Evaluation of Narrow Band Circuits for High Intercept Point Devices in VHF and UHF Low Noise Amplifiers

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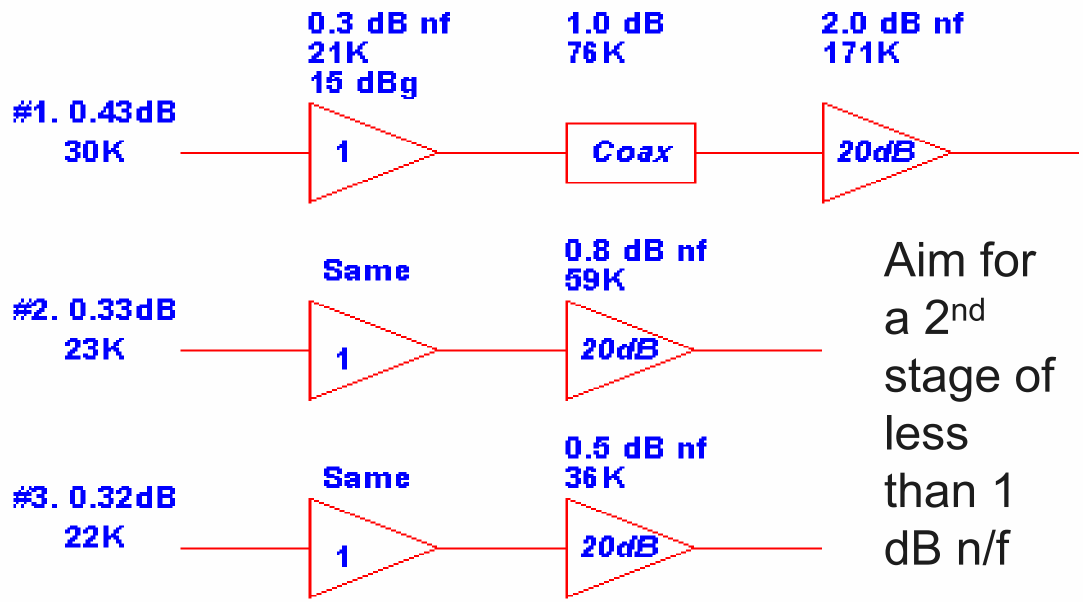
Devices: Past and Present

- The original development of small signal GaAs-FETs, HEMT's and pHEMTs, with excellent noise figures, have a $P1dB_{(OUT)}$ typically between +5 to +8 dBm.
- In today's RF environment, these high gain devices are easily over driven producing IMD from signals in and out of band.
- Possible solutions to reduce IMD's is to use +10 to +20 P1dB devices with filtering.

LNA's & System Noise Figure



Aim for a 2nd stage of less than 1 dB n/f

For every tenth a dB n/f lowered in EME systems (with low Ta), improves sensitivity approximately 0.5 to 1 dB from 0.3 to 10 GHz. The limits are system, galactic, and moon noise.

Pn = log10 (k Ts B)

$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1}$$

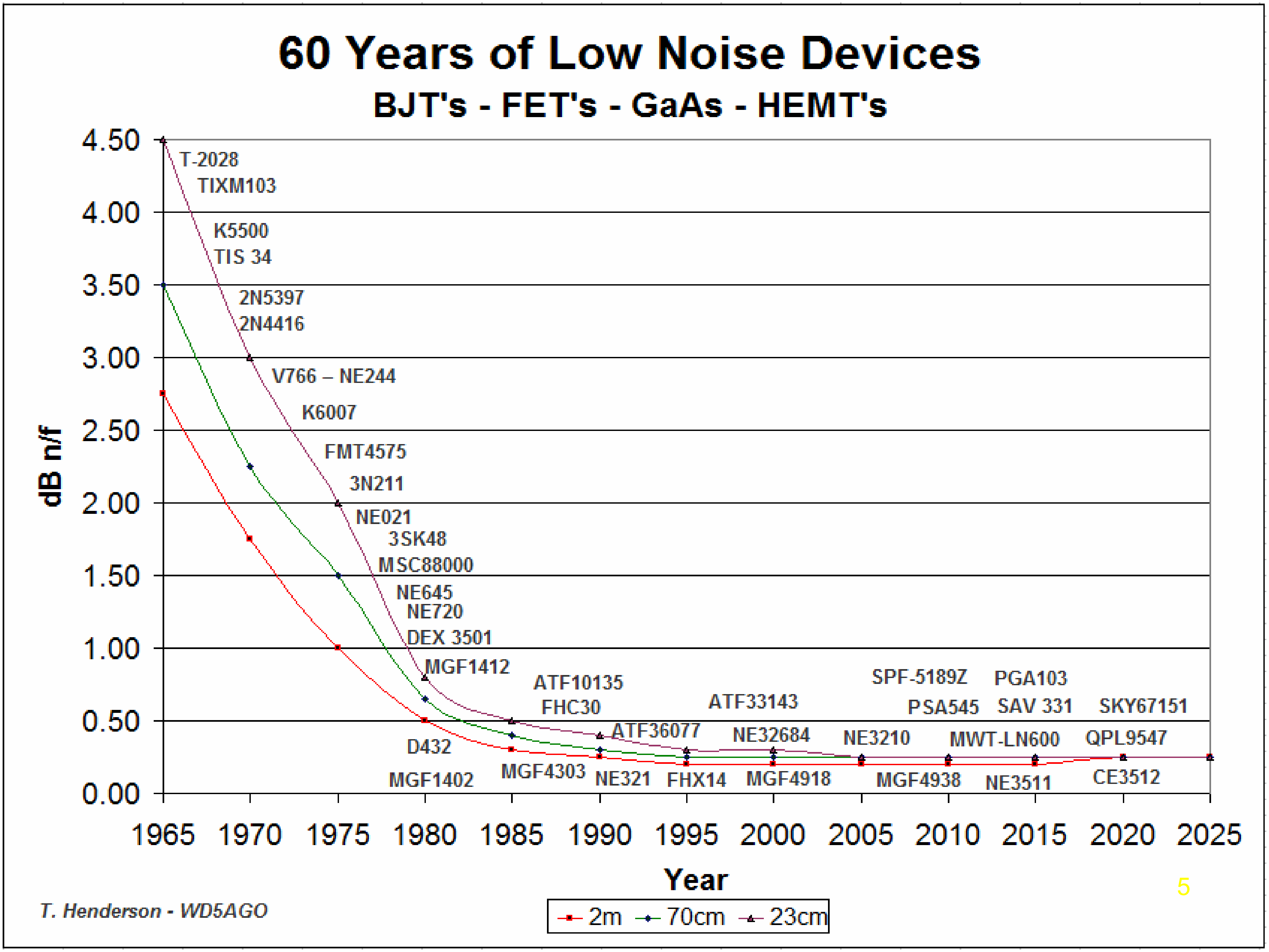
$$NF = 10 \log F$$

NF(dB)	T (K)
0.1	7
0.2	14
0.3	21
0.4	28
0.5	**35**
0.6	43
0.7	51
0.8	59
0.9	67
1	**75**
1.1	84
1.2	92
1.3	101
1.4	110
1.5	**120**
1.6	129
1.7	139
1.8	149
1.9	159
2	170

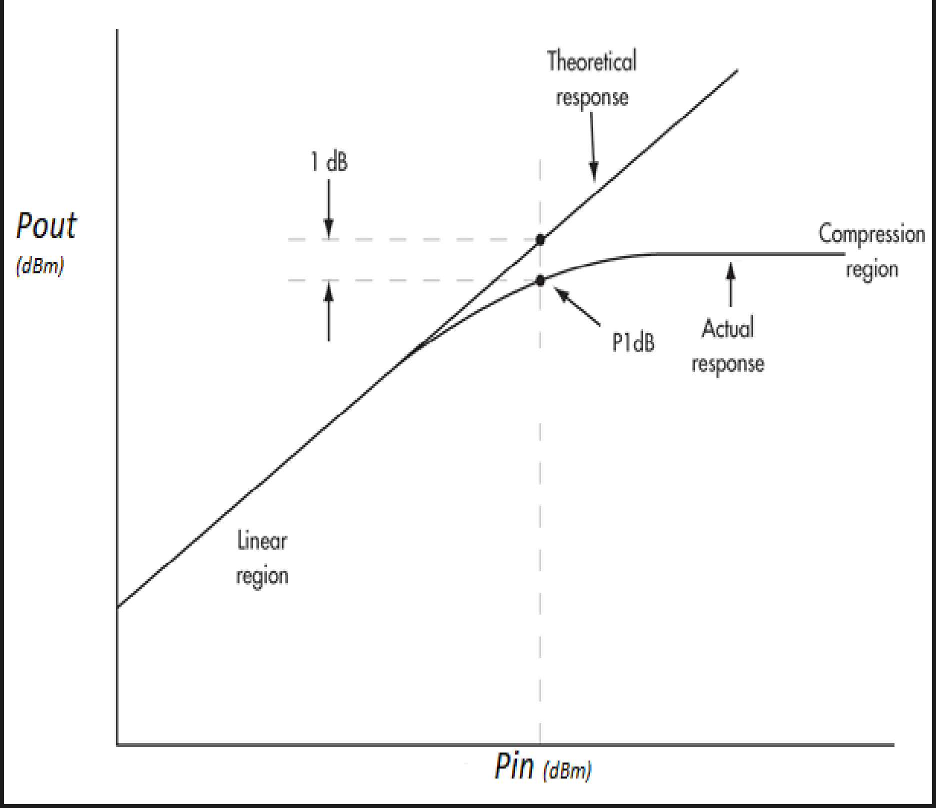
Low Noise Device's – From 60's to Present

• Parametric Amplifier (paramp)	1-3 dB n/f
• Bipolar: PNP, NPN	2 dB
• JFET's	0.8 dB
• MOSFET's	0.7 dB
• GaAsFET – MESFET's	0.5 dB
• HEMT – MODFET's	0.4 dB
• pHEMT	0.3 dB

- mHEMT (50 nmg, mostly in die packaging)
- GaN HEMT (not as low noise yet)


60 Years of Low Noise Devices
BJT's - FET's - GaAs - HEMT's
dB n/f
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
T-2028
TIXM103
K5500
TIS 34
2N5397
2N4416
V766 – NE244
K6007
FMT4575
3N211
NE021
3SK48
MSC88000
NE645
NE720
DEX 3501
MGF1412
ATF10135
FHC30
ATF36077
ATF33143
NE32684
SPF-5189Z
PSA545
NE3210
PGA103
SAV 331
MWT-LN600
SKY67151
QPL9547
D432
MGF1402
MGF4303
NE321
FHX14
MGF4918
MGF4938
NE3511
CE3512
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
2m
70cm
23cm
T. Henderson - WD5AGO

P1dB Compression Point. IP3 is about 10 dB above P1dB. Problematic input signals powers are approximately -10 to -25 dBm.



Which Power method to use?
Industry specifies linear power amplifier performance, typically, using P1dBout or OIP3, while some LNA manufactures may use P1dBin. However, P1dBout is easier to note and to determine the drive levels to the next receiver stage. Therefore, just subtract the LNA's dB gain from P1dBout (P1dB) to know the maximum drive level for linearity. P1dB is power in dBm.

Discontinued (NOS) LNA Devices with mid IP Performance under 0.5 dB n/f

- ATF 54143, 33143 and 34143 (800u, +11 to +15 P1dB)
- RFMD: FPD750SOT89 (1500u gate)
- Celeritek: CFB0301 (600u, +15 P1dB)
- Filtronic: LP7612P70 (+20 P1dB)
- MicroWave Tech: MwT-LN600 (20 dBm @ 12 GHz)
- Mitsubishi: MGF 1801 and similar power FET's (+20 P1dB)
- One approach to higher P1dB performance is operate the Device at its max rated current and higher voltage. An improvement of 3 dB was noted from 3v @ 25mA to 3.6V @ 40mA.

Current HEMT-FET and MMIC Devices

Device	P_{1dB}	Gain	Noise Figure	Frequency
CE3512k2	+9	14	0.3	0.1 – 12 GHz
SAV 331	+19	24	0.5	0.01 – 4 GHz
SKY65050	+10	16	0.5	0.45 – 6 GHz
SKY67183	+20	17	0.6	0.4 – 6 GHz
PGA 103	+22	16	0.6	0.05 – 4 GHz
MAAL-011078	+17	23	0.5	0.7 – 6 GHz
BGU8051X	+19	18	0.45	0.3 – 1.5 GHz
TQP3M9037	+20	20	0.4	0.7 – 6 GHz
MAAL-010705	+18	21	0.5	0.5 – 1.6 GHz
PSA-545	+20	20	0.8	0.05 – 4 GHz

LNA Design - Input Circuits

- Direct Inductive or Capacitive Match (Q < 3)
- Lumped Element-LC: Traditional Coil and Cap, forming a Tank circuit. (Q 50 – 200)
- Stripline or Microstrip (Q 400 – 700)
- Helix (Q 600 – 1000)
- Cavity – ¼ λ Line (Q 1000 – 5000)

23cm HEMT Inductive matched with 0.4 dB n/f

MITSUBISHI
ELECTRONIC DEVICE GROUP

MGFC-4400 SERIES
MGF-4300A SERIES
MGF-4400A SERIES
MGF-4900B SERIES

Measured Noise Figures as low as any VHF LNA. Near perfect match using Series L for devices from 0.7 to 3 GHz. Very large BW ~ 800 MHz! Performance is conditional stable on VHF with this technique, even with Ls. Circuit not advised below 700 MHz.

