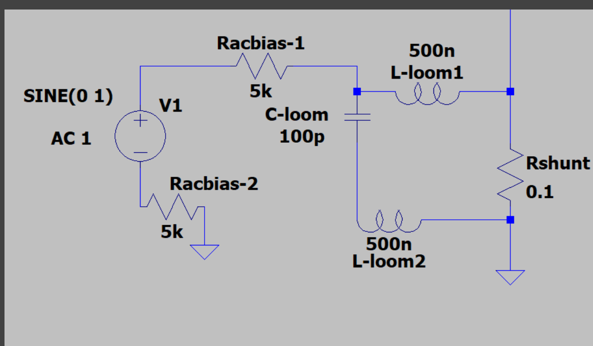
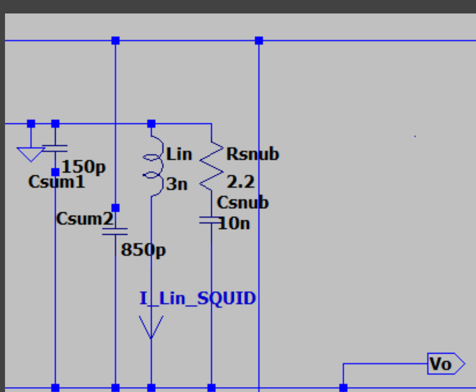
Investigating
on the sawtooth wave features in the carrier leakage









- LC Resonators
- Series and shunt resistors (current, voltage divider)
- Input looms (Out of band resonance)
- C_Summing points (Out of band resonance)
- RC filter circuit (Snubber)

(damping out of band reoance)

- Input Inductance*
- R-TES *

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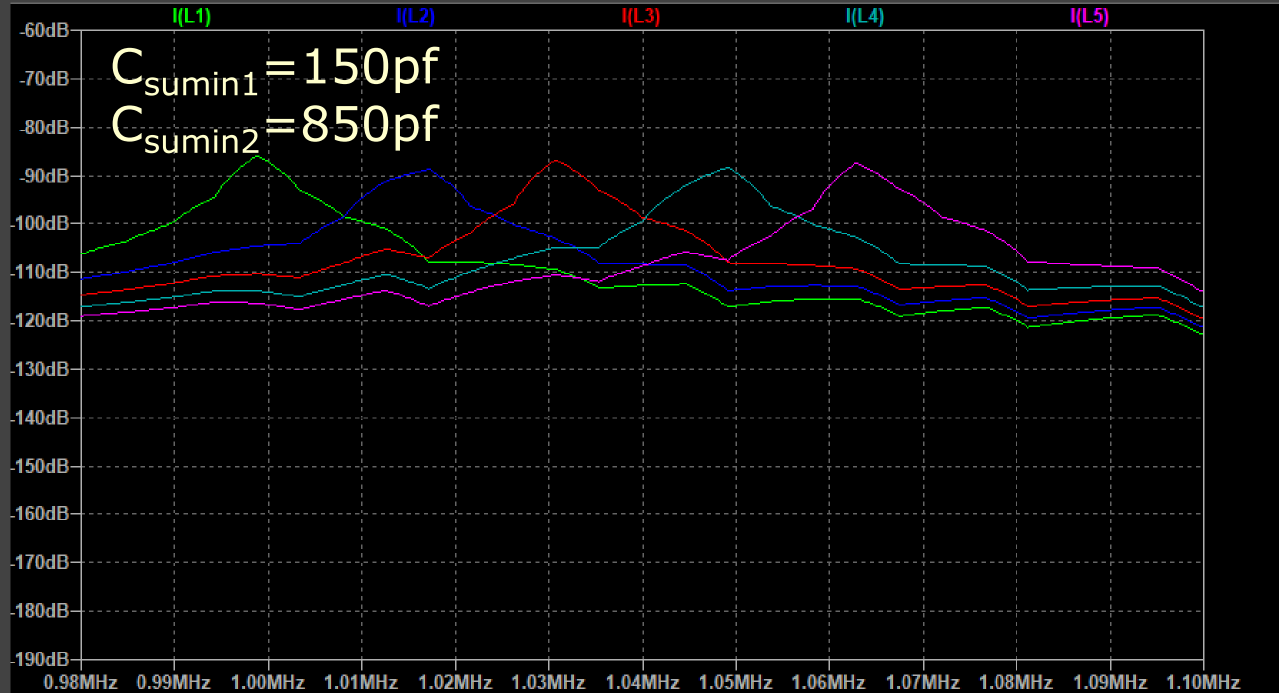
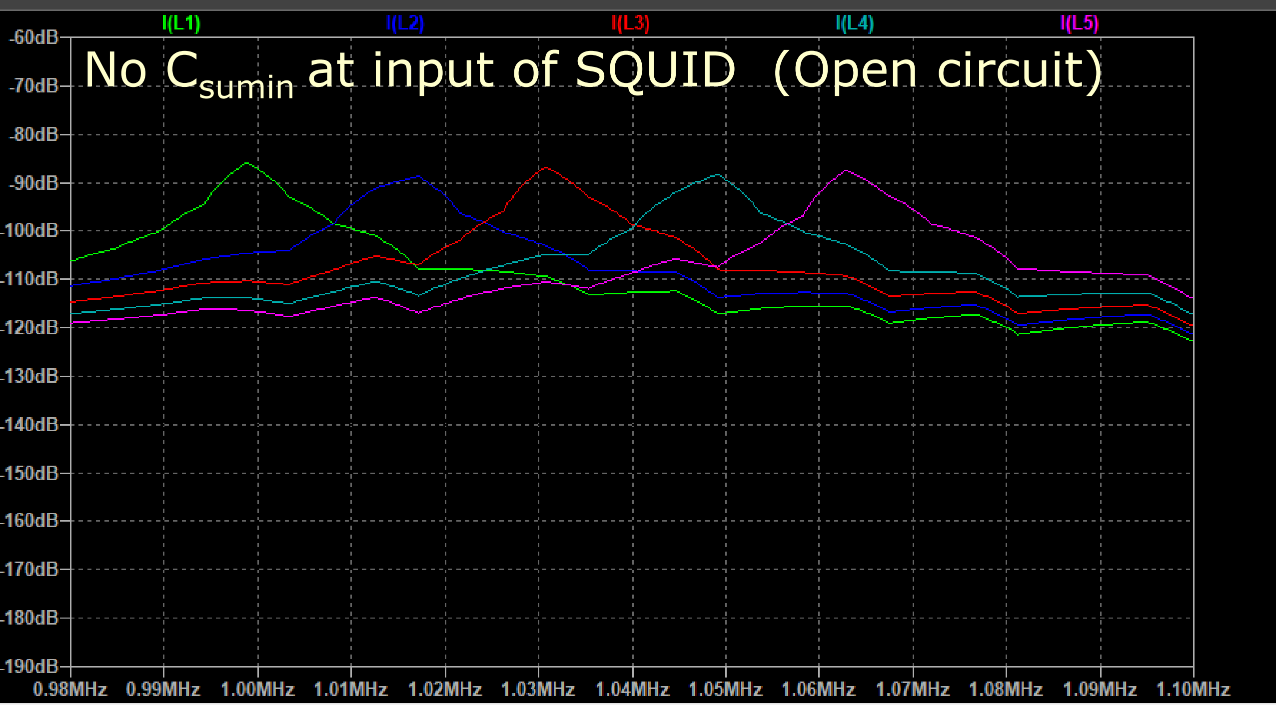
$C_{sumin1,2}$

