200 Ω Chopper development update:
helix performance and some driver ideas

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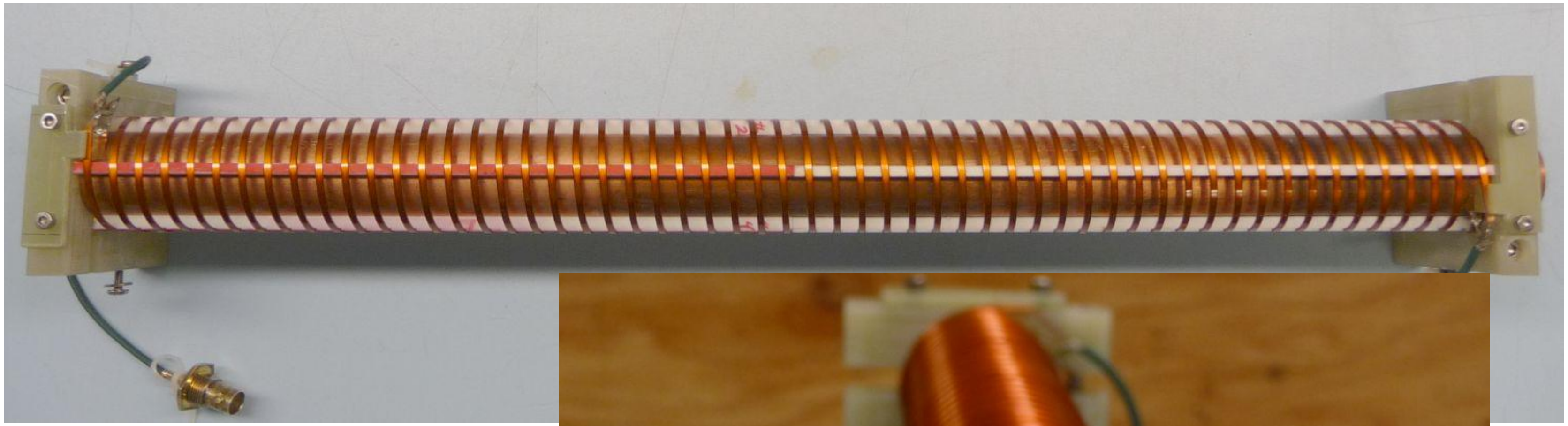
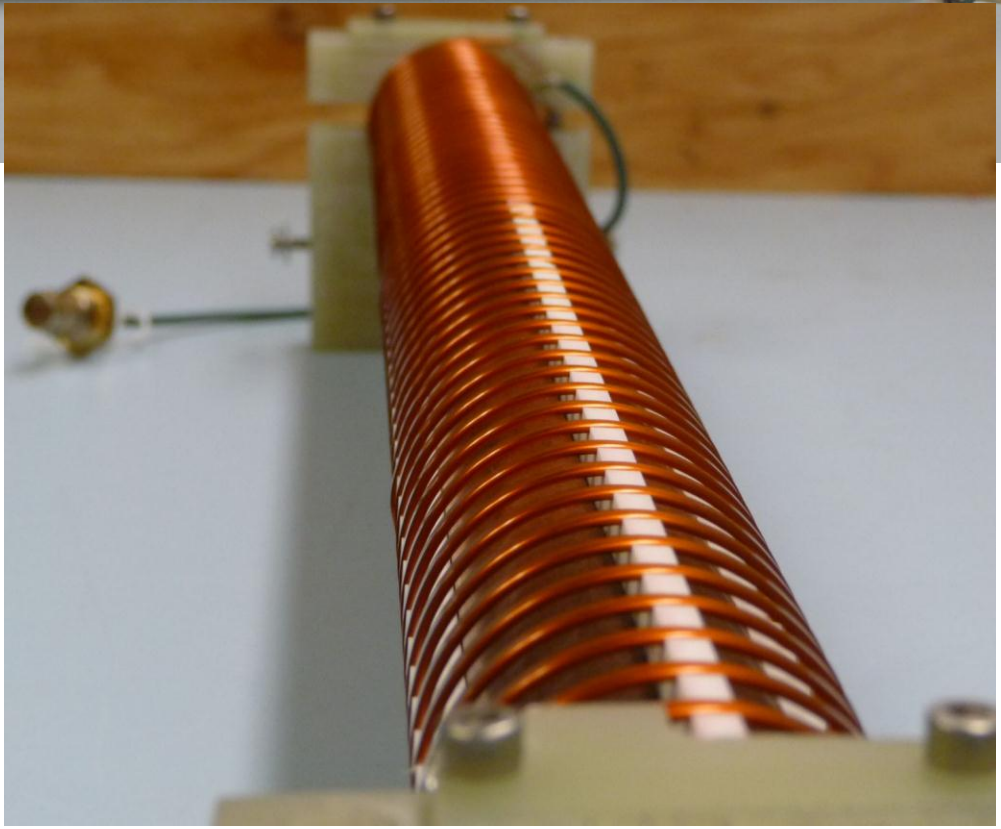
Efforts pursued

- Evaluated a 0.5m long helical microstrip line prototype having these key features:
  - Zo = 200 Ohm to minimize power dissipation (driver, helix structure and load termination)
  - Attached electrodes and ceramic supports introduce tolerable time domain effects
  - Relatively simple construction
- Began investigating the design a high speed switch as a driver

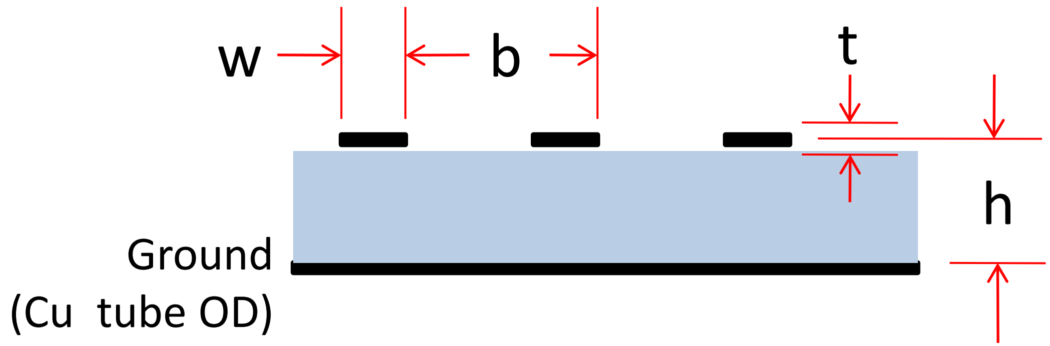
.5 m long helix





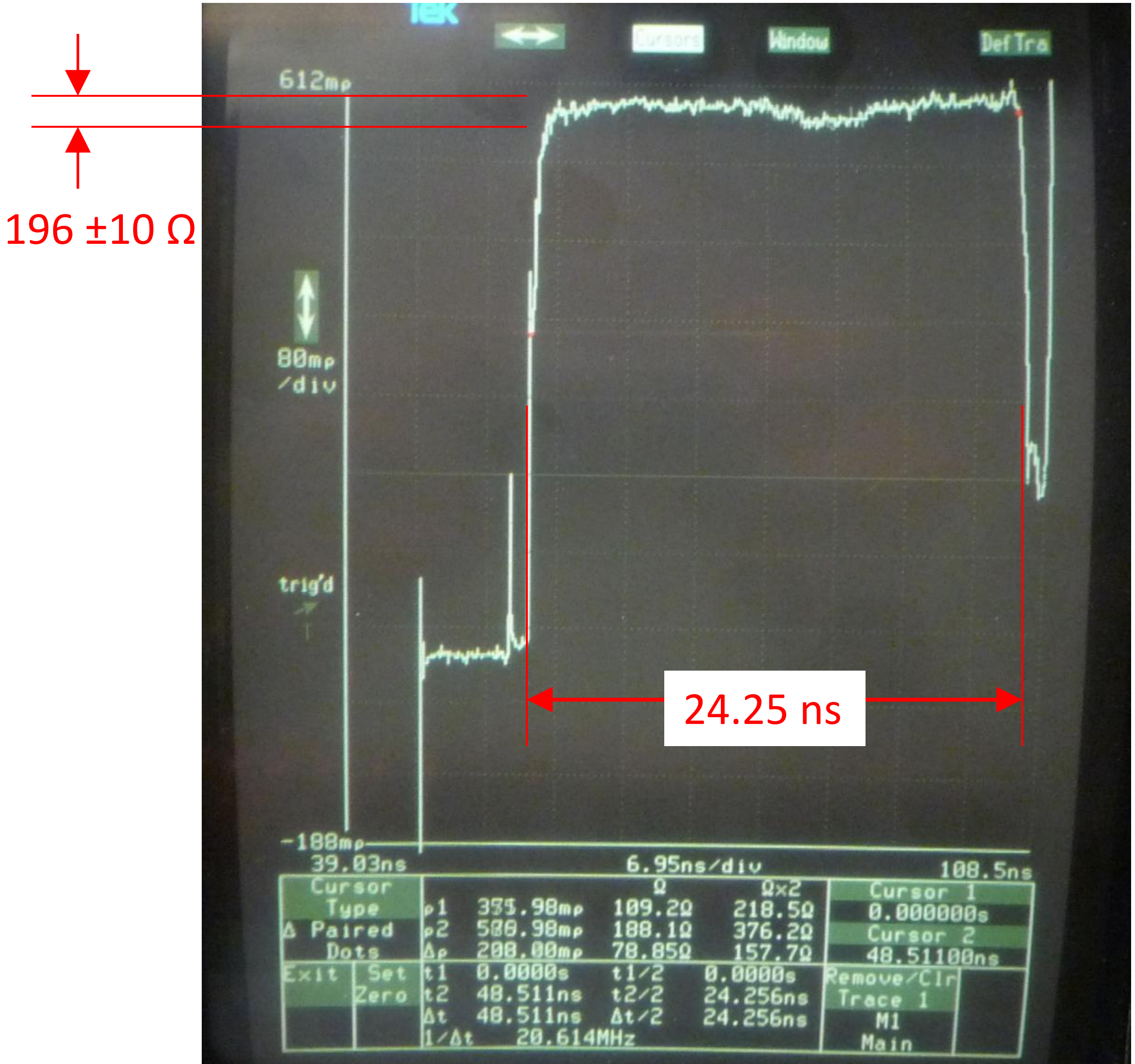
Helix
- #13 flat magnet wire
- supported by 4 machined ceramic spacers