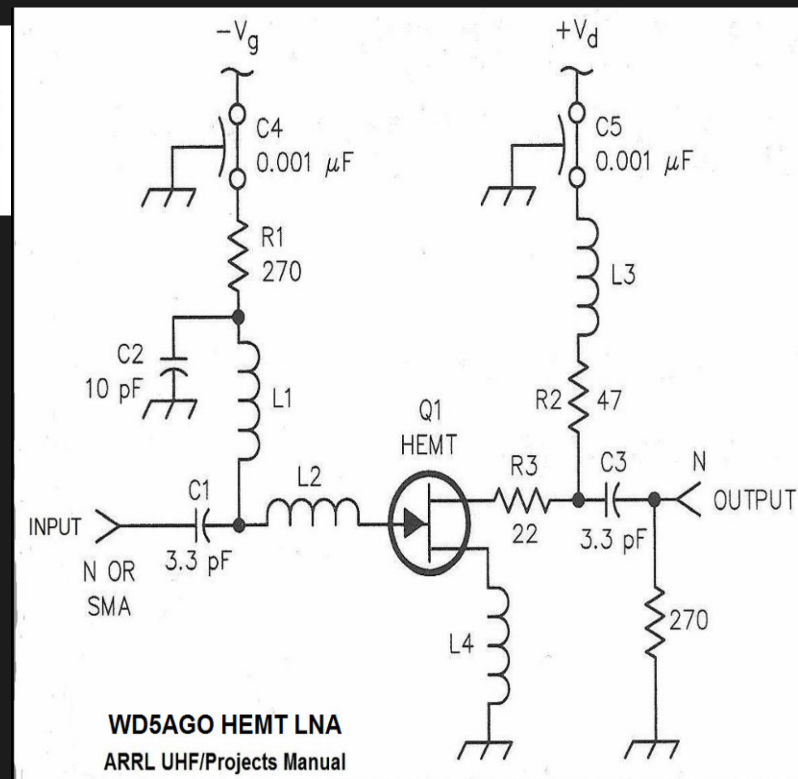
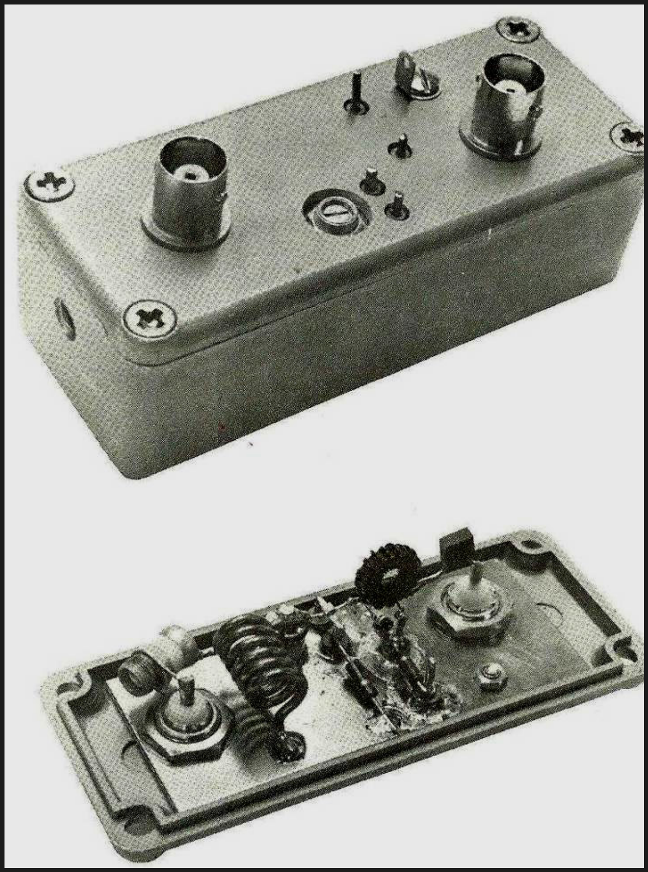
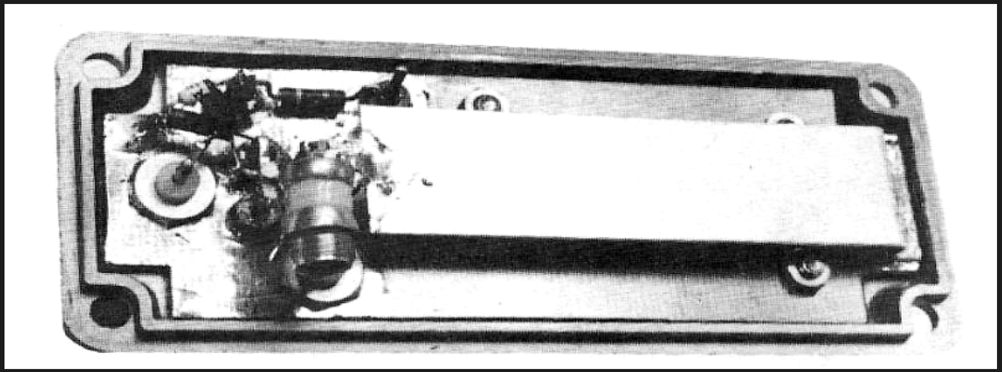


Fig 1—Schematic of the 1296-MHz HEMT preamplifier. Resistors are ¼-W carbon film or composition. Capacitors are 100-mil ATC chips. WD5AGO 1989 - MGF4303, FHC30LG, NE32184, ATF36077

W6PO Designs using the D432, DXL2501 or MGF1402, +5 P1dB





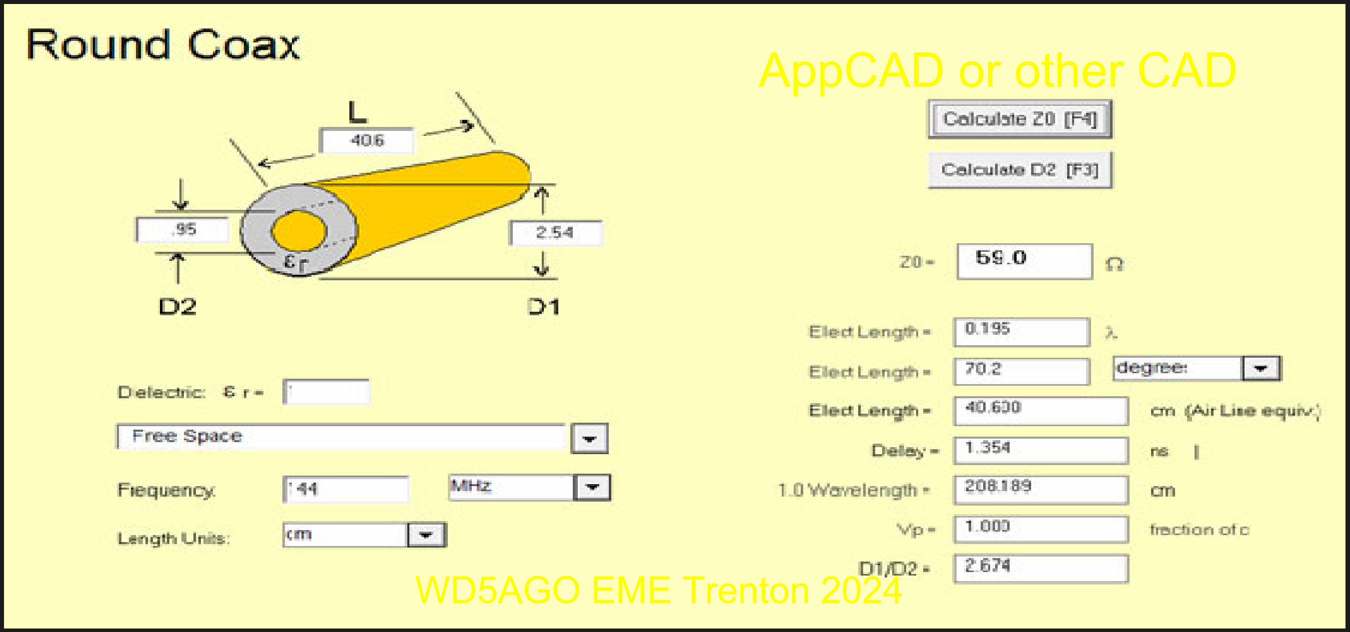
Incorporating input filters as part of the Device matching network to reduce losses. Lowest noise figure typically operated with 2V @ 12 mA.

- **Cap coupled L/C Tank for 144 MHz**
- **Cap coupled Air Microstrip for 432 MHz**

Cavity LNA circuits for VHF and UHF to achieve narrower BW

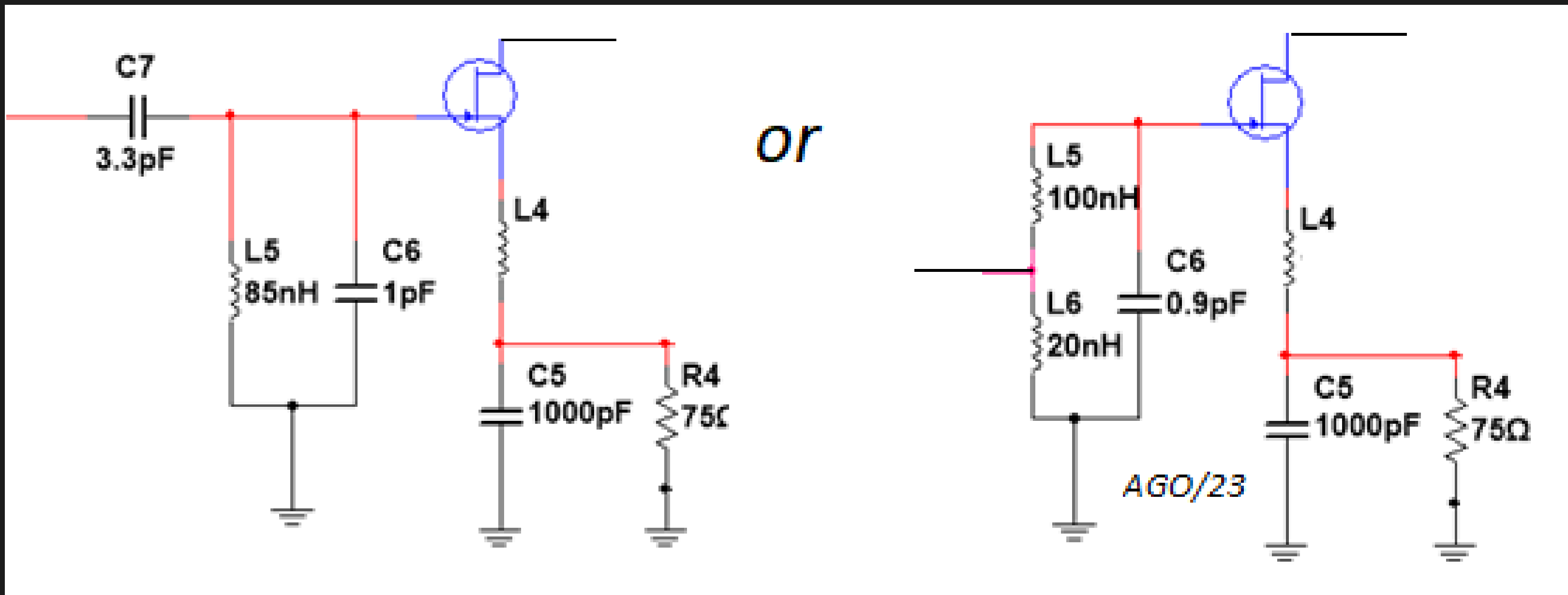
- Published designs in the 432 MHz and Above News Letters by K4QIF, WA7CJO, WD5AGO and others.
- Tapped L (Prefer due to mechanical stability) or Capacitive Coupled. Silver plating is a bonus!

Impedance of the input Cavity Line is not critical. Values from 50 to 80 ohms have worked fine. Line length will depend on the loading effects of the Device. A Low Z device will require the line to be shorter.



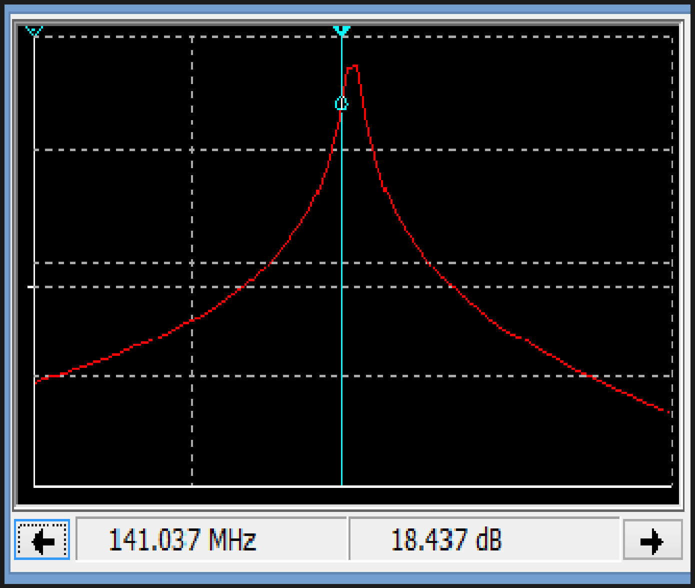
AppCAD or other CAD

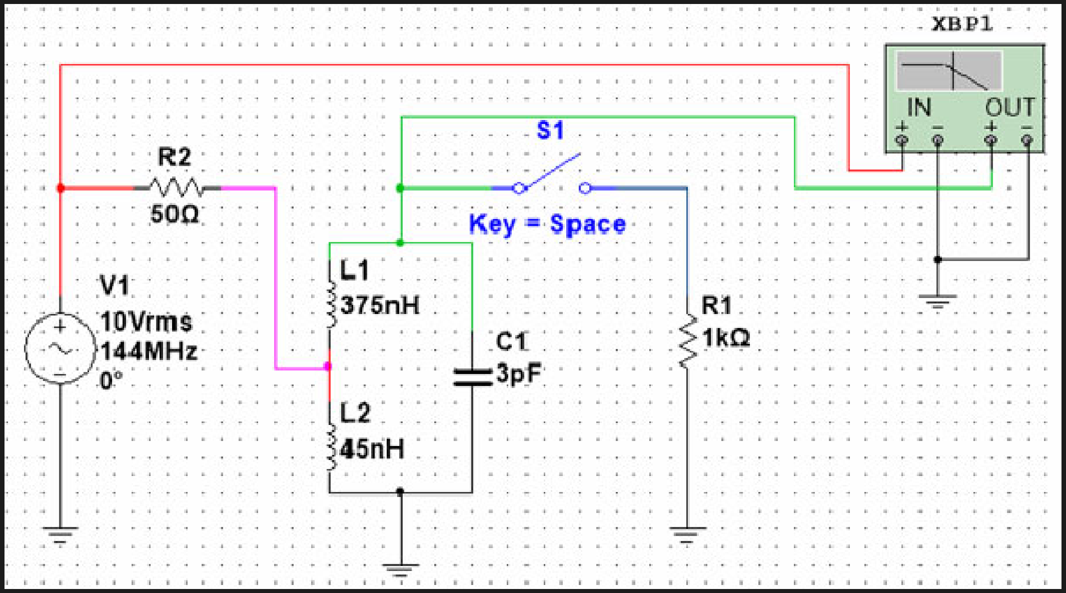
Select low loss components for the input and adjust for lighter capacitive coupling or low inductive tap to reduce BW.



Capacitive or Inductive Coupling

Typical Q for a 144 MHz Network, using Tapped L, w/o load or Device.



