CCDTL module 2
low power RF measurements

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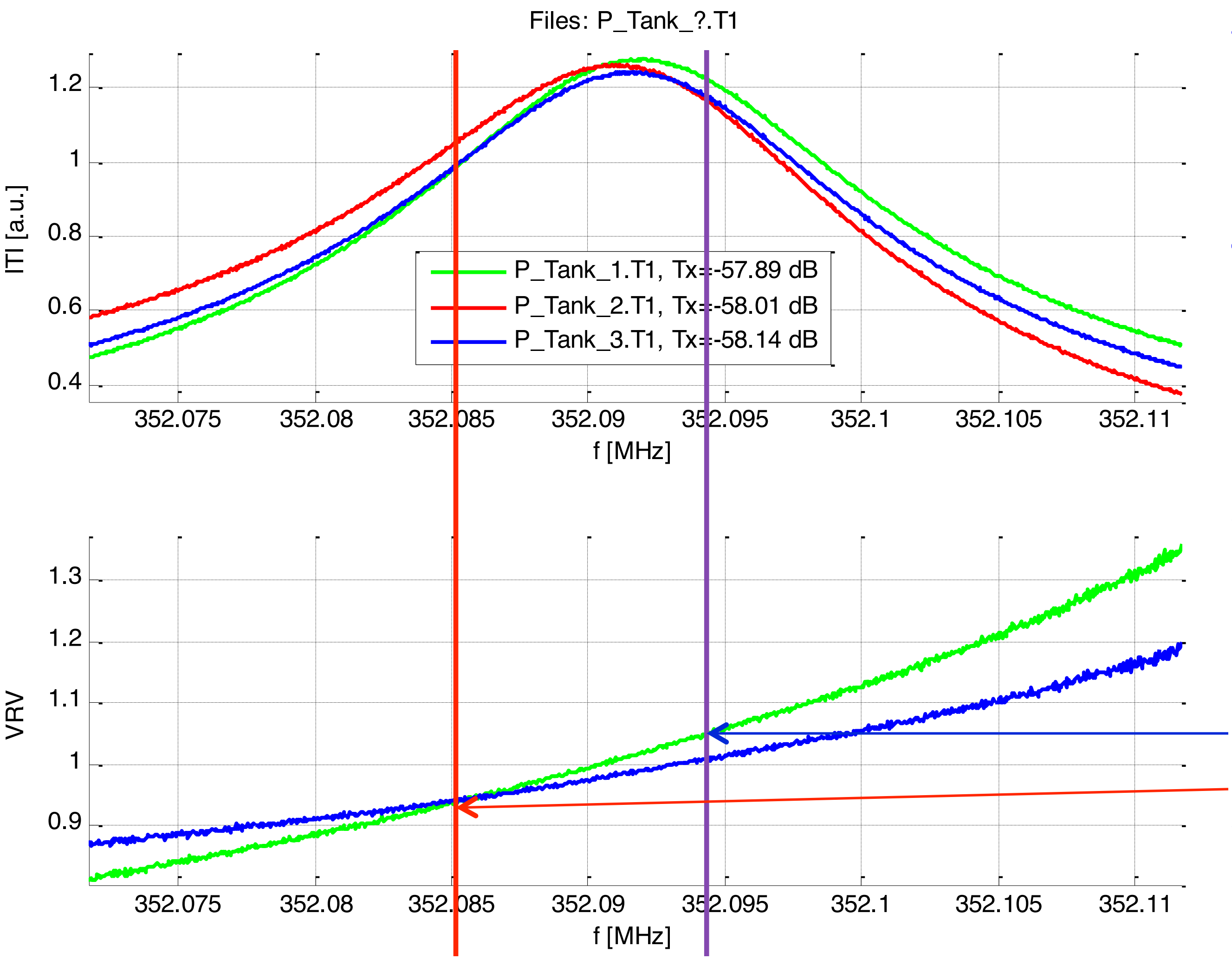
Motivation

- After observing **field distribution changes with frequency** in the order of several %/kHz during the high power test, low power measurements have been done to investigate the reason.
  * Can this effect be seen also in low power measurements, what is the **source of the effect**?
  * How **stable is the field distribution** over frequency?
  * How much is the field distribution **disturbed** when a **tuner in tank 2** (central tank) changes the frequency of the operational pi/2 mode by ~80 kHz (ΔT ~ 10K) ?
  * How does the **cavity-to-waveguide coupling** influence the field distribution (operation @ β~1.3 & 1.0 without & with beam)

Transmission WG => Pickups, air

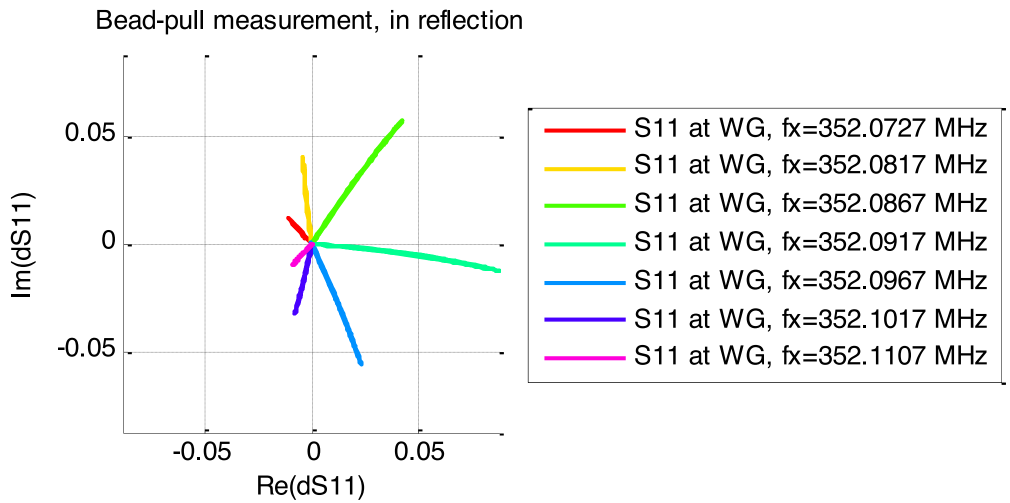


T=22.2°C,
pressure 954 hPa,
humidity 46%

Transmission WG to pickups has clear frequency dependence
=> **reason** for power readings during high power test @ different frequencies

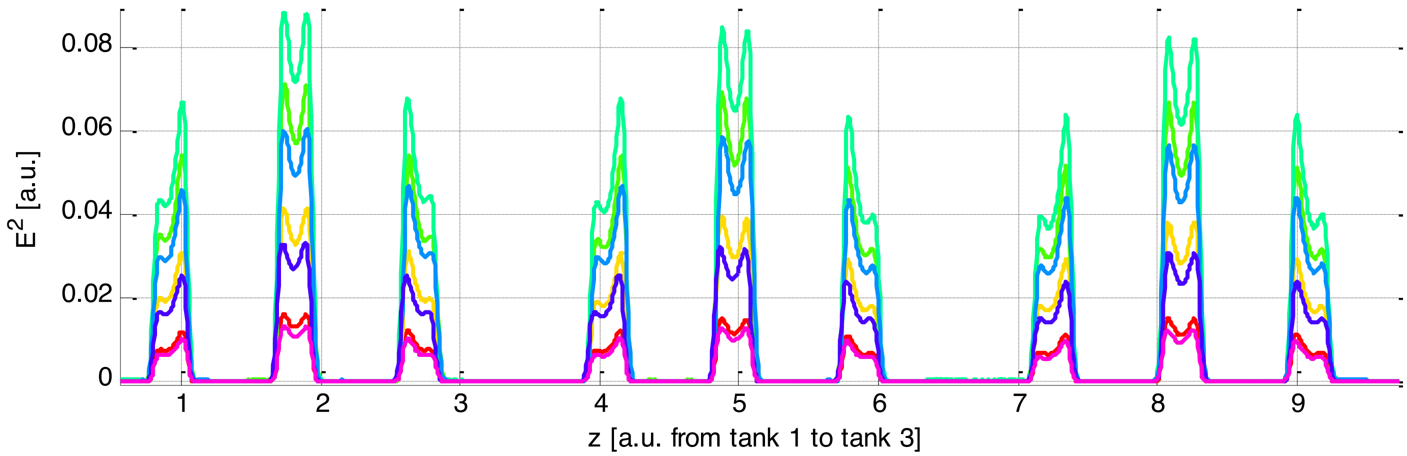
example:
purple: P(T2 & T3) ~ 90% P(T1)
red: P(T1 & T3) ~ 90% P(T2)
for a frequency change of <10 kHz