Helix dimensions

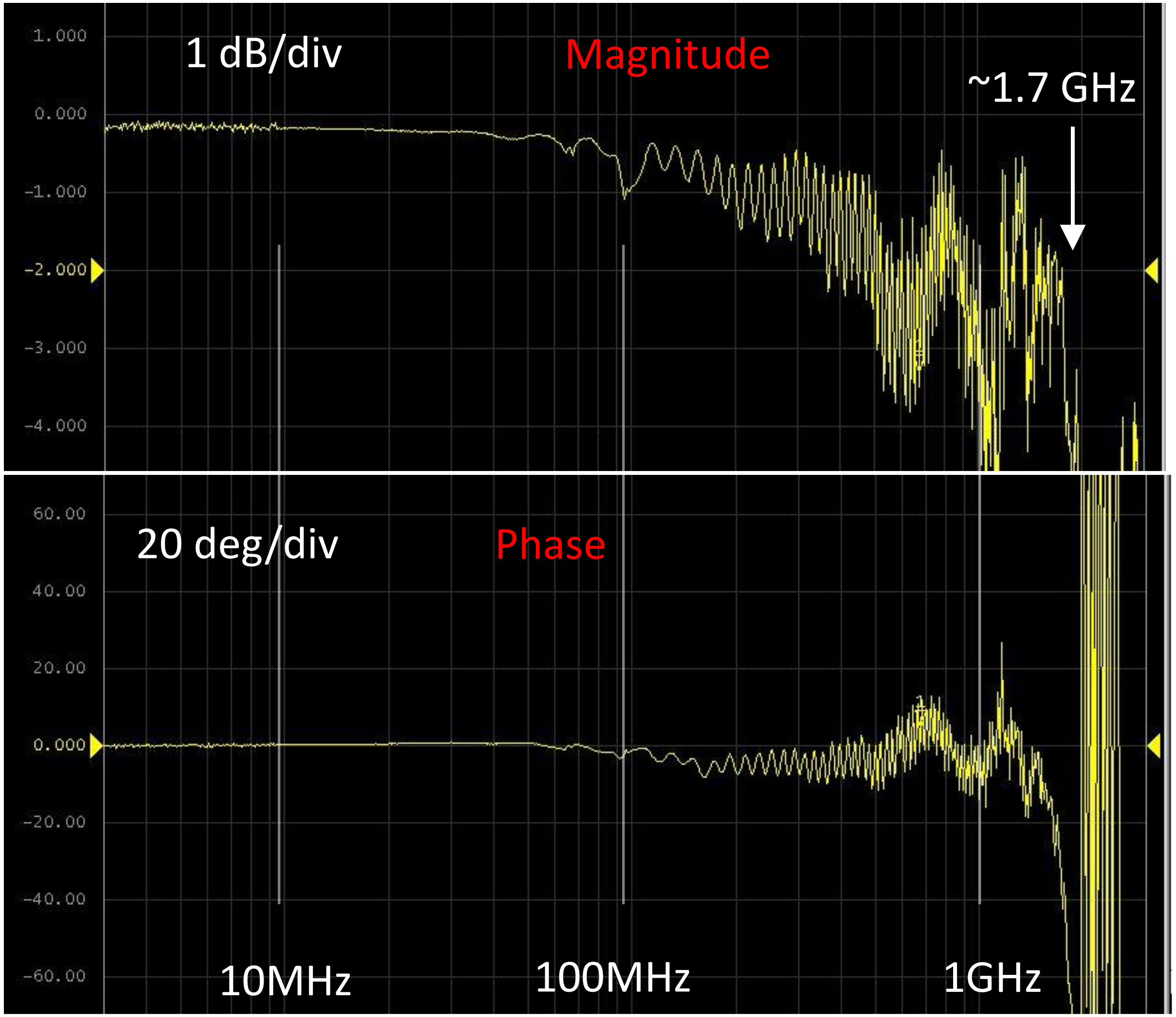


Microstrip Z_O	196 ± 10 Ω (measured)
#13 wire dimensions (w x t)	0.105” x 0.034”
Pitch (b) (β = .073)	8.46 mm (0.333”)
Strip height (h)	0.185”
Helix OD (wire center-to-center)	1.506”
Ground tube OD	1.125”
helix length (55 turns)	46.6 cm (18.35”)
Electrode dimensions	5.58 x 20 x .5 mm

TDR impedance measurement (helix only)



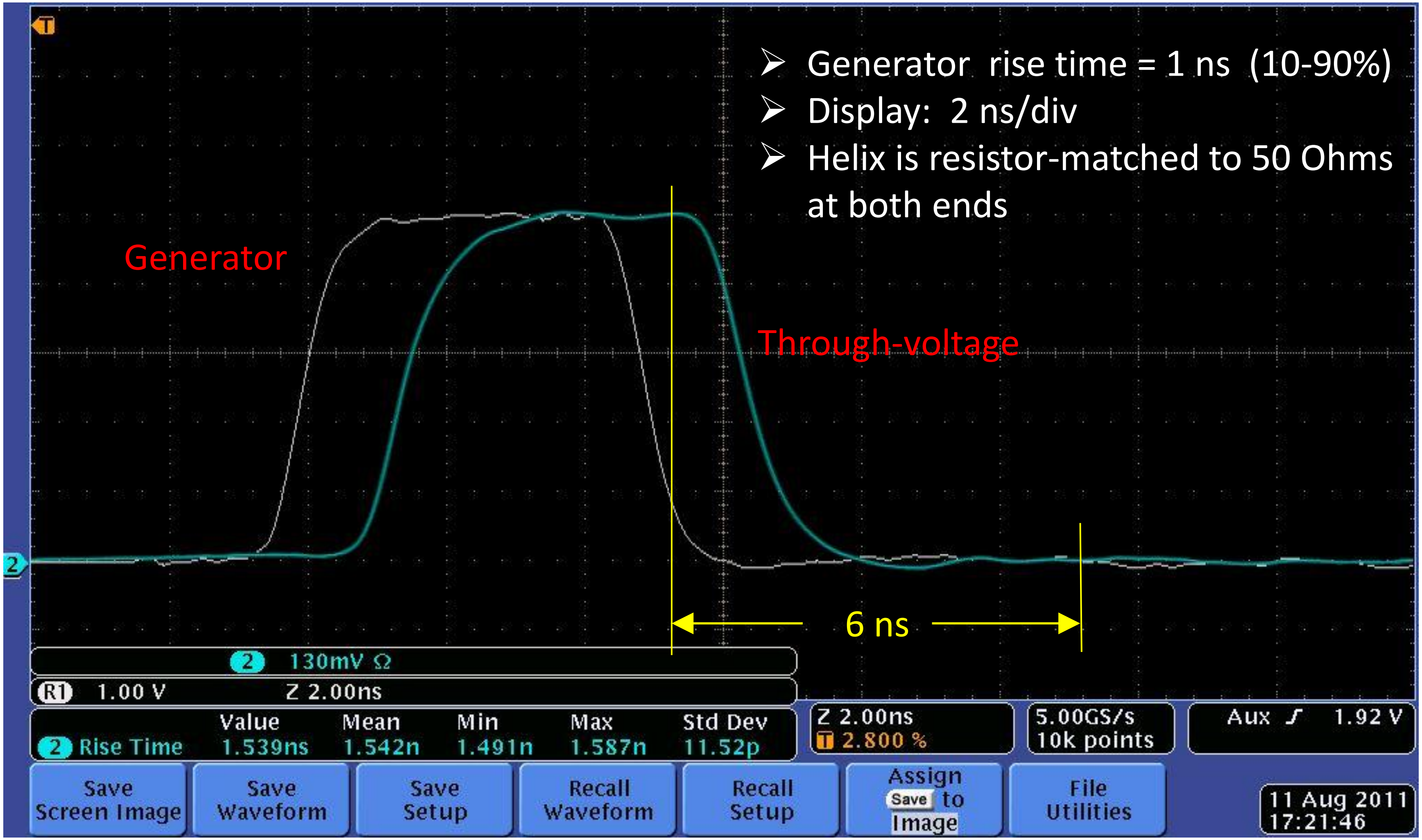
S21 measurement (helix only)