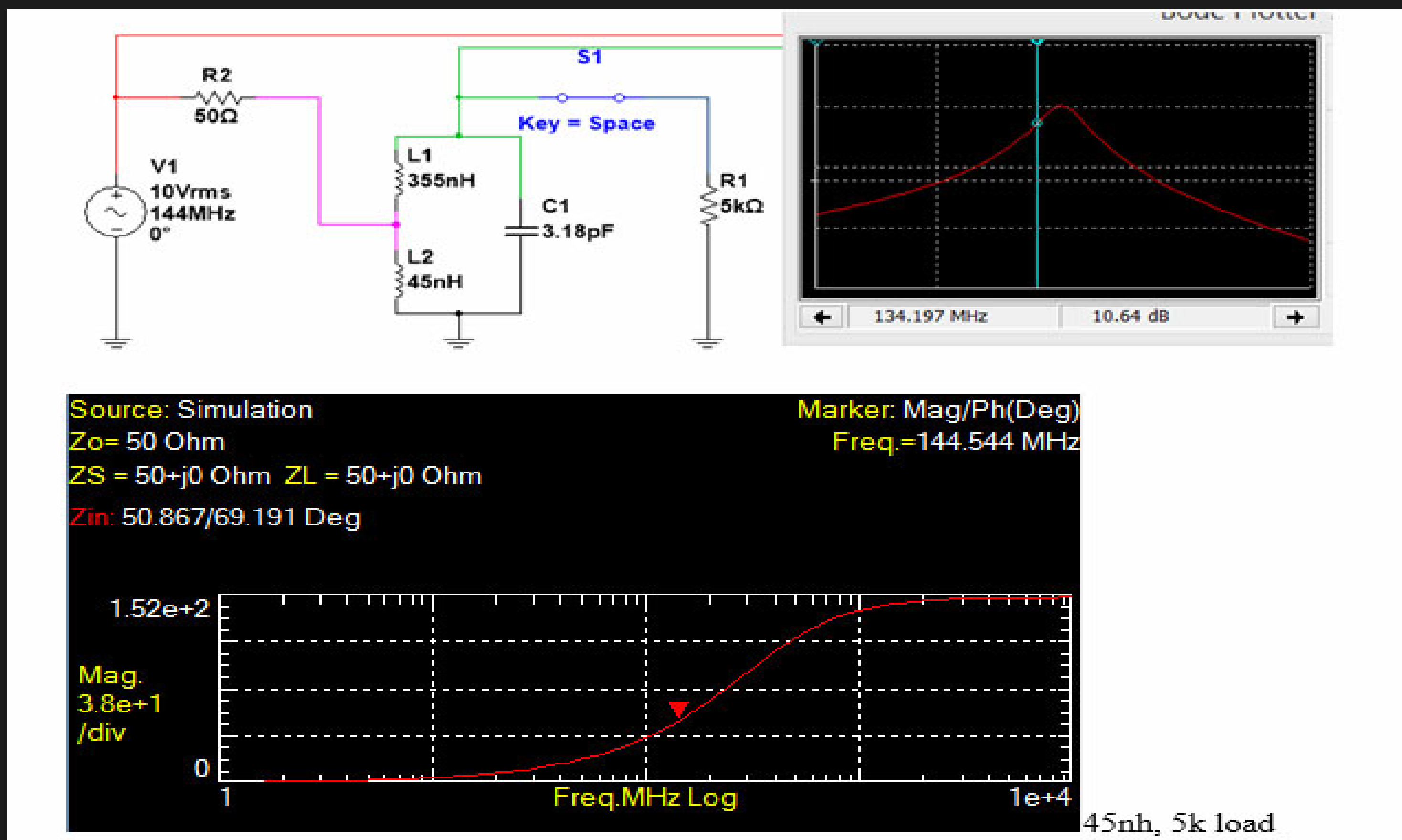


$$Q_p = \frac{R}{\omega_0 L}$$

$$BW = \frac{Fr}{Q}$$

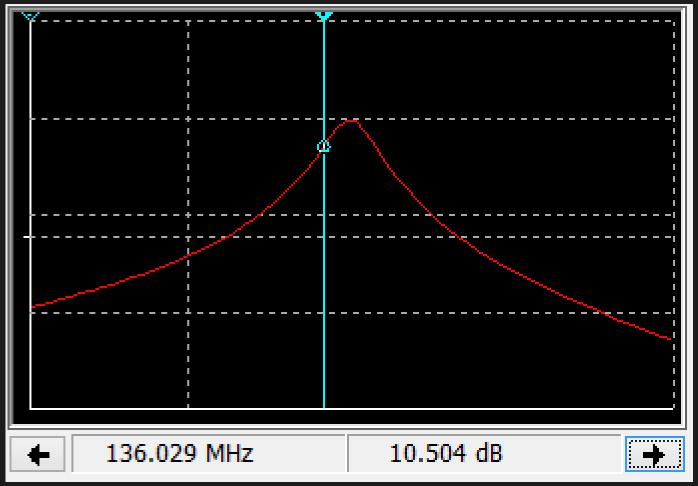
$$Q_s = \frac{\omega_0 L}{R}$$

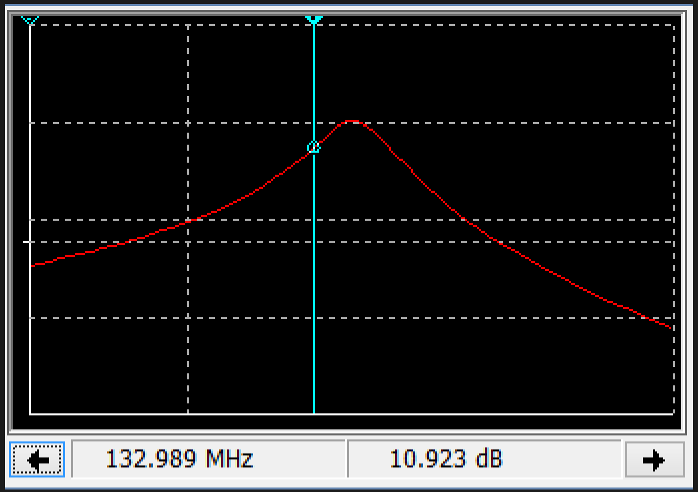
With 5k Load, 14 MHz added BW. Placing inductive tap closer to ground, narrows BW however, reduces Zin.

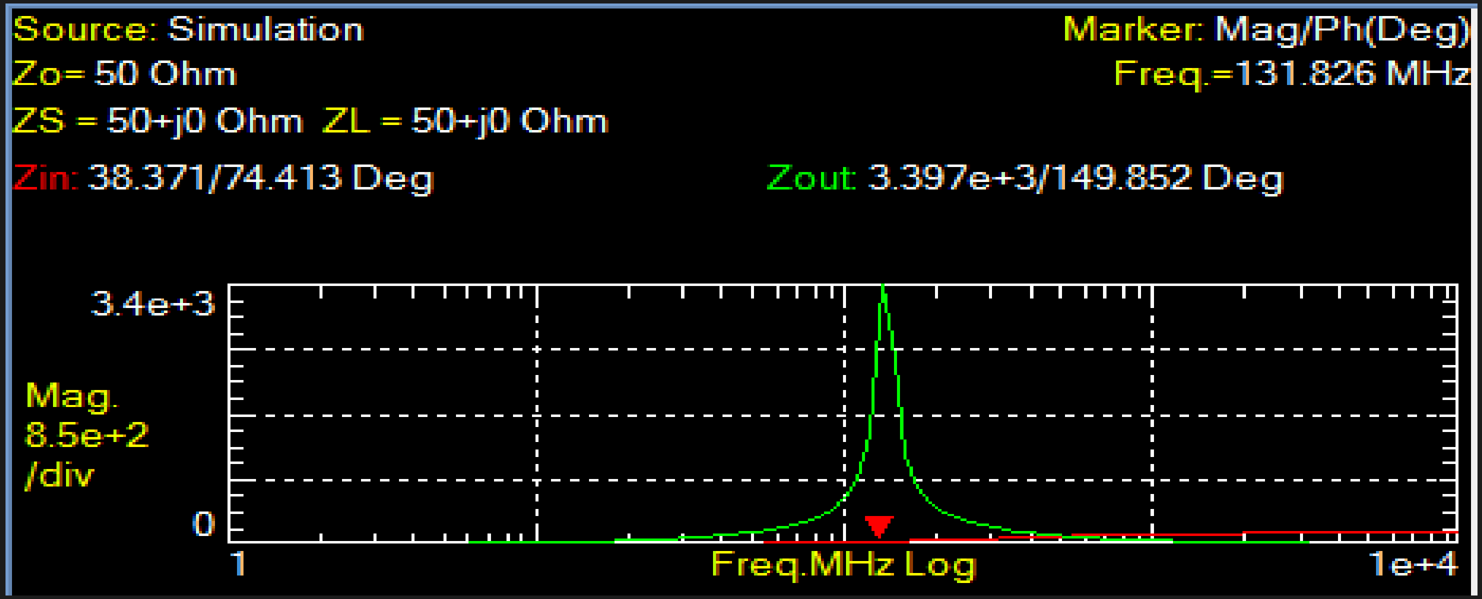


35 nH Tap, 5k Load

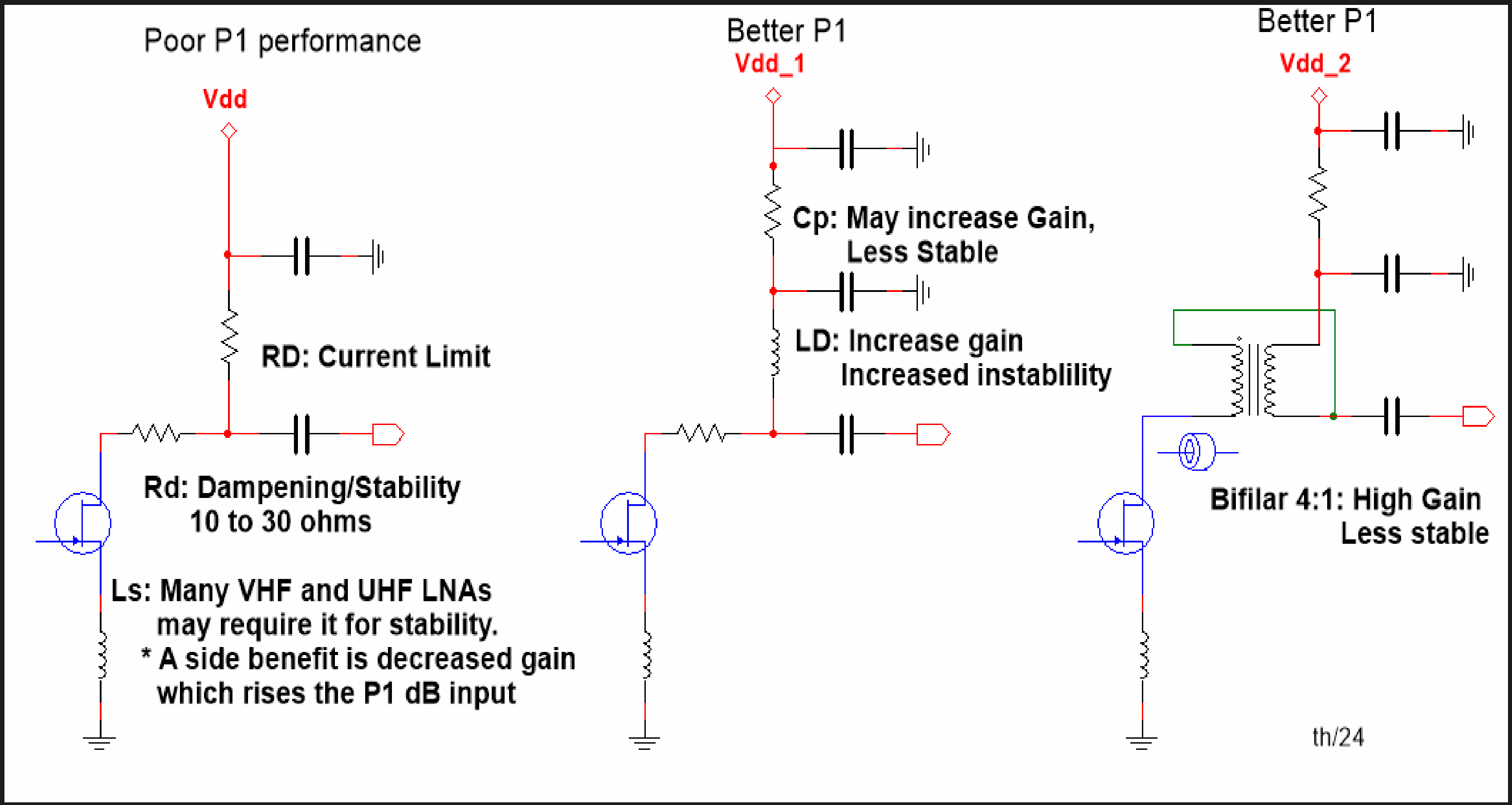
75nH Tap, 5k Load





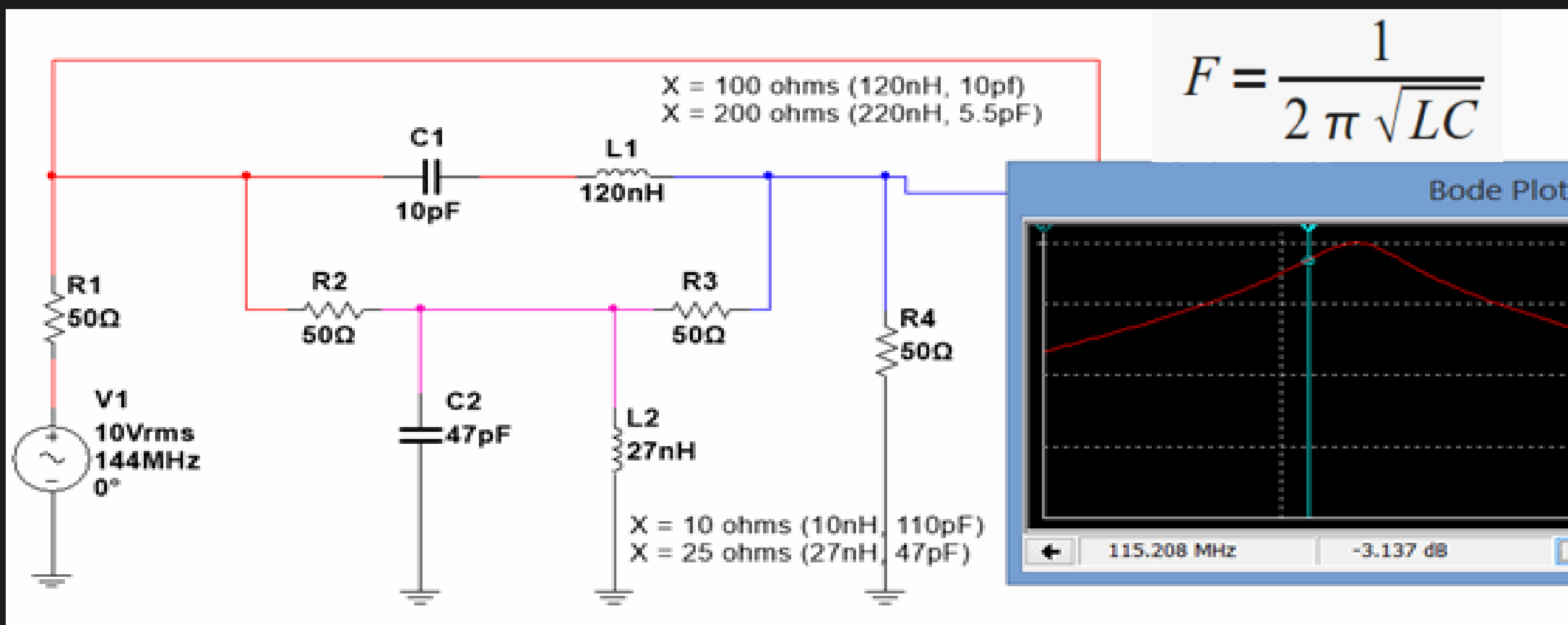


Output Circuits: R/C's, L/C's, Transformers, or a Diplexer.



