

Millimeter Wave Measurements

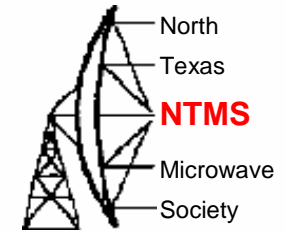
Al Ward

W5LUA

Microwave Update 2010

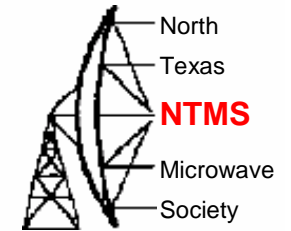
October 23, 2010

Outline



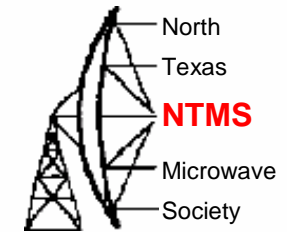
- Measurements from MUD2009
- Things learned since MUD2009
- Evaluation of the WA1MBA 78 GHz LNAs
- Sun and Moon Measurements on 78 GHz
- WA1MBA Part II – Progress on the LNAs

HP 8757 Scalar Analyzer

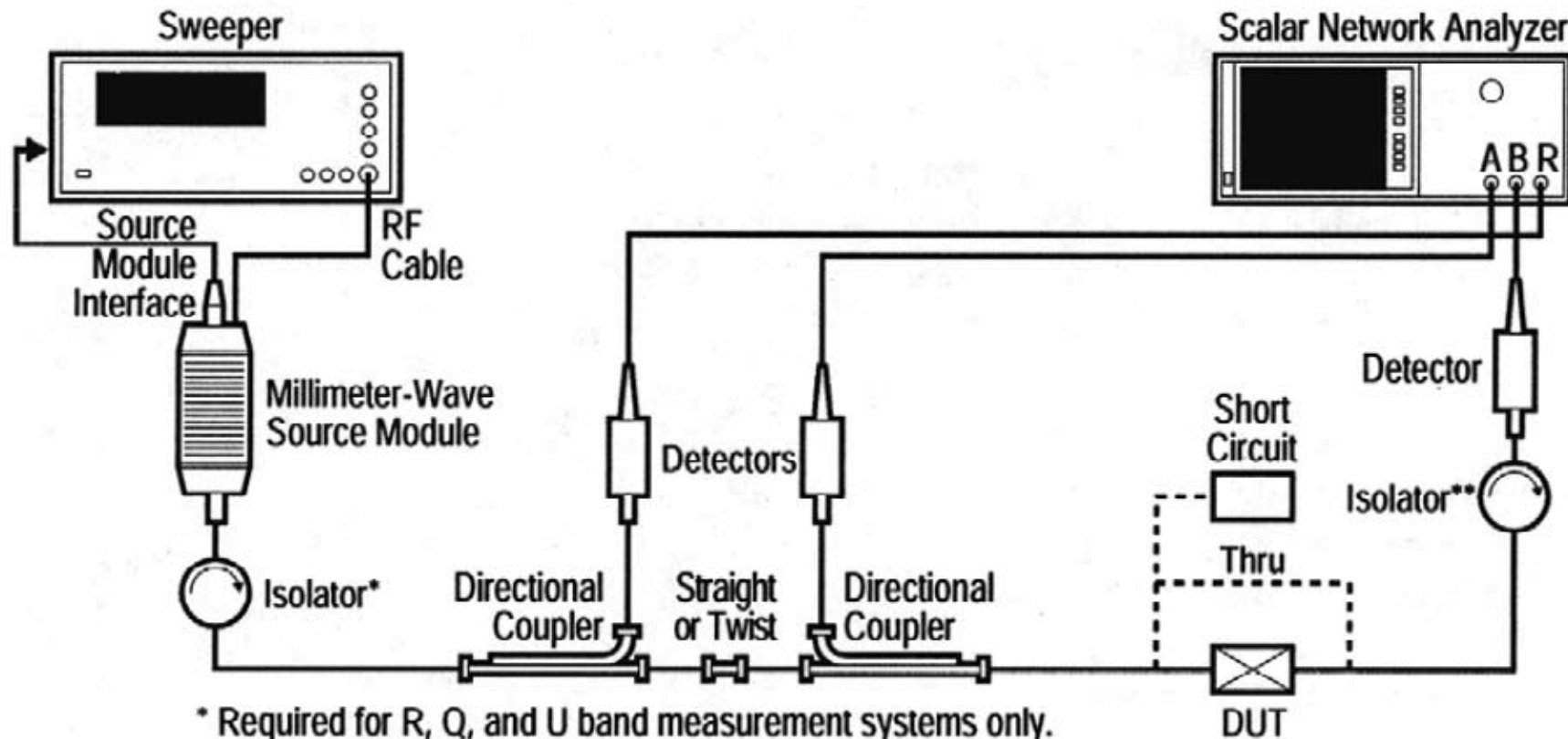


Swept frequency determined by sweeper – GPIB controlled or sweep input
Detect modulated RF signals with detectors connected to A, B, or C ports
Use 11664A and 85025A detectors
Responds well to modulated (27.778 kHz) RF signals that are multiplied to get onto “higher” frequencies
Plot to KE5FX 7470 emulator with Prologix GPIB to USB adapter

Scalar Analyzer Set Up

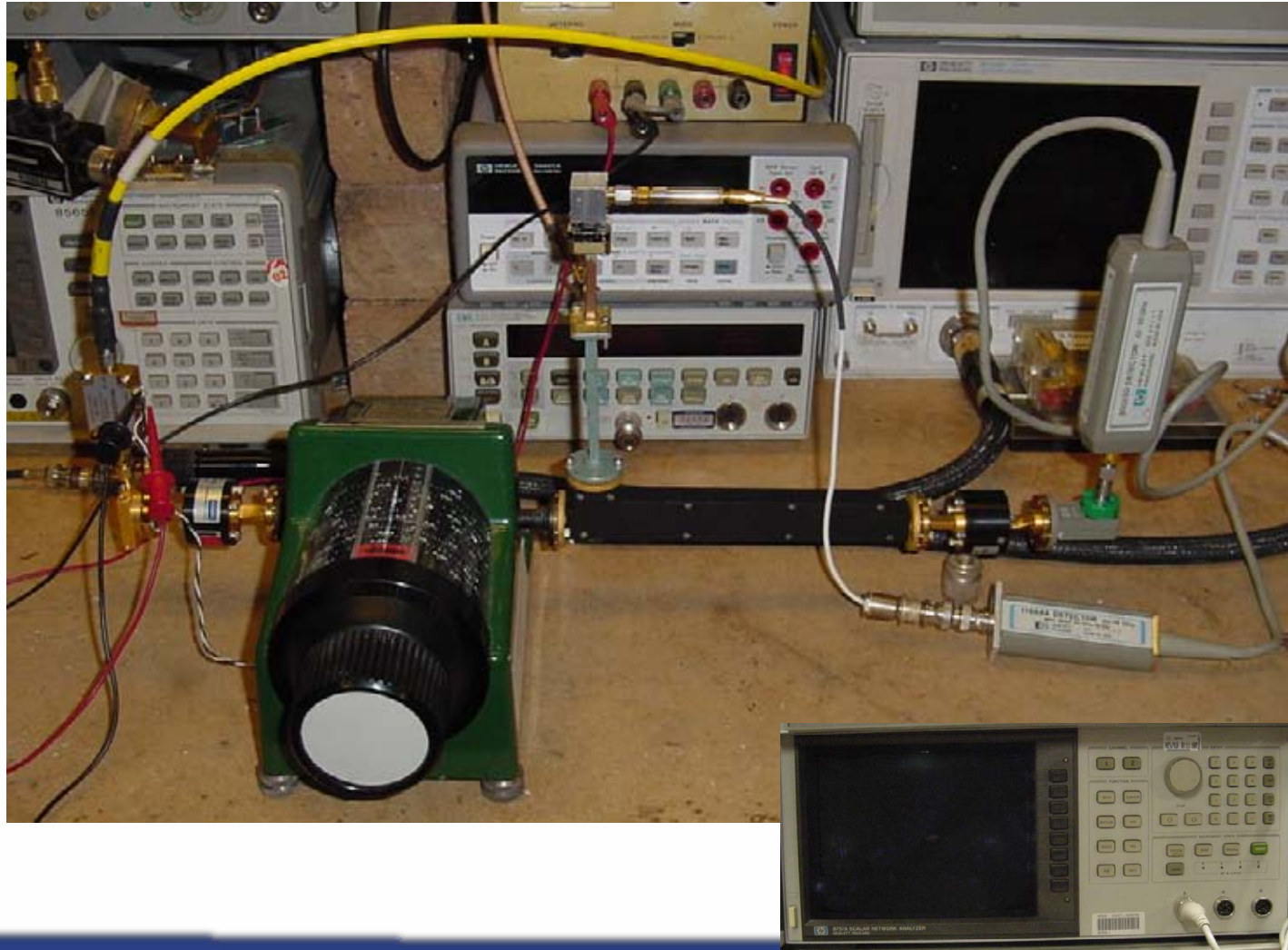
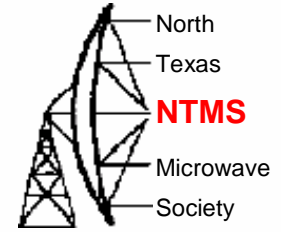


8620, 8350, 8341, etc.