Beadpull at different frequencies

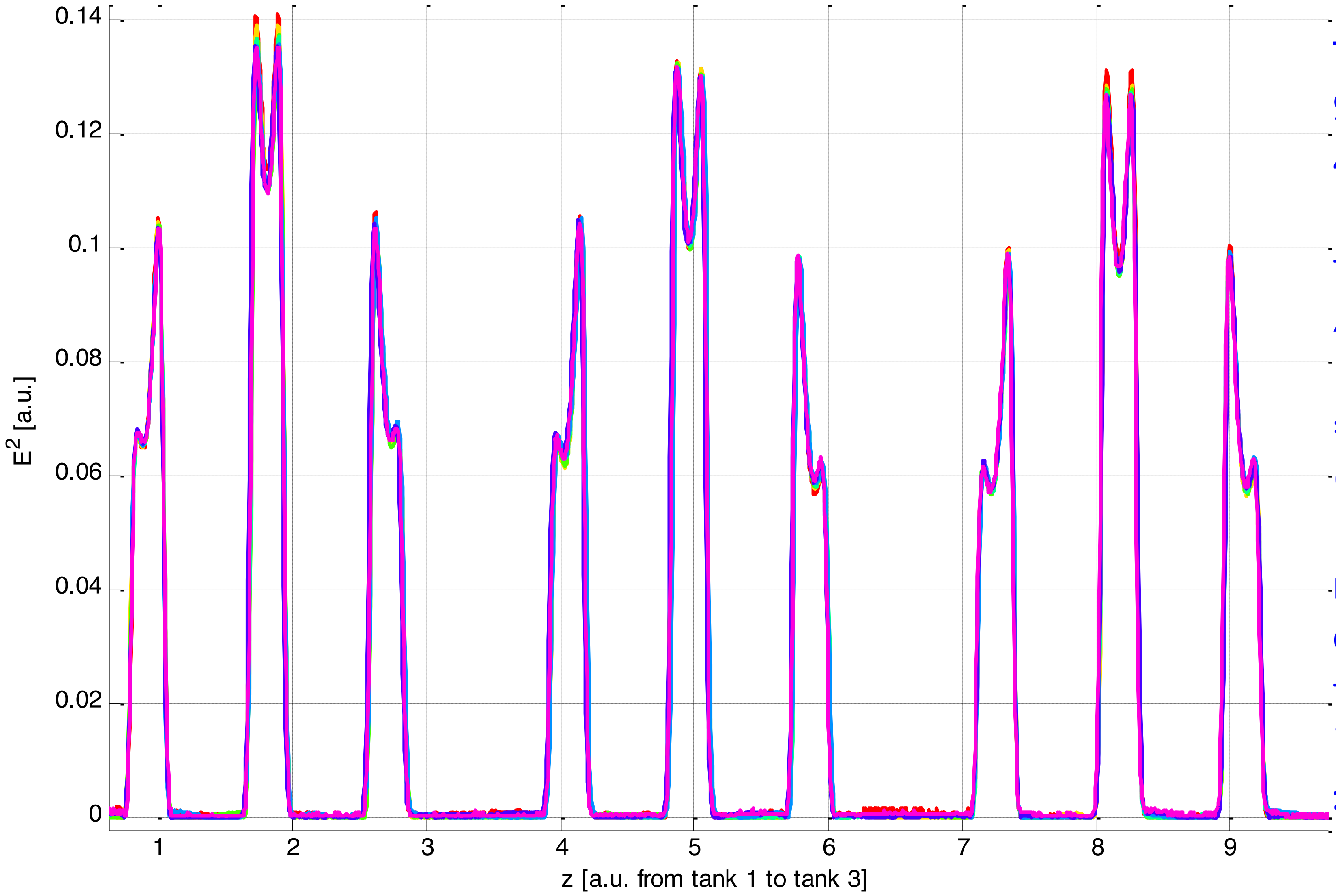


T=22.2°C, pressure 954 hPa, humidity 46%

$f_{\pi/2}$=352.0917 MHz
Δf= ±0, 5, 10, 19 kHz



Beadpull at different frequencies



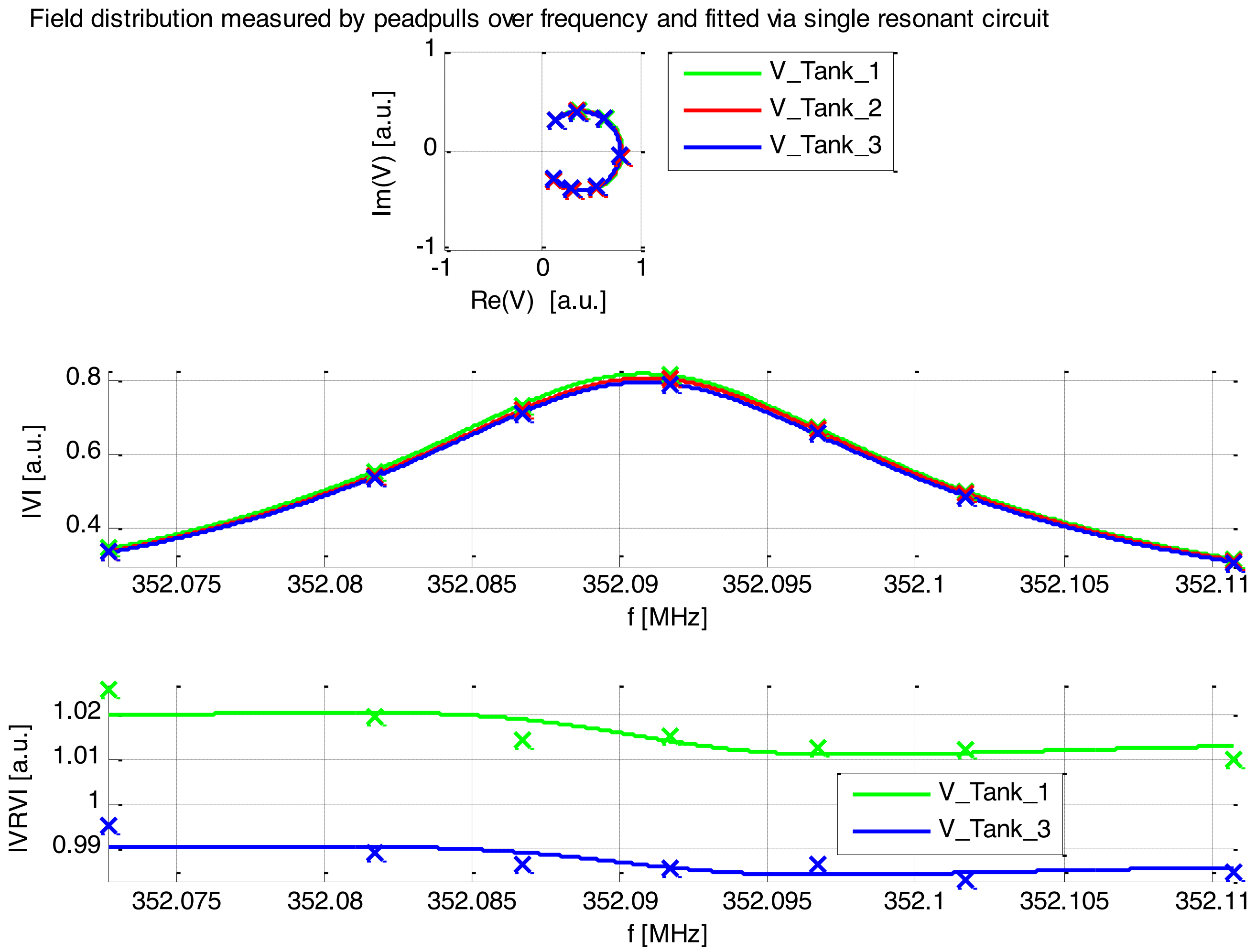
T=22.2°C, pressure 954 hPa, humidity 46%

$f_{\pi/2}$=352.0917 MHz
Δf= ±0, 5, 10, 19 kHz

=> normalised fields (for comparison)

nearly identical field distribution for all frequency variations in the range of **±20 kHz**

Beadpull at different frequencies

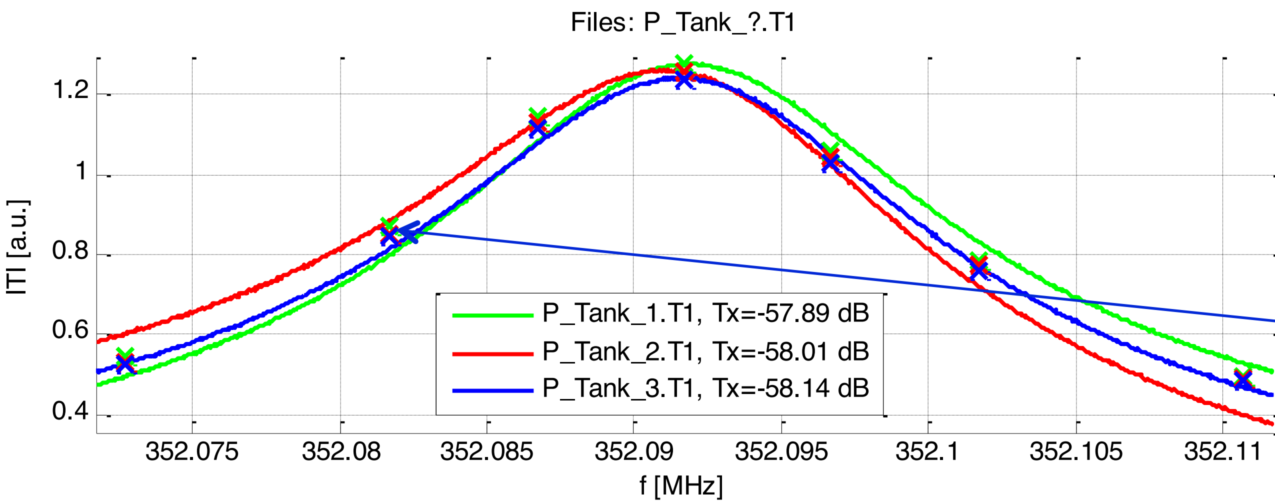


$f_{\pi/2}$=352.0917 MHz
Δf= ±0, 5, 10, 19 kHz

fields in the 3 tanks determined by beadpull measurements

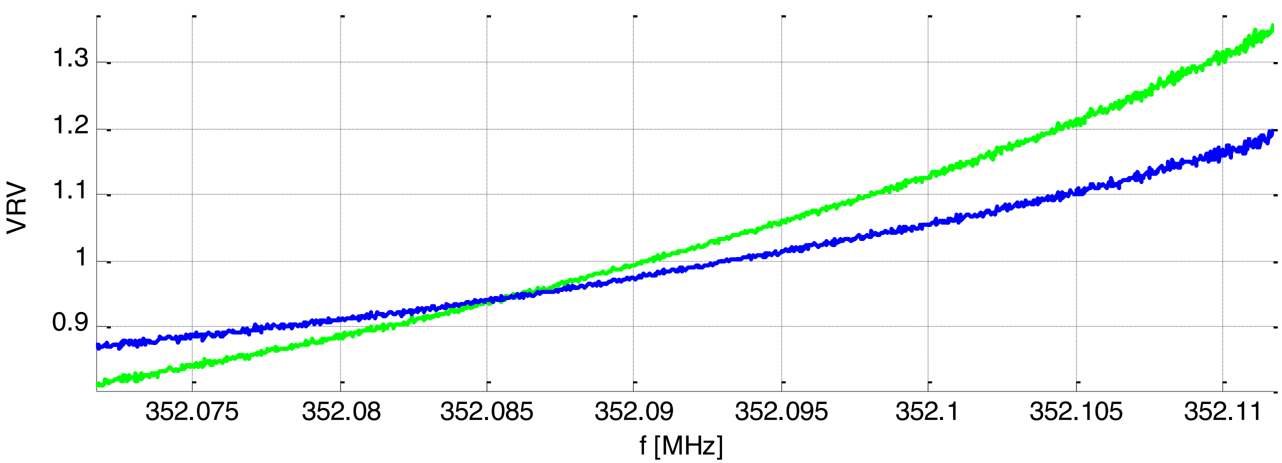
nearly identical field distribution over frequency in the range of ±20 kHz [change <2% for 40 kHz]

Transmi. WG => Pickups & Beadpulls



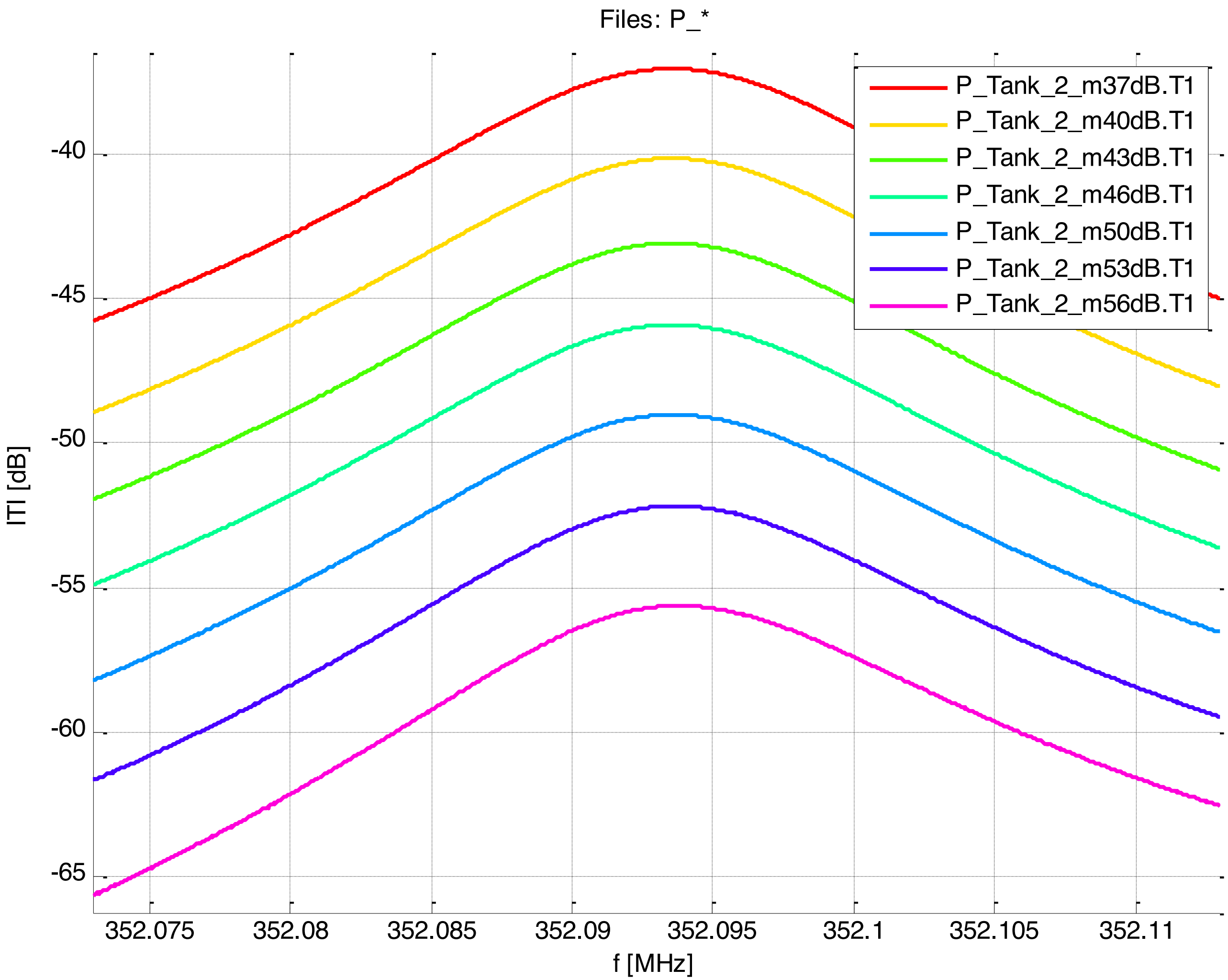
T=22.2°C, pressure 954 hPa, humidity 46%