- The Resonance curves are not affected by Summing point C_s



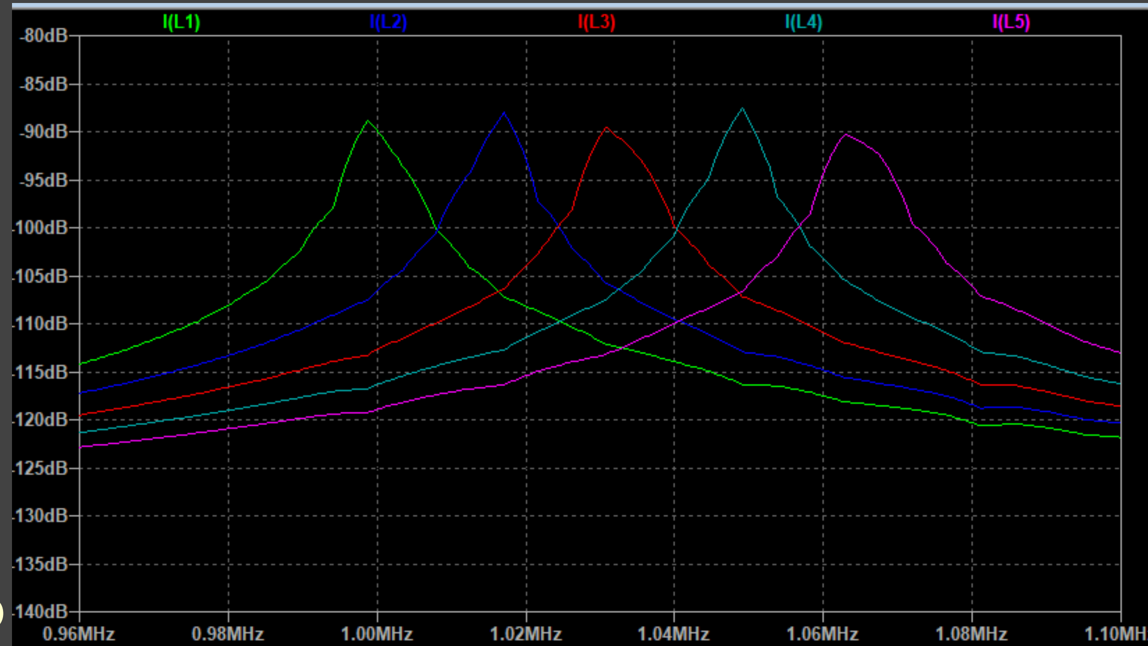


- The Res. frequency shift is not observed either.