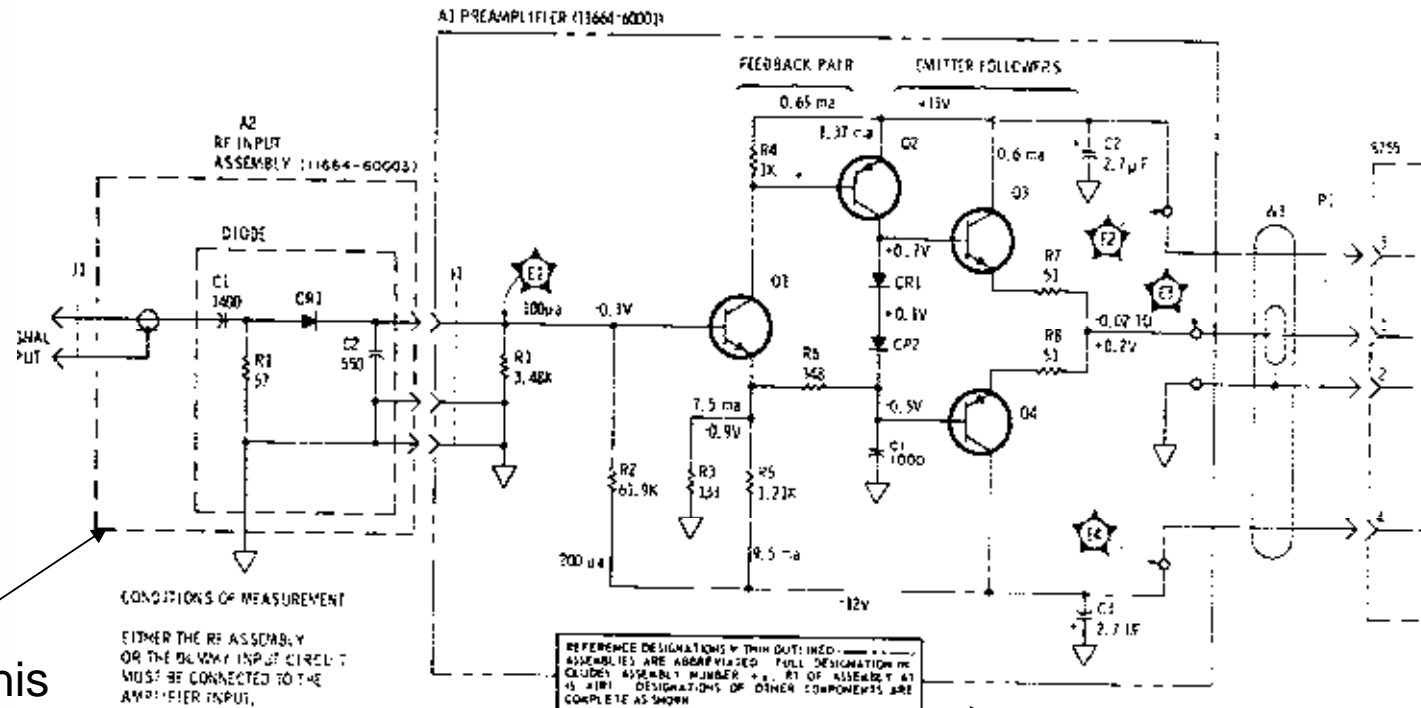
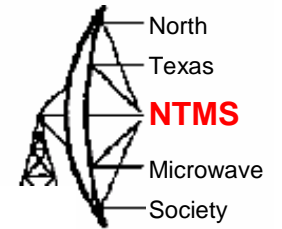


* Required for R, Q, and U band measurement systems only.
 ** Required for V and W band measurement systems only.

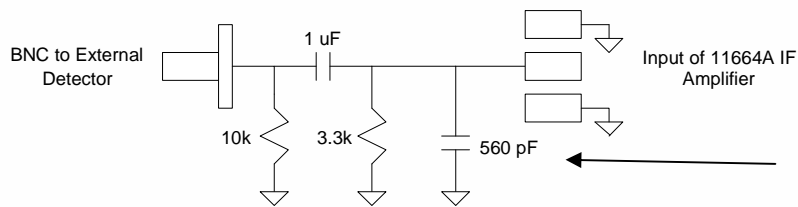
40 to 60 GHz Test Setup



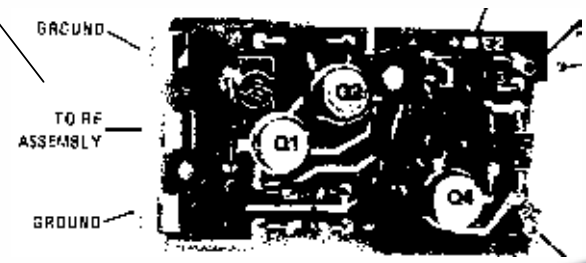
HP 11664A Detector



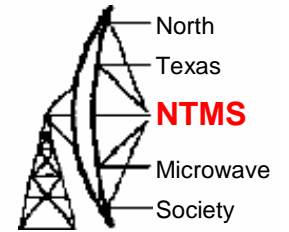
Remove this



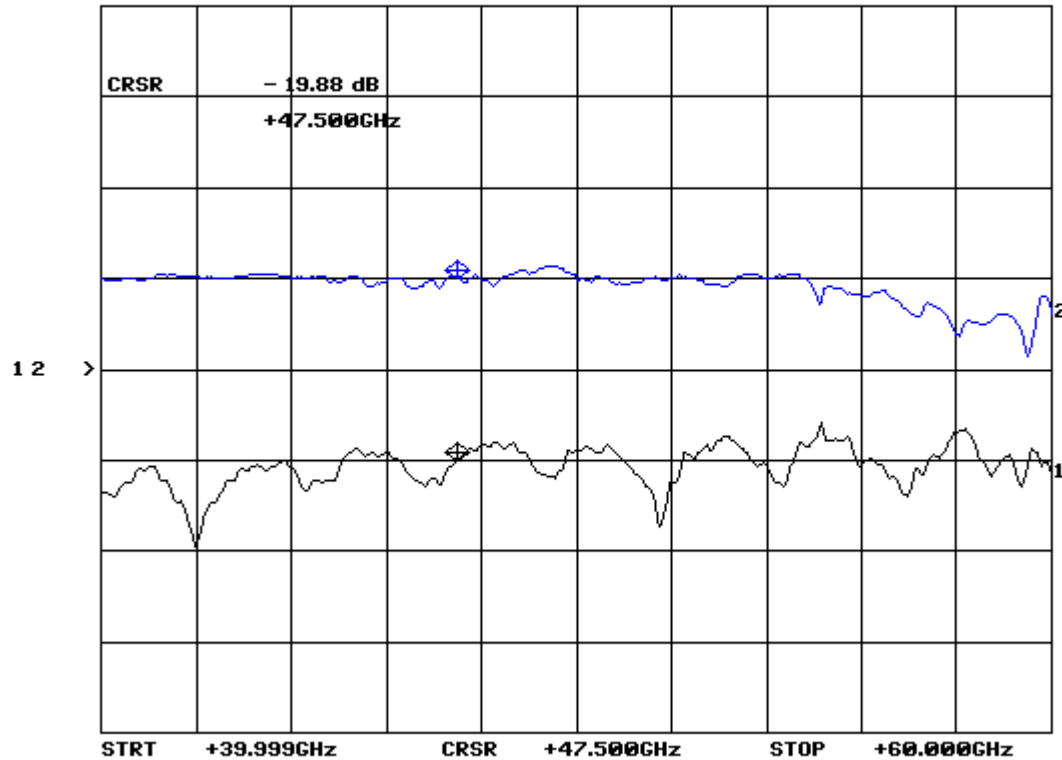
Add this to allow external detectors to be used



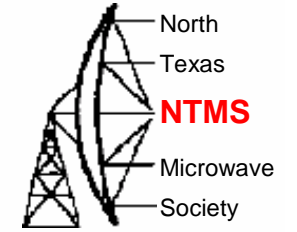
8757 40 to 60 GHz S21 & S11



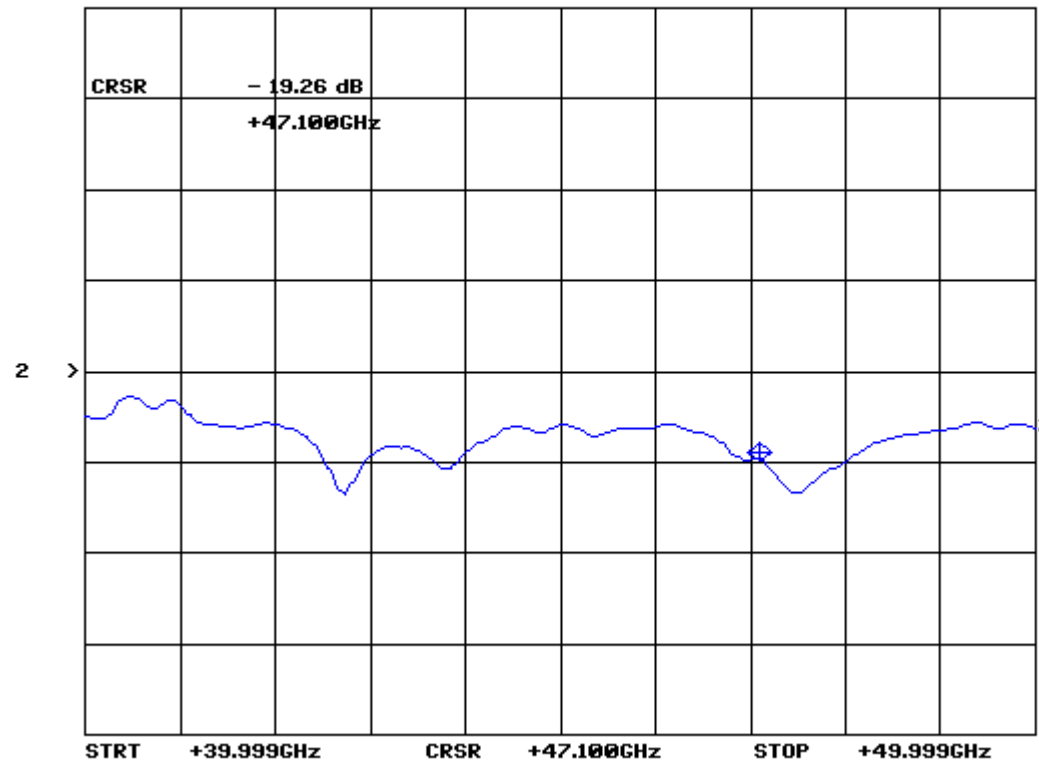
CH1: A -M -19.88 dB CH2: B -M +20.15 dB
 20.0 dB/ REF - .00 dB 20.0 dB/ REF - .00 dB