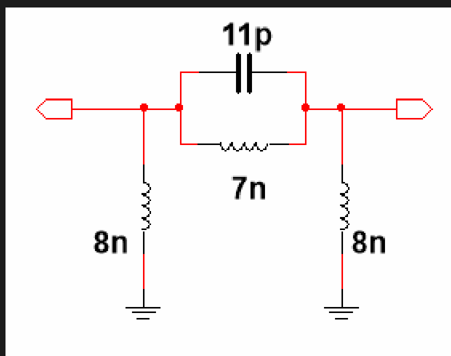
Bridged Tee Diplexer Circuit

Design L&C for resonance. Make the shunt circuit reactance's each equal 10 to 25 Ω and the series circuit equal 100 to 200 Ω. 144 MHz examples below with a Q of approximately 2 and 4:

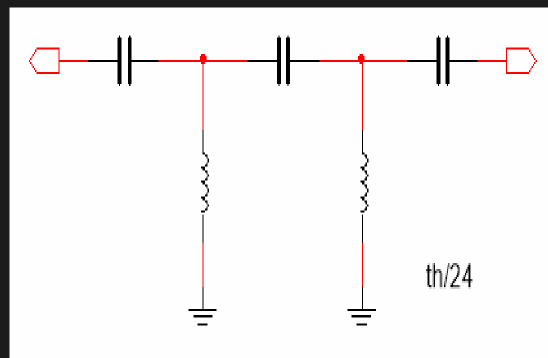


Additional Output Filtering

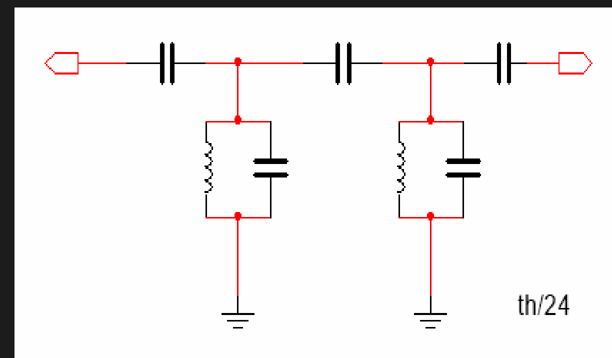
3 pole Elliptic HP

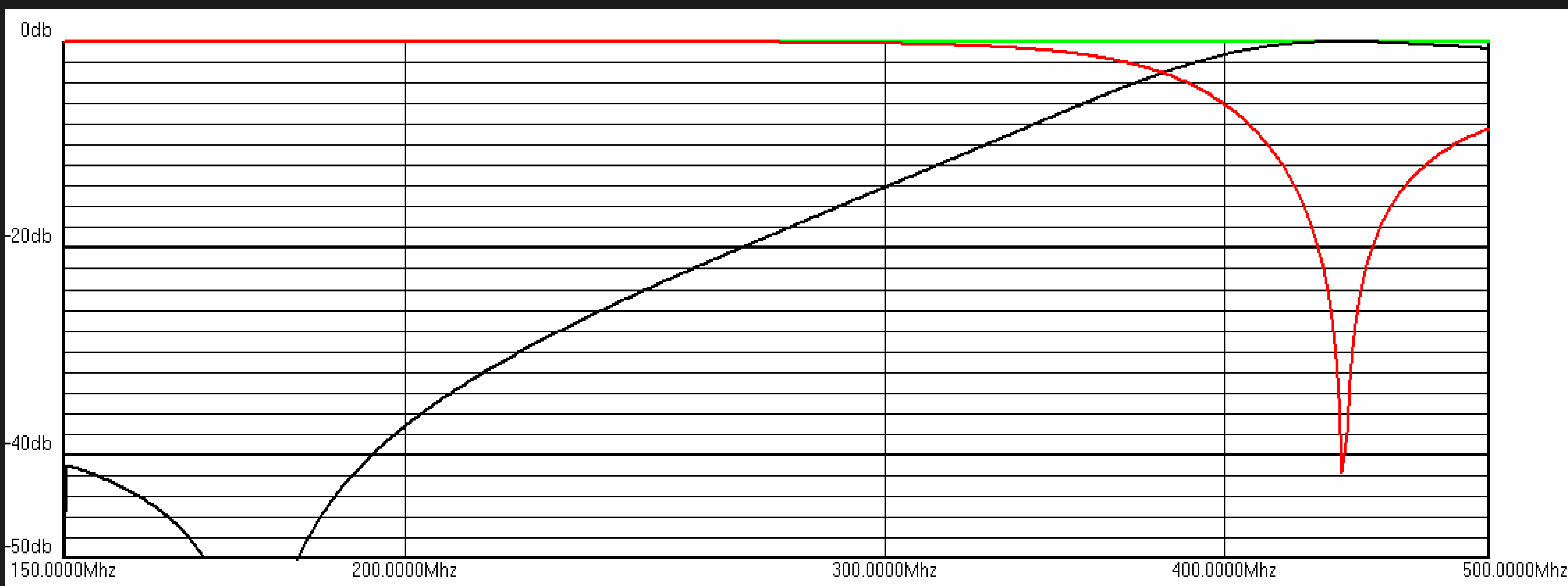


5 pole HP



BP Coupled Resonator

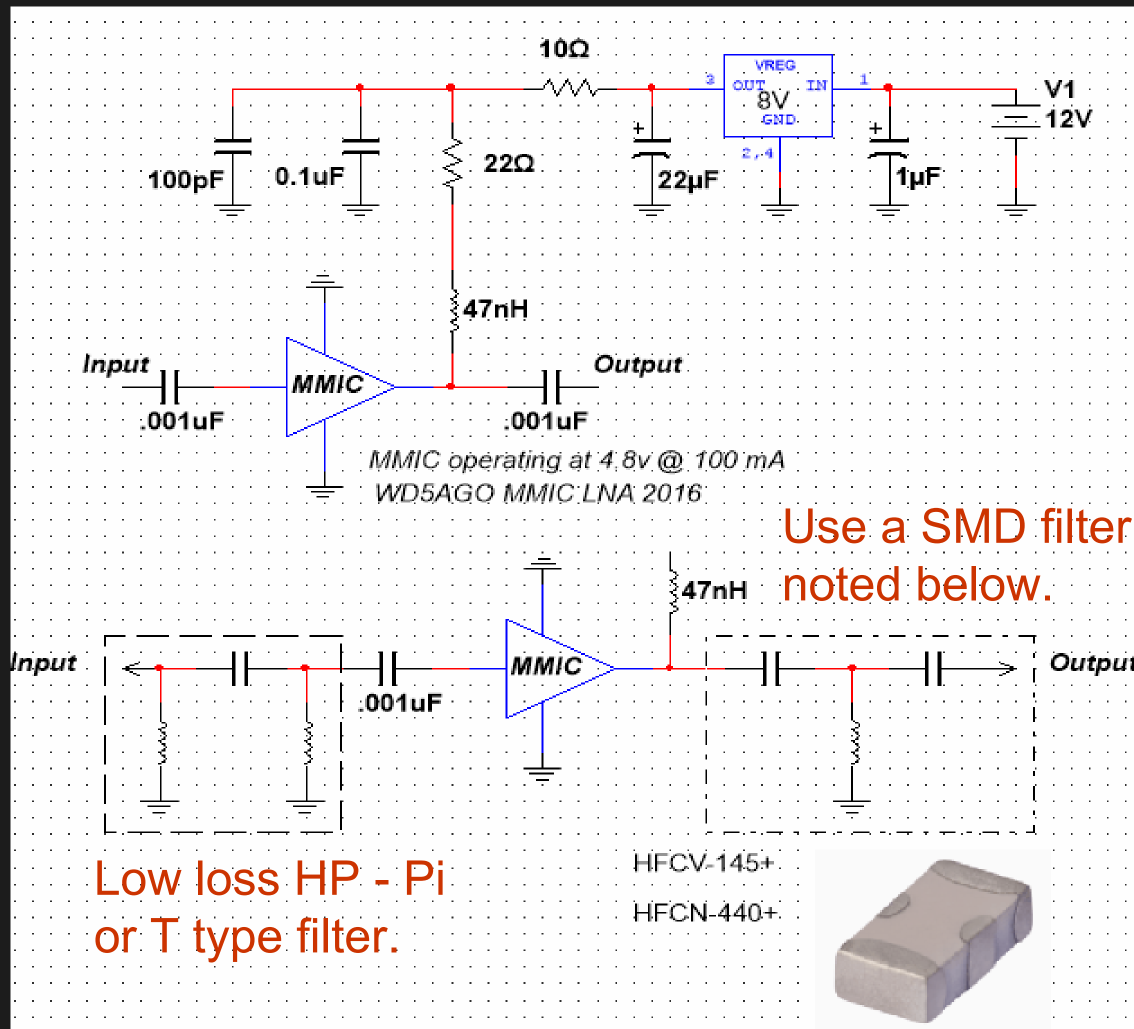




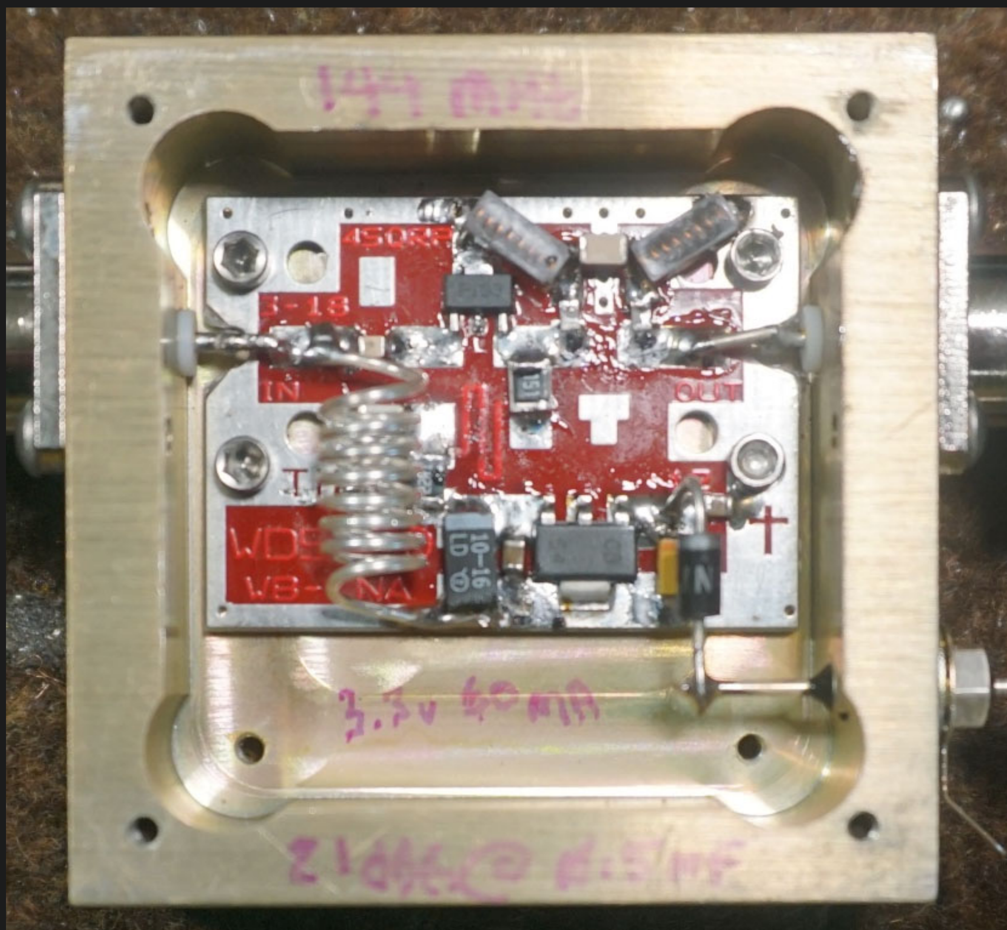
MMIC Circuit and using a SMD Filter

All LNA circuits should have decoupling circuits used in the power supply to reduce regulator noise. Using a 10 ohm dropping resistor also makes current measuring easier.

To narrow the MMIC's BW, add input and output filtering circuits for a n/f of 0.5 to 1dB from 50 to 400 MHz.

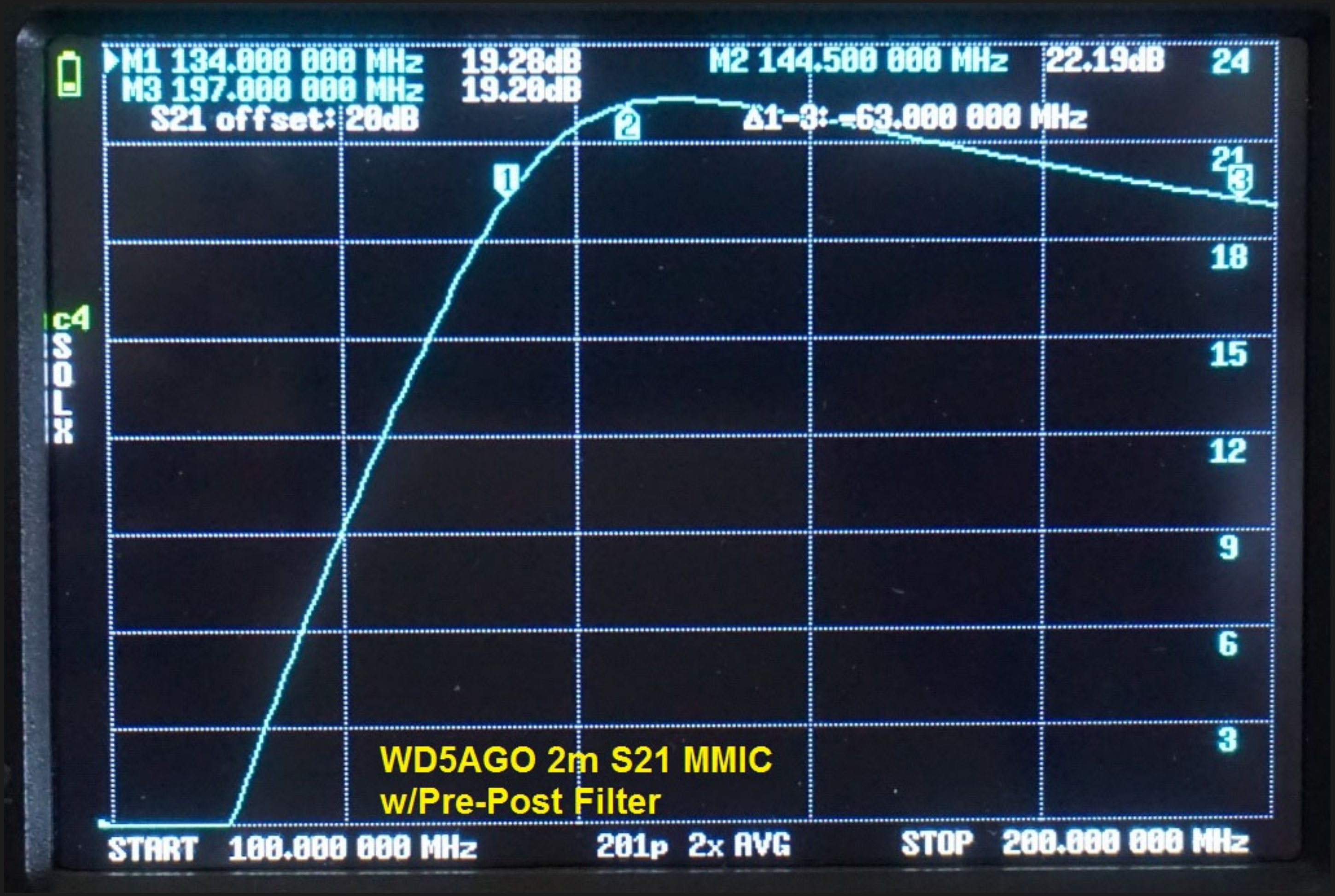


2m MMIC LNA w/ T type-Elliptic HP input and Pi type HP on output filtering.