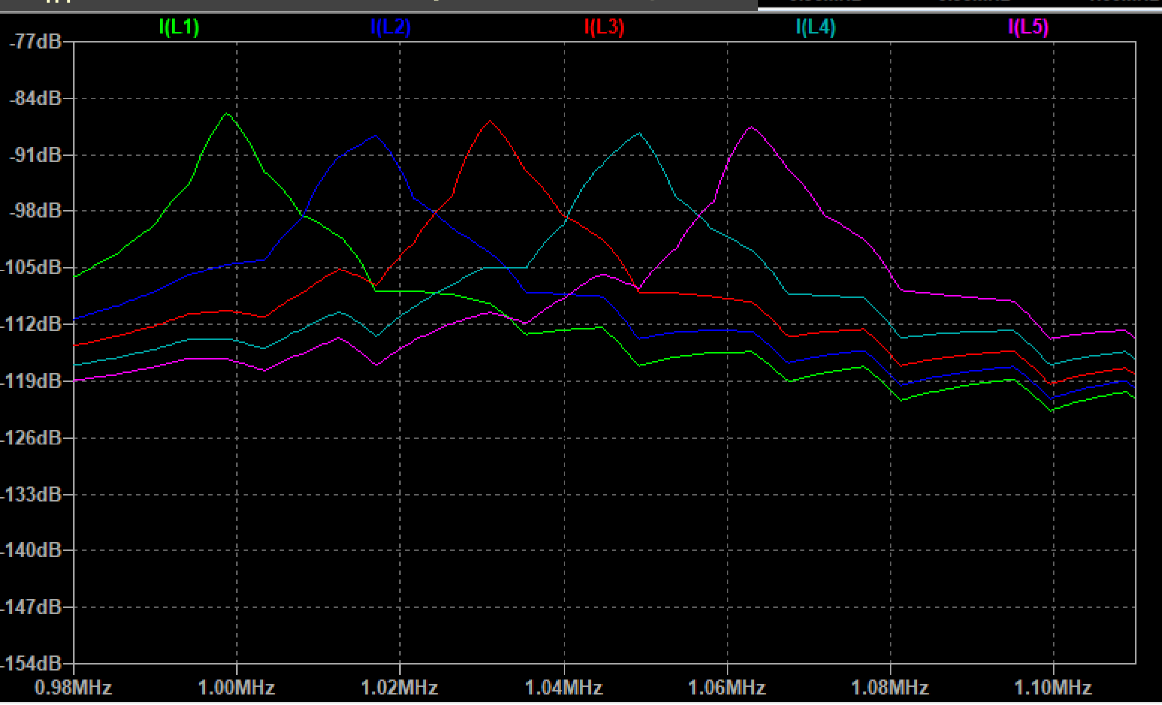
L_{in}

- L_{in} seems to be the cause of the sawtooth feature
- The Res. frequency shift is negligible

- No L_{in} at input of SQUID (Short circuit)



L_{in}=3nH at the input of SQUID



Sawtooth Feature, Rt

- Rt nominal value 40mOhm
- To see the extreme cases, Rt is set to 20mOhm-50mOhm
- By increasing R_t, the sawtooth feature in I_L (and Rt) decreases
- Codes: Resonators-176pix-CrossTalk-test-M (Simulation)