W5LUA 47 GHz W2IMU Feed for EME

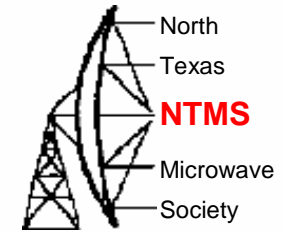


CH2: B -M - 19.26 dB
20.0 dB/ REF - .00 dB

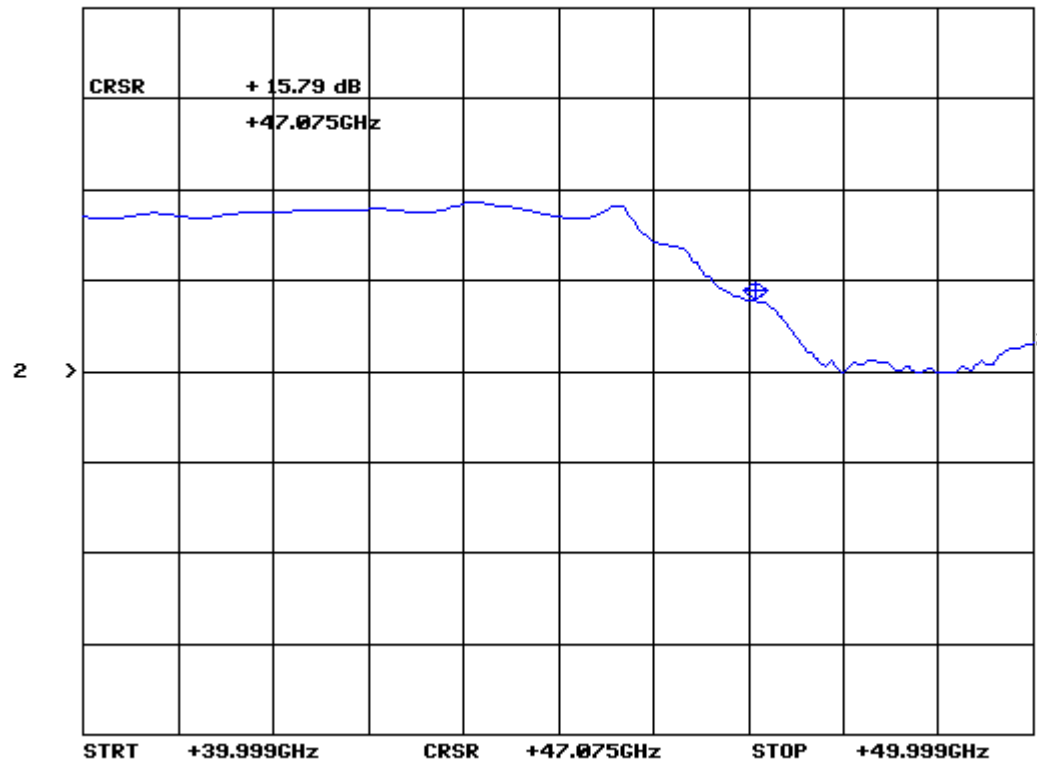


W0EOM SMT S90-1240 Amplifier

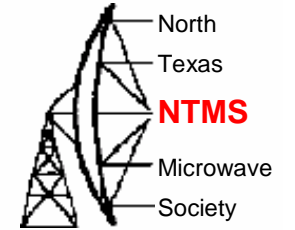
RF Drive level = -30 dBm



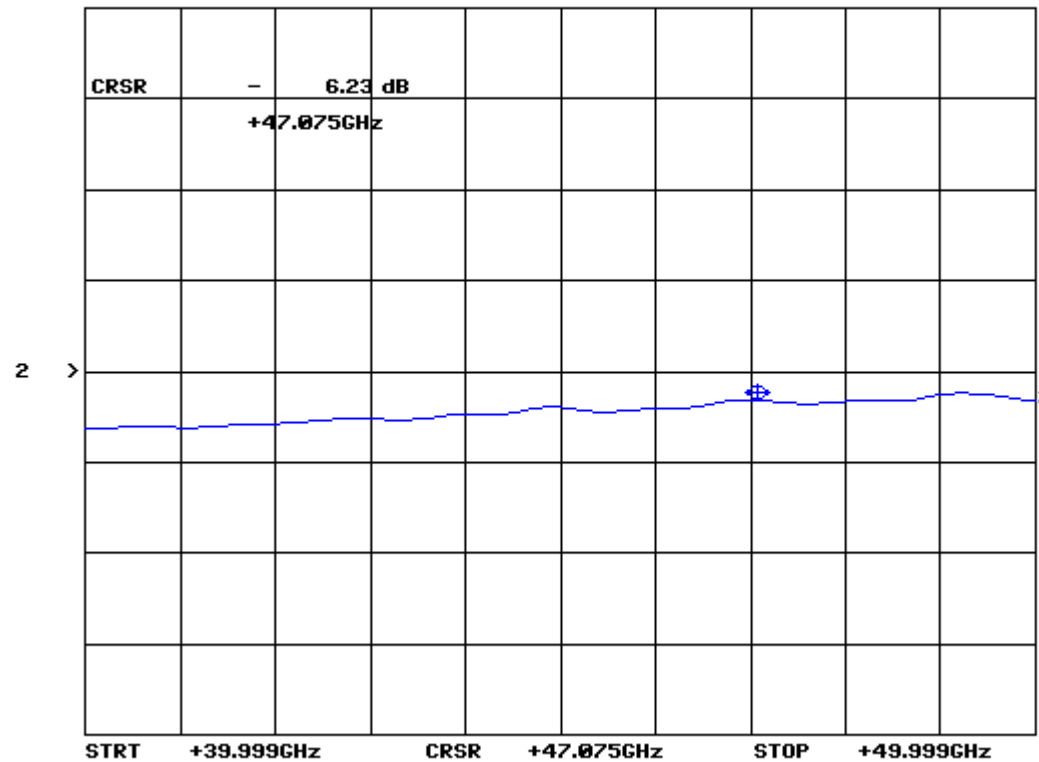
CH2: B -M + 15.79 dB
20.0 dB/ REF - .00 dB



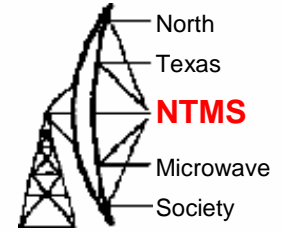
W0EOM Anritsu 52956 Shaped Attenuator 156



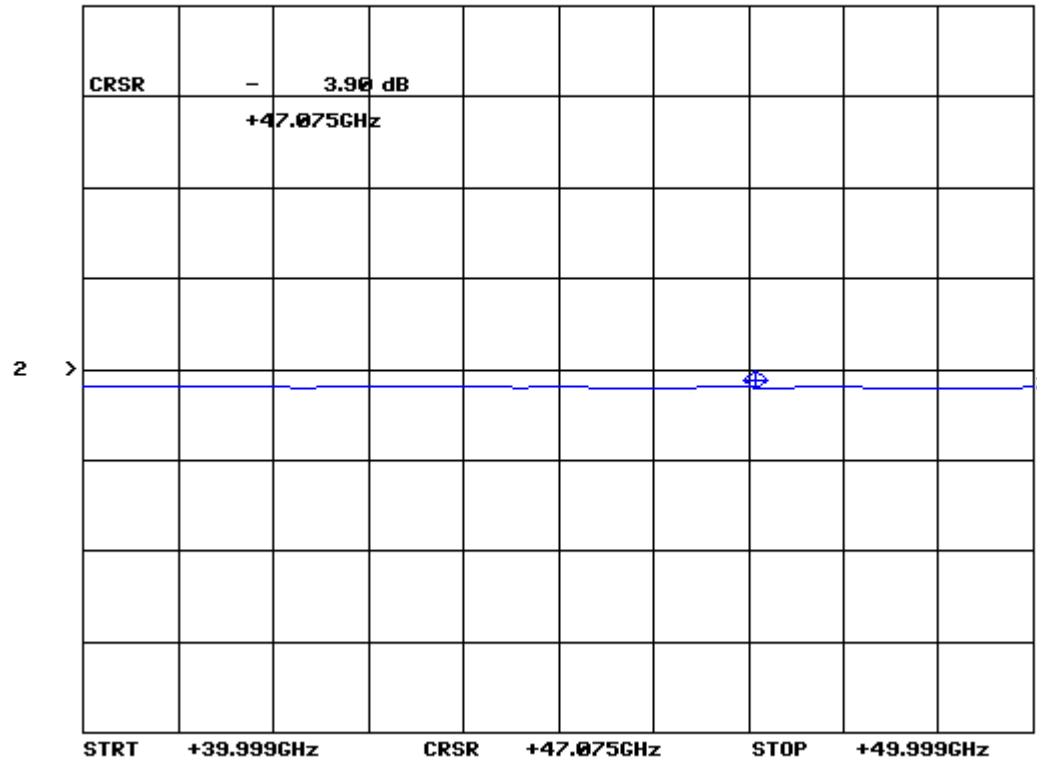
CH2: B -M - 6.23 dB
20.0 dB/ REF - .00 dB



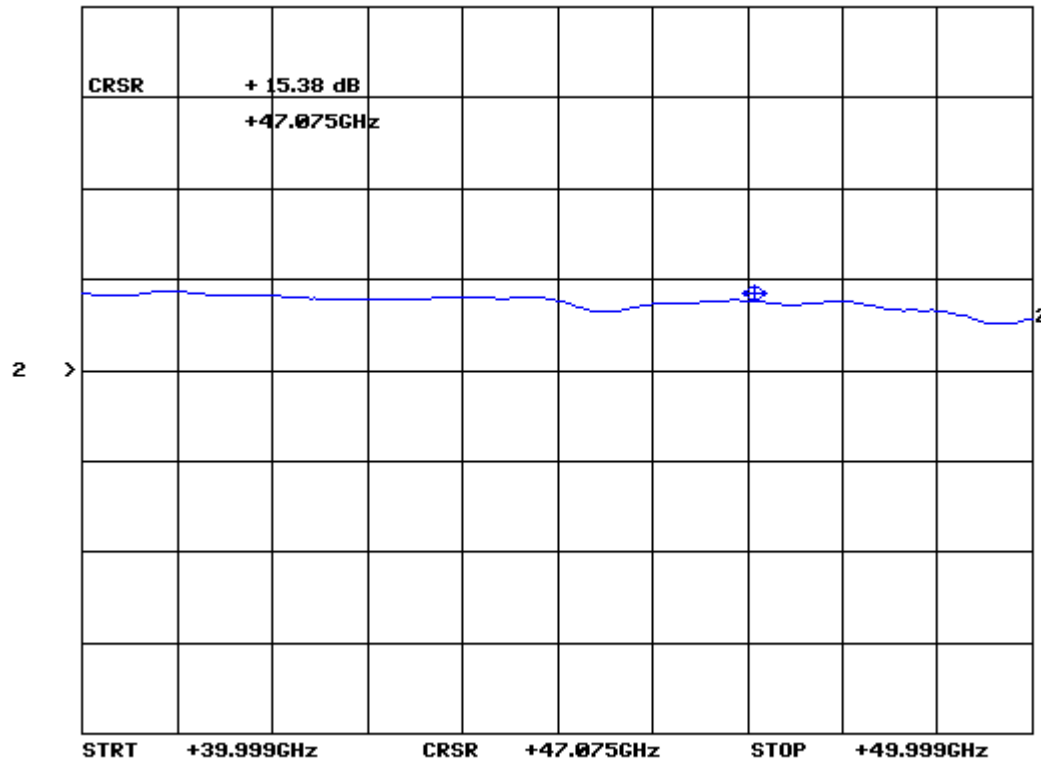
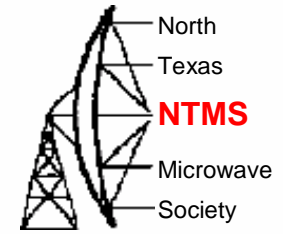
W5LUA Wiltron 3 dB Attenuator



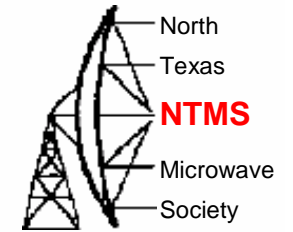
CH2: B -M - 3.90 dB
20.0 dB/ REF - .00 dB