- PGA-103 MMIC 3.3V @ 60 mA
- 21.5 dBG, 0.5 dB n/f, +16 P1 dB
- Not a bad n/f for 6 or 2m EME
- Alter output filter with HFCV145

2m MMIC S21 results

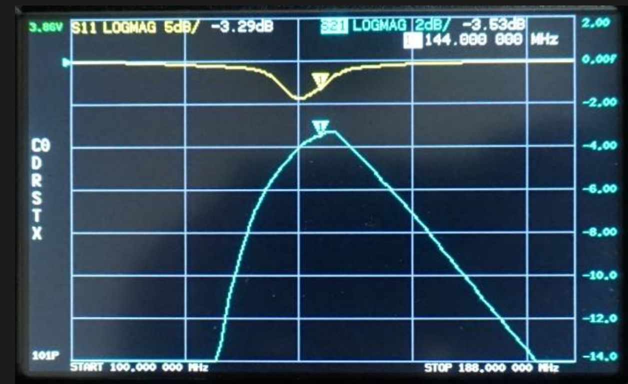


PHEMT Inductive LC Match Analysis

7 turn HELIX 1t Tap ~ 25 ohms,

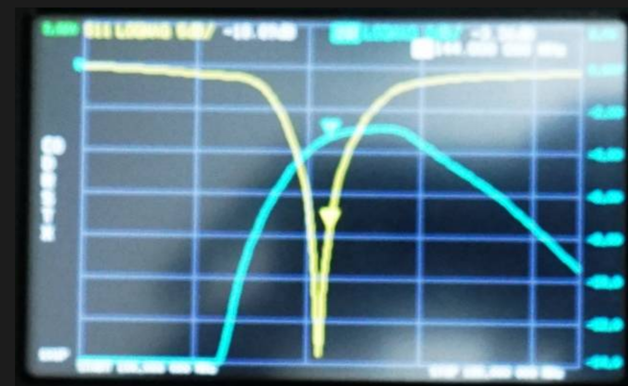
Narrower BW, less gain and higher n/f.

WD5AGO 2m Helix LNA



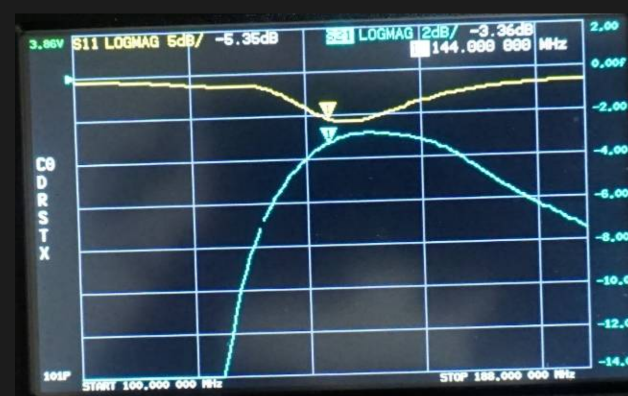
2t Tap, ~ 50 ohms, with Ls. 15 dB RL, 24 dBG.

Optimum n/f and gain.

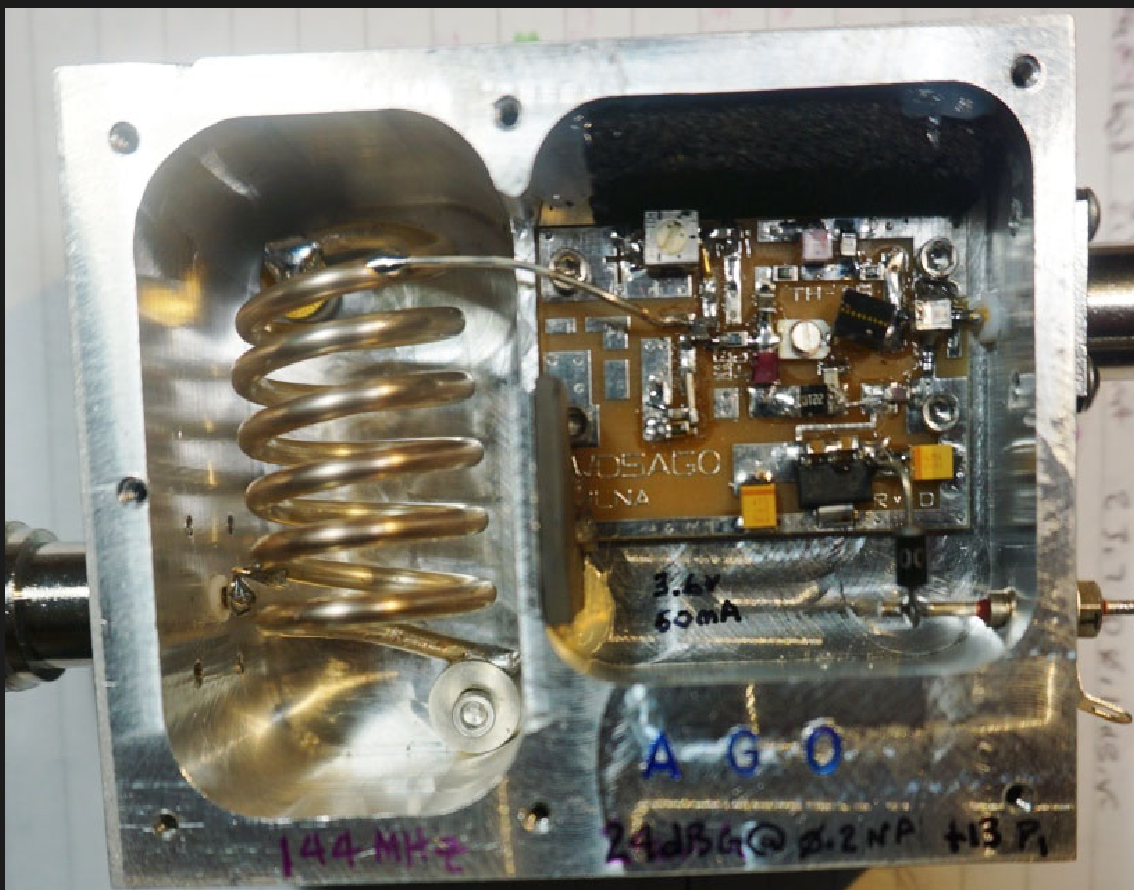


3t Tap ~ 75 ohms,

Wider BW, lower n/f, higher gain



Larger 2m Helix LNA, does it help?

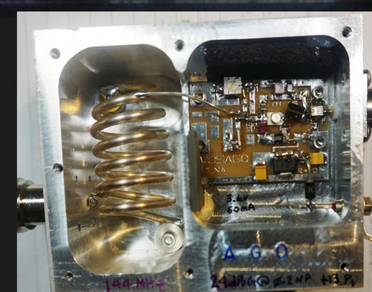


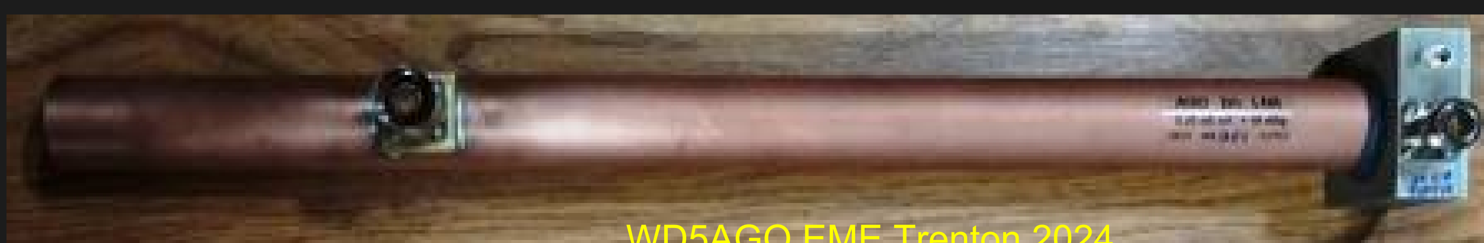
- 6 t Helix in a 1" cavity
- Tap 1.5 turns
- SAV 331
- 24 dBG, 0.25 dB n/f, +13 P1dB

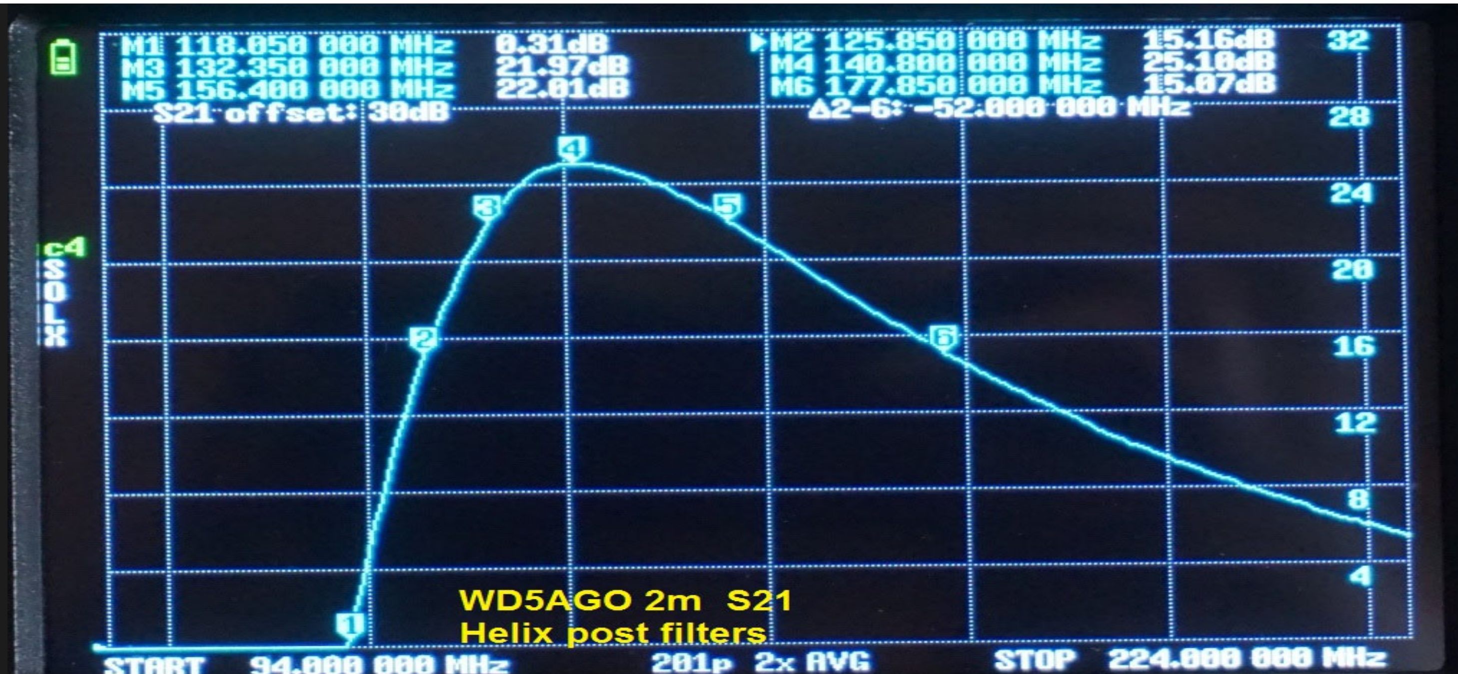
2m Helix S11

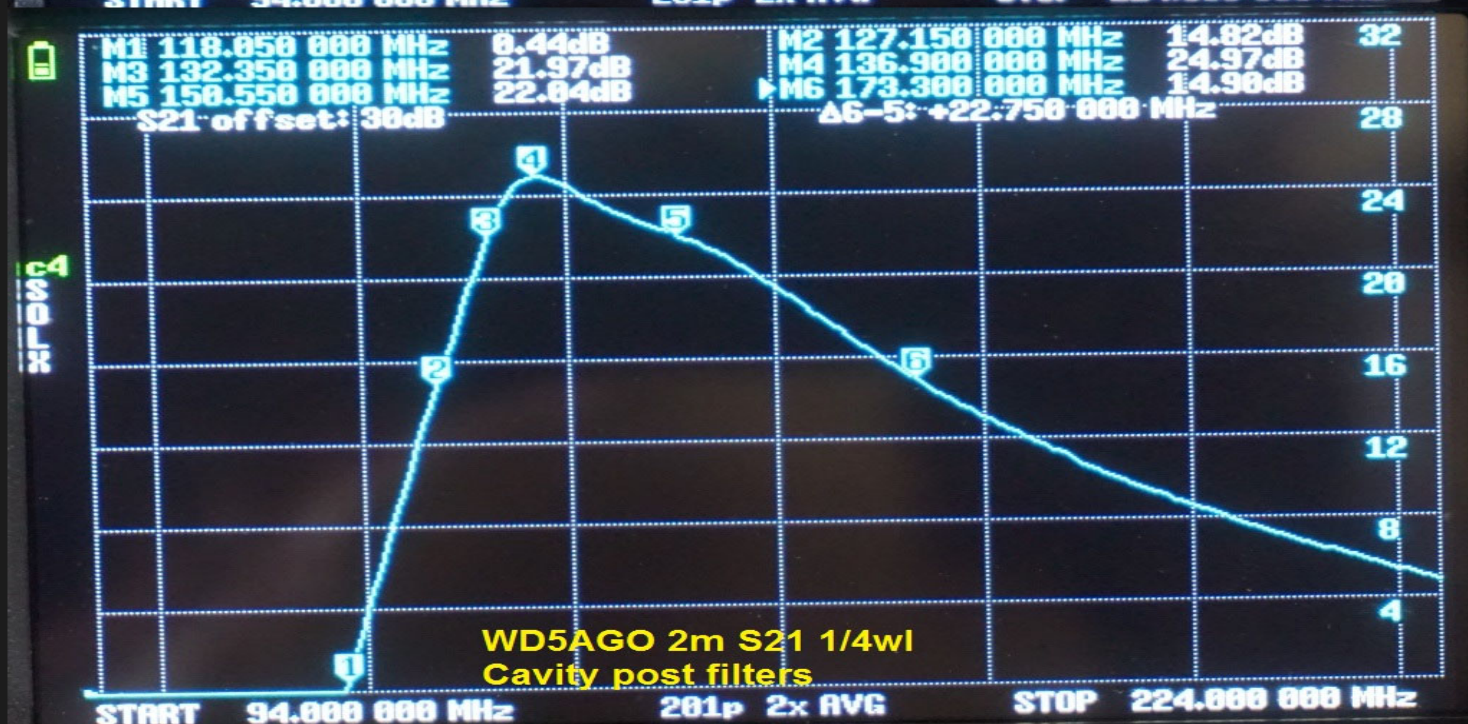

S11 LOGMAG 4dB/ -4.08dB
M1: 144.250 000 MHz
4
0
-4
-8
-12
-16
-20
-24
WD5AGO 2m S11
START 125.000 000 MHz
201p 2x AVG
STOP 175.000 000 MHz

Comparing S21 for Helix and ¼ λ Cavity w/o Filter.