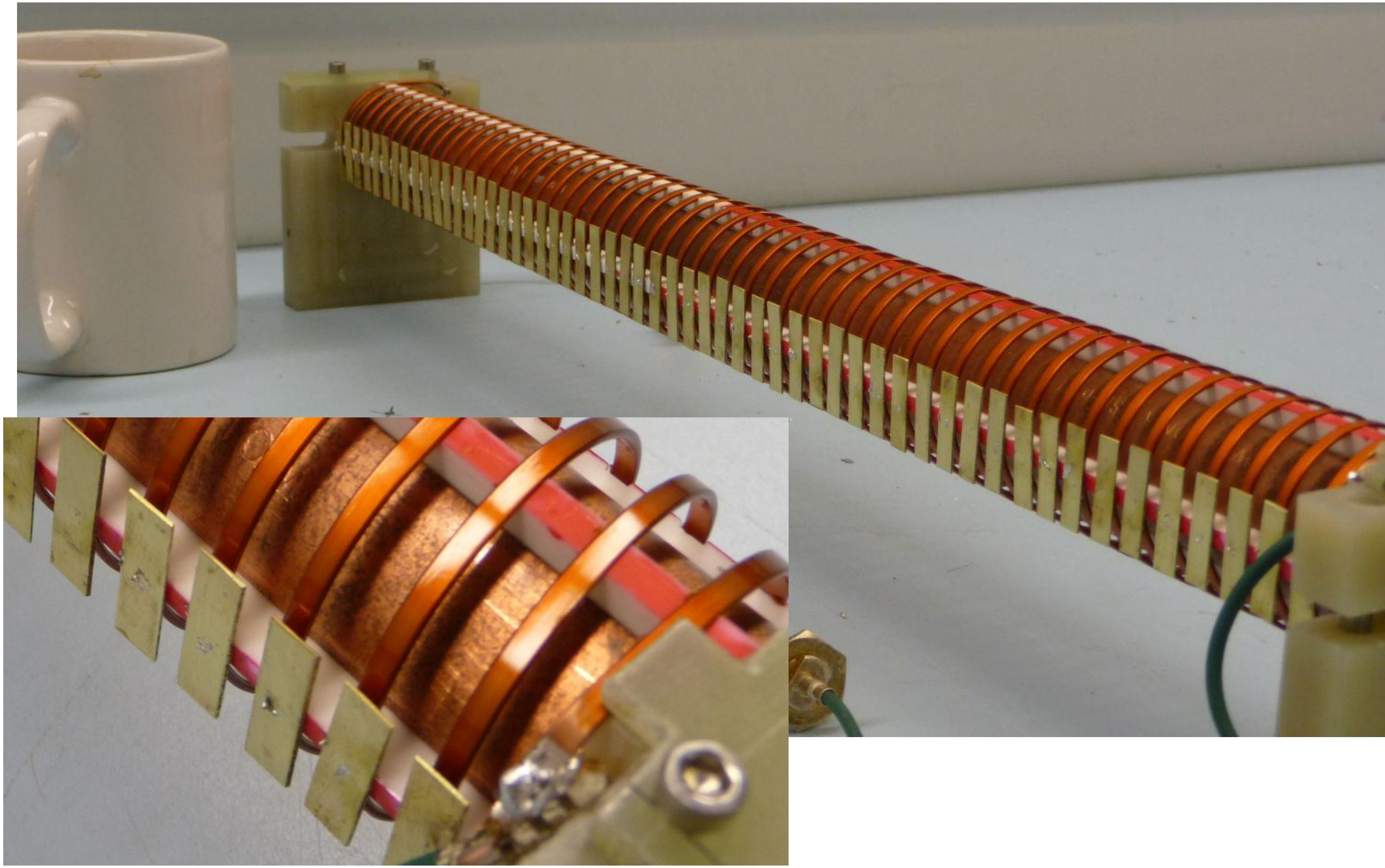
3 MHz - 3 GHz Sweep.

Impedance matching network and cables are calibrated out.

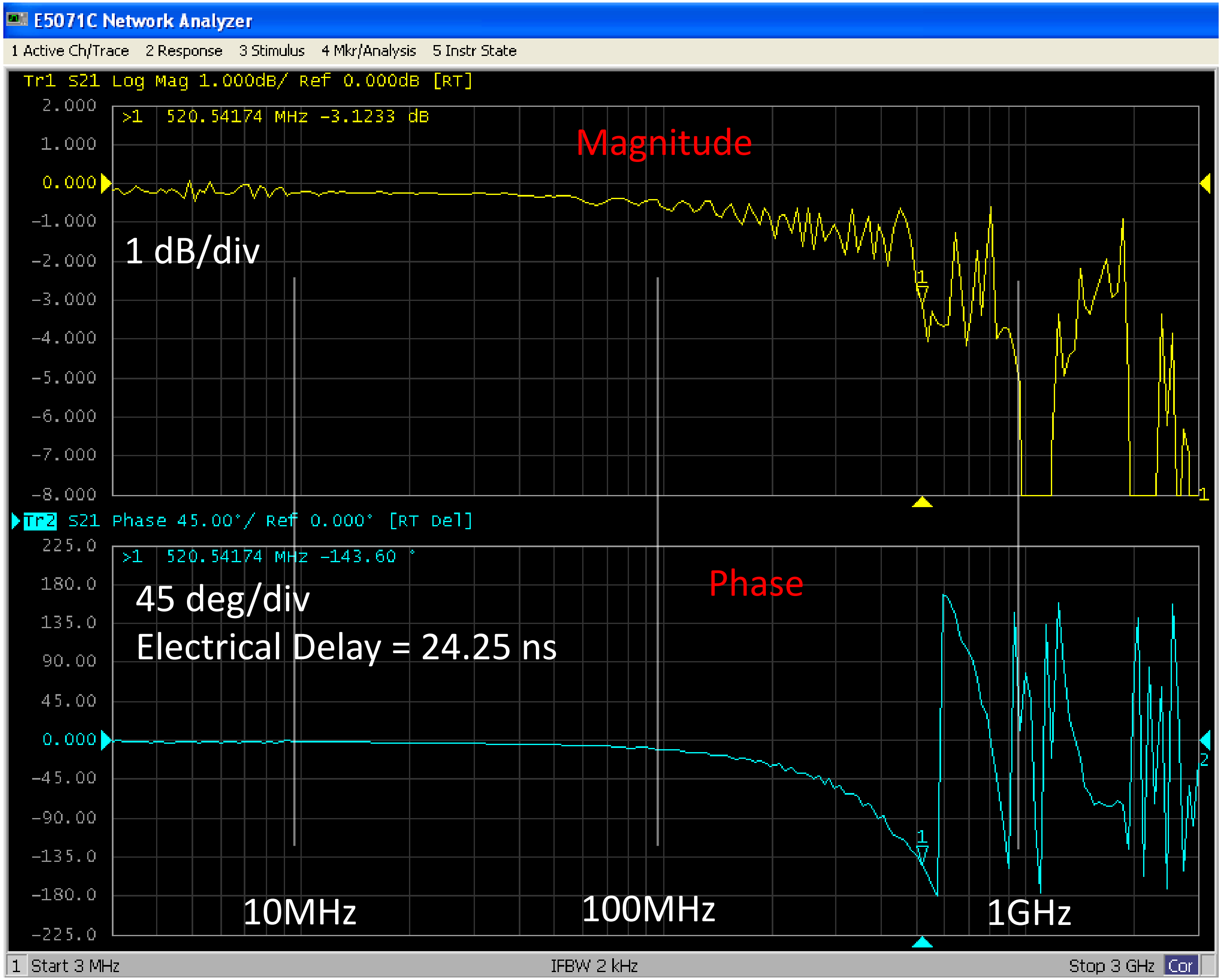
Through-voltage (helix only)