Avago AMMC-6241



Hughes WR-15 Noise Figure Test Set

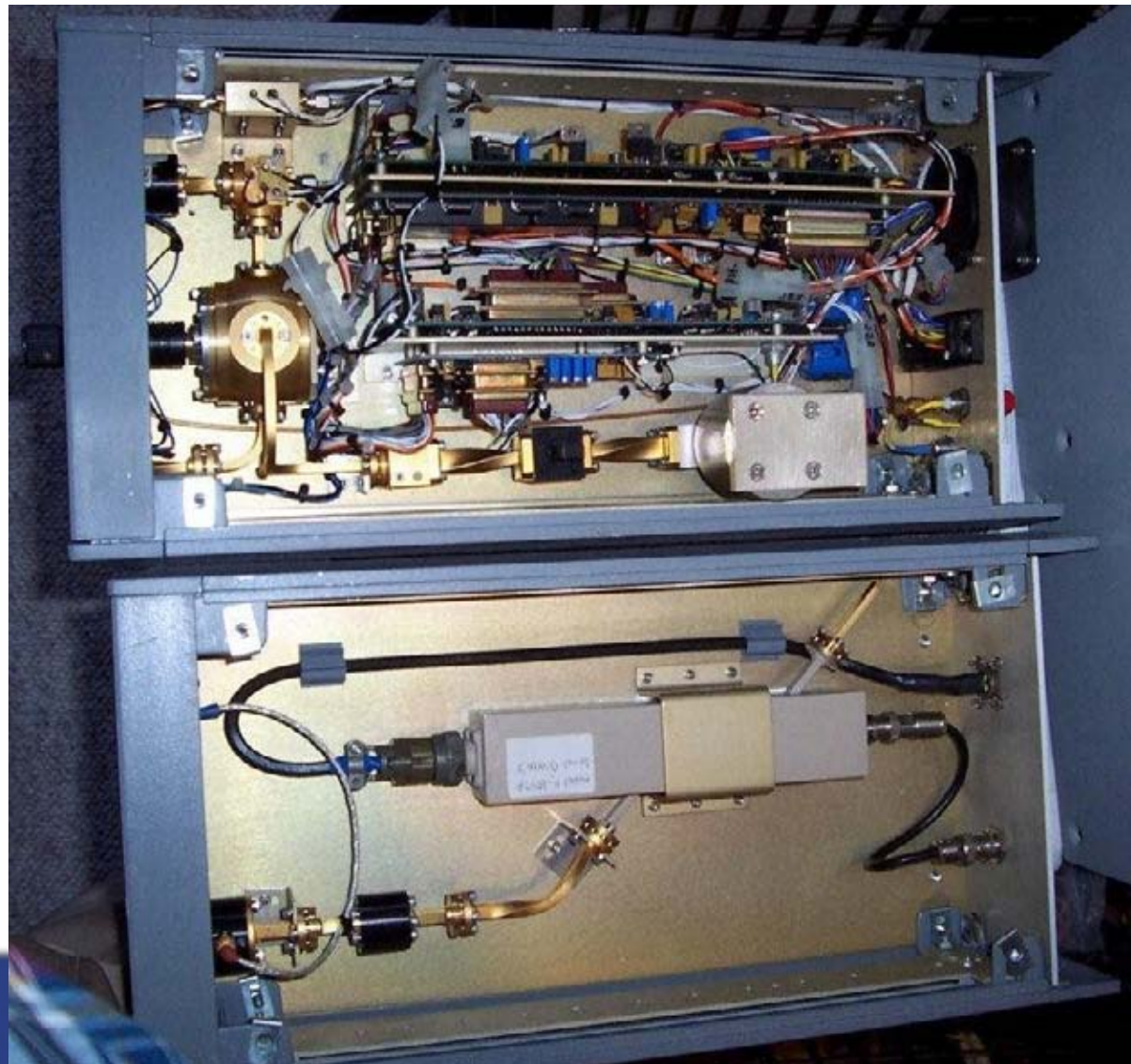


RF Input →

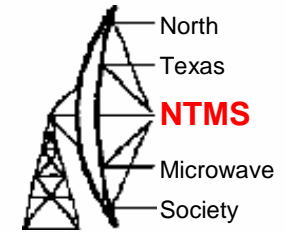
RF Output ←

Output from
noise
source

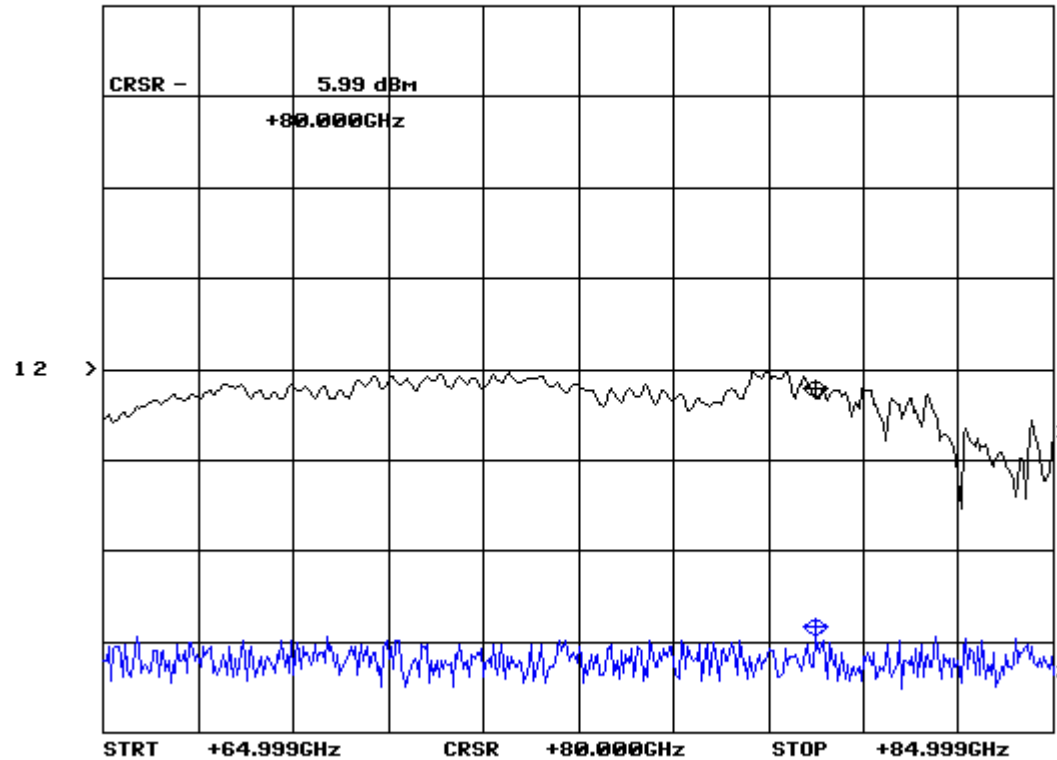
IF Output
→



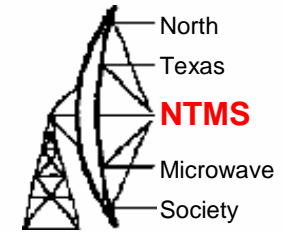
WR-15 detector swept from 65 to 85 GHz



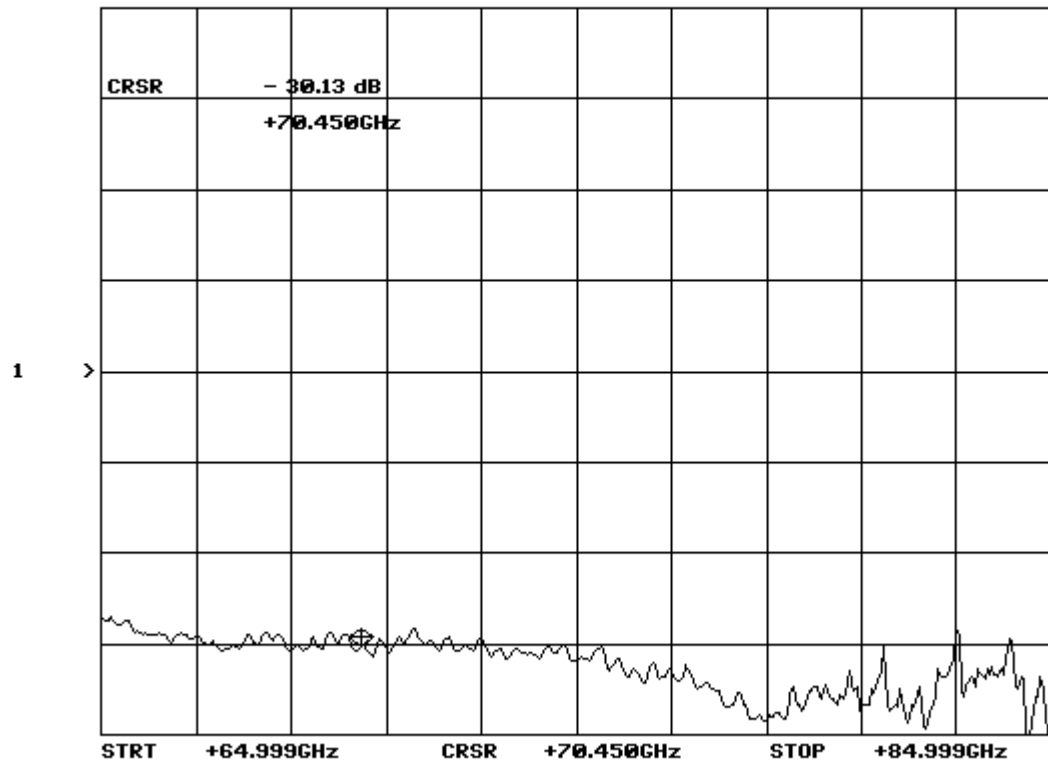
CH1: A - 5.99 dBm CH2: B - 58.57 dBm
 20.0 dB/ REF + .00 dBm 20.0 dB/ REF + .00 dBm