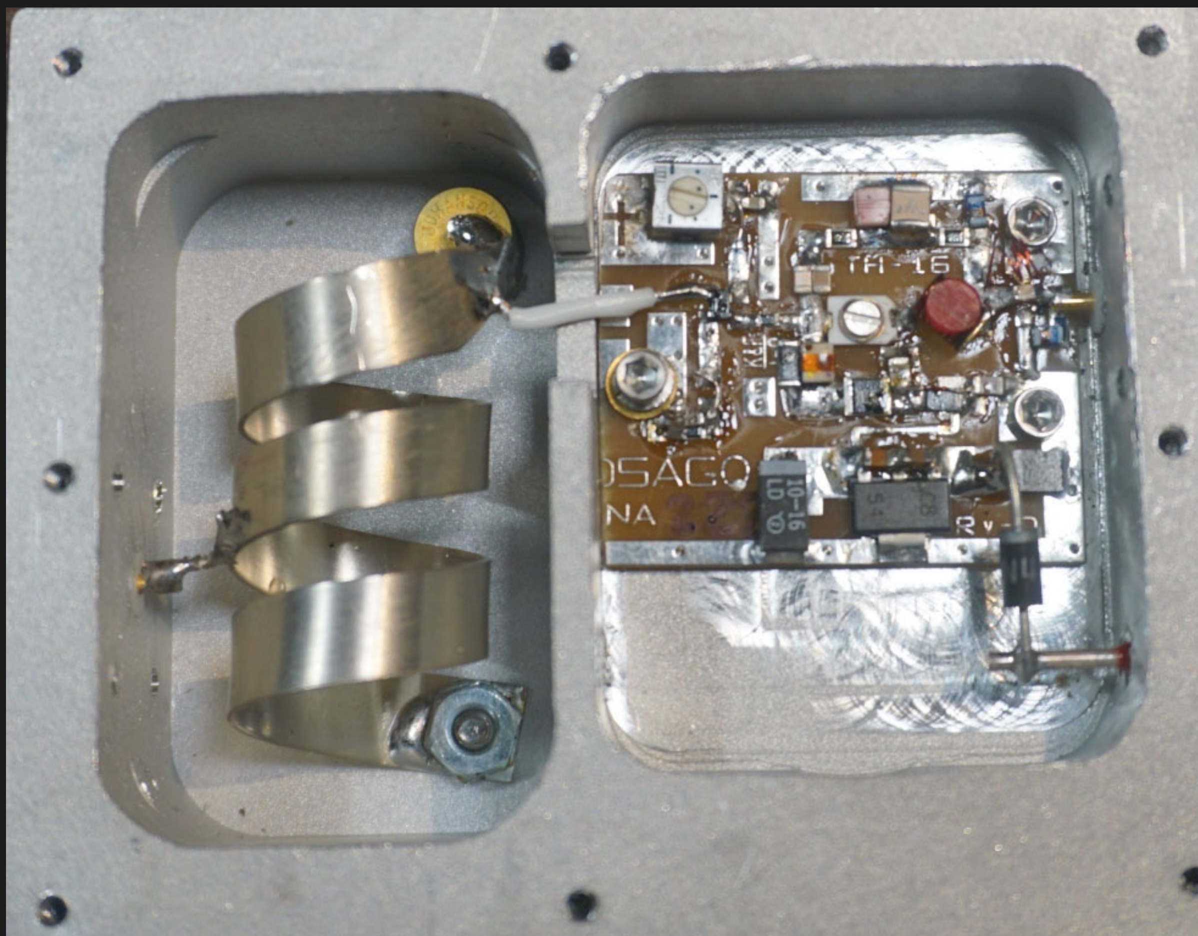





M1 118.050 000 MHz 0.31dB
M3 132.350 000 MHz 21.97dB
M5 156.400 000 MHz 22.01dB
S21 offset: 30dB
M2 125.850 000 MHz 15.16dB
M4 140.800 000 MHz 25.10dB
M6 177.850 000 MHz 15.07dB
Δ2-6: -52.000 000 MHz
32
28
24
20
16
12
8
4
WD5AGO 2m S21
Helix post filters
START 94.000 000 MHz
201p 2x AVG
STOP 224.000 000 MHz


M1 118.050 000 MHz 0.44dB
M3 132.350 000 MHz 21.97dB
M5 150.550 000 MHz 22.04dB
S21 offset: 30dB
M2 127.150 000 MHz 14.82dB
M4 136.900 000 MHz 24.97dB
M6 173.300 000 MHz 14.90dB
Δ6-5: +22.750 000 MHz
32
28
24
20
16
12
8
4
WD5AGO 2m S21 1/4wl
Cavity post filters
START 94.000 000 MHz
201p 2x AVG
STOP 224.000 000 MHz

222 MHz Helix LNA

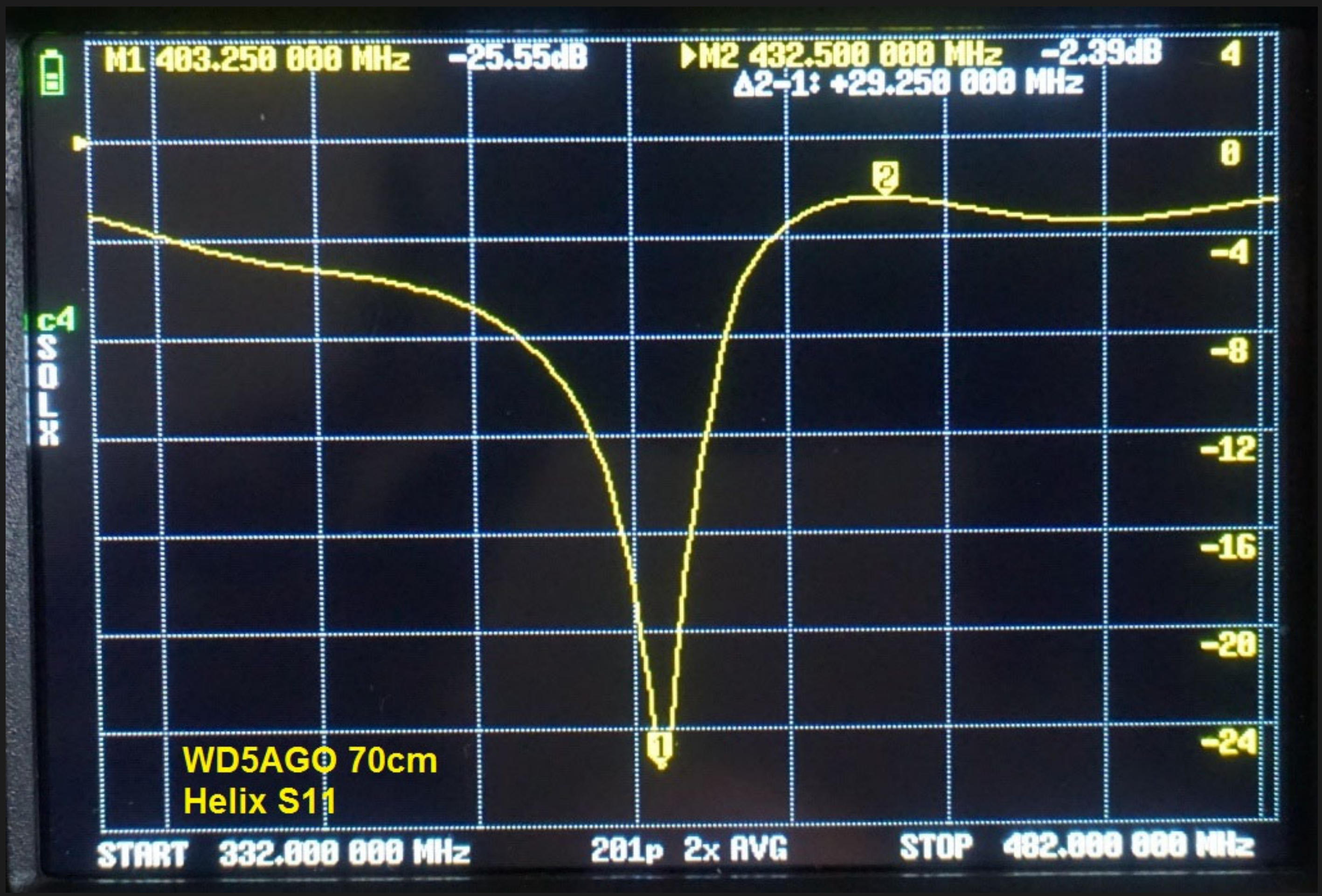


- 1” cavity
- 3t of 0.25” flat stock
- Tap 1.5t
- 20 dBG, 0.25 dB n/f, +11 P1dB
- SAV 331 w/3.5v @ 60mA

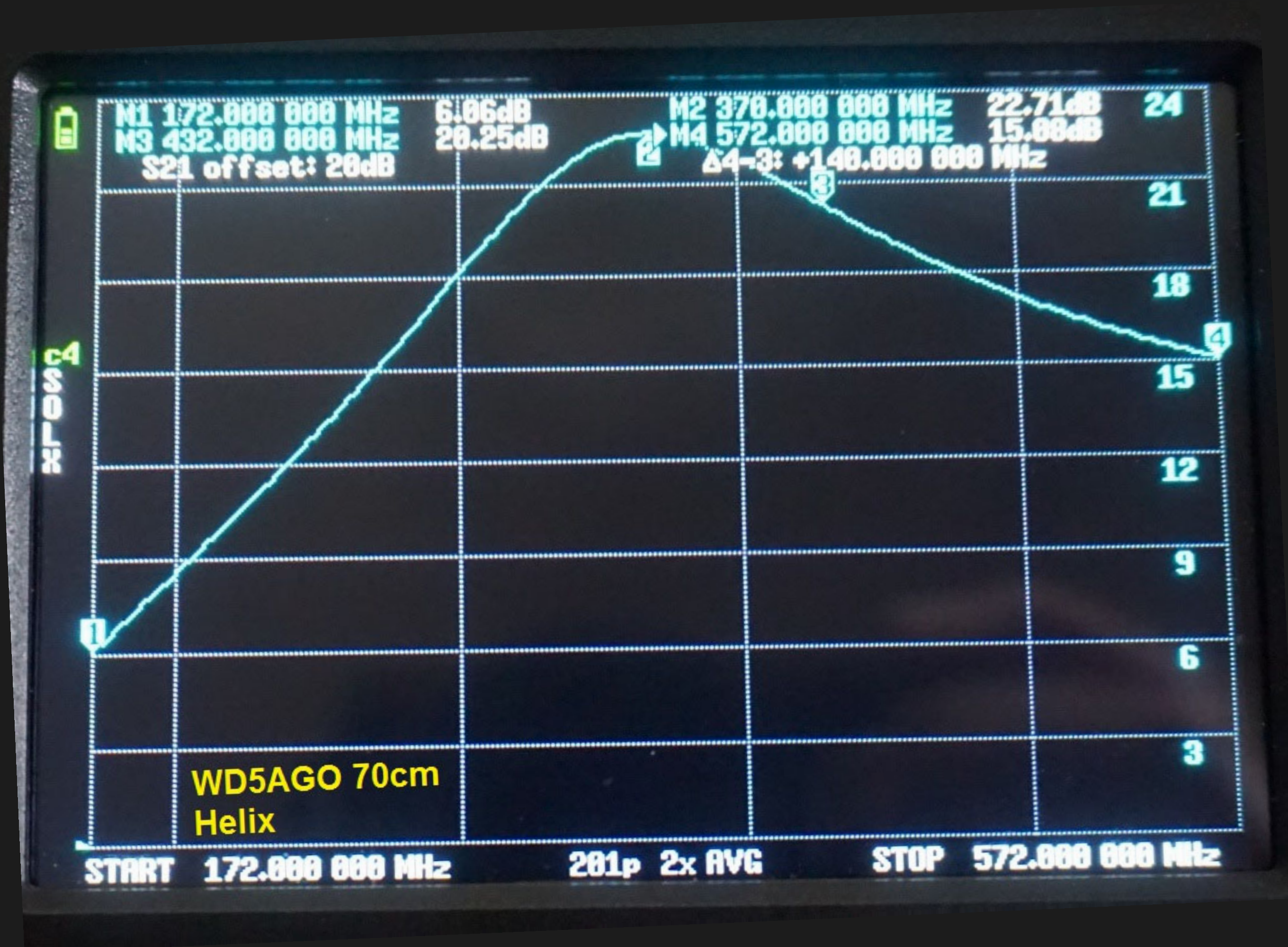
432 MHz Helix LNA

- 0.8" cavity
- 1 wide spaced turn, of 0.25" W tap at 0.6 turns.
- 19 dBG, 0.33 n/f, +12 P1dB
- SAV 331, 3.6V@ 60 mA

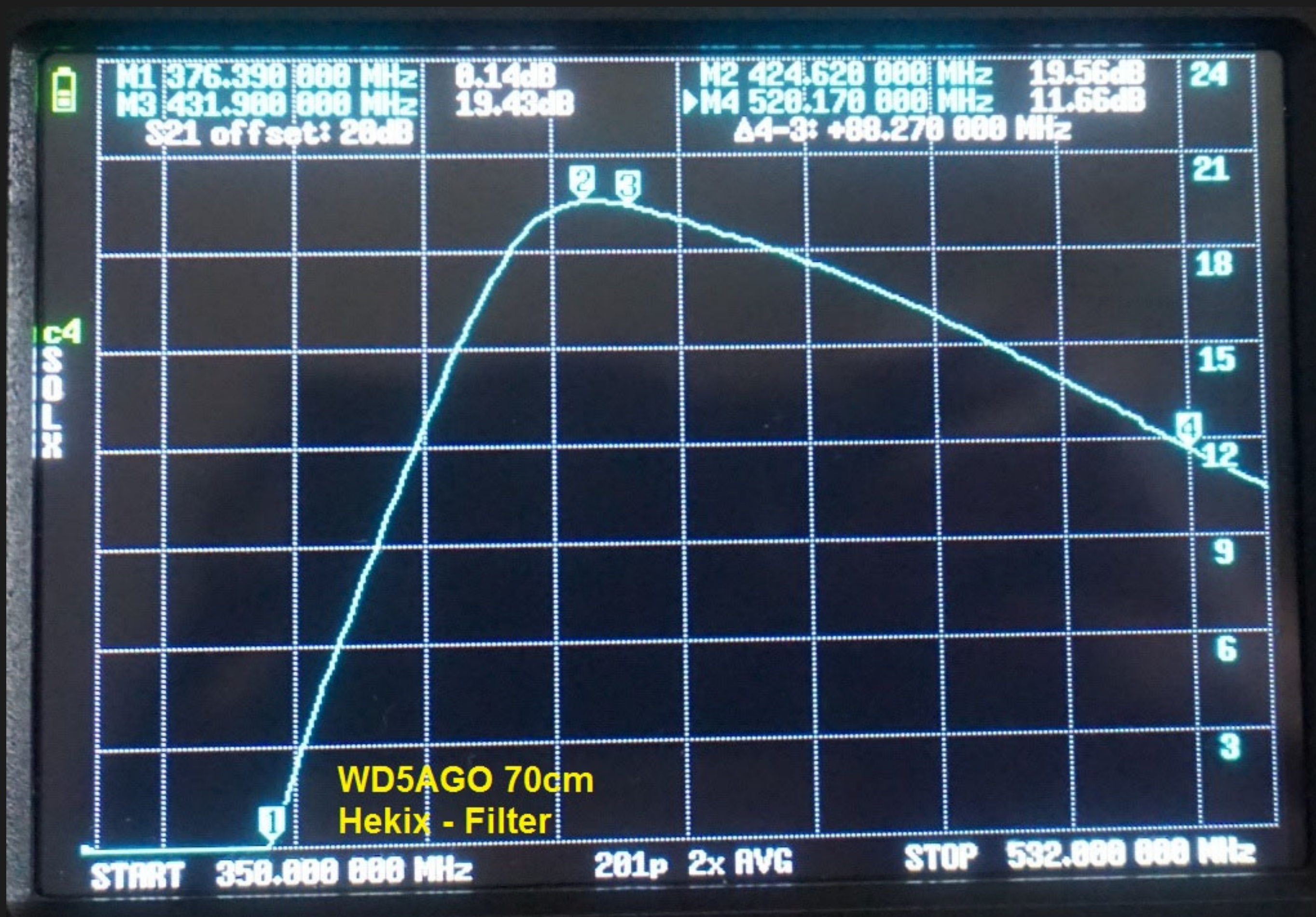
432 MHz S11


M1 403.250 000 MHz -25.55dB
▶M2 432.500 000 MHz -2.39dB
Δ2-1: +29.250 000 MHz
4
0
-4
-8
-12
-16
-20
-24
c4
S
O
L
X
WD5AGO 70cm
Helix S11
START 332.000 000 MHz
201p 2x AVG
STOP 482.000 000 MHz