Beadpull measurements



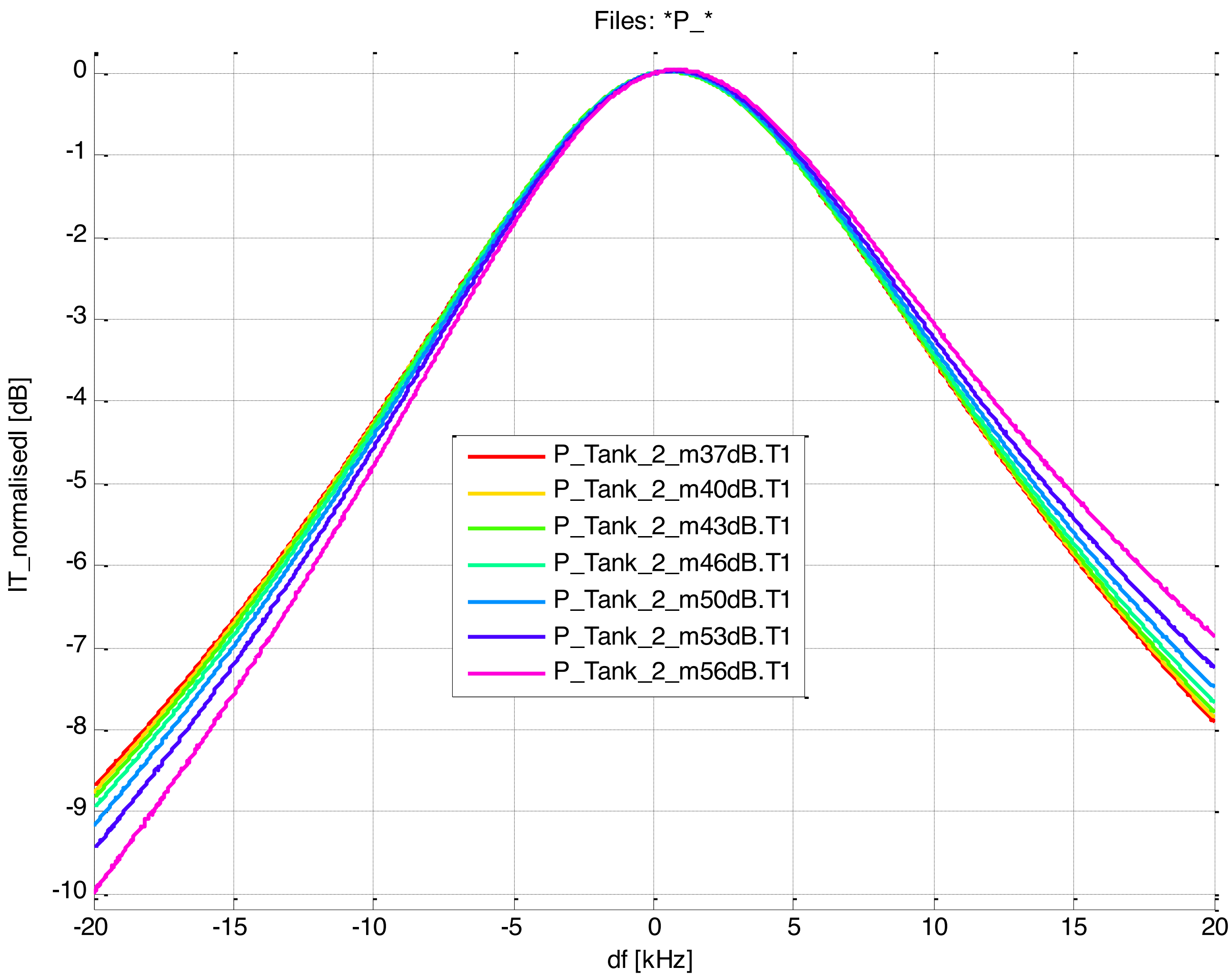
Pickups do not follow field distribution with frequency
=> do they have a frequency dependent transfer function ????

Investigation of Pickups



measuring transmission from WG to pickup of tank 2, changing the coupling of the pickup

Investigation of Pickups

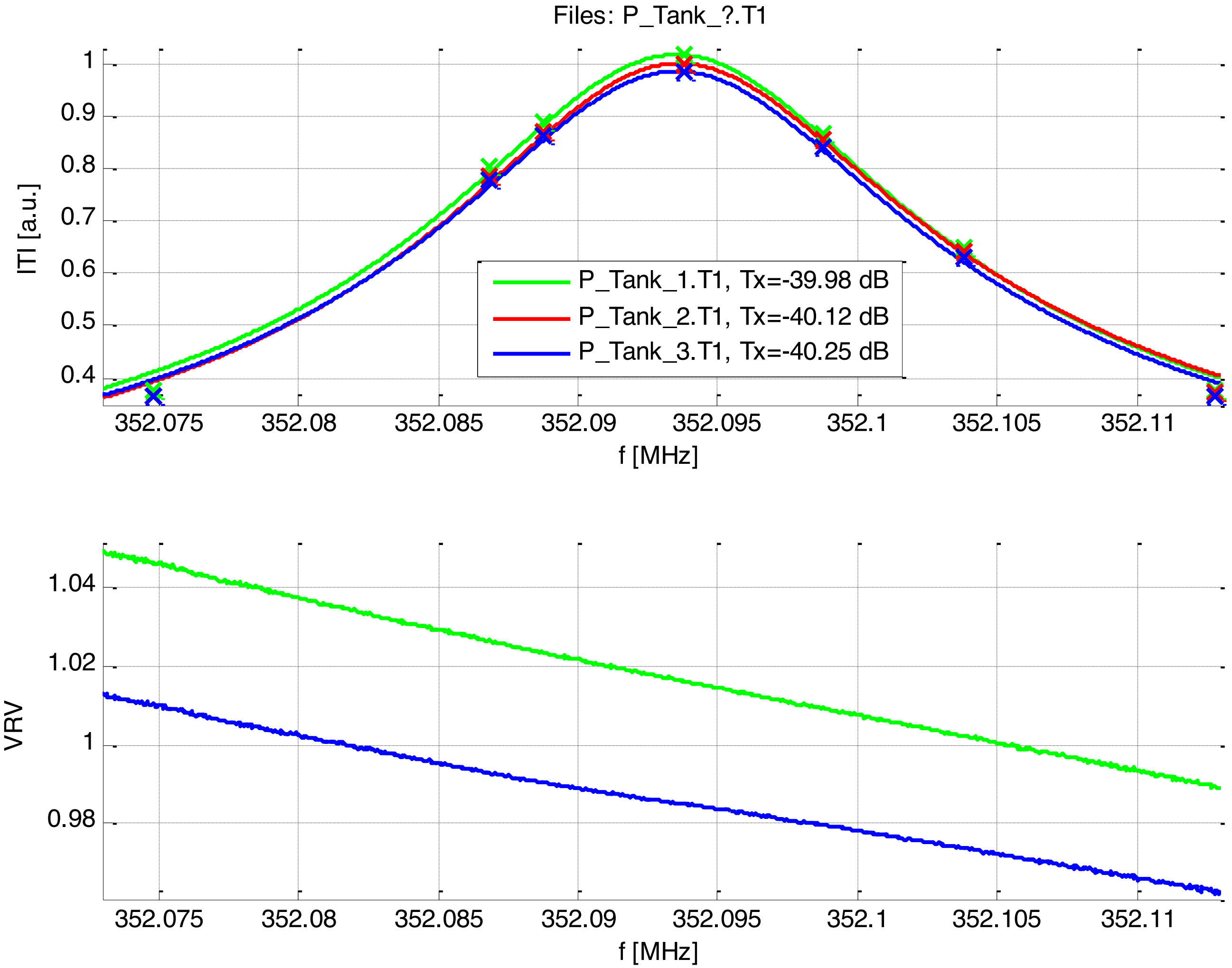


measuring transmission from WG to pickup of tank 2, changing the coupling of the pickup

=> the pickup system itself has a frequency dependent transfer function ! That's the source of our trouble

A quick & dirty solution is to couple stronger to reduce the frequency dependence, a better solution is to reduce the parasitic, frequency dependent coupling

Transmi. WG => Pickups & Beadpulls



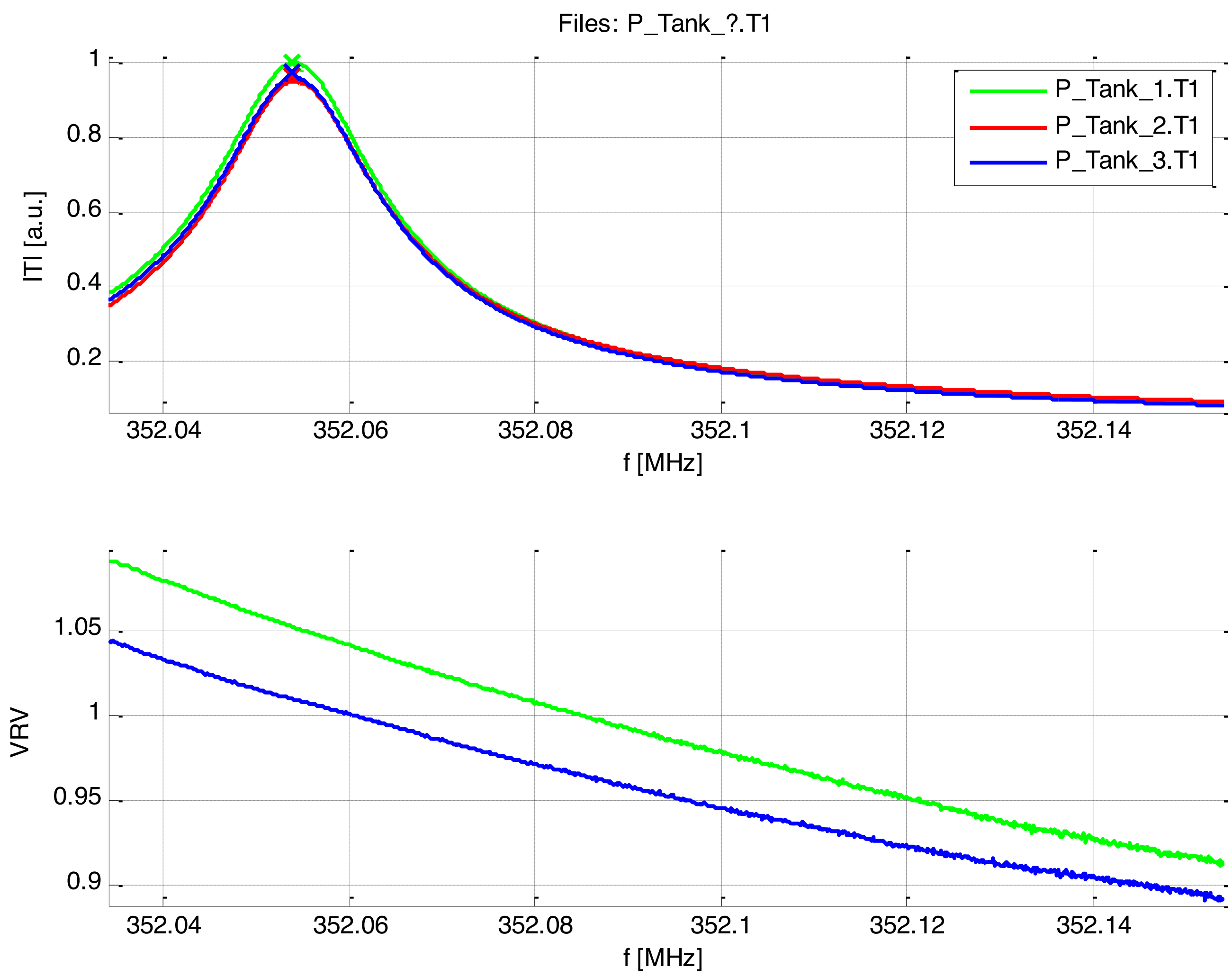
T=21.3°C, pressure 964 hPa, humidity 37%

Pickups coupled stronger (-40 dB)

Field distribution determined by Pickups follows beadpull measurements better than before but sill a clear deviation can be seen (~ ±3% error in power readings over ±10 kHz)

$VRV_{beadpull}$: [1.02, 0.99]