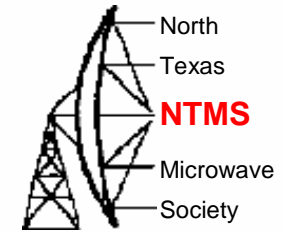
WR-15 30 dB Attenuator



CHI: A -M - 30.13 dB
10.0 dB/ REF - .00 dB

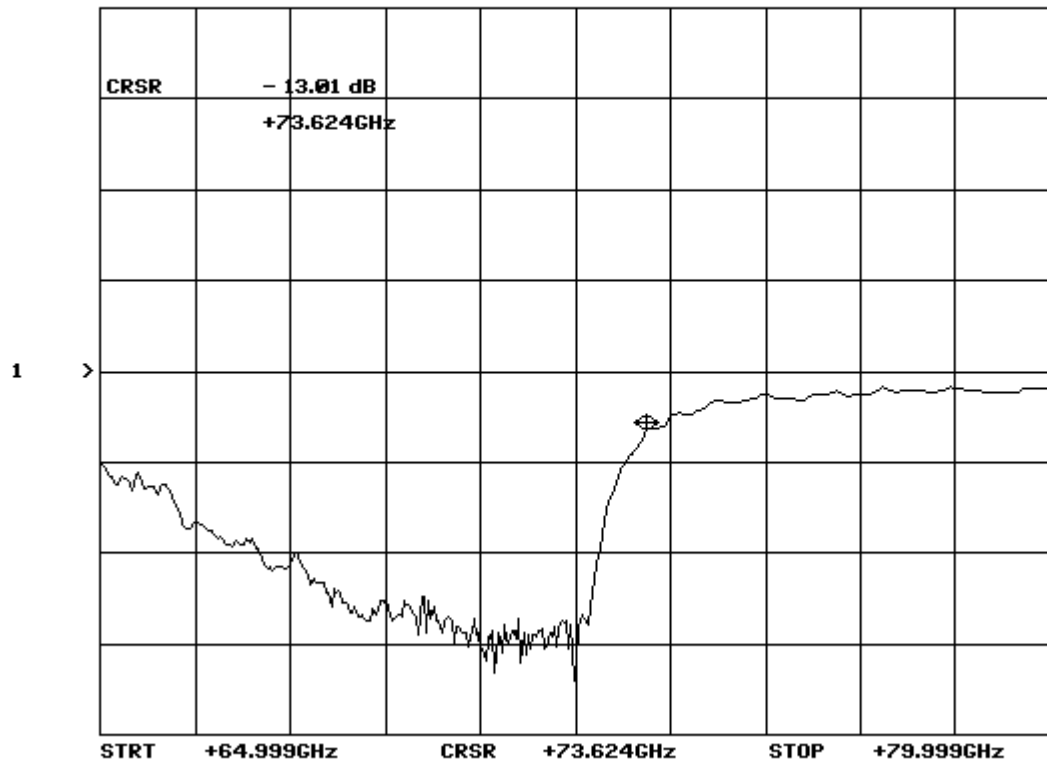


WA5VJB WR-8 (90 -140 GHz)

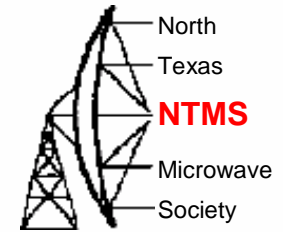


CHI: A -M -13.01 dB
20.0 dB/ REF - .00 dB

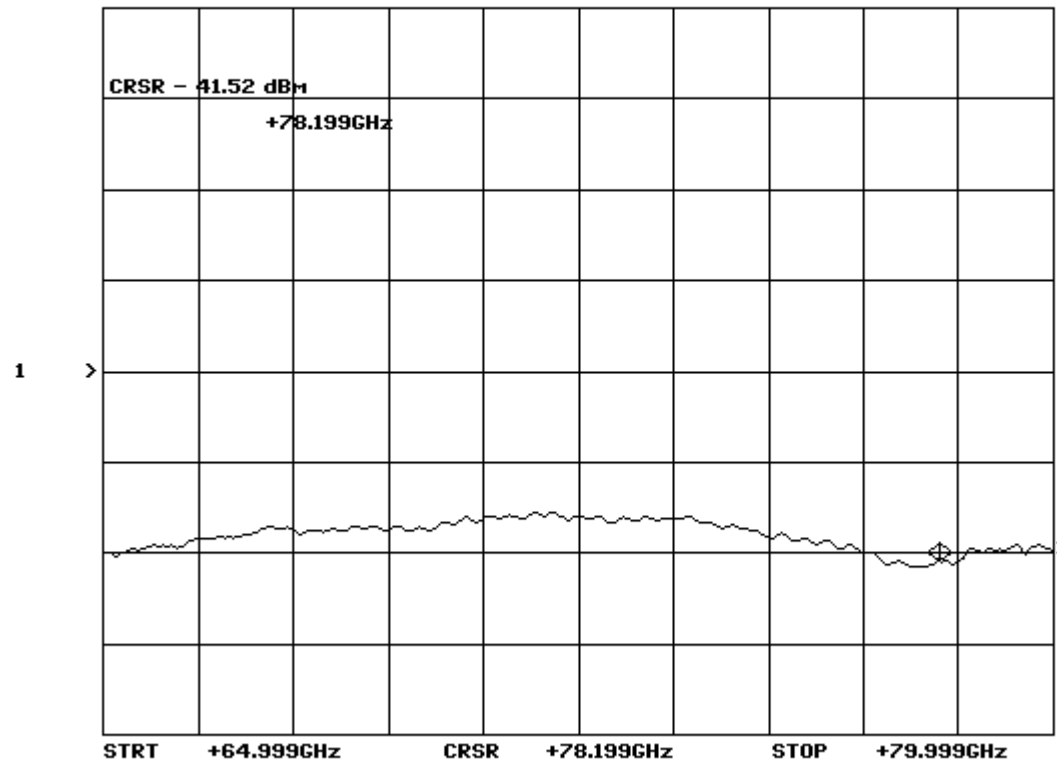
73 GHz cutoff



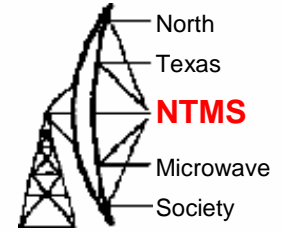
RF Input Level for LNA Tests



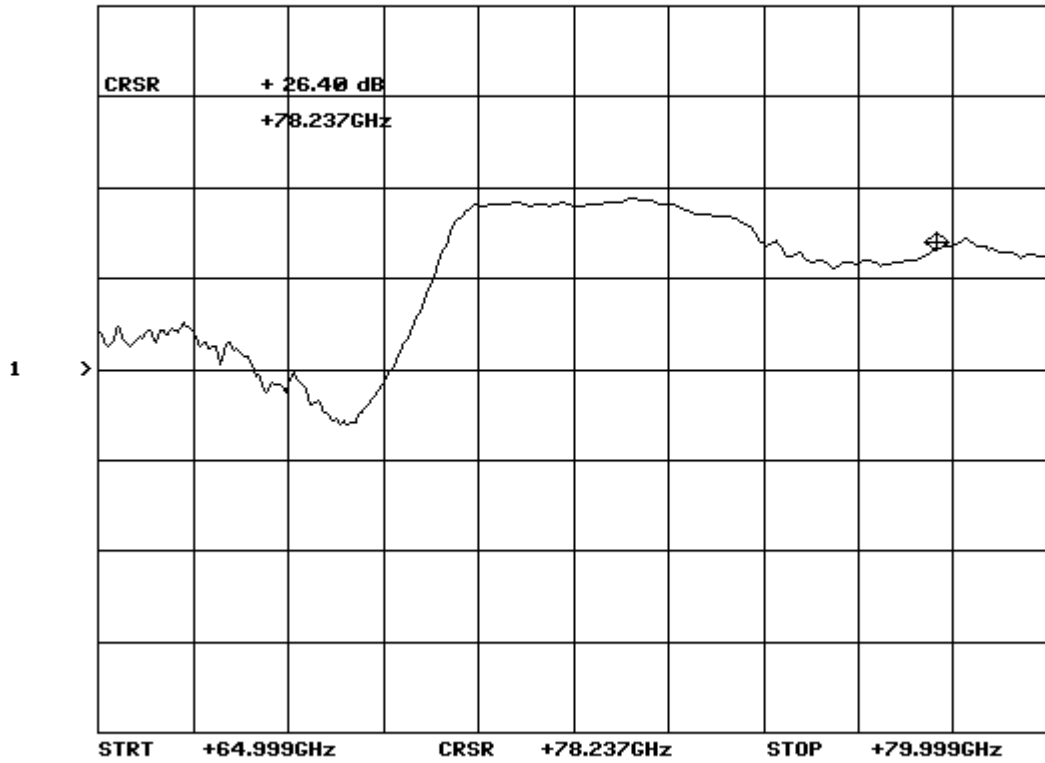
CHI: A - 41.52 dBm
20.0 dB/ REF + .00 dBm



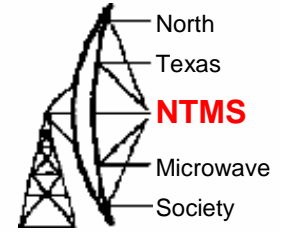
WA1MBA LNA#1



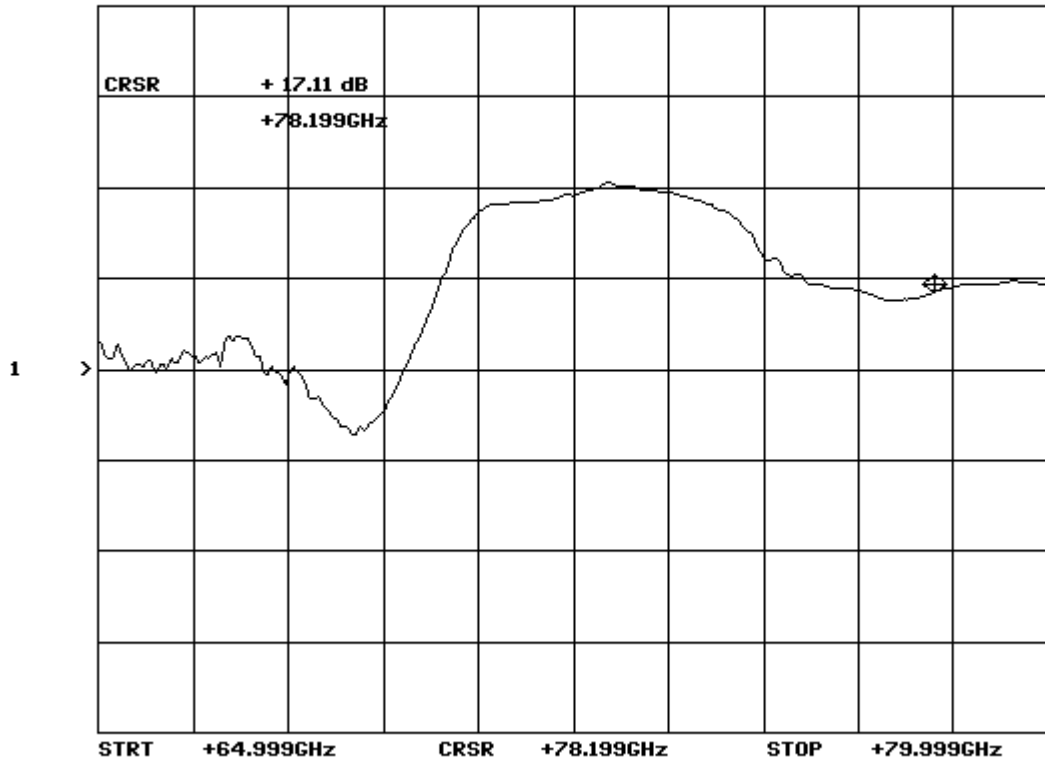
CHI: A -M + 26.40 dB
20.0 dB/ REF - .00 dB