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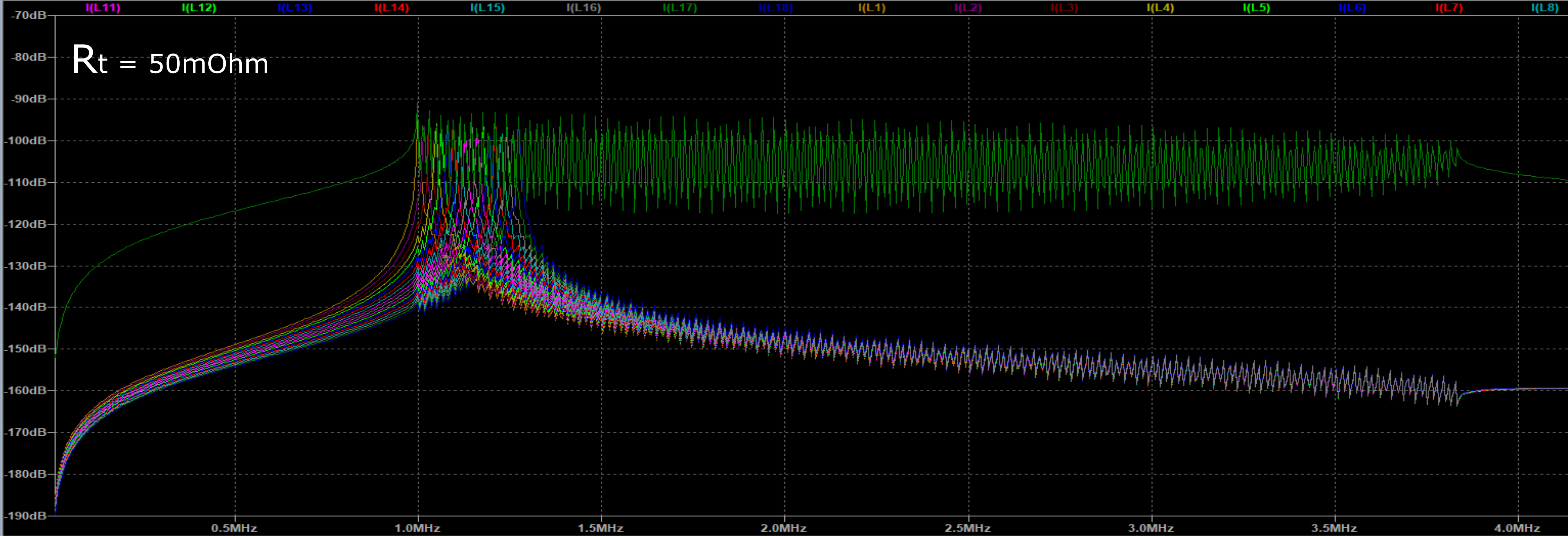
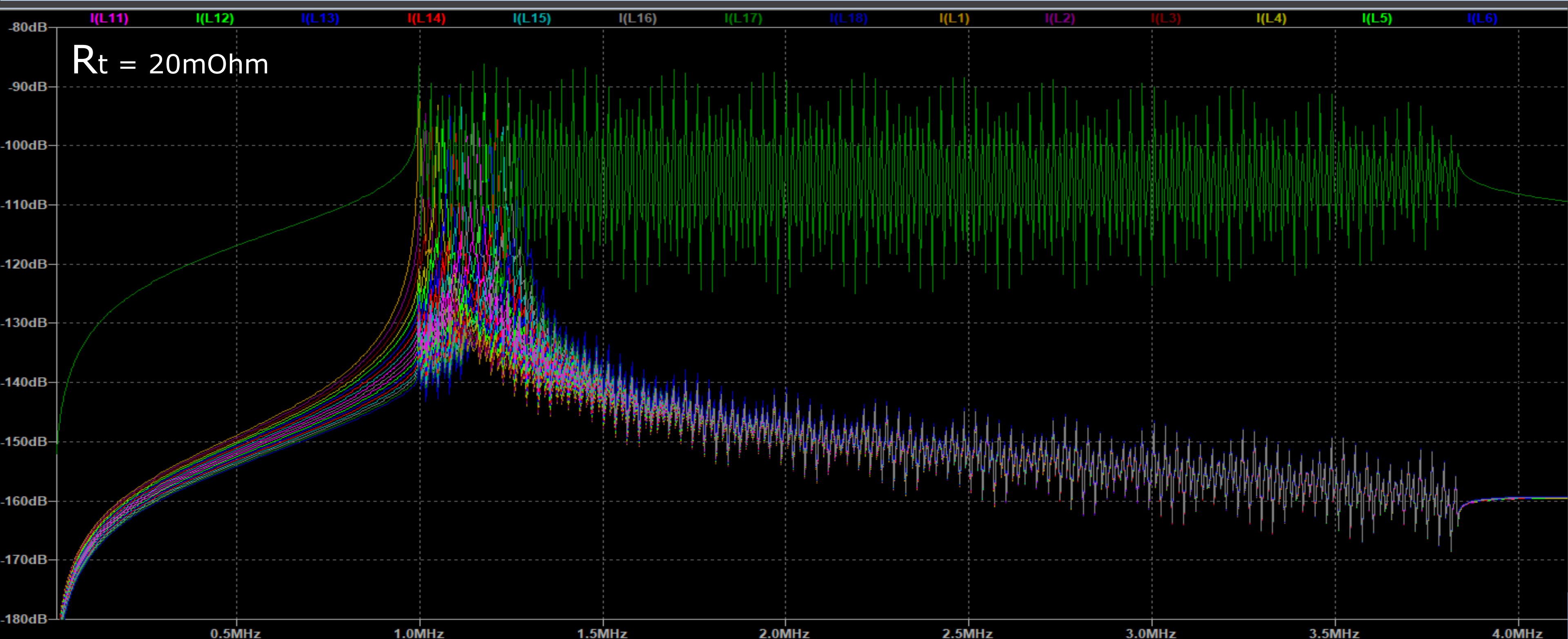