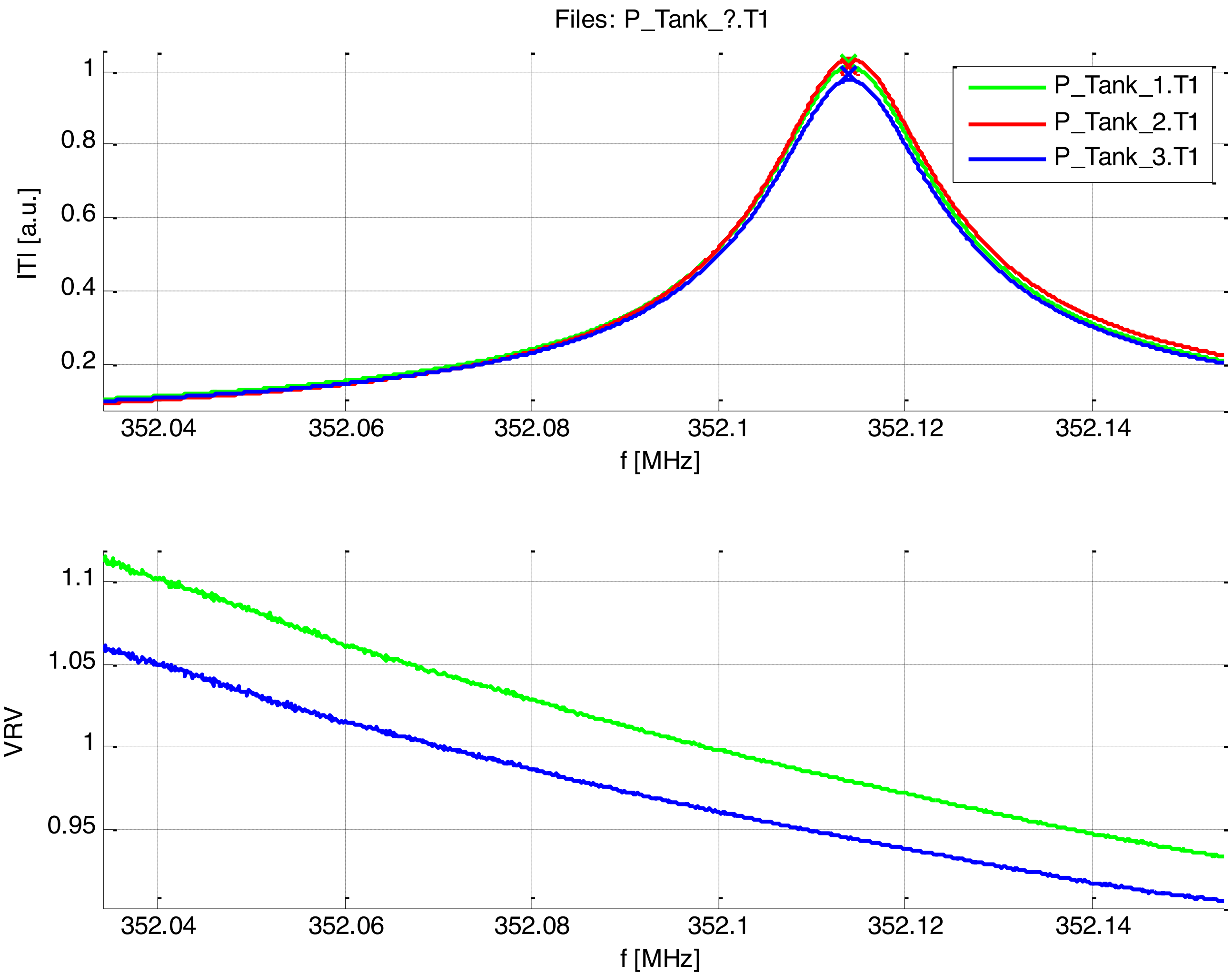
Tuner taken partly out, $\Delta f_{\pi/2}$=-40 kHz



T=21.5°C,
pressure 964 hPa,
humidity 36%
Pickups coupled ~-40 dB

tuner: $\Delta f_{\pi/2}$=-40 kHz
$VRV_{beadpull}$: [1.04, 1.01]
$VRV_{pickups}$: [1.05, 1.01]

Tuner deeper penetrated, $\Delta f_{\pi/2}$=+40 kHz

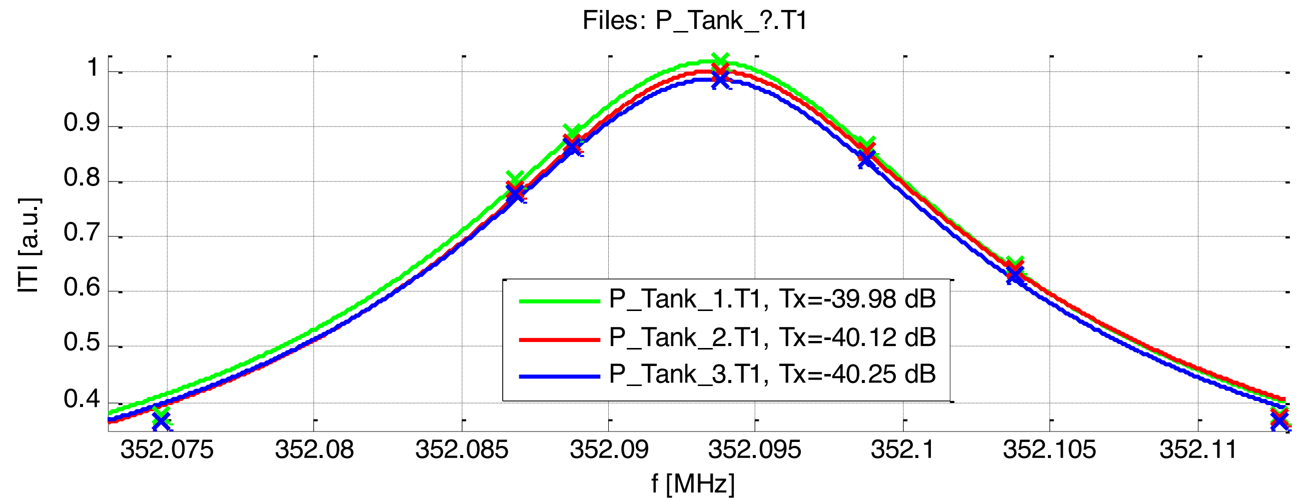


T=21.6°C,
pressure 964 hPa,
humidity 36%
Pickups coupled ~-40 dB

tuner: $\Delta f_{\pi/2}$=+40 kHz
$VRV_{beadpull}$: [1.01, 0.98]
$VRV_{pickups}$: [0.98, 0.94]

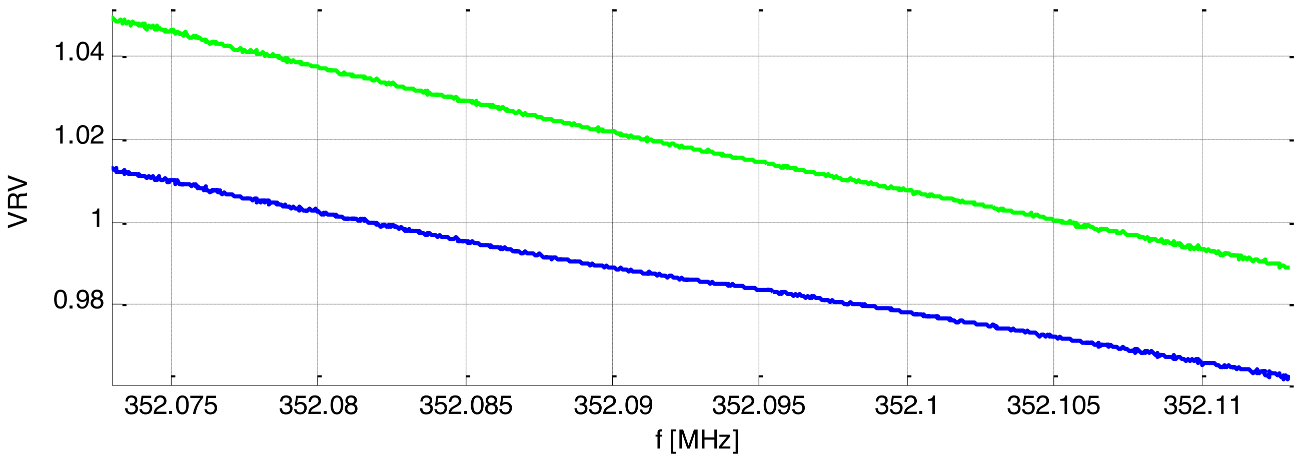
=> CCDTL field level changes ≤ ±1.5% for tuning of ±40 kHz of the π/2-mode => very stable!

Influence of cavity-to-WG coupling

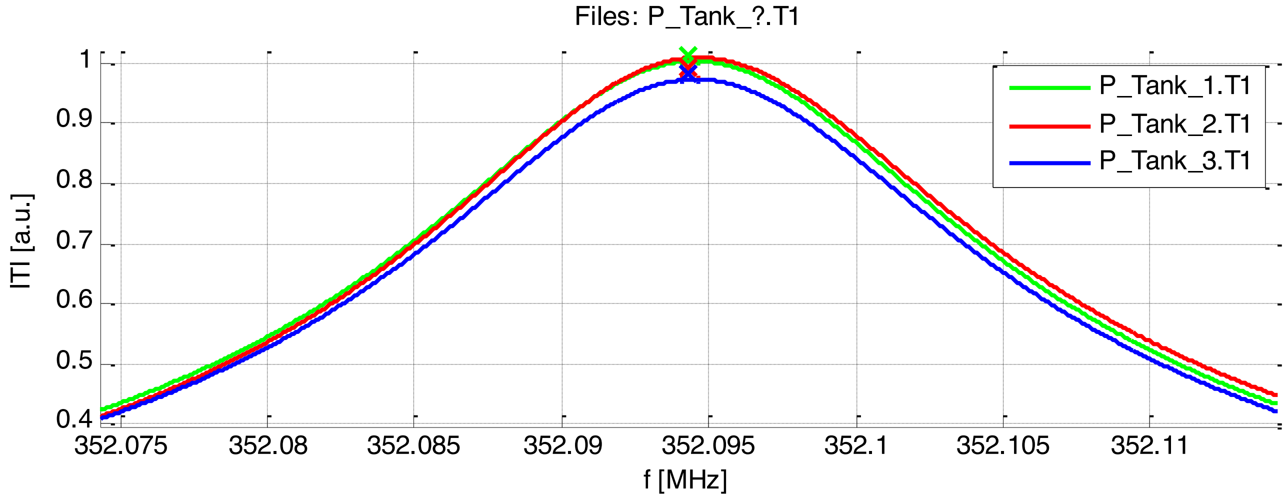


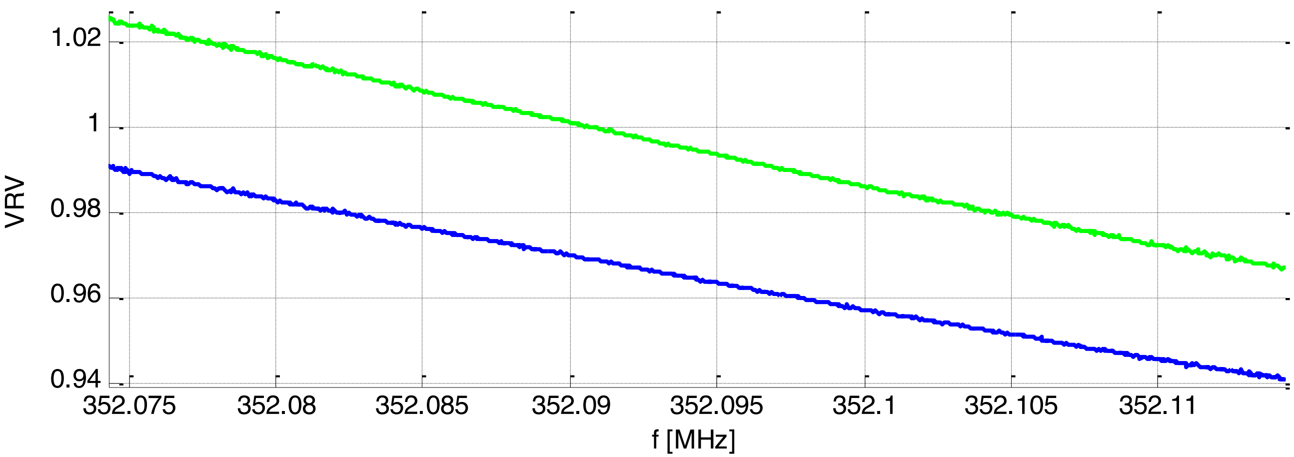
T=21.3°C,
pressure 964 hPa,
humidity 37%
Pickups coupled ~-40 dB

WG coupling: β=1.05
$VRV_{beadpull}$: [1.01, 0.98]
$VRV_{pickups}$: [1.01, 0.98]