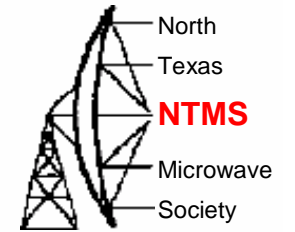
WA1MBA LNA#4



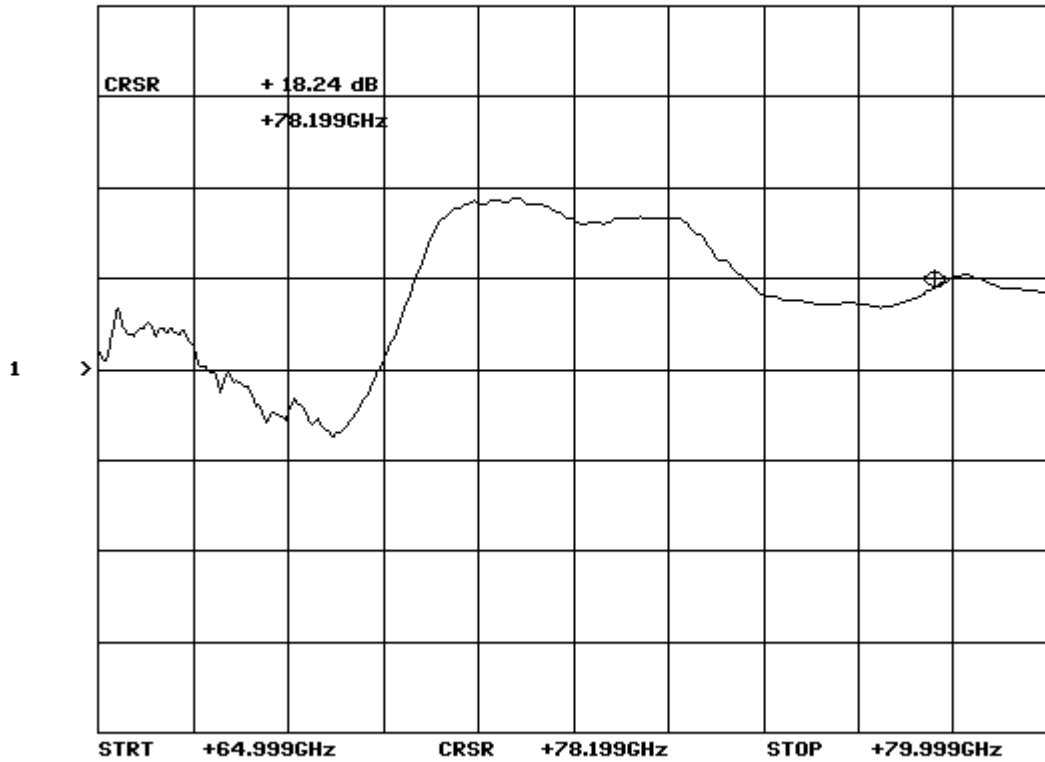
CHI: A -M +17.11 dB
20.0 dB/ REF - .00 dB



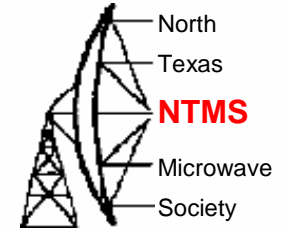
WA1MBA LNA #5



CHI: A -M + 18.24 dB
20.0 dB/ REF - .00 dB

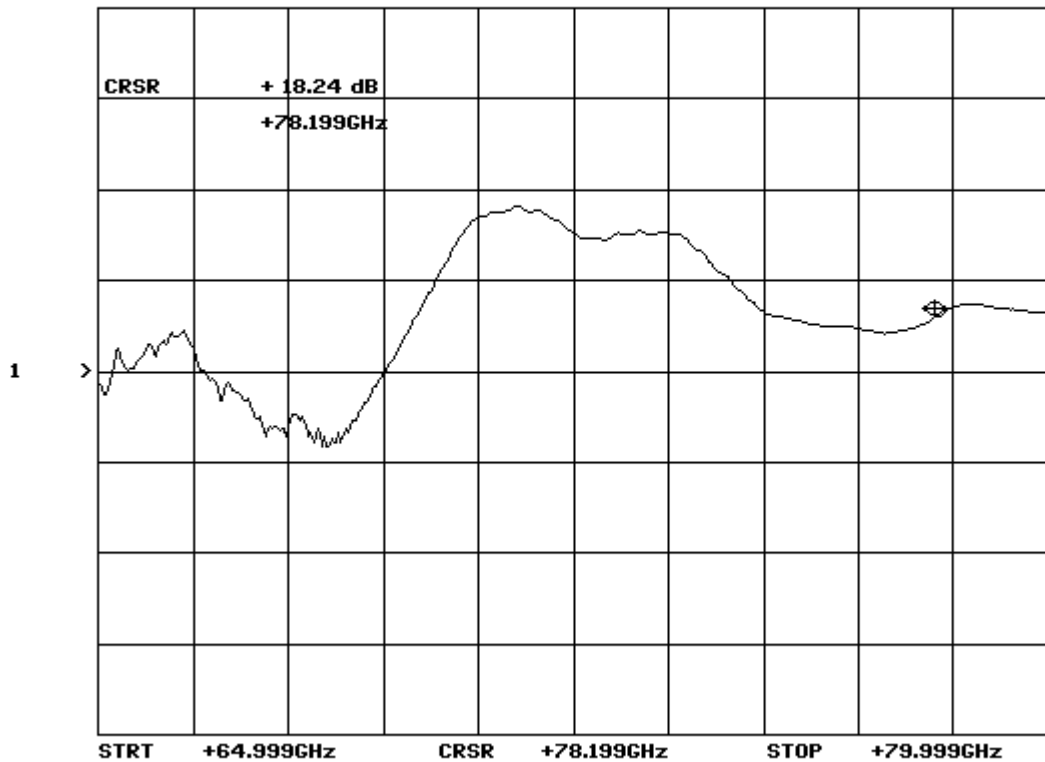


WA1MBA LNA #6

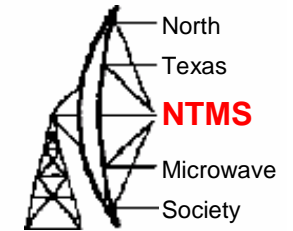


CHI: A -M + 11.99 dB
20.0 dB/ REF - .00 dB

Forgot to reset curser, s/b around 16 dB

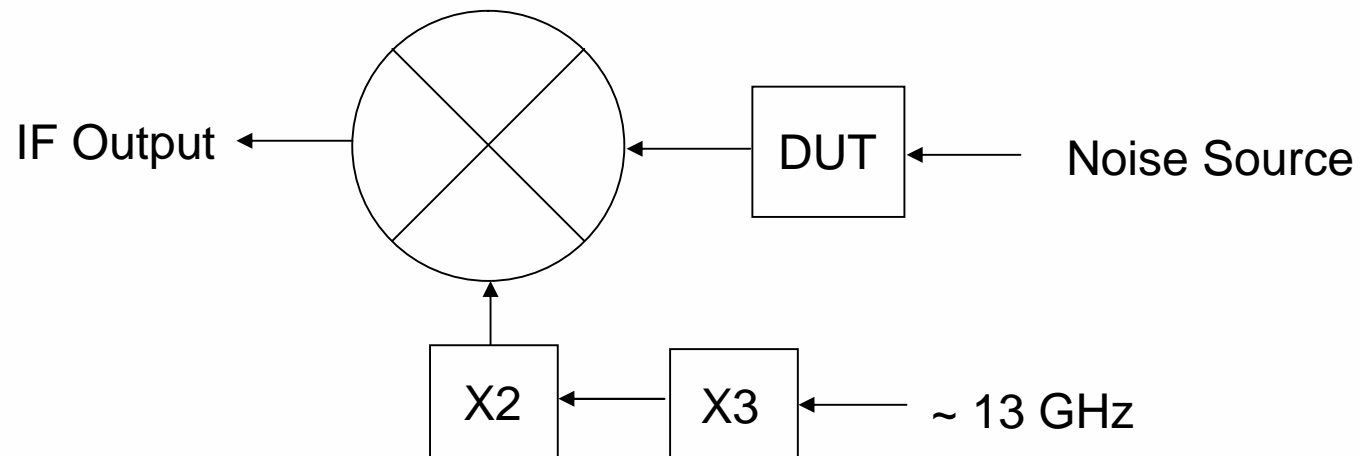


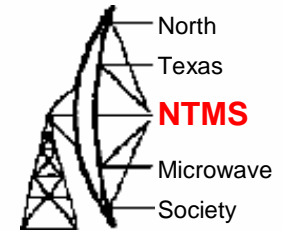
DSB NF Measurements performed at MUD 2009



				NF (dB)	Gain (dB)
78 GHz	WA1MBA	LNA#4	2 Stage CHA1077	7.75	19.8
	VE4MA	Converter	Mixer/IF Amplifier	14.00	12.2
	W5LUA	Converter	Isolator/BPF/Mixer/IF Amplifier	20.20	15

Fundamental Mode WR-15 Mixer

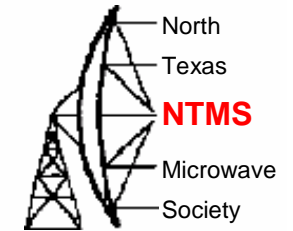




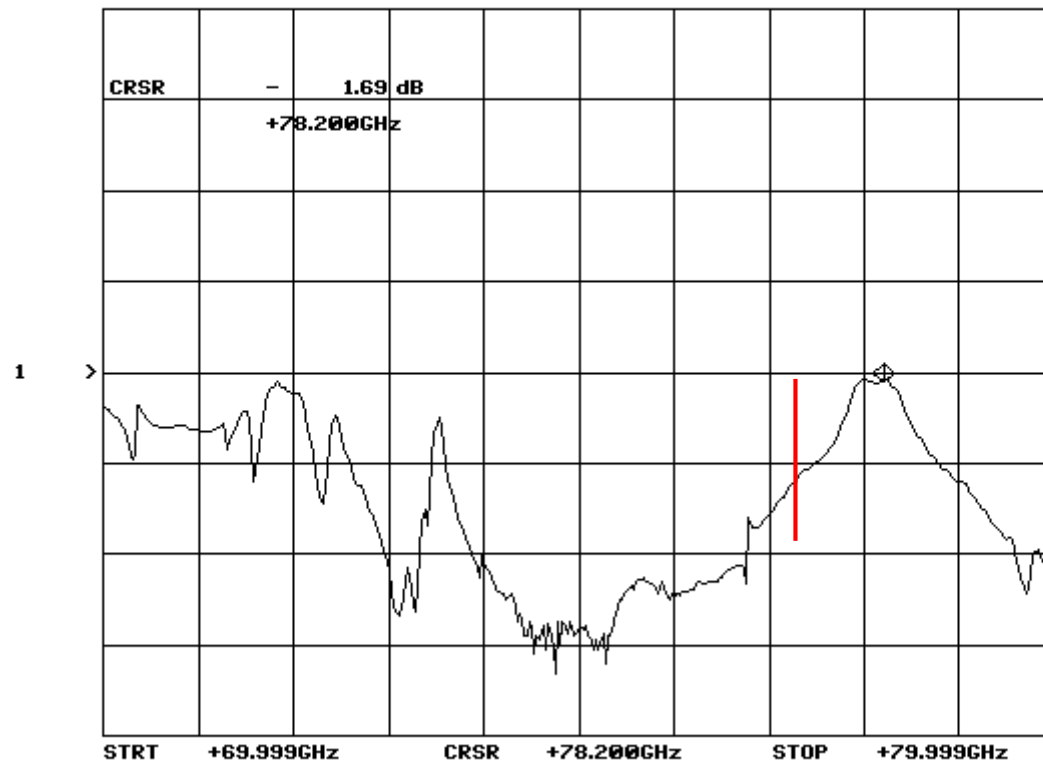
Although DSB noise figure measurements provide an average noise figure at $LO \pm IF$, it was felt that with all the low frequency gain of the WA1MBA amplifier that some sort of filtering was required to keep from saturating the mixer. This was accidentally verified on the bench when the LO was inadvertently turned off and I was still able to make a noise figure measurement!