Rt = 50mOhm
I(L11) I(L12) I(L13) I(L14) I(L15) I(L16) I(L17) I(L18) I(L1) I(L2) I(L3) I(L4) I(L5) I(L6) I(L7) I(L8)
-70dB -80dB -90dB -100dB -110dB -120dB -130dB -140dB -150dB -160dB -170dB -180dB -190dB
0.5MHz 1.0MHz 1.5MHz 2.0MHz 2.5MHz 3.0MHz 3.5MHz 4.0MHz


Rt = 20mOhm
I(L11) I(L12) I(L13) I(L14) I(L15) I(L16) I(L17) I(L18) I(L1) I(L2) I(L3) I(L4) I(L5) I(L6)
-80dB -90dB -100dB -110dB -120dB -130dB -140dB -150dB -160dB -170dB -180dB
0.5MHz 1.0MHz 1.5MHz 2.0MHz 2.5MHz 3.0MHz 3.5MHz 4.0MHz

Summary-I:

1. The Sawtooth features in FDM are due to the input inductance ($Lin_{\_SQUID}$)

2- Career leakage at a fixed TES (LC169) is 11.9% which is consistent with lab measurement

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The SAFARI FDM Crosstalk

b) The impact of cryogenic looms

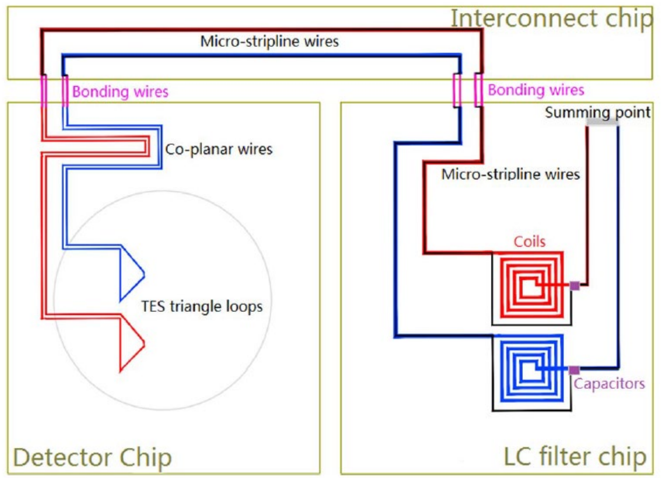


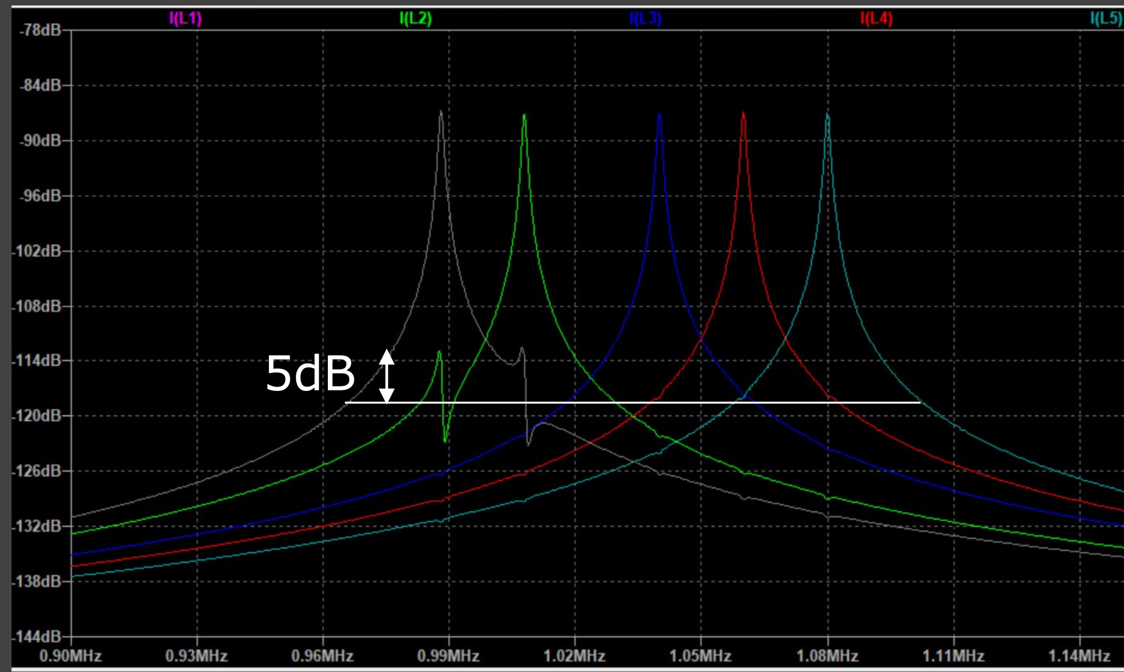
Fig. 4. Schematic layout of two neighbouring channels from SRON's 160 pixel FDM setup as shown in Fig. 1. Note it is out of scale for the illustration.