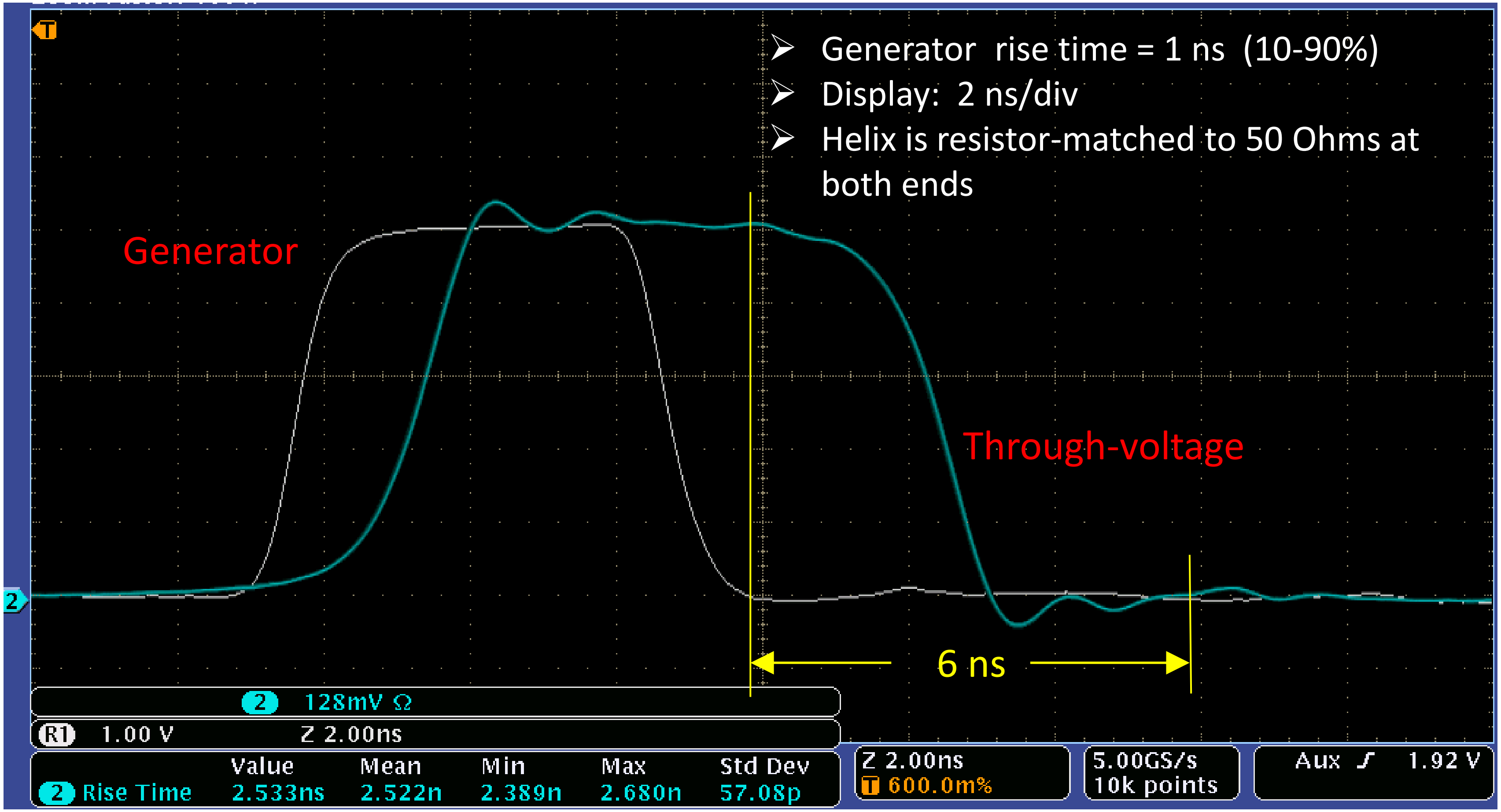
Helix with electrodes attached



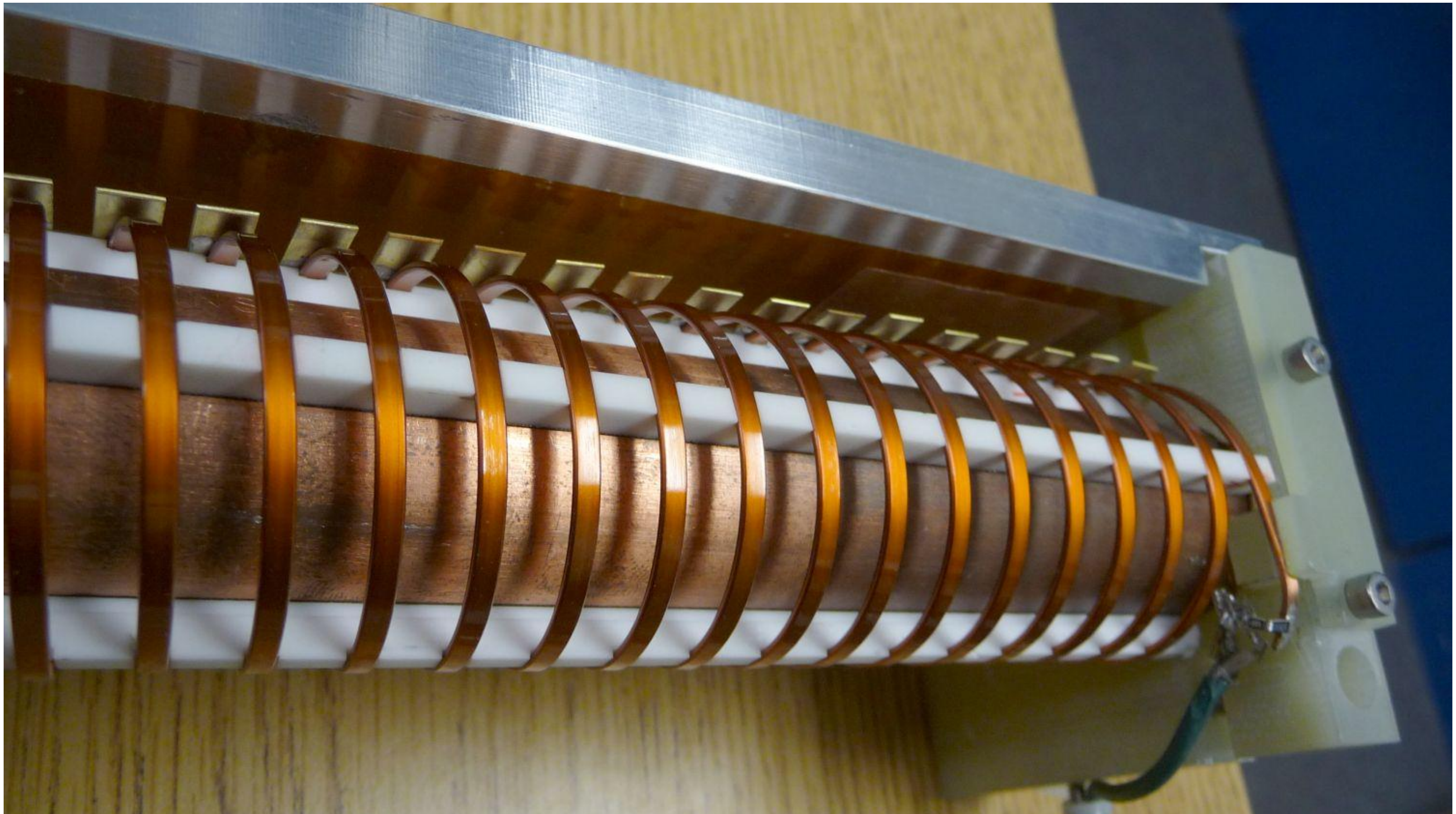
S21 measurement (w/ electrodes attached)



Through-voltage (electrodes attached)