Influence of cavity-to-WG coupling





T=21.3°C,
pressure 964 hPa,
humidity 37%
Pickups coupled ~-40 dB

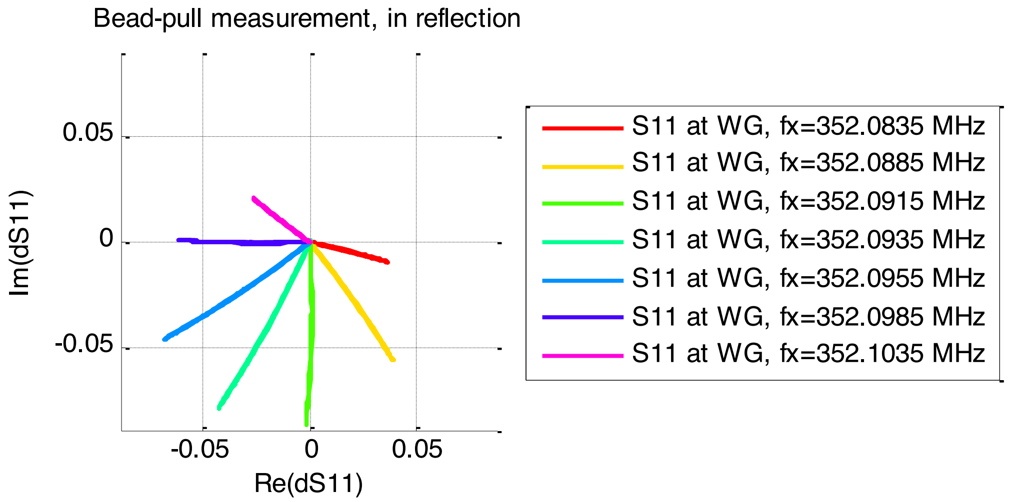
WG coupling: β=1.32
$VRV_{beadpull}$: [1.02, 0.99]
$VRV_{pickups}$: [0.99, 0.96]

=> CCDTL field level changes ≤ ±0.5% for change of cavity-to-waveguide coupling from 1 to 1.3 => very stable, cavity can be tuned for either coupling

Modification of Pickups

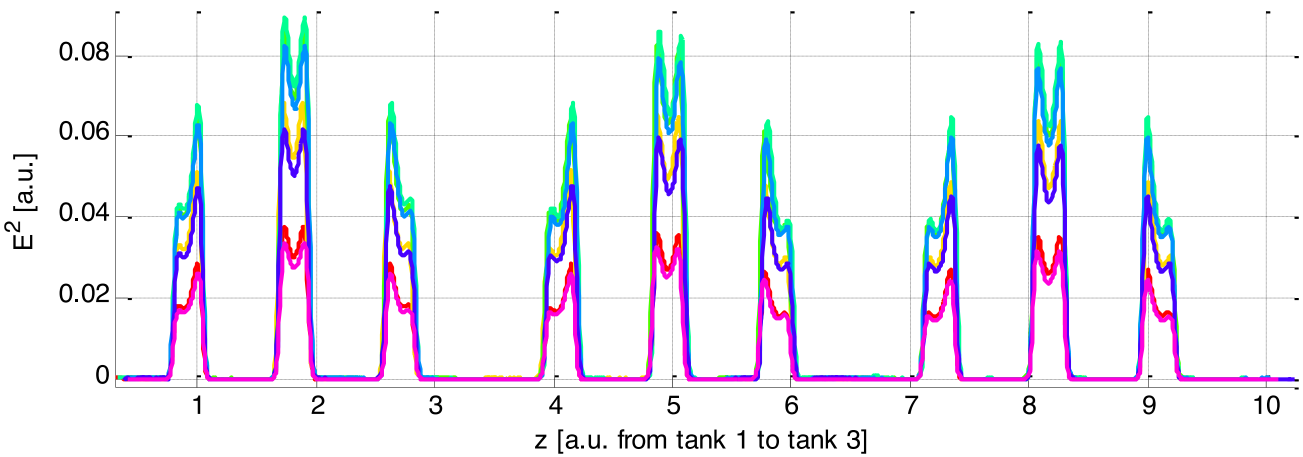
- pickups shortened by 18 mm
- a 6 dB attenuator attached to each pickup
- pickups calibrated to ~-56 dB (including attenuators) – similar situation as in previous high power test

Final measurements in air

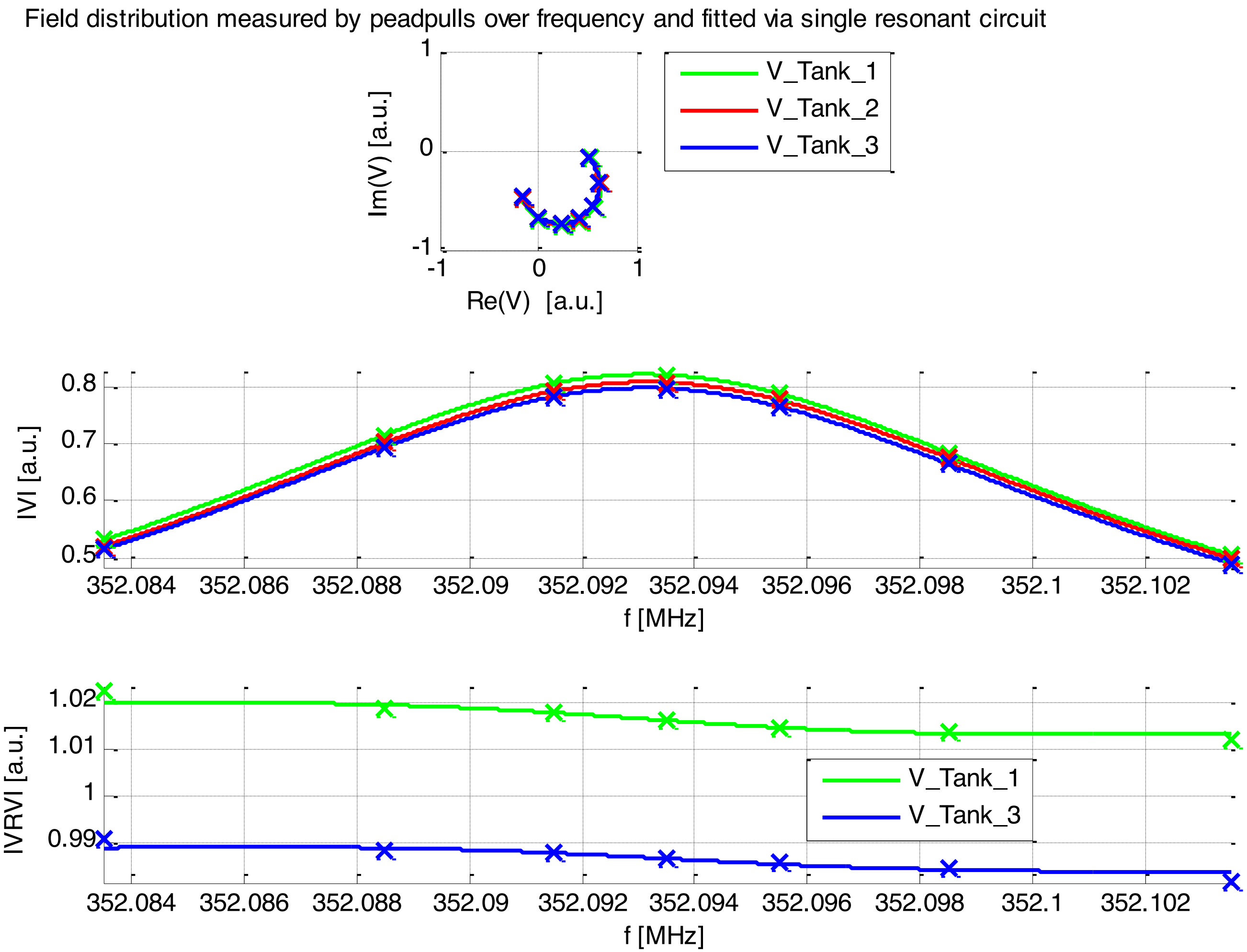


T=21.0°C,
pressure 958 hPa,
humidity 52%

$f_{\pi/2}$=352.0935 MHz
Δf= ±0, 2, 5, 10 kHz



Final measurements in air



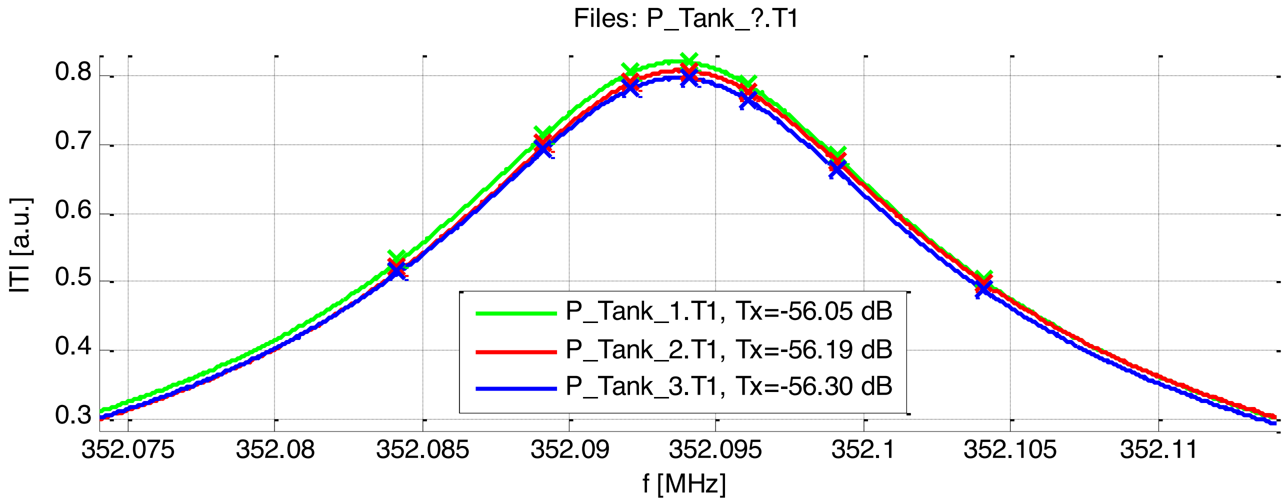
$VRV_{resonance}$= [1.016, 0.987]

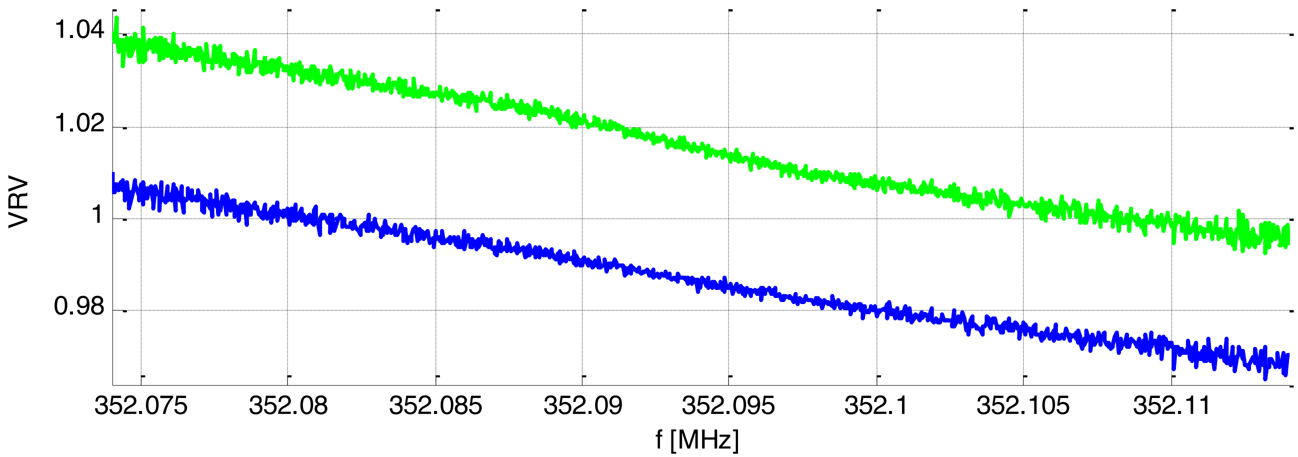
Q_{0_fitted}= [21'656, 21'661, 21'679]

Pickup calibration

	tank 1	tank 2	tank 3
VRV by BP (352.0934 MHz)	1.016	1.000	0.987
VRV by BP [dB]	0.14	0.00	-0.11
WG 2 pickups [dB]	-56.49	-56.19	-56.24
relative pickup ratios [dB]	-0.30	0.00	-0.05
relative pickup ratios	0.966	1.000	0.994
pickup calibration correction factors	1.052	1.000	0.993
pickup calibration to field/power distribution [dB]	**-56.63**	**-56.19**	**-56.13**