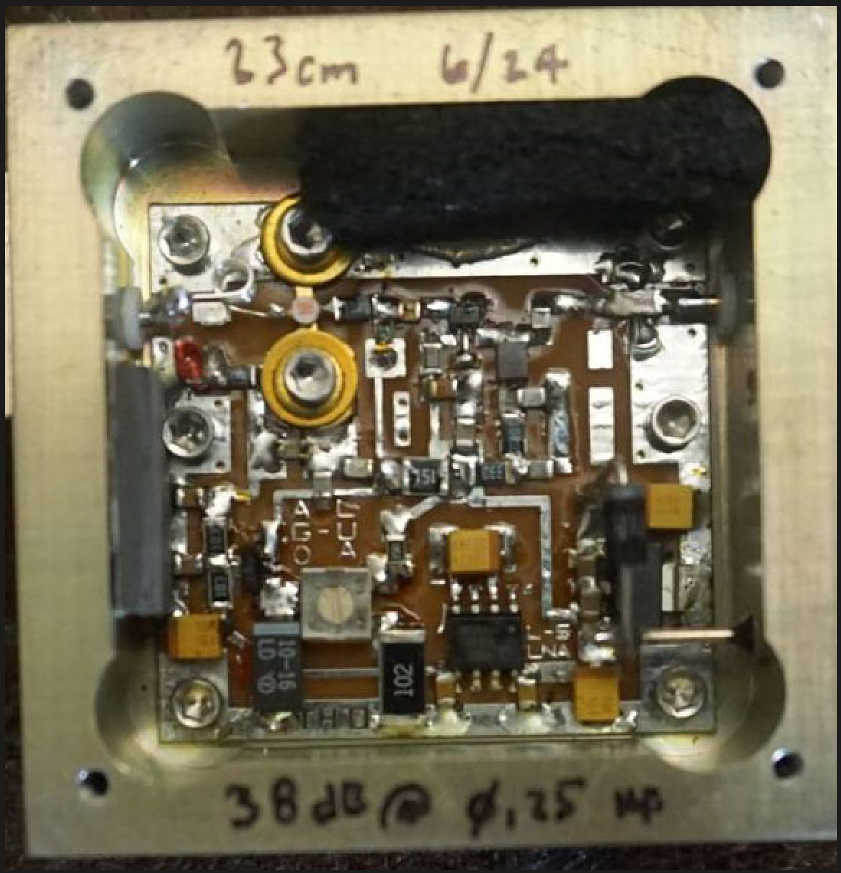
432 MHz Helix S21 w/o Filter



432 MHz Helix LNA w/ Diplexer followed by an Elliptic Filter

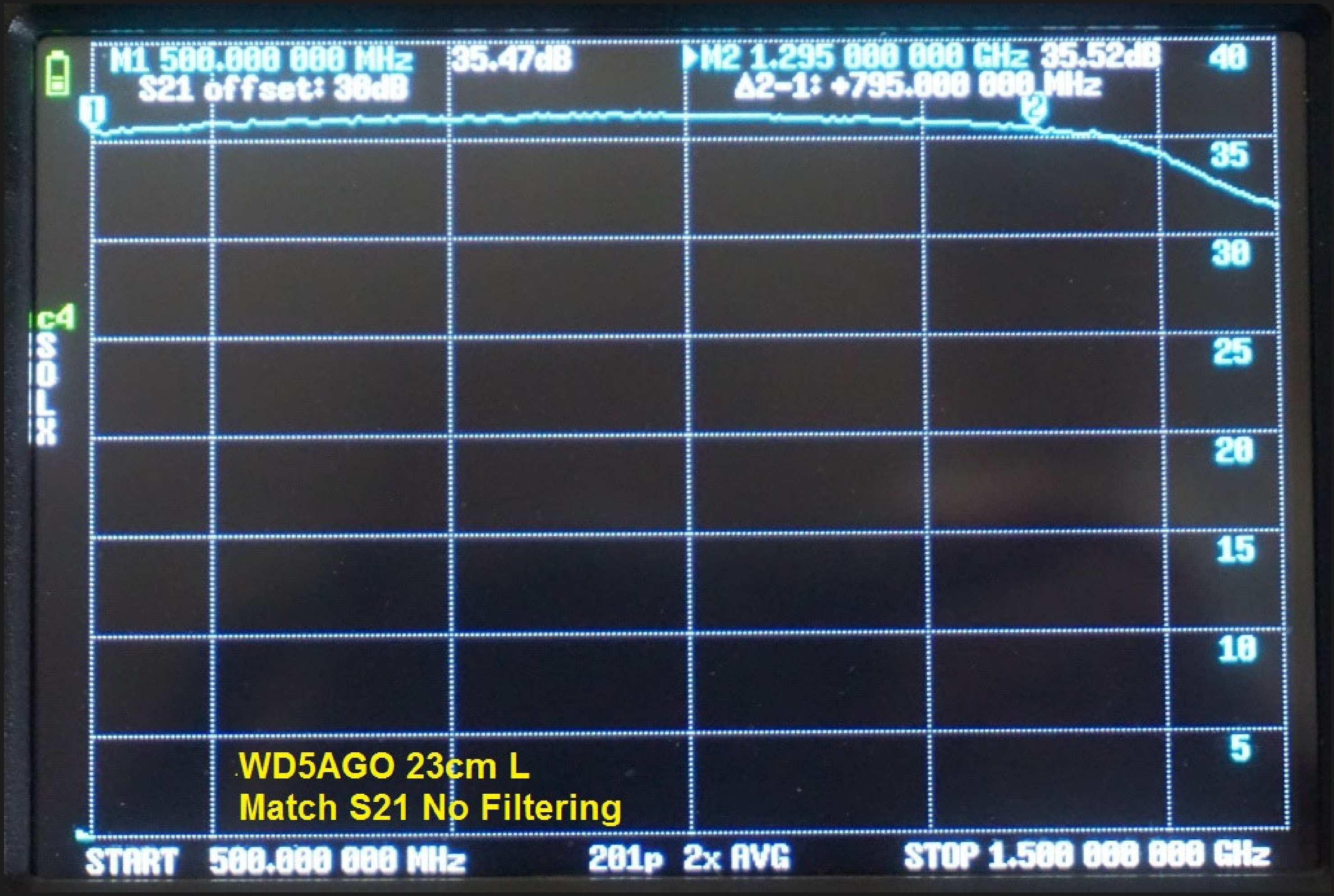


Standard 23cm Inductive Match LNA

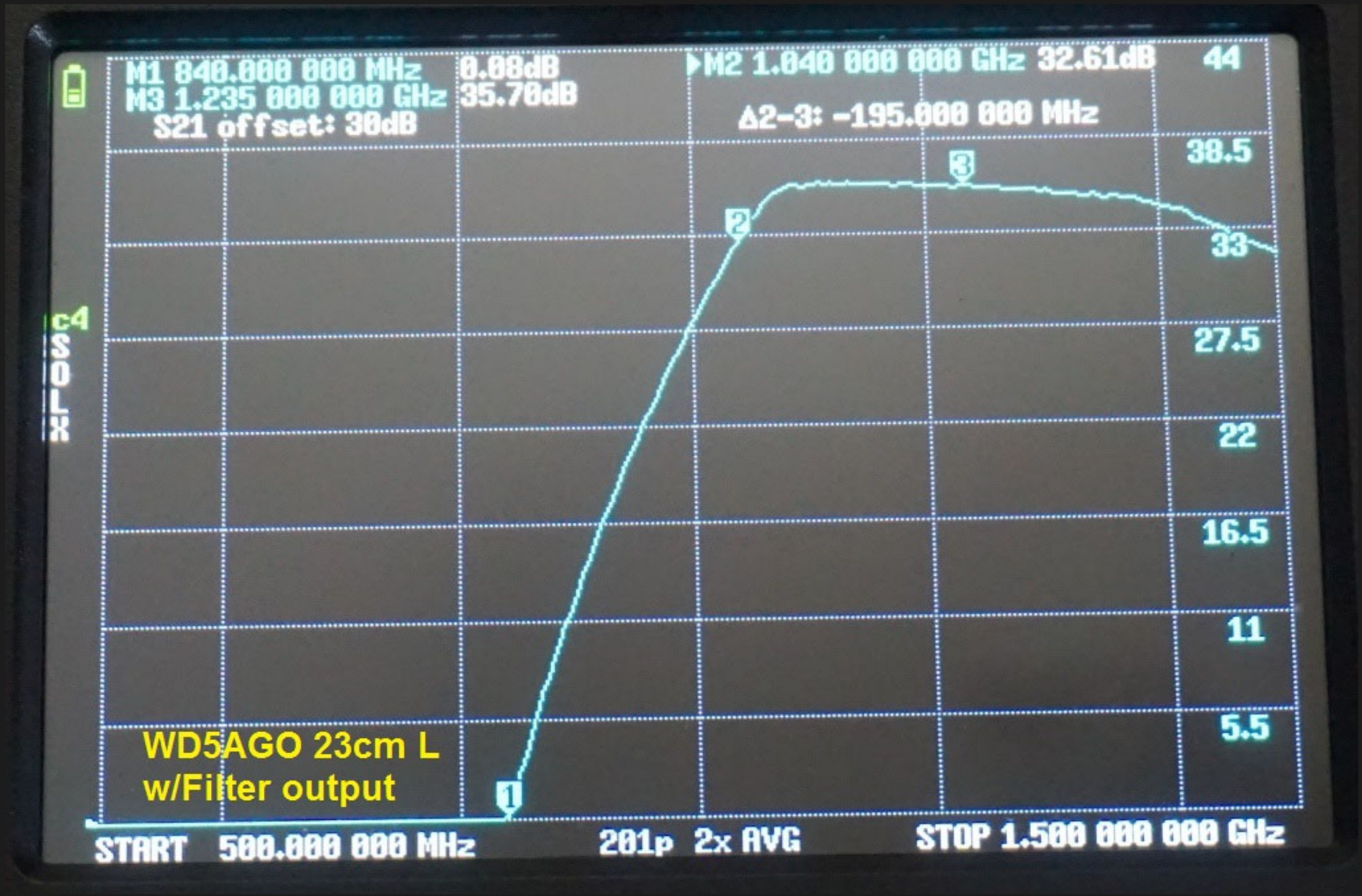


- 2 Stages, Active Bias
- MGF4918 HEMT – PSA 545 MMIC (3.3V @ 41mA)
- 38 dBG, 0.25 dB n/f, +16 P1dB
- Only filter is a Mini-Circuits HP 1200 SMD.
- Controlled Source inductance.