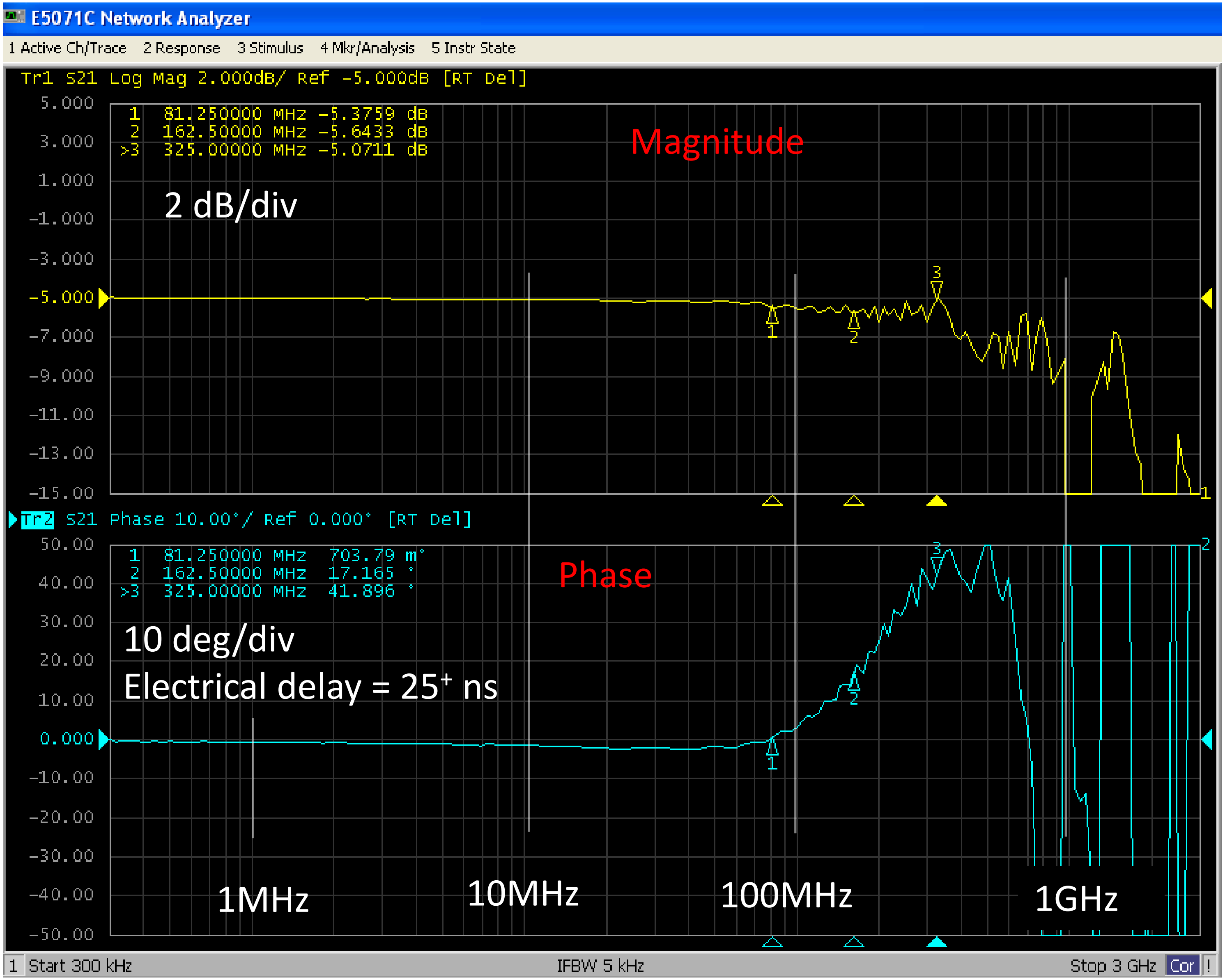
Helix with electrodes and zero voltage plane



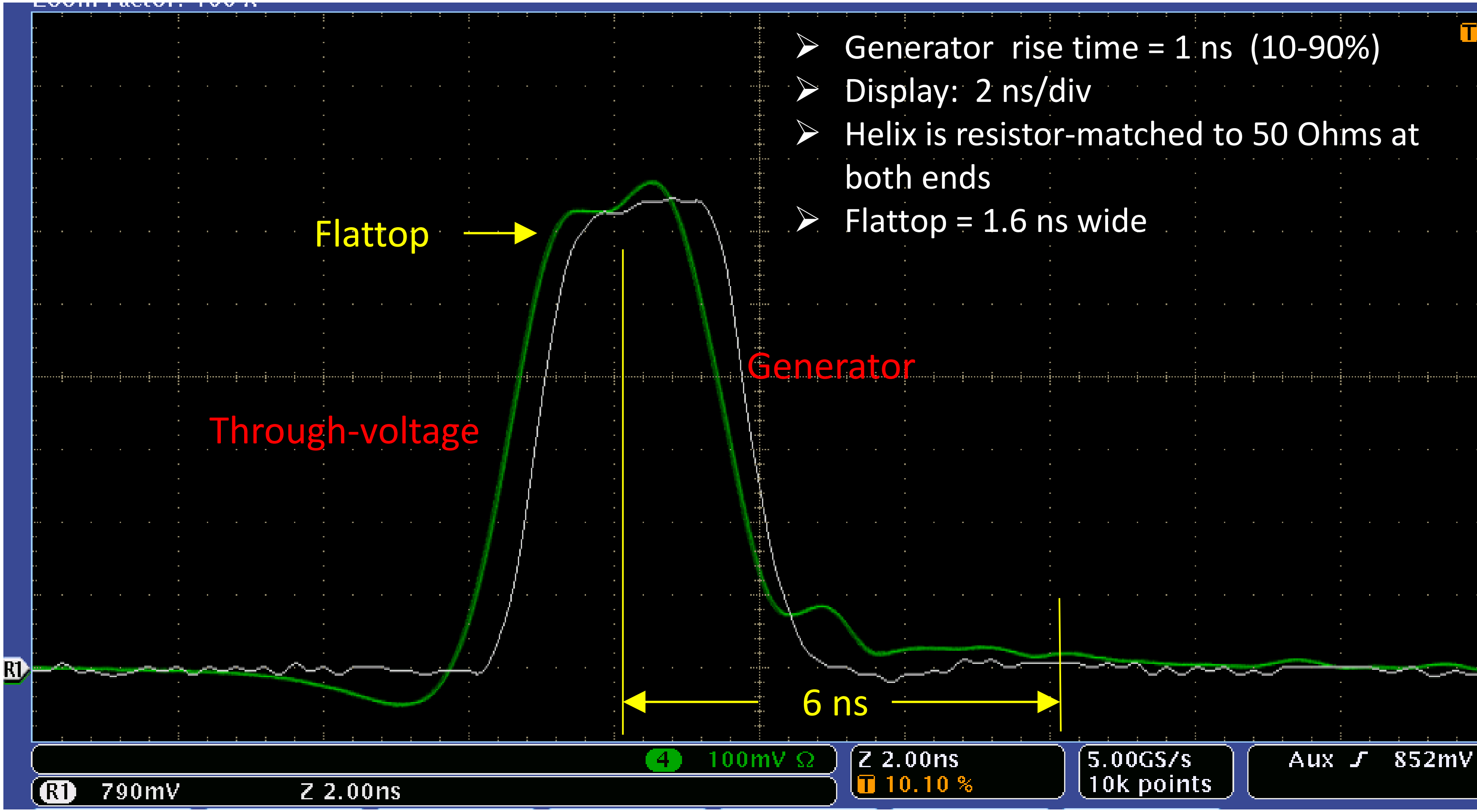
Zero voltage plane:

- Located 8.25 mm from electrode
- extends 20.3 mm above beam-center

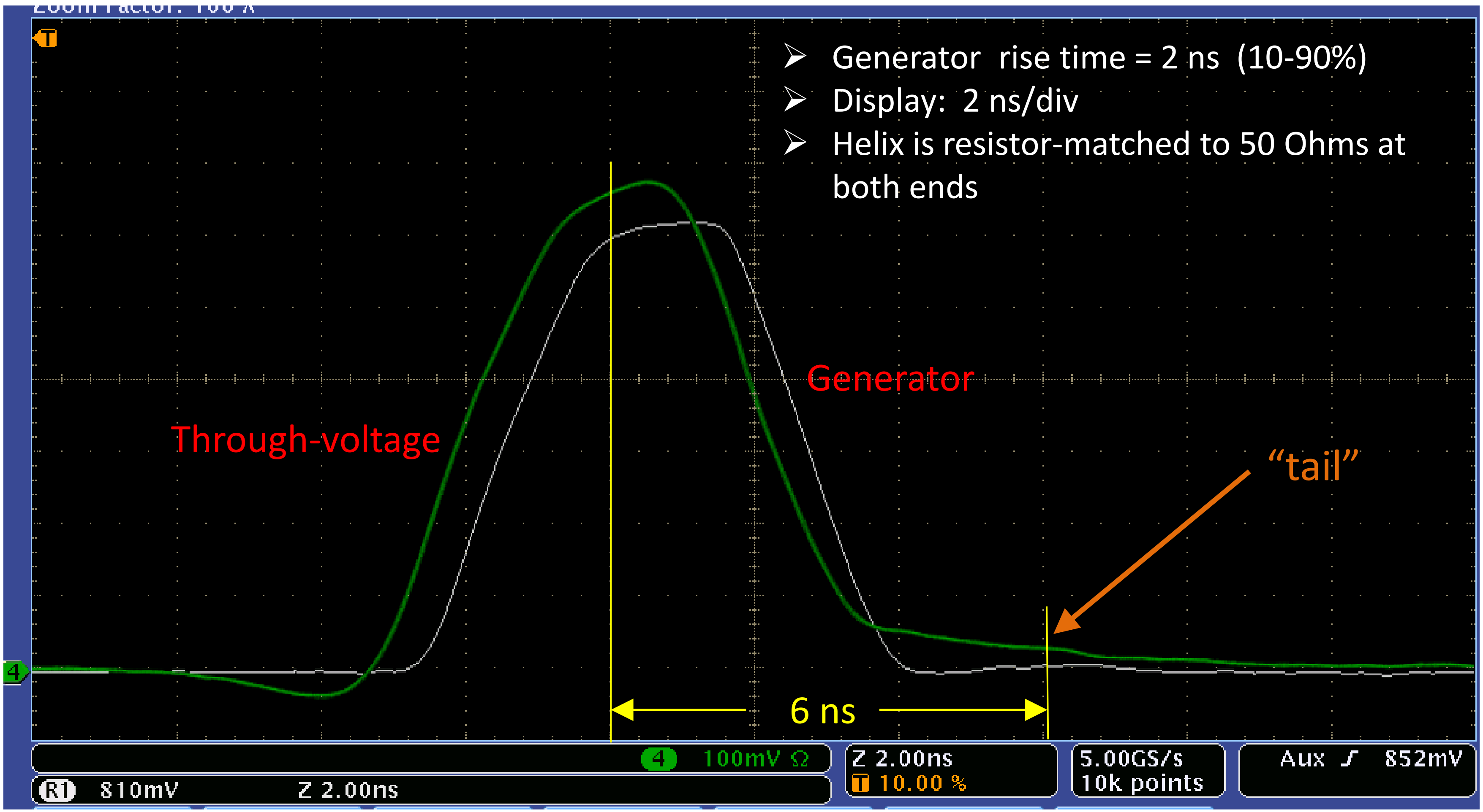
S21 measurement (w/ electrodes & zero voltage plane)



Through-voltage (w/ electrodes & zero voltage plane)



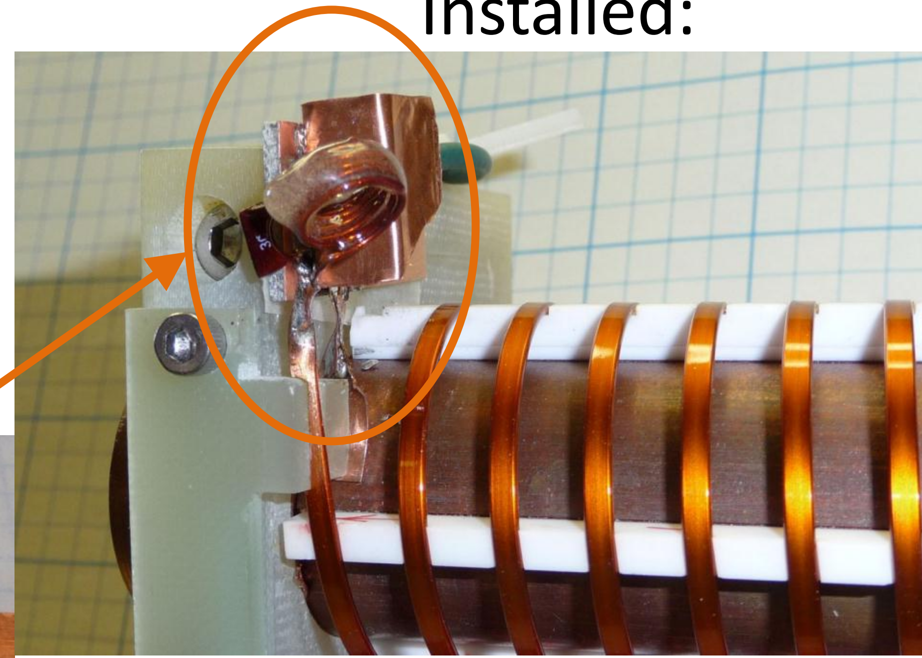
Through-voltage (w/ electrodes & zero voltage plane)

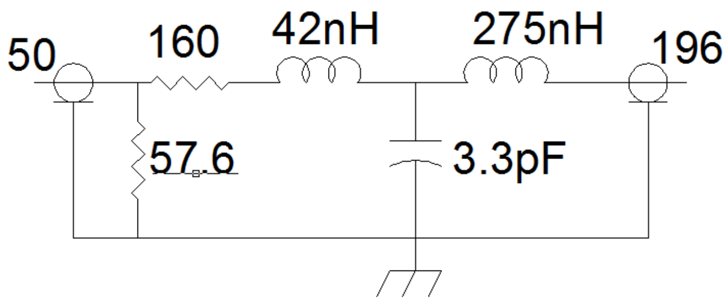


3-Pole Bessel filter

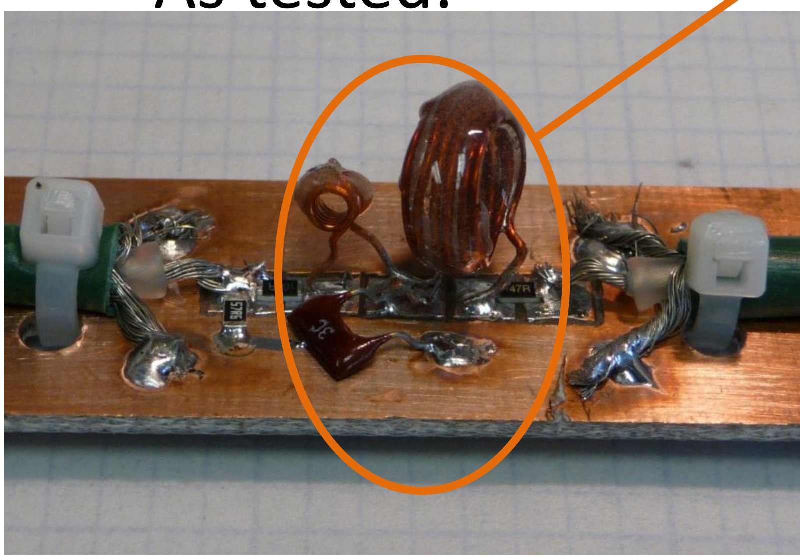
Question: Will the use of a filter improve the “tail” by attenuating the higher frequency magnitude and phase components?

Installed:





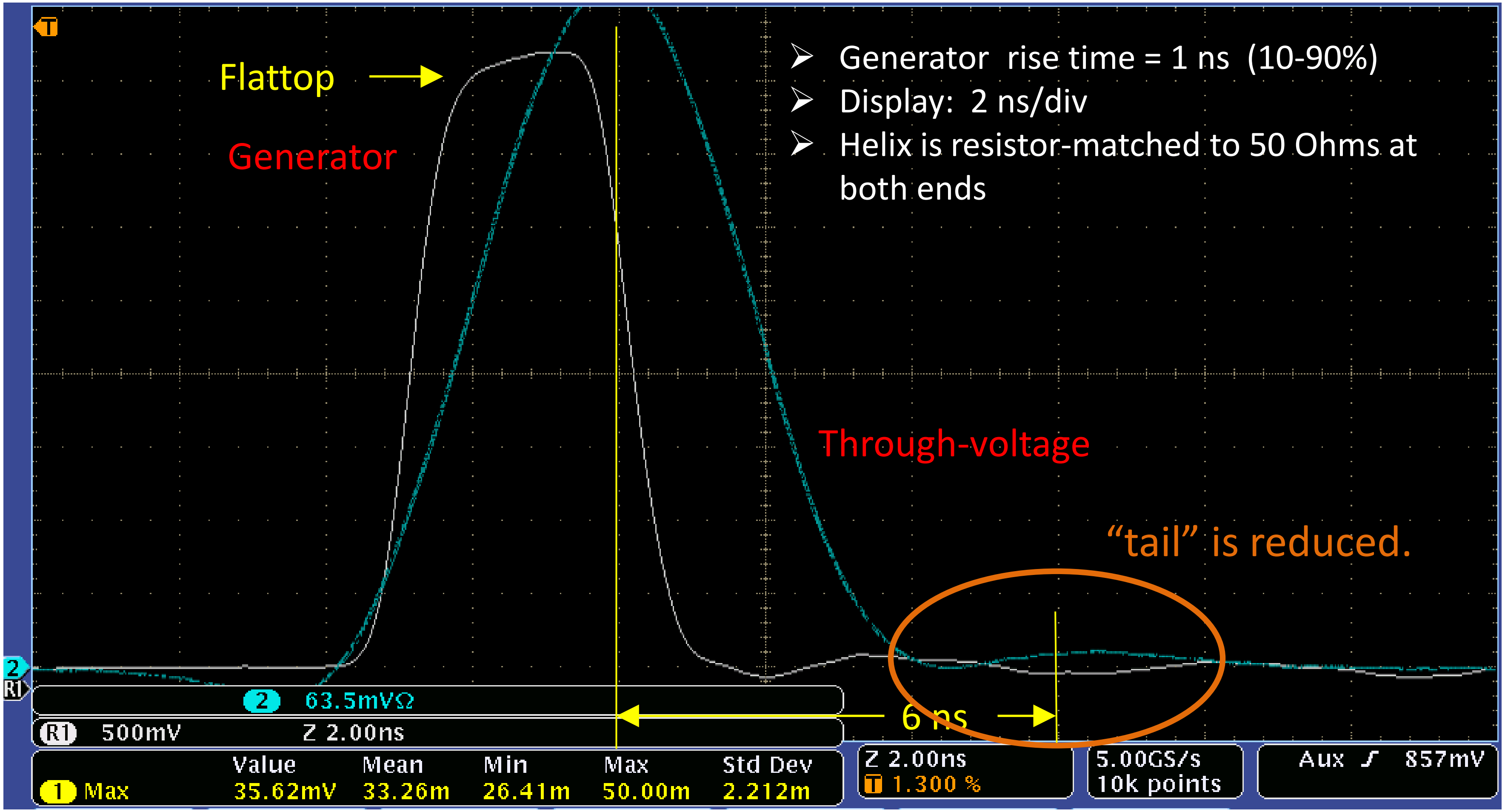
As tested:



3-Pole Bessel design

- Impedance Zin = Zo = 200 Ω
- Designed for f_C = 250 MHz
- Measured f_C = 200 MHz

Through-voltage (Bessel filter installed)



- Generator rise time = 1 ns (10-90%)
- Display: 2 ns/div
- Helix is resistor-matched to 50 Ohms at both ends

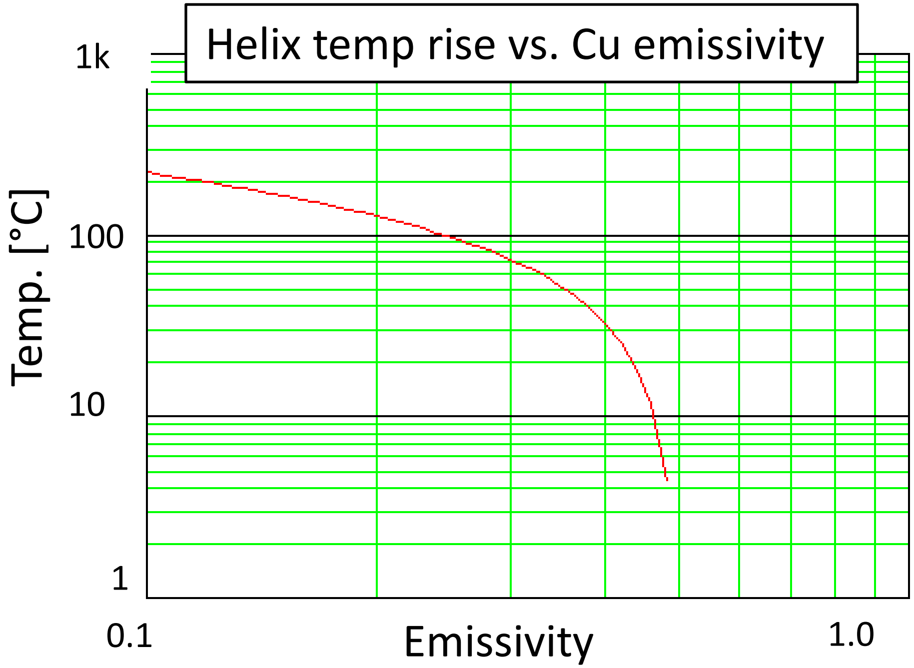
Helix temperature rise (resistive losses only)

- 400 V peak amplitude
- Duty factor = 90%
- Expression of temperature rise:

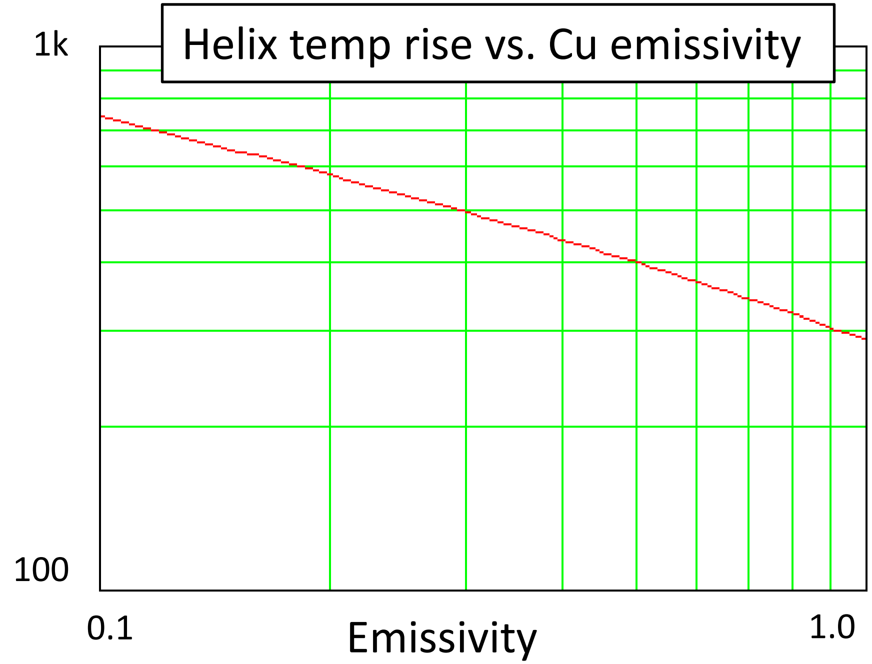
$$Tcu_n := \sqrt[4]{\frac{P_L \cdot DF}{em_n \cdot \sigma \cdot W_w} - (T_0)^4} - 273$$

where:
- P_L - I^2R power loss + beam power
- DF - duty factor
- em_n - emissivity
- σ - Stefan-Boltzmann constant
- W_w - conductor radiating width
- T_0 - ambient temperature

200 Ω Helix (skin effect losses = 2.2W/m @33MHz)

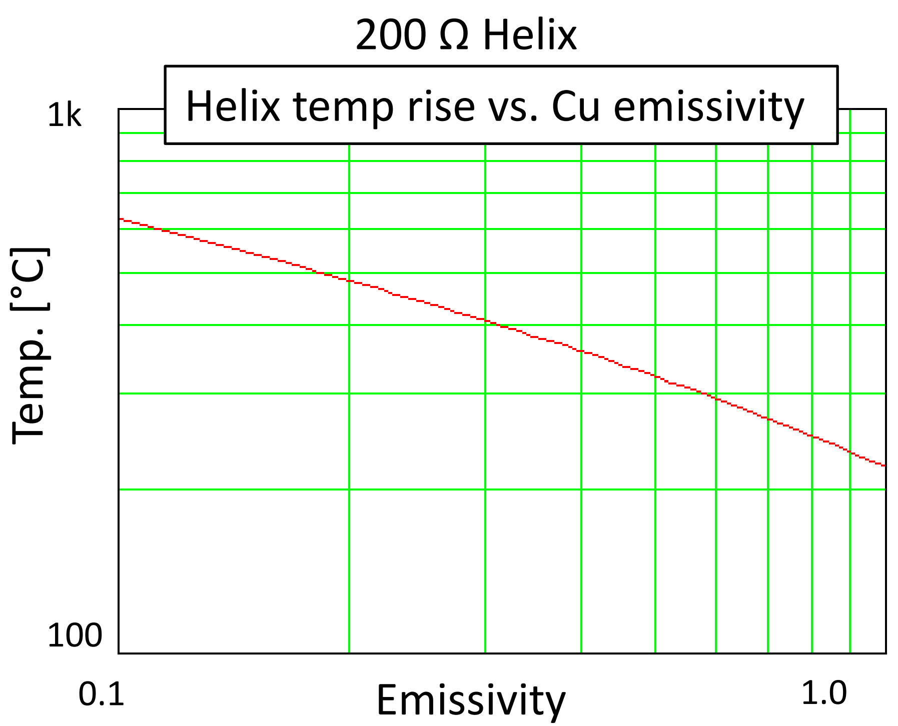


50 Ω Helix (skin effect losses = 35.5 W/m @33MHz)