Transmi. WG => Pickups & Beadpulls





T=21.0°C, pressure 958 hPa, humidity 52%

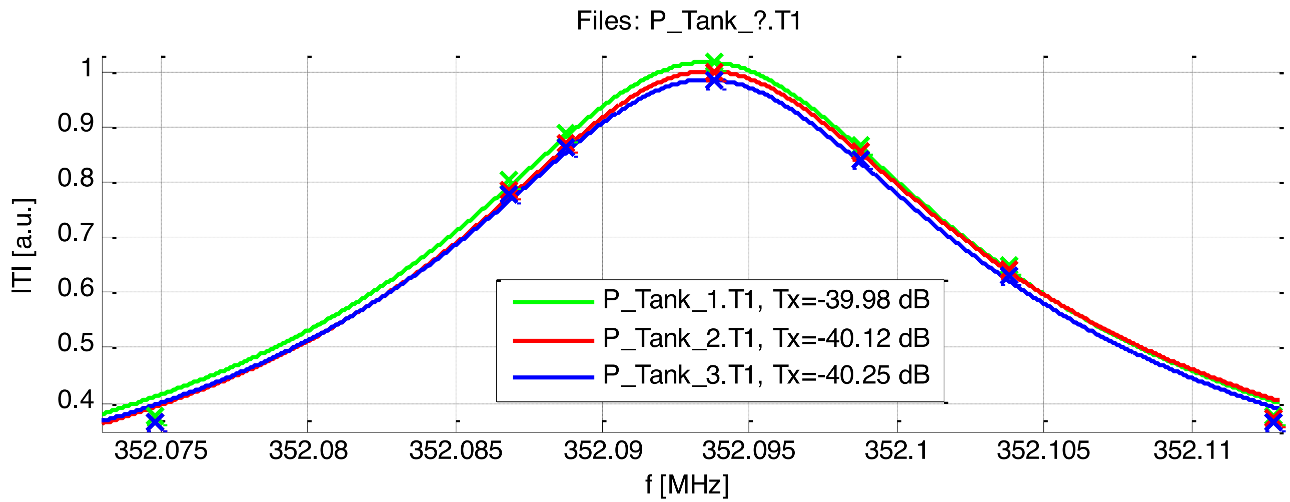
$f_{\pi/2}$=352.0935 MHz
Δf= ±0, 2, 5, 10 kHz

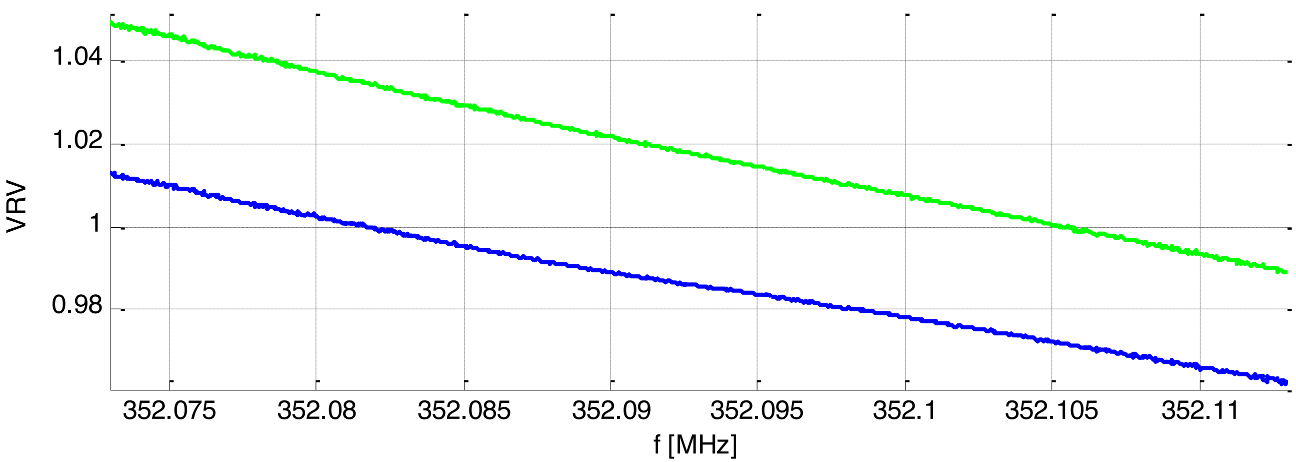
$VRV_{beadpull}$=
[1.016, 0.987]
±0.005 over ±10 kHz

$VRV_{pickups}$=
[1.016, 0.987]
±0.012 over ±10 kHz

=> error ~±0.7% in field level
<=> ±1.4% in power readings over ±10 kHz

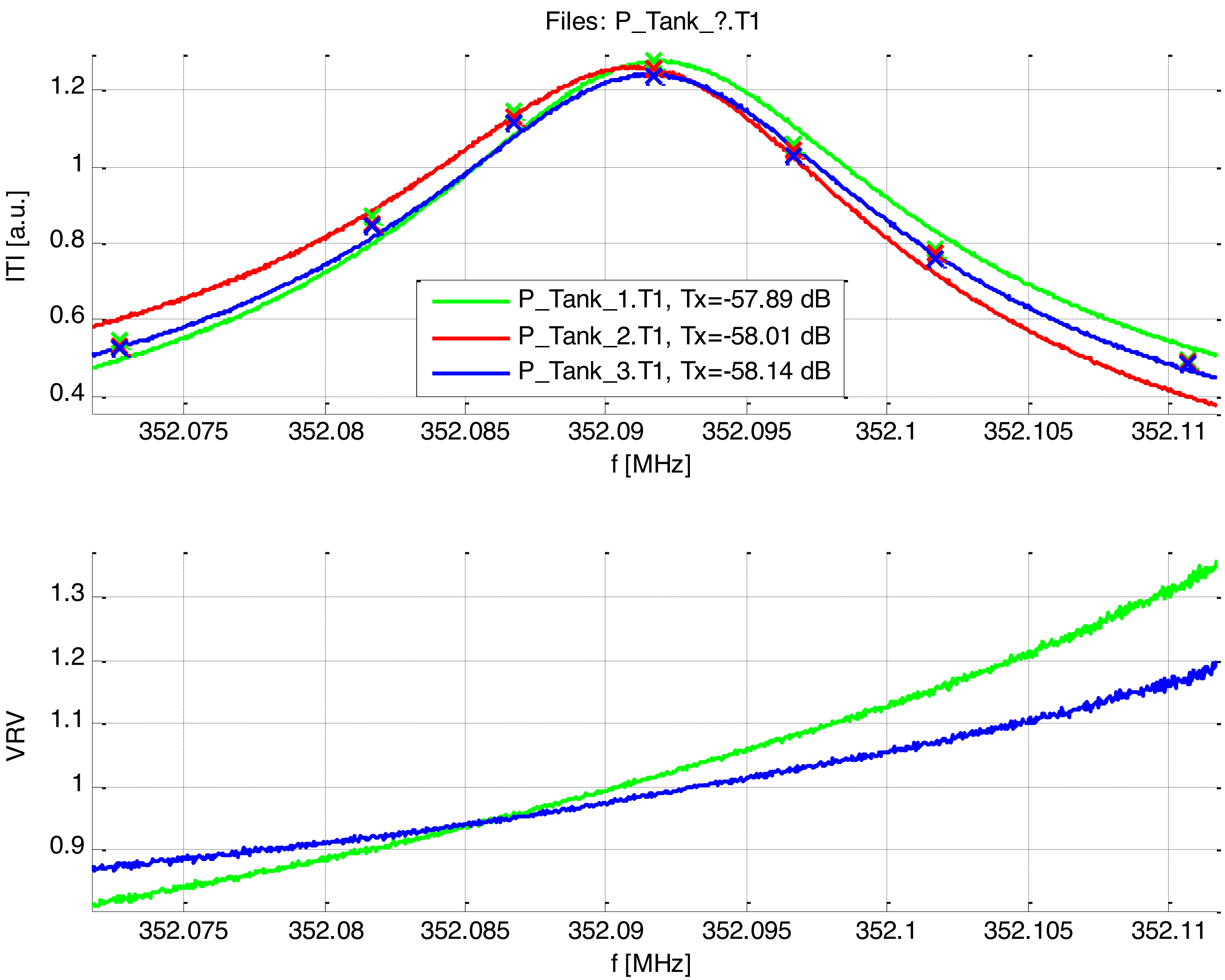
Comparison: old pickups -40 dB coupled





error ~±1.5% in field level
<=> ±3.0% in power readings over ±10 kHz

Comparison: initial situation

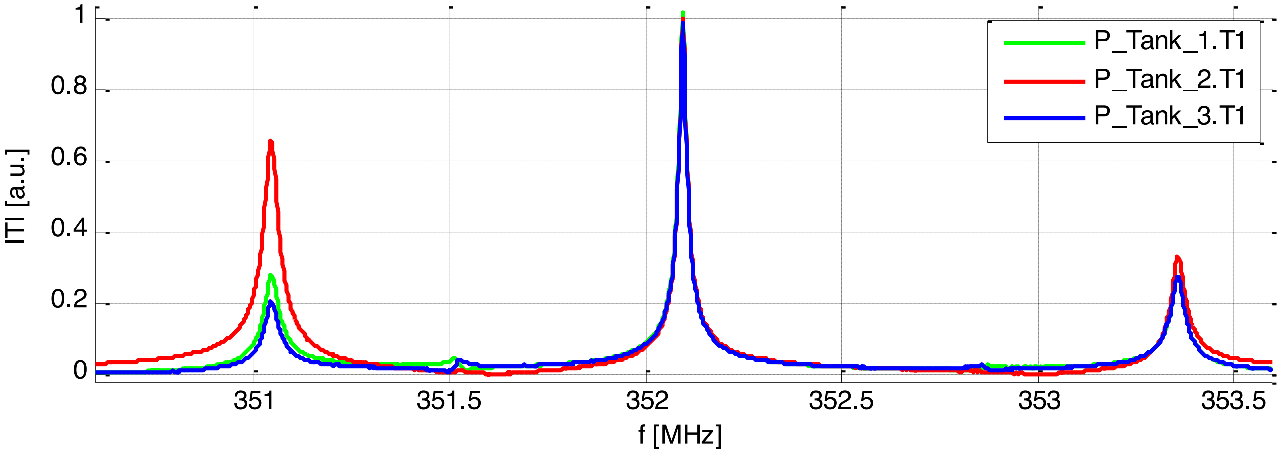


error ~±5% in field level
<=> ±10% in power readings over ±10 kHz

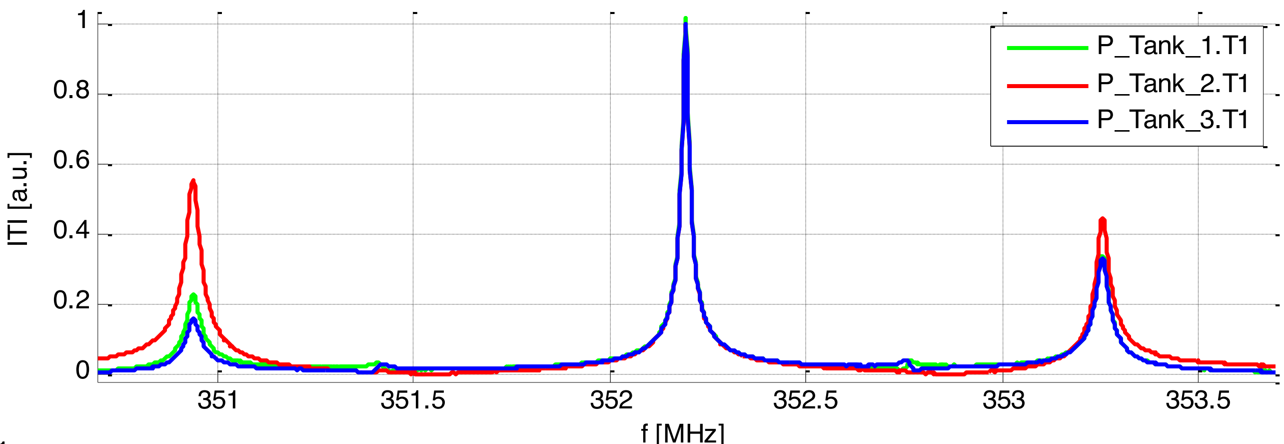
Results of modified pickups

- remaining error in field level reading <±1% over ±10 kHz (= bandwidth)
  => not perfect but sufficient for operation (by tuning assumed to remain within ±1 kHz around resonance)