23cm L match S21, no filters



23cm L Match with filter 2nd stage

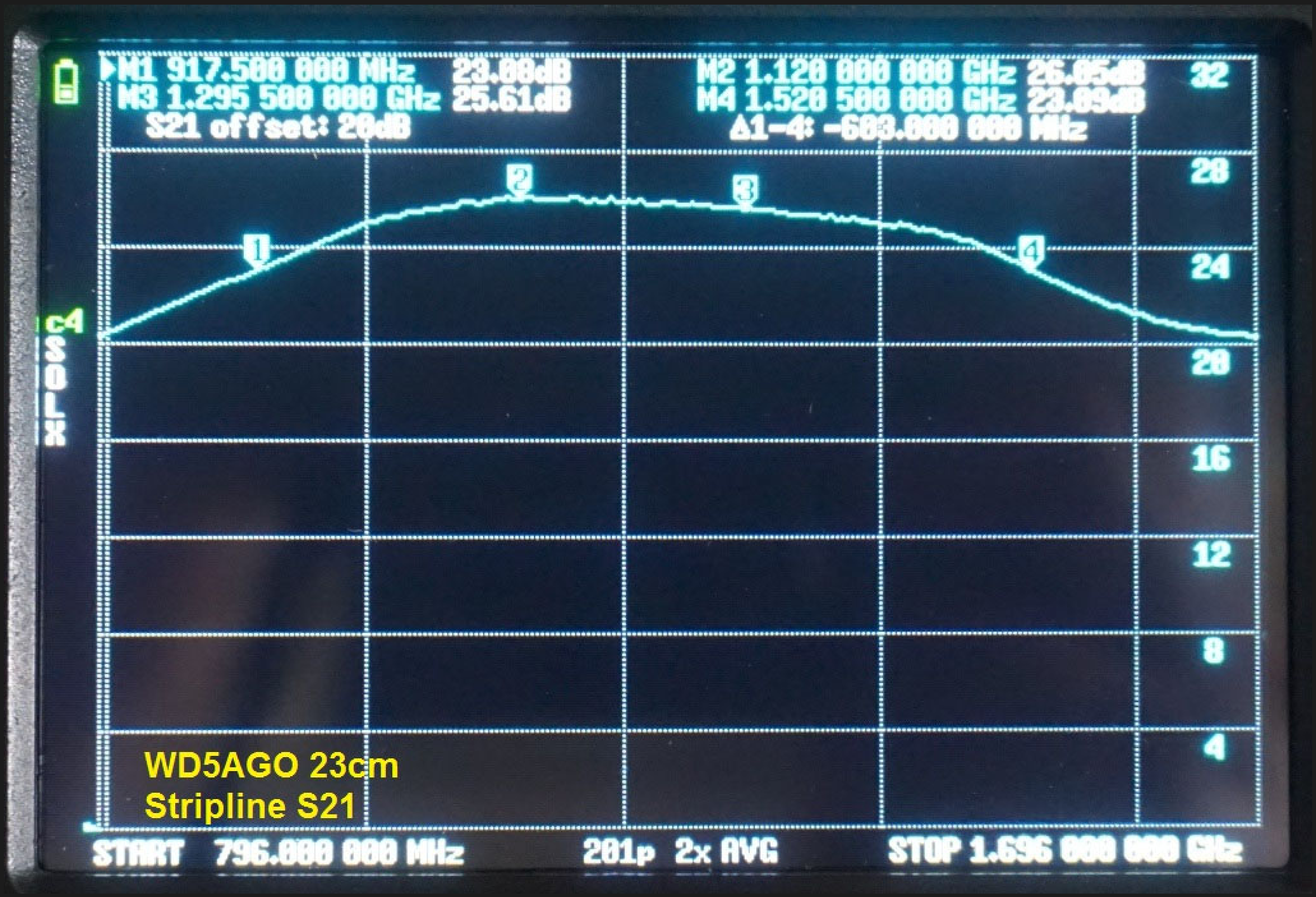


23cm Stripline LNA

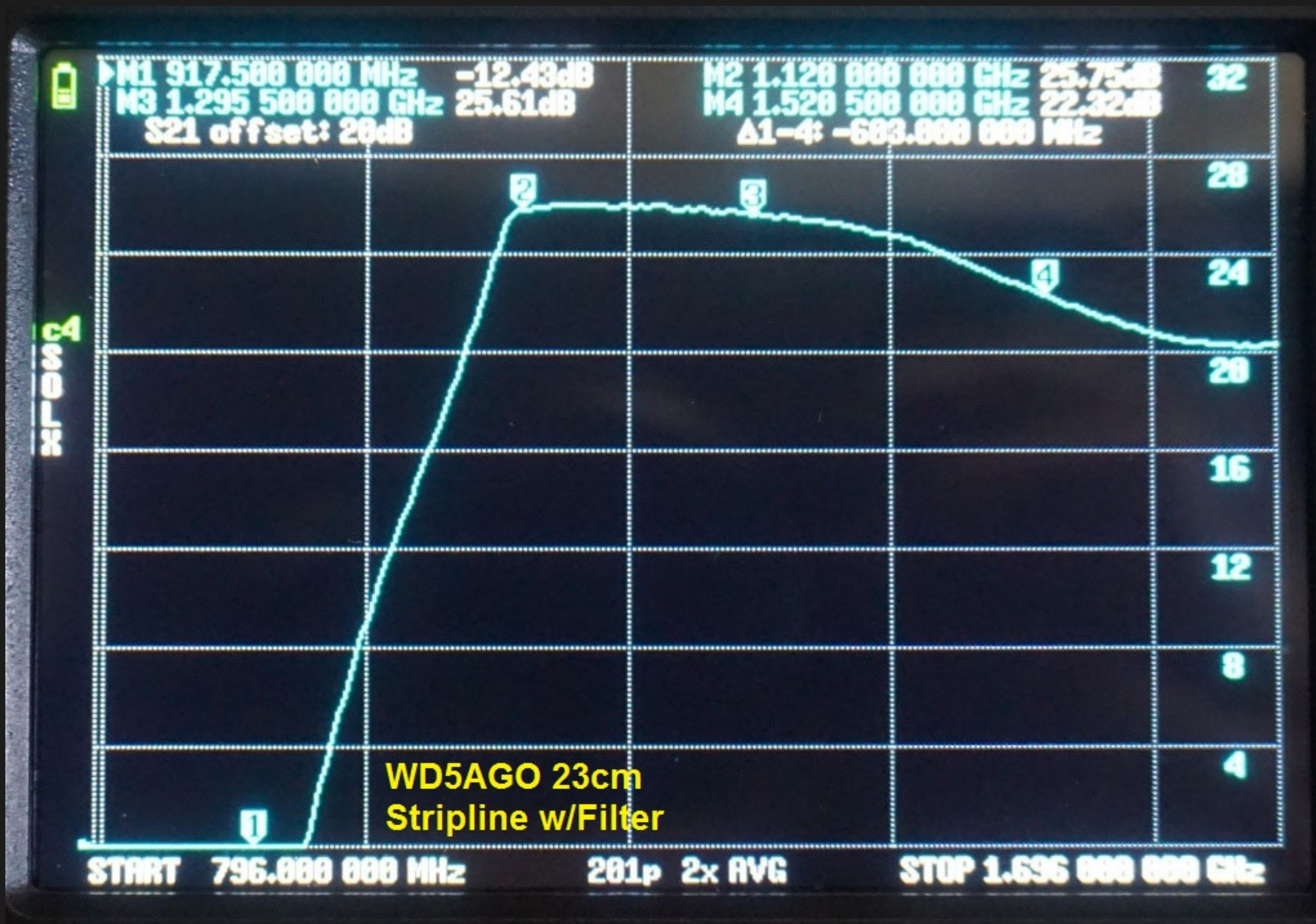
- 1” cavity
- 1.6 x 0.5” line, tap is 0.7”
- Self Biased
- MGF4919 HEMT – PGA103 MMIC
- 1.5V@ 21mA
- 4V@ 70mA
- 31 dBG, 0.27 dB n/f, +11 P1dB
- Mini-ckts HP1200 filter.

23cm Stripline S11

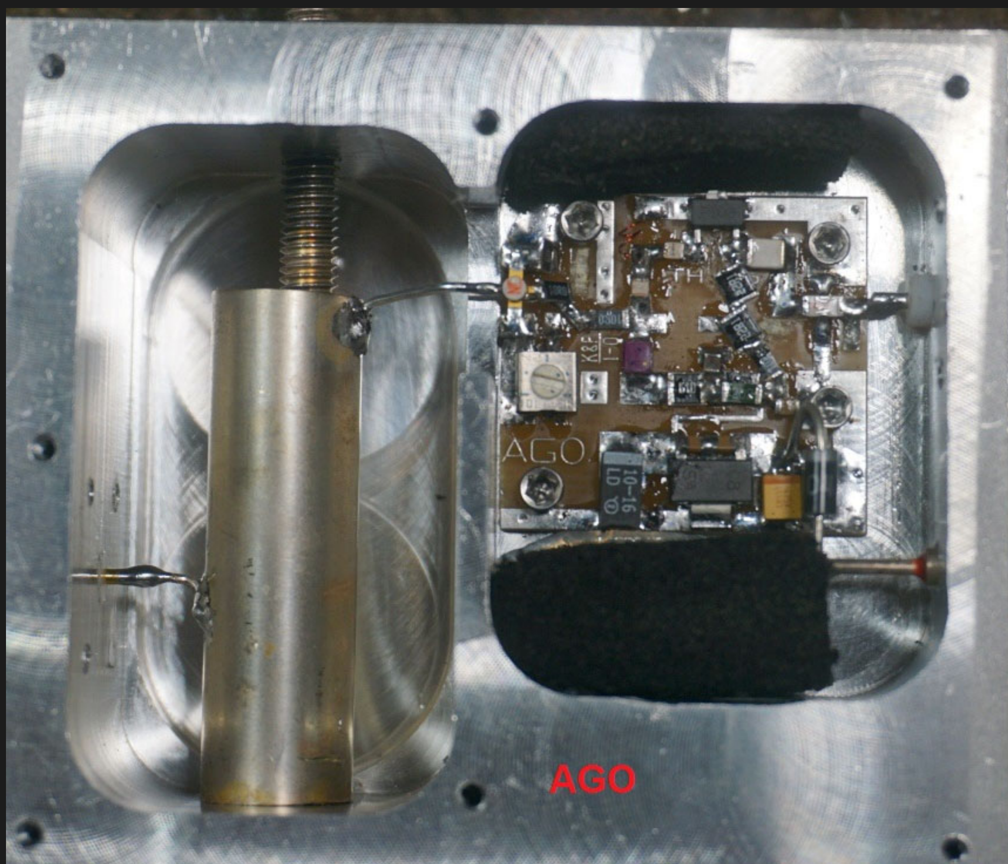
23cm Stripline w/o output filter



23cm Stripline with SMD filter



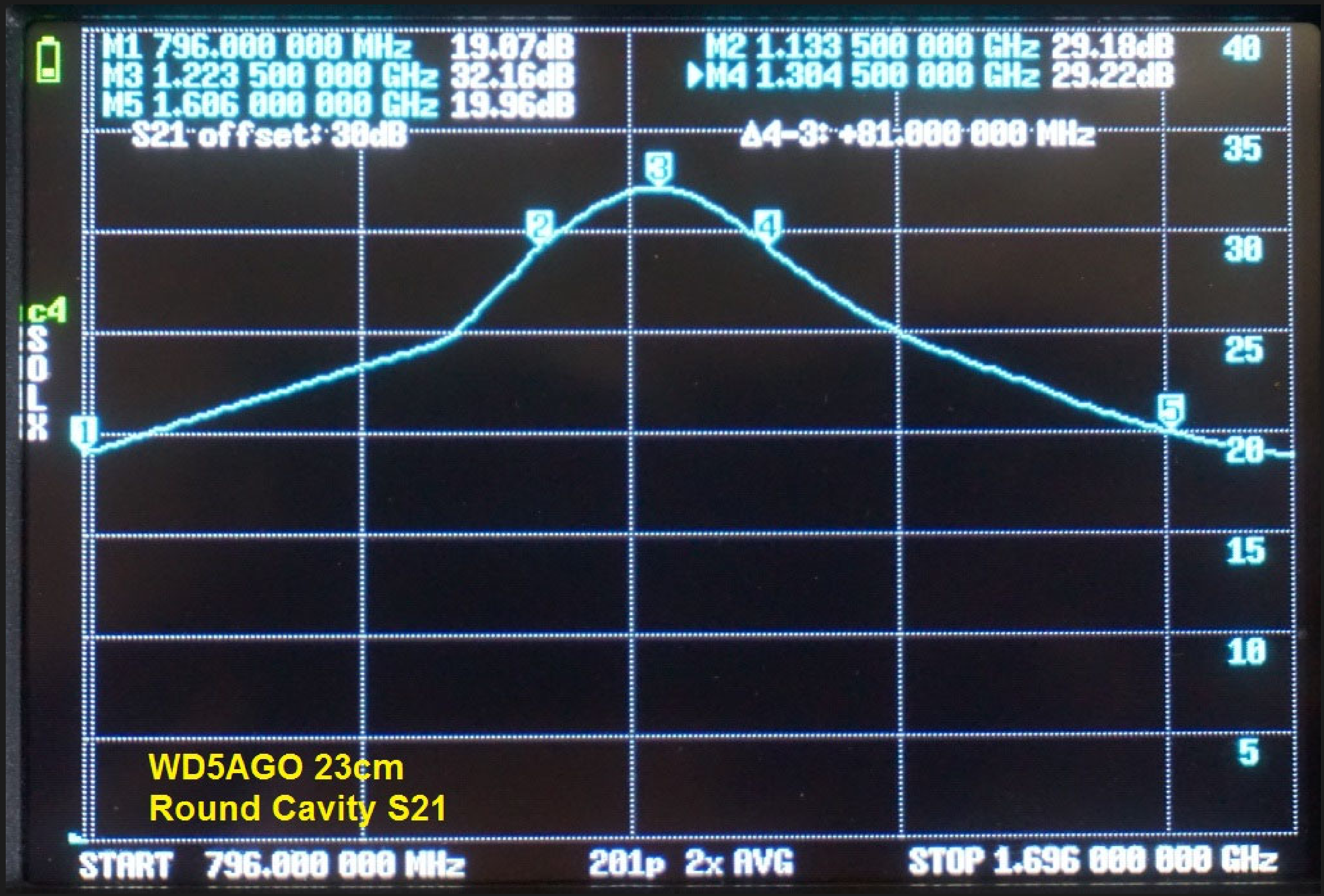
23cm ¼ λ Cavity LNA



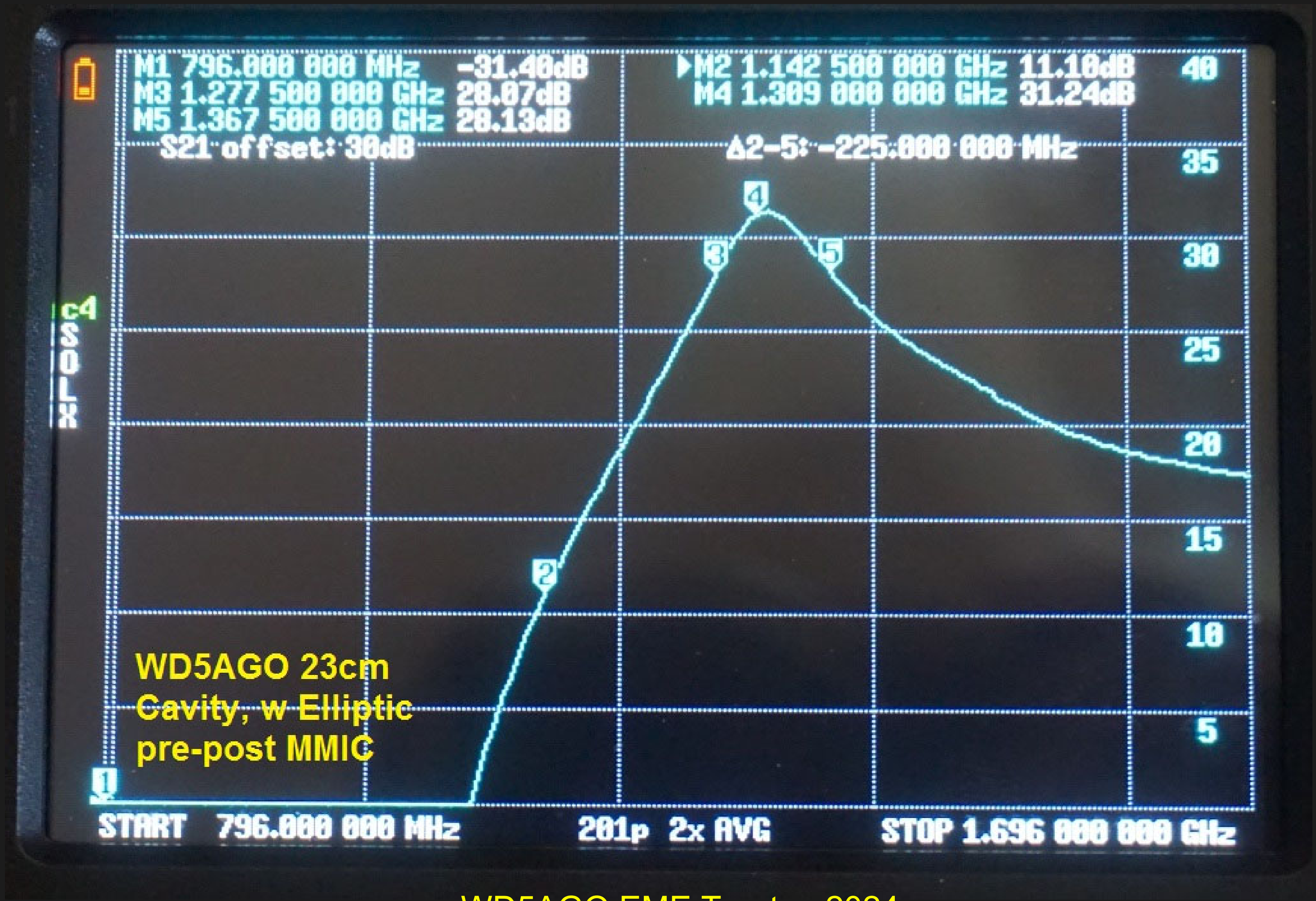
- 1" cavity with 1.6" long line, tap 0.6"
- Self Biased
- MGF4919 HEMT – PGA103 MMIC
- 32 dBG, 0.28 dB n/f, +14 P1dB.
- Add Pre and Post filtering of MMIC.

23cm Cavity S11

23cm Cavity S21 w/o filters



23cm Cavity w/ Output Filters



Conclusions

- 2m through 23cm LNA's benefit from Hi-Q front ends (Cavity, Helix, or Stripline) to help prevent out of band RF from being amplified, however, at higher frequencies, matching losses are much higher.
- Only a slight BW performance between ¼ λ Round, Stipline, and Helix Cavities.
- Newer, Low Noise HEMT devices are not as stable on VHF frequencies, even with added source inductance. New and NOS P1dBm >+10 HEMT, 800u Devices, have greater stability, however, with lower input Z's (0.5 to 5k) which will increase the BW for a given Hi Q input circuit.
- Using Source Inductance to increase VHF stability is a matter of luck without modeling in CAD and even then it will need to be adjustable. Output Diplexer helps LNA.

…Continue

- A simple L or C input match or coupling (DC block) is not advised for LNA's below 700 MHz.
- A high IP LNA driving a low IP receiver is not advised. Increase the Mixer with a higher level +17 dBm. The 2nd stage of an LNA should be +13 P1dB or higher.
- A 20 dB gain LNA with +10 P1dB is a good start (-9 dBm input). It may take a +13 P1dB LNA to help your IMD problems. Design for a higher operating voltage. Use a Spectrum Analyzer to measure the power of sources in your area.
- MMIC's are available with mid-IP performance, a 50 ohm match, and lower n/f compared to decades ago. An 0.4 dB n/f device can be a competitive LNA below 250 MHz when used with a low loss pre-filter.
- Thank You!

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