But..... where to find a filter?

OE9PMJ 47 GHz BPF Retuned to 78 GHz

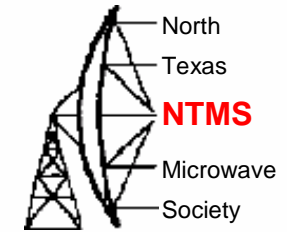


CHI: A -M - 1.69 dB
20.0 dB/ REF - .00 dB

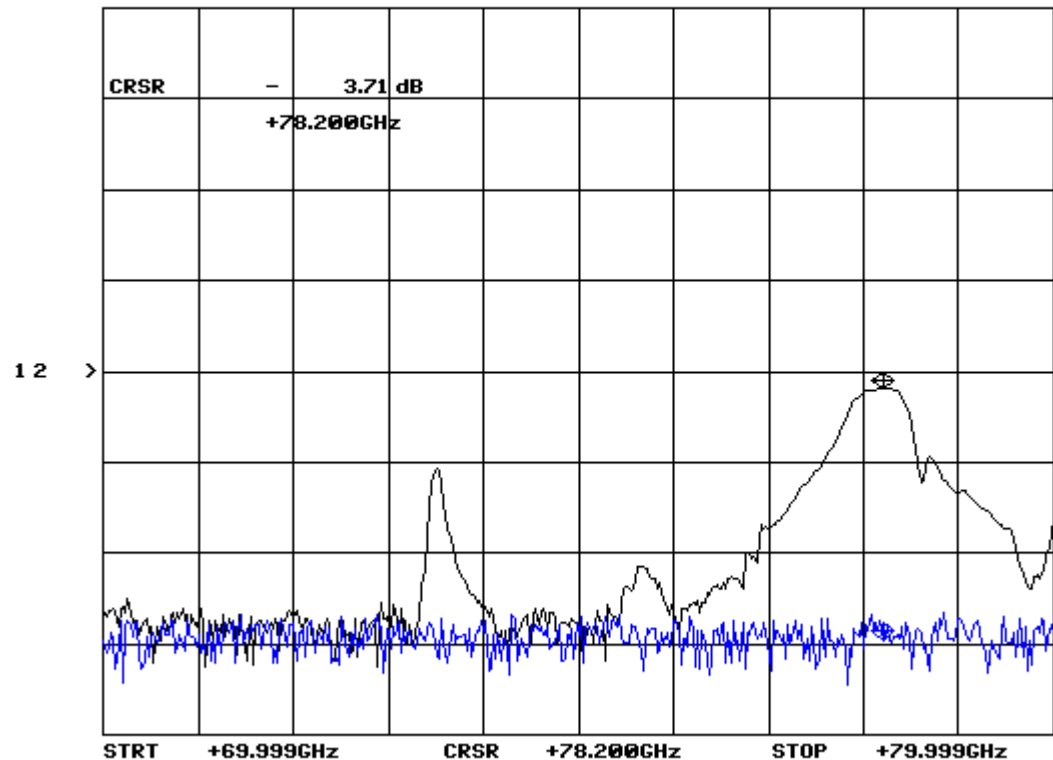


Approximately
20 dB image
rejection at
77.328 GHz

OE9PMJ 47 GHz BPF Retuned to 78 GHz with WR-8 in series

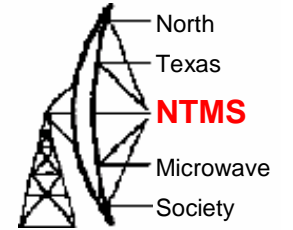


CH1: A -M - 3.71 dB CH2: B - 58.90 dBm
20.0 dB/ REF - .00 dB 20.0 dB/ REF + .00 dBm

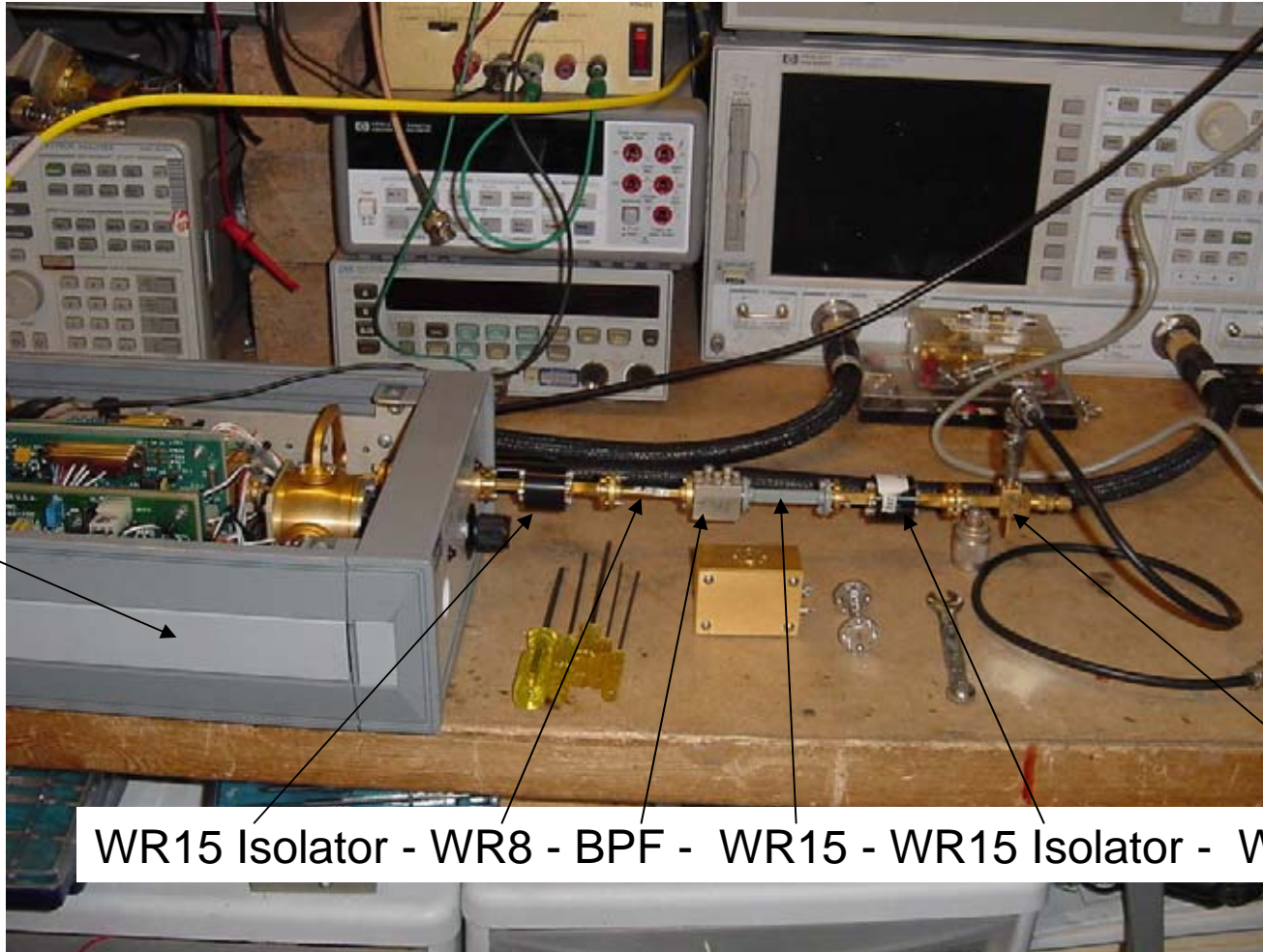


The WR-8 piece of waveguide provides additional attenuation below 73 GHz

Testing the OE9PMJ 47 GHz Filter on 78 GHz

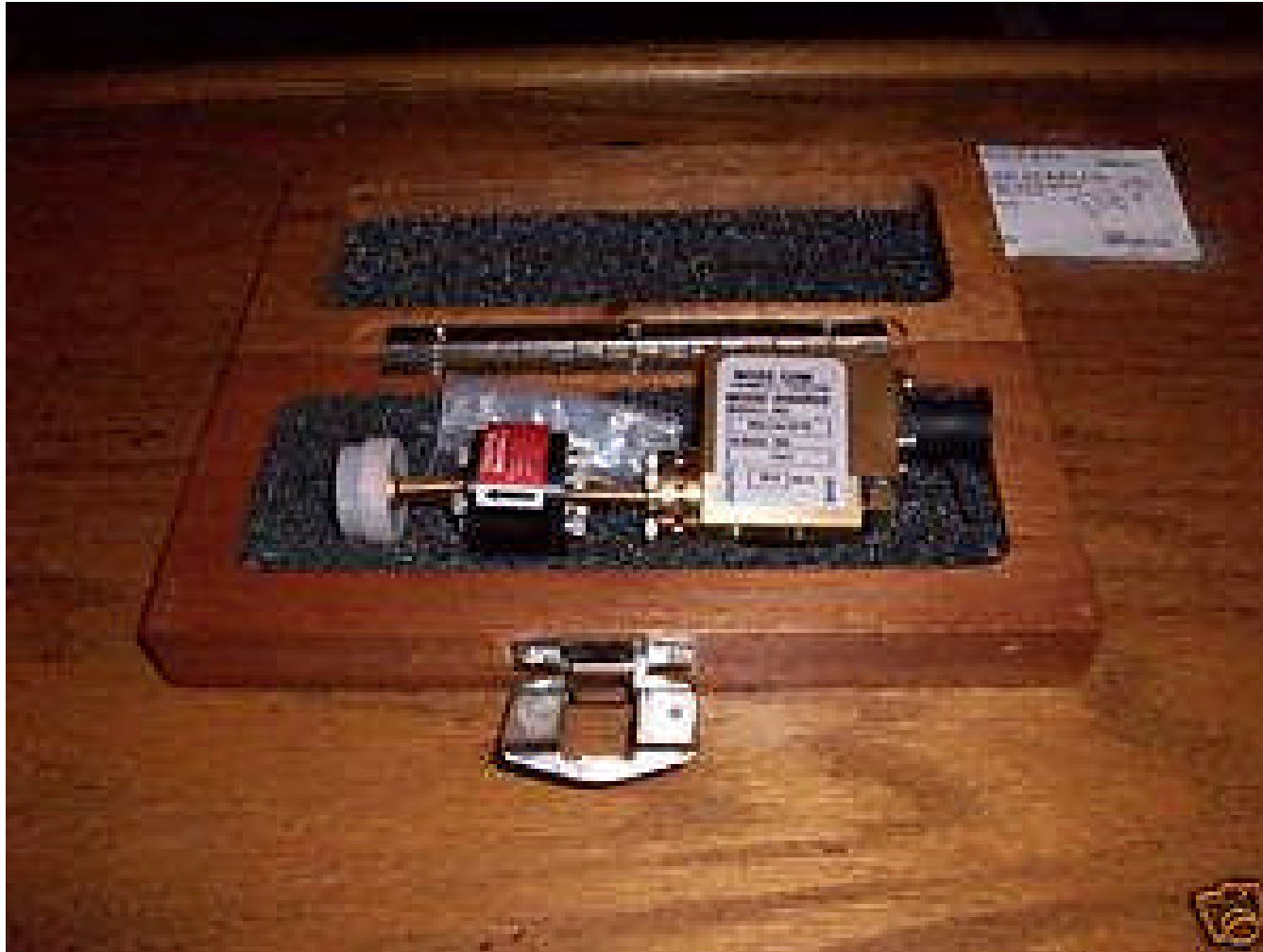
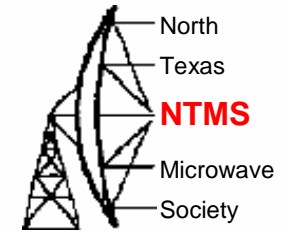