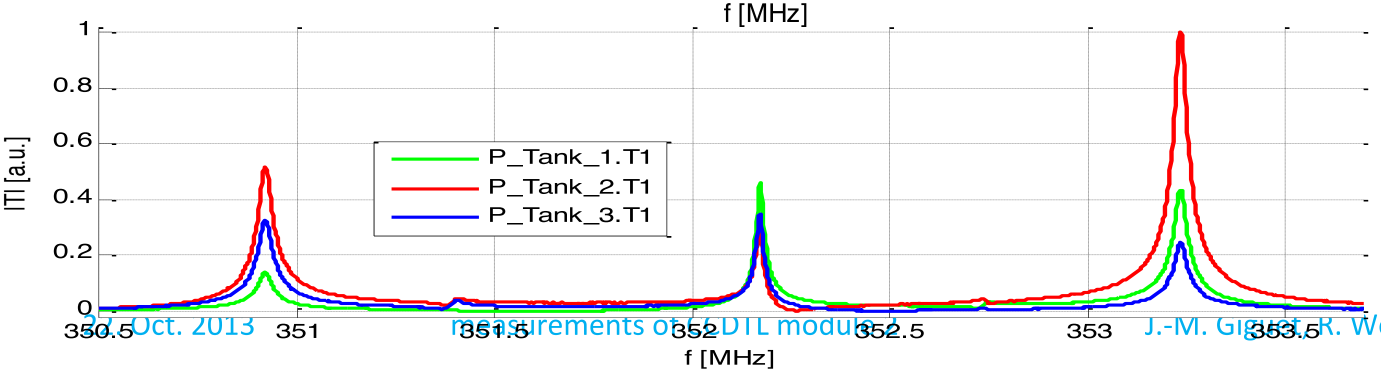
Air <=> Vacuum changes



Air, 07.11.2013
T=21.0°C,
pressure 958 hPa,
humidity 52%

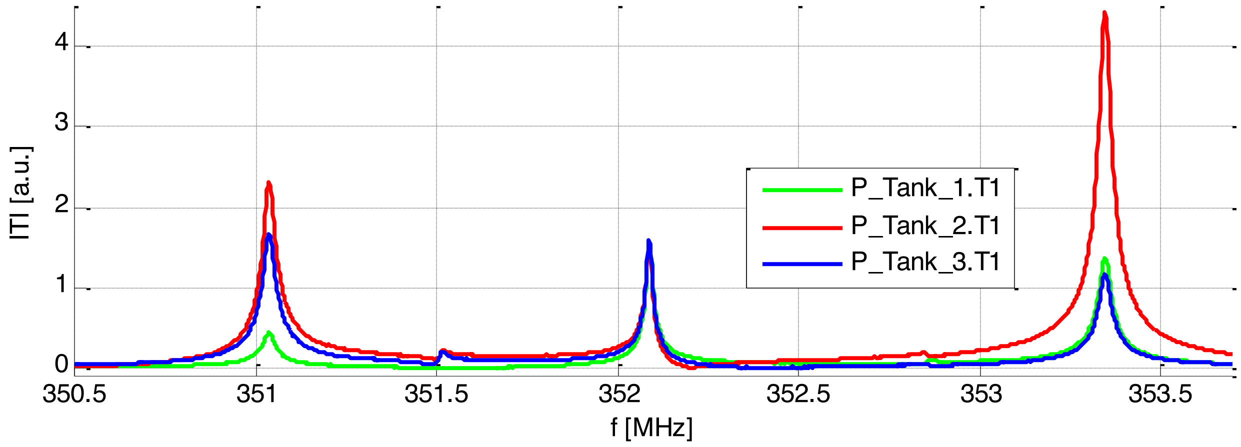


Vacuum, 11.11.2013
T=21.0°C

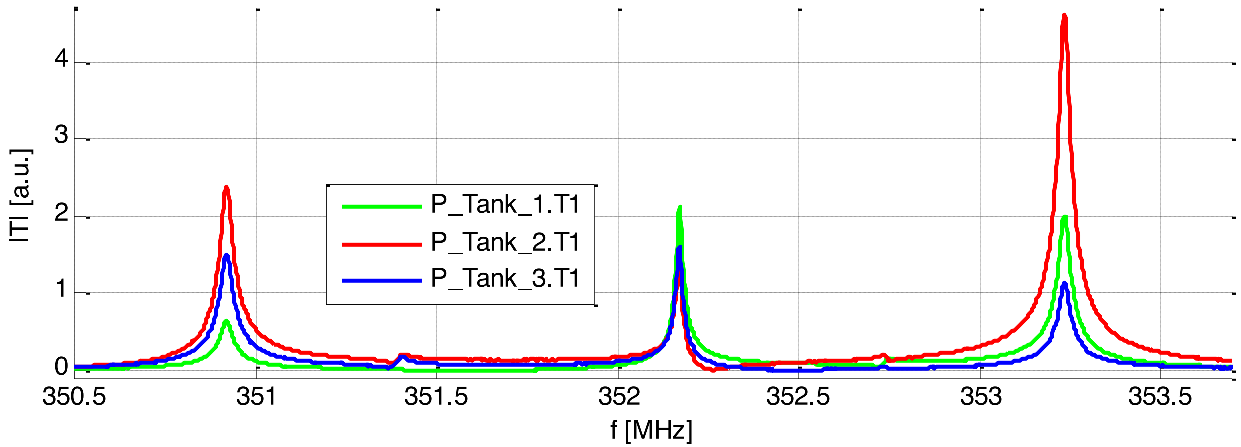


Vacuum, 18.10.2013
T_{air}=21.9°C
T_{water}=26 to 28°C

Comparison: Vacuum <=> N_2 changes

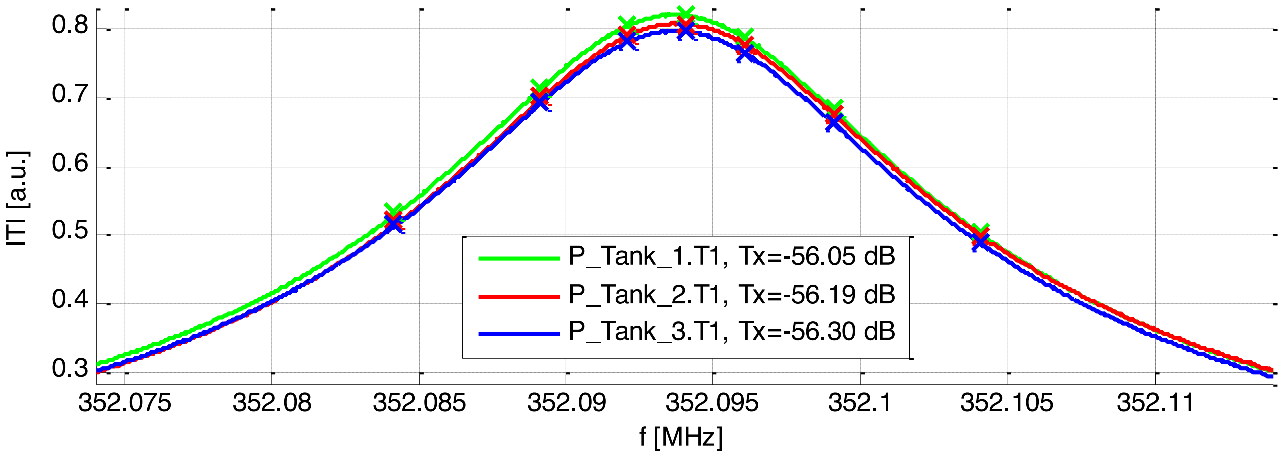


N_2, 18.10.2013
T_{air}=21.9°C
T_{water}=26 to 28°C

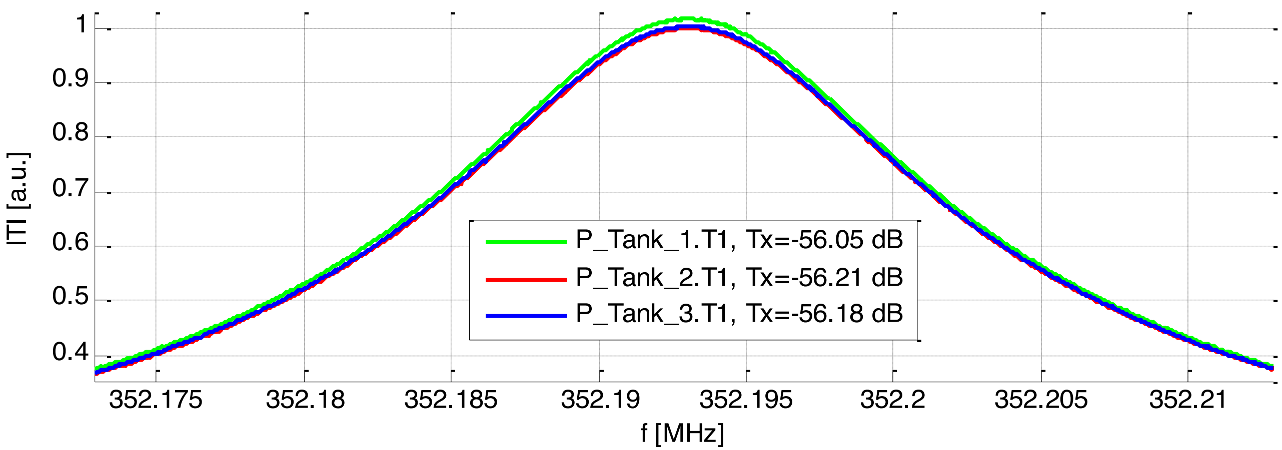


Vacuum, 18.10.2013
T_{air}=21.9°C
T_{water}=26 to 28°C

Air <=> Vacuum changes

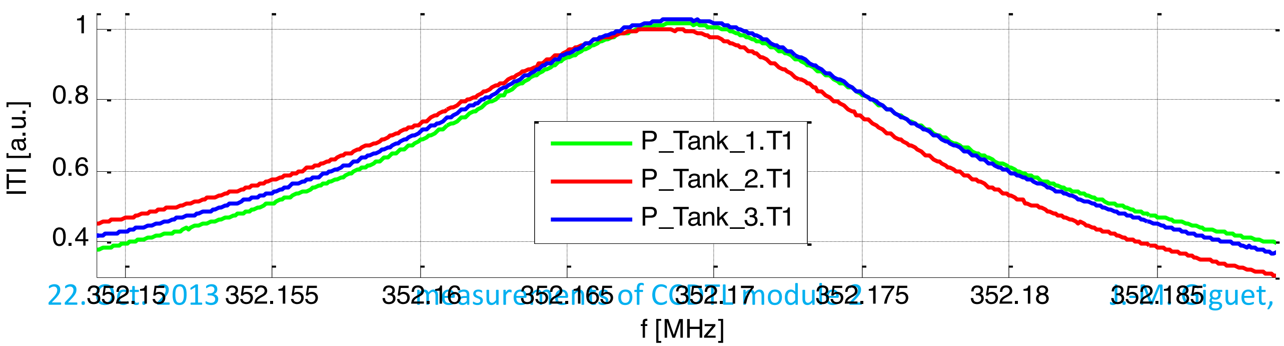


Air, 07.11.2013
T=21.0°C,
pressure 958 hPa,
humidity 52%



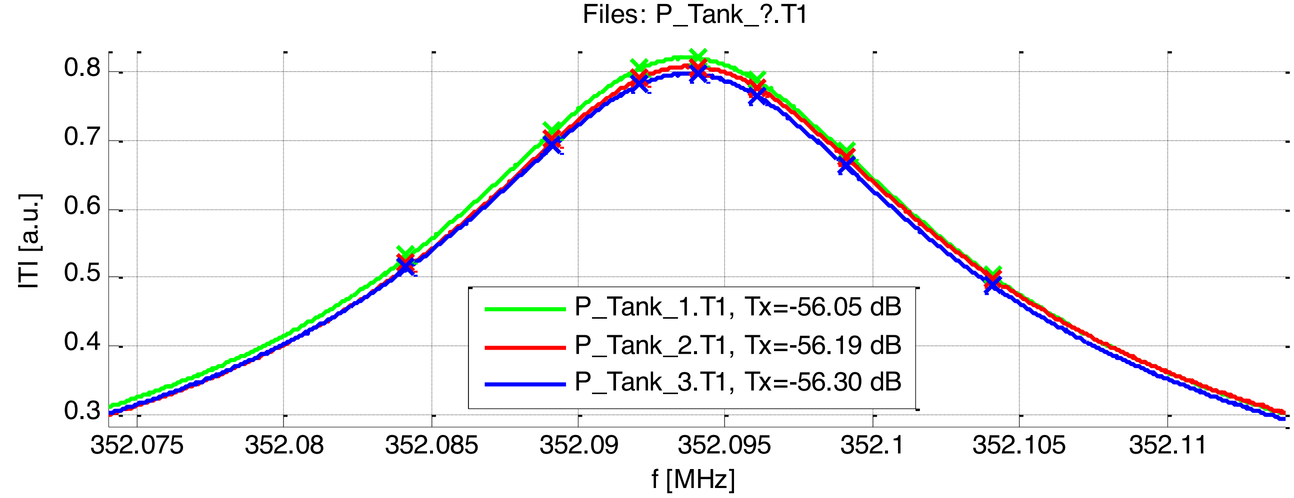
Vacuum, 11.11.2013
T=21.0°C

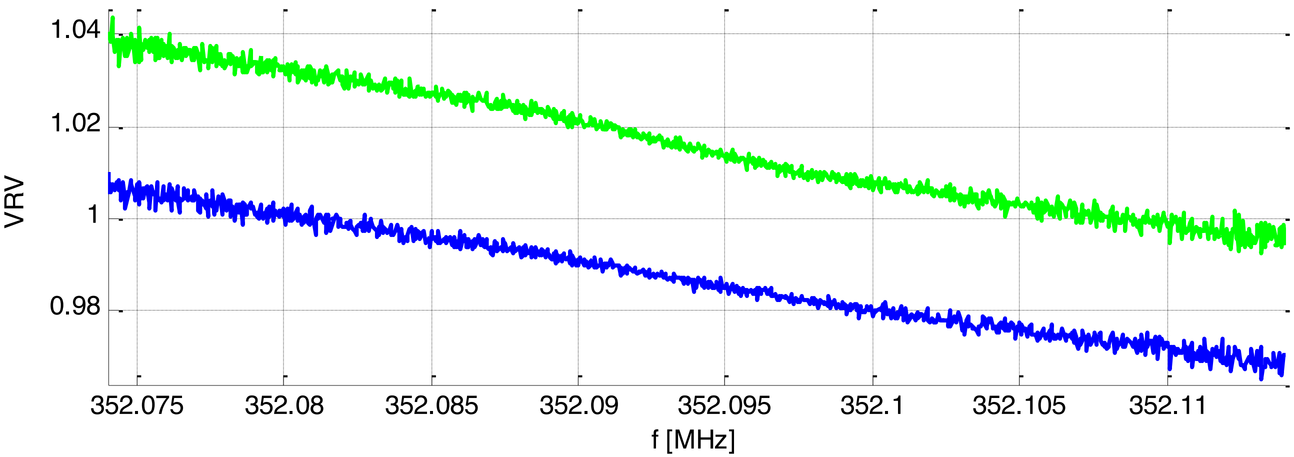
$\Delta f_{\pi/2}$~ +100 kHz



Vacuum, 18.10.2013
T_{air}=21.9°C
T_{water}=26 to 28°C

Air – modified pickups





T=21.0°C, pressure 958 hPa, humidity 52%

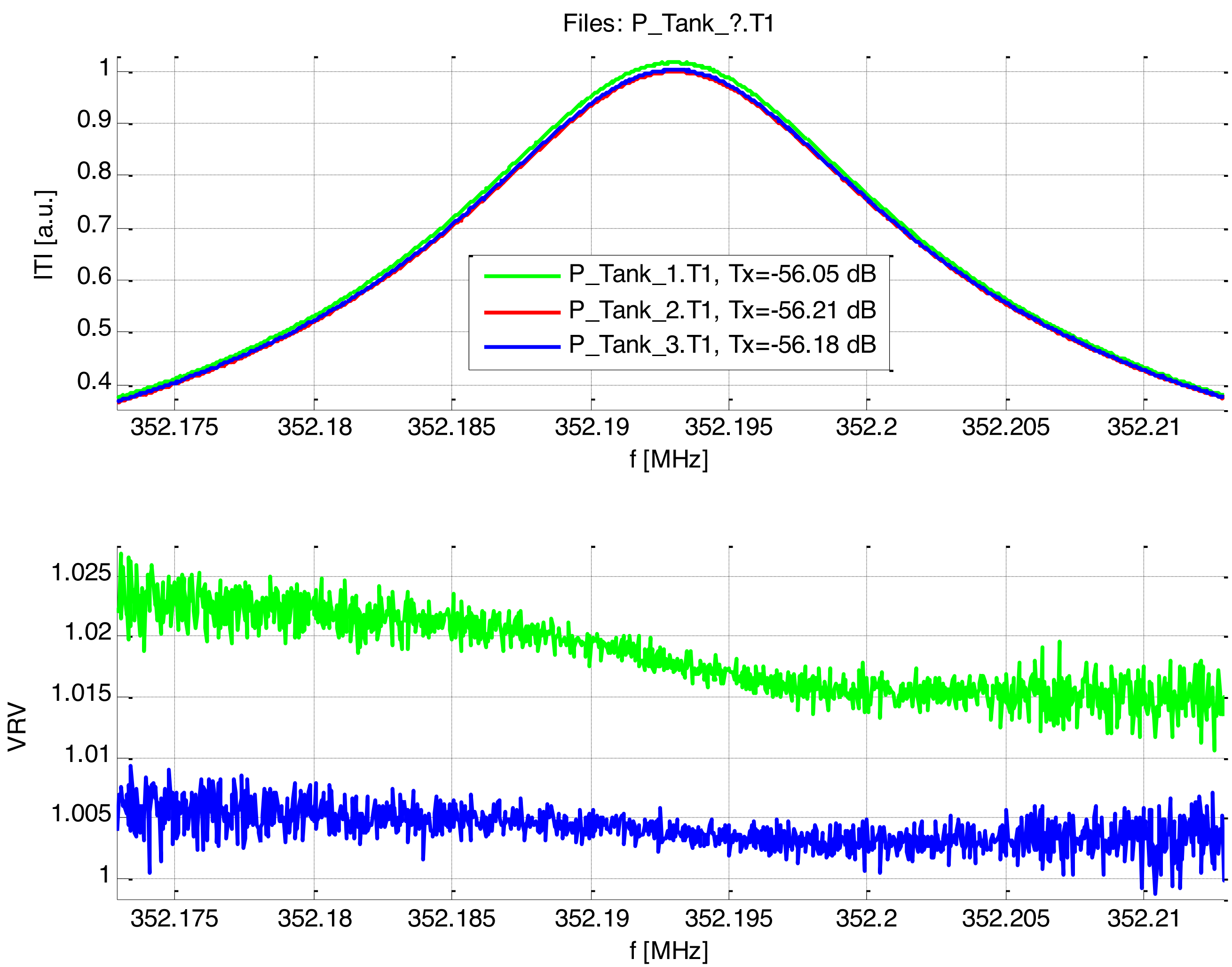
$f_{\pi/2}$=352.0935 MHz
Δf= ±0, 2, 5, 10 kHz

$VRV_{beadpull}$=
[1.016, 0.987]
±0.005 over ±10 kHz

$VRV_{pickups}$=
[1.016, 0.987]
±0.012 over ±10 kHz

=> error ~±0.7% in field level
<=> ±1.4% in power readings over ±10 kHz

Vacuum – modified pickups



11.11.2013,
T=21.0°C

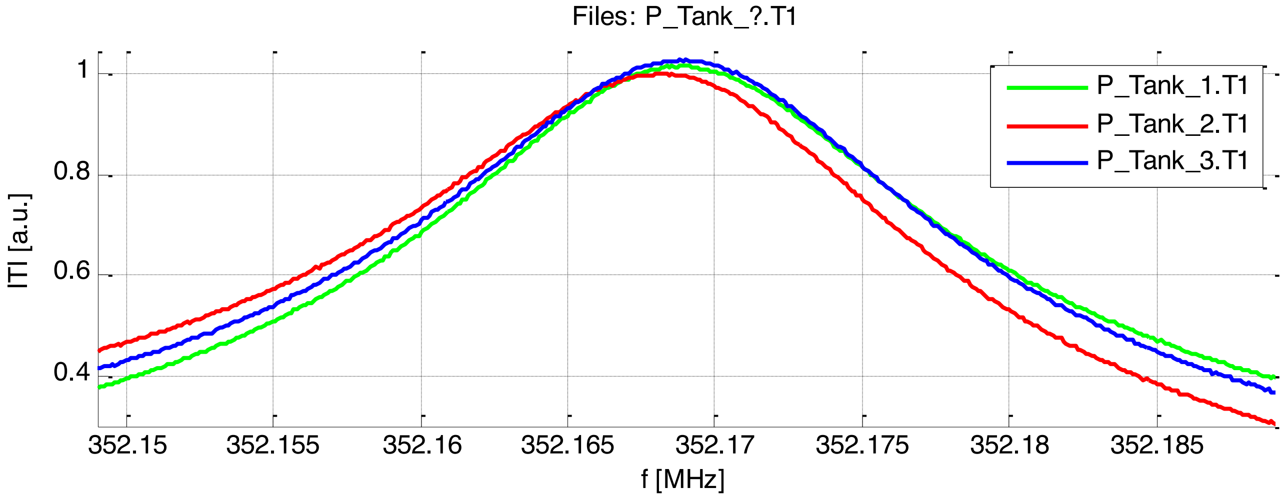
$f_{\pi/2}$=352.193 MHz

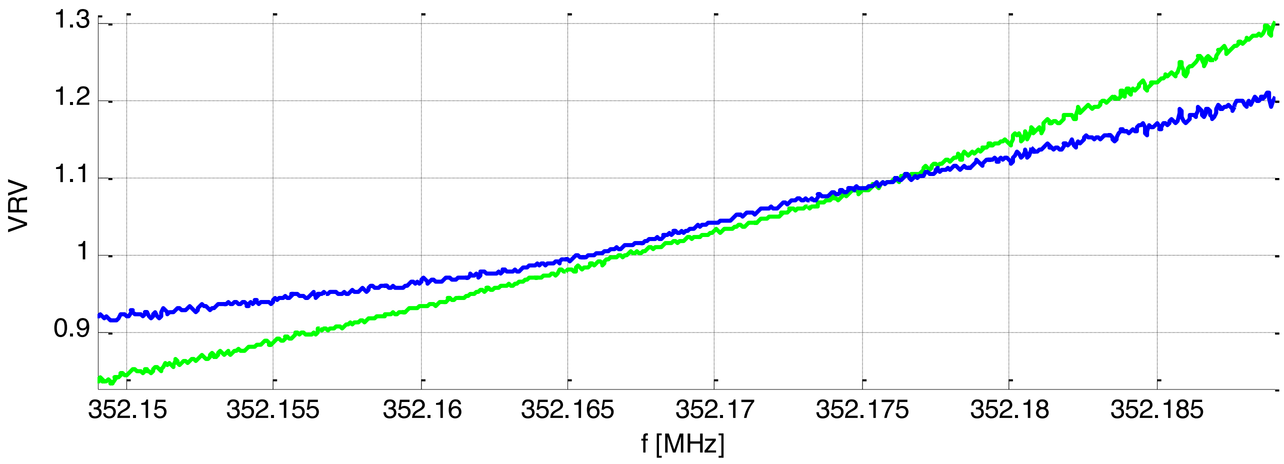
$VRV_{pickups}$=
[1.017, 1.004]
±<0.005 over ±10 kHz

error in field level was ~±0.7%, coincidental error compensation or precise cavity tuning?

=> now much better power reading coherence @ high power test expected !

Comparison: Vacuum – original pickups





18.10.2013

T_{air}=21.9°C

T_{water}=26 to 28°C

$f_{\pi/2}$=352.169 MHz

$VRV_{pickups}$=
[1.03, 1.02]
±0.200 over ±10 kHz

Open questions / outlook

- Coherent pickup reading in vacuum at ambient temperature.