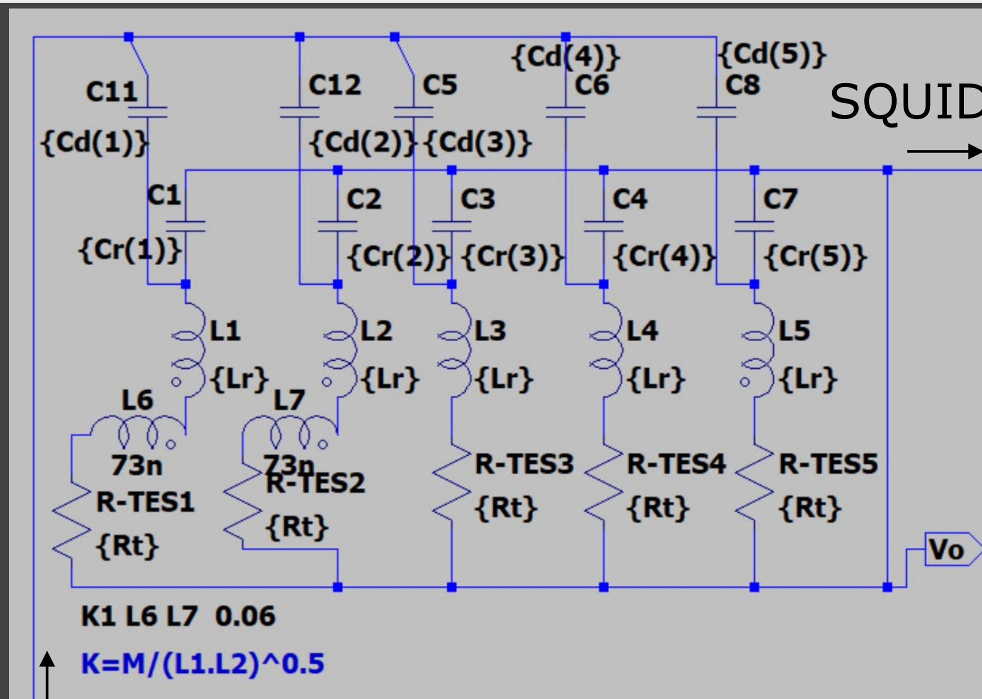
TABLE I
LIST OF SELF-INDUCTANCE OF THE WIRES FROM EACH SECTION, THEIR CONTRIBUTION IN %, AND THE TOTAL SELF-INDUCTANCE. THE DEFINITION OF EACH SECTION IS GIVEN BY FIG. 4

Sections	Self-inductance (nH)	Percentage
TES triangle loop	2.06	0.1%
Co-planar wires	29.94	1.5%
Bonding wires	4.48	0.2%
Coil inductors	1960.00	97.6%
Micro-striplines	12.03	0.6%
Total	2008.51	100 %

TABLE II
LIST OF MUTUAL INDUCTANCE OF THE WIRES FROM EACH SECTION, THEIR CONTRIBUTION IN %, AND THE TOTAL MUTUAL INDUCTANCE. THE DEFINITION OF EACH SECTION IS GIVEN BY FIG. 4

Sections	Mutual inductance (nH)	Percentage
TES triangle loop	0.01	0.4%
Co-planar wires	1.70	59.4%
Bonding wires	0.22	7.7%
Coil inductors	0.89	31.1%
Micro-striplines	0.04	1.4%
Total	2.86	100 %