Helix temperature rise (resistive losses + beam power)

- 400 V peak amplitude
- Duty factor = 90%
- 20 Watts of CW beam power absorbed by 1 m of helix



The Driver — Potential switches

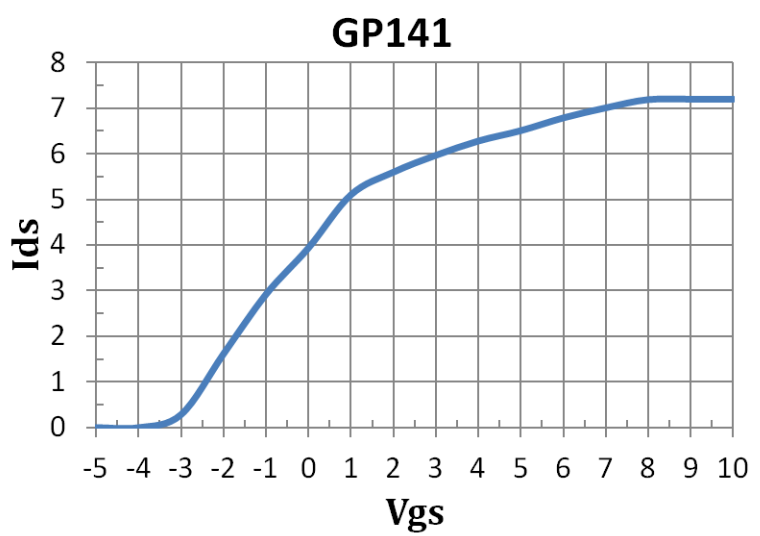
- Vacuum tubes having bandwidth ≥350 MHz
  - 3CPX800 (500 MHz, 0.6 Adc)
    - Plate capacitance limits rise time to ~3 ns
  - Eimac 8847 or Y503 (3 GHz, low DC current spec)
    - R&D needed to determine speed limit combining numerous tubes in parallel
- GaN FET transistors (>x10 faster and smaller than MOSFETs)
  - 600V parts are not available yet
  - 200V parts are available today
    - Very low capacitance suggests investigating a multi-cascode topology
    - Potential "show stoppers" are currently under investigation

GaN FET transistor

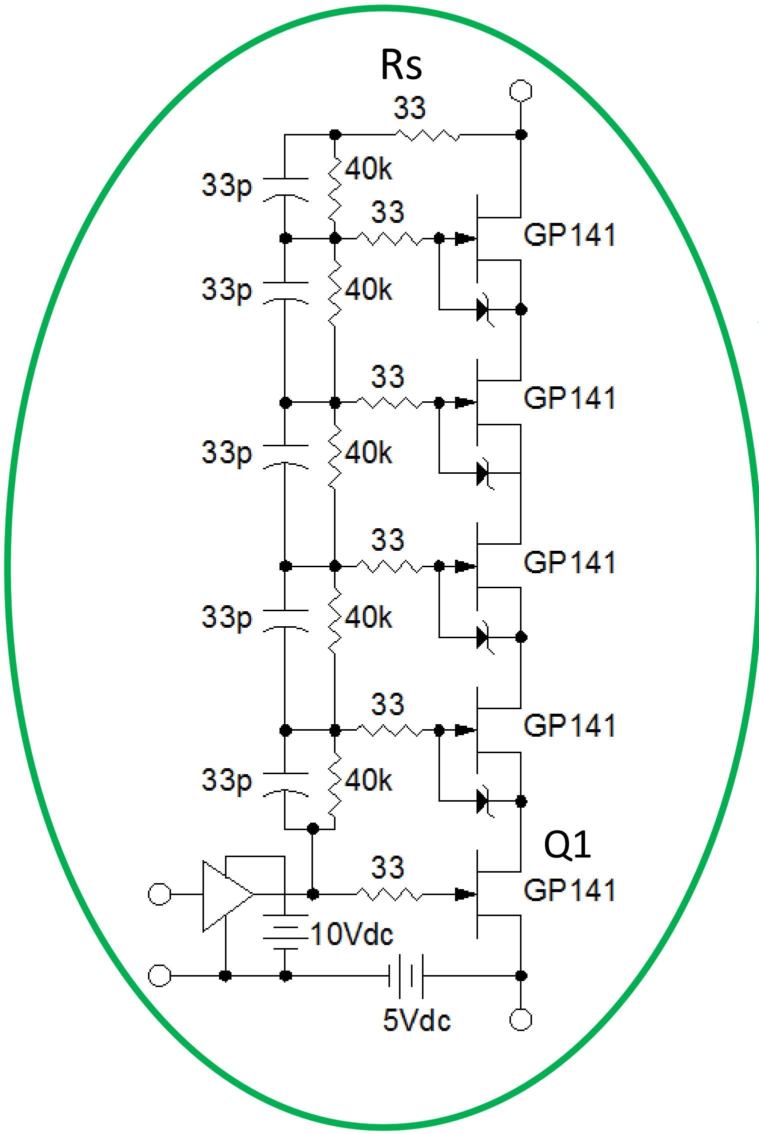
polyfet rf devices

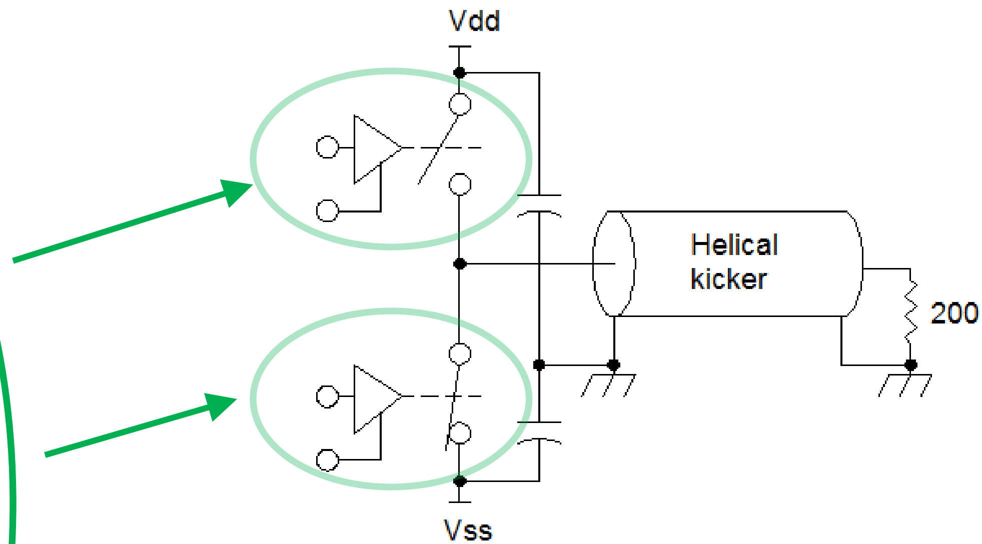
GP141

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
	Total device dissipation			40	Watts	
Bvdss	Drain breakdown voltage	200			V	Idss = 7mA, Vgs = -8V
Ciss	Common source input cap.		12.5		pF	Vds = 48V, Vgs = -8V
Crss	Common source feedback cap.		0.4		pF	Vds = 48V, Vgs = -8V
Coss	Common source output cap.		5.5		pF	Vds = 48V, Vgs = -8V
gm	Gain			1	A/V	
Rds	Drain to source resistance		0.51		Ohms	



Cascode switch scheme (one per helix)





Estimations for Vdd-Vss = 400V:

- Pds switching loss = 1.3 W @ 33MHz, 80 Vds each GP141
- Transition switching losses = 0.7 W each GP141, assuming 2 ns rise/fall time
- P_{Rs} = 35 W
- Q1 Gate-drive power = 60 mW @ 33MHz, 10 V, gate = 17 pF
- Rise/fall time <x2 rise/fall time of one GP141

Summery

- 200 Ω helical kicker is ready for mechanical design to build beam-ready prototype
  - Inclusion of a Bessel filter may help reduce "tail"
  - Bessel filter practical only if pulse rise time is sufficiently fast (~1 ns)
- Chopper temperature rise cannot be ignored
- There exists at least two switch schemes to pursue as a driver

Next things to do

- Mechanical design issues to be resolved
  - Brazing/high-temp soldering method(s)
  - Support structure design
  - Vacuum feed-thru choice/design
  - Thermal analysis
  - Surface conditioning to maximize radiated heat
- Electrostatics modeling
  - Minimize electrode size
- Find a suitable 200 Ω termination
- Complete cascode circuit development
  - Determine performance limits
  - Alternatively, design high-speed tube driver from what was learned