  What is the **behaviour during high power** test when drift tubes are water cooled/heated while parts of the body are not water cooled?
  => (quick) high power test needed
- Fields stay flat in air when a tuner in the central cell shifts the $\pi/2$ mode.
  What is the **behaviour under vacuum**? => test with mov. tuner (at low power) needed, can be evaluated after high power test. Test: changing frequency of $\pi/2$ and reading all 3 pickups

Summary I

- **CCDTL module 2 is well tuned in air and even better under vacuum !!!**
- The **problems experienced of incoherent power readings** was caused by a frequency dependency of the 3 **pickup loops**.
- A (quite simple) **solution is to shorten the pickups** (inner and outer conductors) by 18 mm. For module 2, the coupling of the pickups was adjusted to -50 dB and further attenuated by 6 dB attenuators.

  The pickup calibration values for CCDTL module 2 are: transmission from waveguide to pickup in
  tank 1: -56.63 dB, tank 2: -56.19 dB, tank 3: -56.13 dB.

Summary II

- Considerable changes in the mode spectrum have been seen when going from **air to vacuum**. CCDTL module 2 is well tuned in air and very well tuned under vacuum.
- The CCDTL module 2 **can be tuned with a single tuner** in the central tank without perturbing the fields much (≤±1.5% field change for a detuning of ±40 kHz of $\pi/2$ mode in air).
- A change of the **cavity-to-waveguide coupling does not perturb the fields** much (<0.5% field change between β=1.0 and β=1.3 in air)
  => RF tuning is less difficult as it can be done either at β=1.0 or β=1.3 to include beam loading.
- **Pickups** have been **calibrated in air.** The calibration value of each pickup is its **transmission from the waveguide, scaled by the relative field distribution** within the module. A small bead and observation of the input reflection at the waveguide (pickup independent) have been chosen for beadpull measurements.