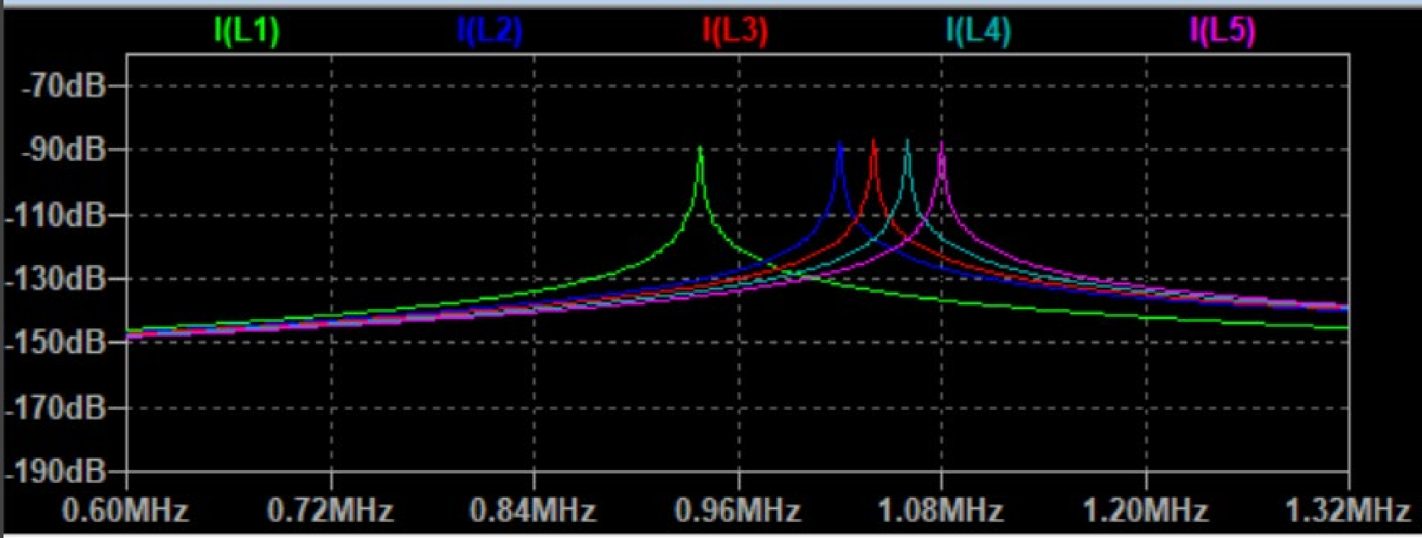




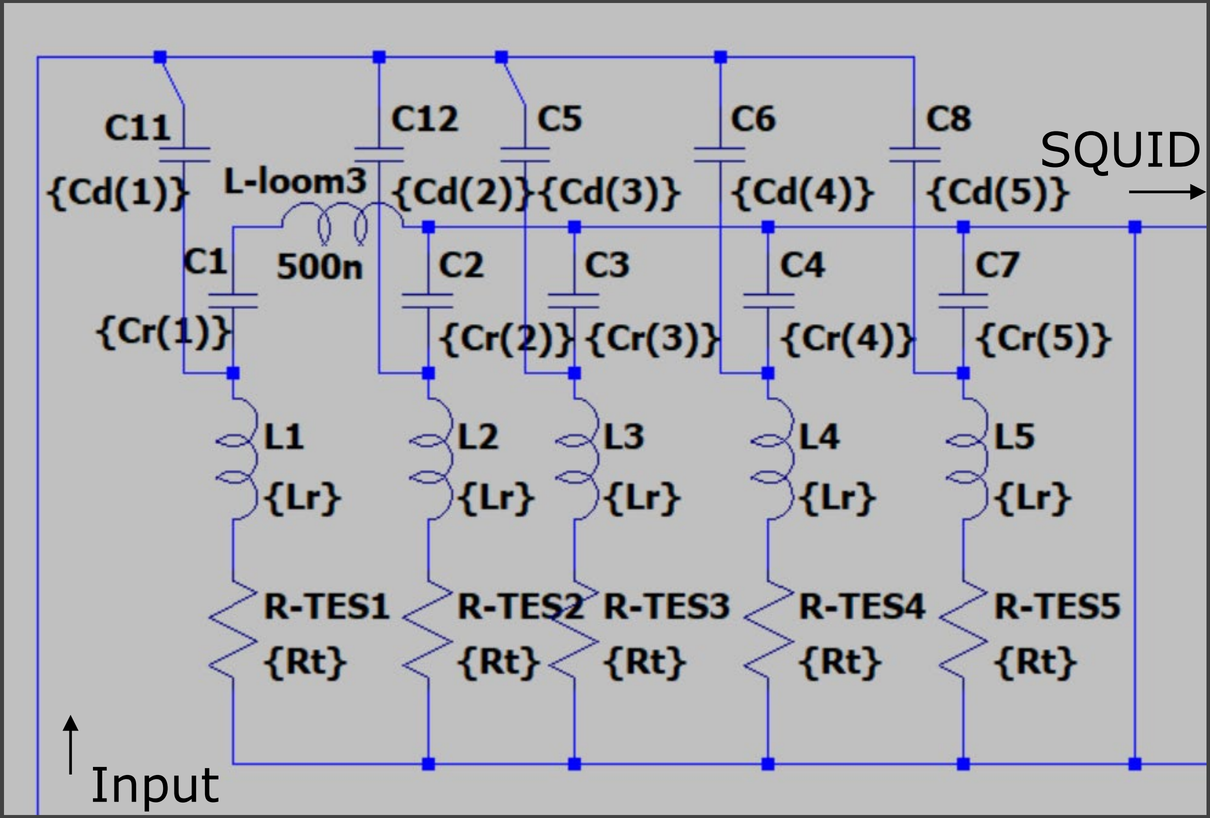
X Yan et al., 2015

Input

Connection between LC Filters



Any parasitic inductance between LC filters causes a change in frequency spacing



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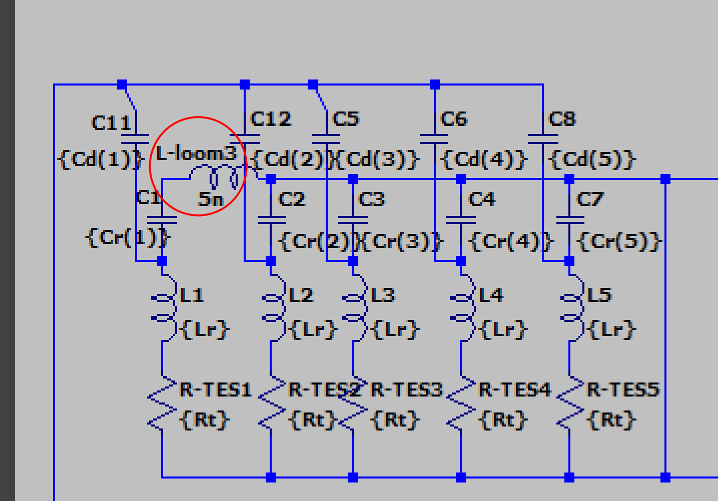
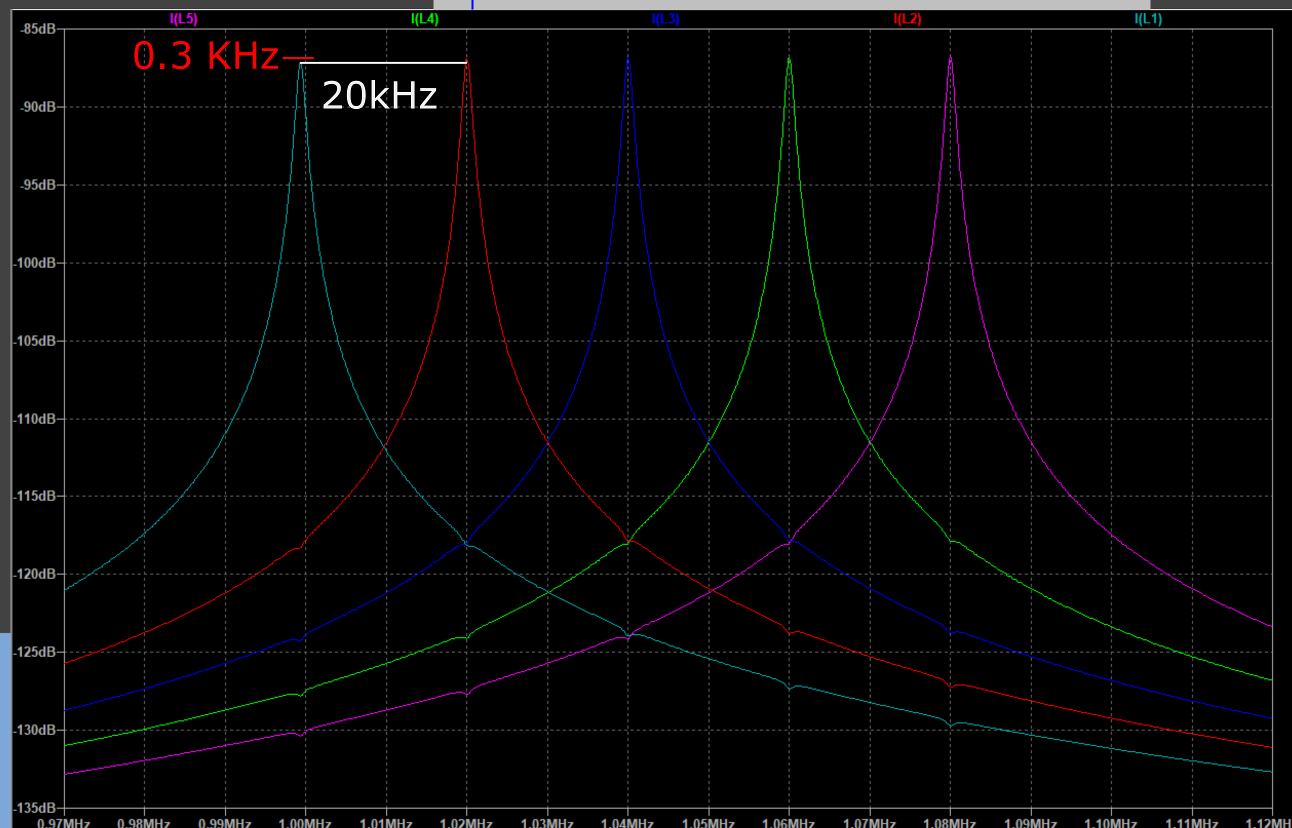
5nH Loom

0.3 KHz frequency shift

20kHz Frequency Spacing

0.3/20=1.5% frequency shift per 5nH





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Summary-II:

The impact of looms is modelled by mutual inductances and leakage capacitances.

1. In LC Filters it changes the frequency spacing

2. It worsen the cross talk by increasing the leakage current in order of 5 dB

References:

- Truong, T. K., Twisted-pair transmission line distributed parameters

- X. Yan et al., Modeling Inductances of Wiring for a TES Array Read by FDM, IEEE Transactions on Applied Superconductivity, Vol. 25, No. 3, 2015.

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