Hughes
Test Box
with X2
doubler to
78 GHz

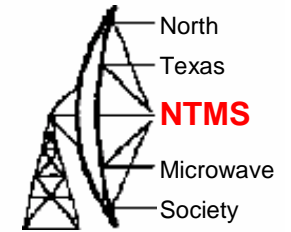


WR15 Isolator - WR8 - BPF - WR15 - WR15 Isolator - WR15 Detector

Barry's New Baby – A 75 to 100 GHz Noise Source!



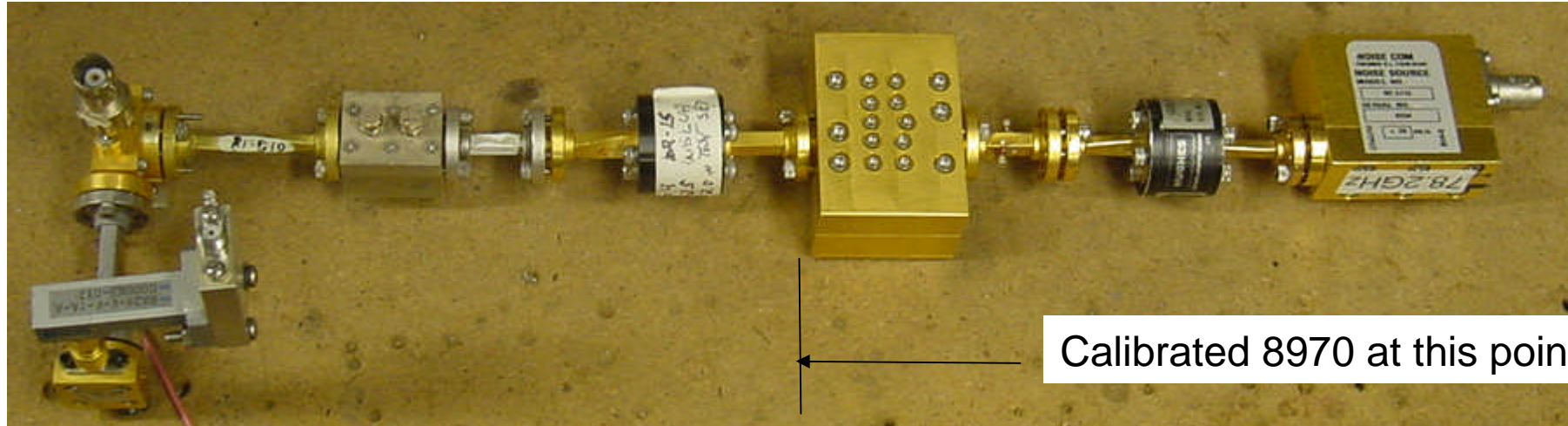
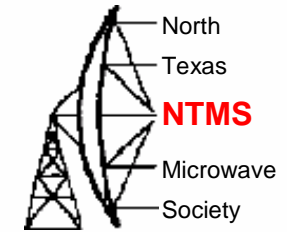
WA1MBA 78 GHz LNAs using VE4MA WR-10 NoiseCom Noise Source



LNA #	NF		Gain	
	w/o tuner	w/tuner	w/o tuner	w/tuner
4	10.6 dB	8.5 dB	14.6 dB	17.3 dB
5	11.8 dB	7.7 dB	14.9 dB	19.1 dB
6	11.5 dB	6.9 dB	9.7 dB	14.5 dB

It seems like we are going no where with these noise figures – something must be wrong!

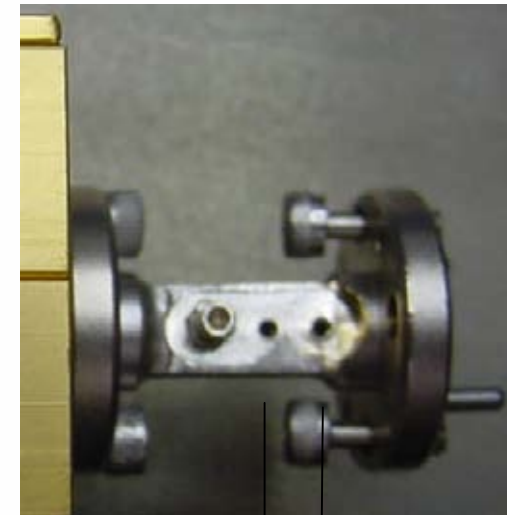
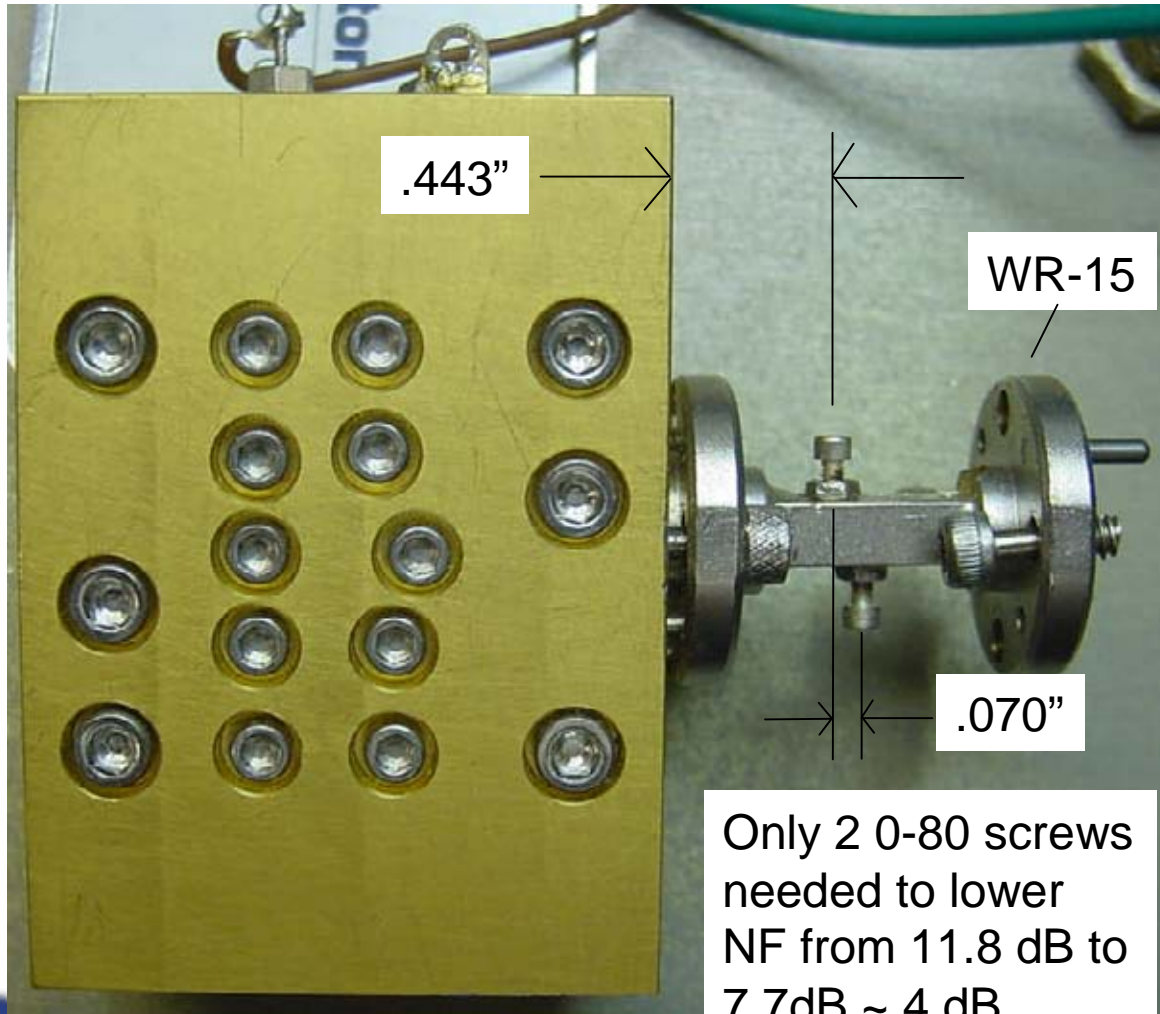
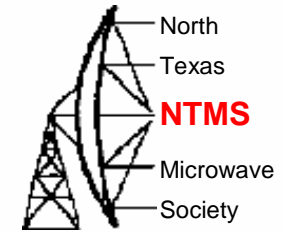
WA1MBA 78 GHz LNA#6 with W/G Tuner measured at W5LUA



The indicated NF is measured with the input waveguide tuner in place. Without the tuner the Gain is 9.7 dB and the NF is 11.5 dB. Gain can be increased above 14.5 dB with the addition of a waveguide tuner at the output of the LNA



WA1MBA 78 GHz LNA#5 with W/G Tuner

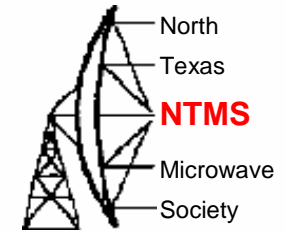


.140"
2pl on top

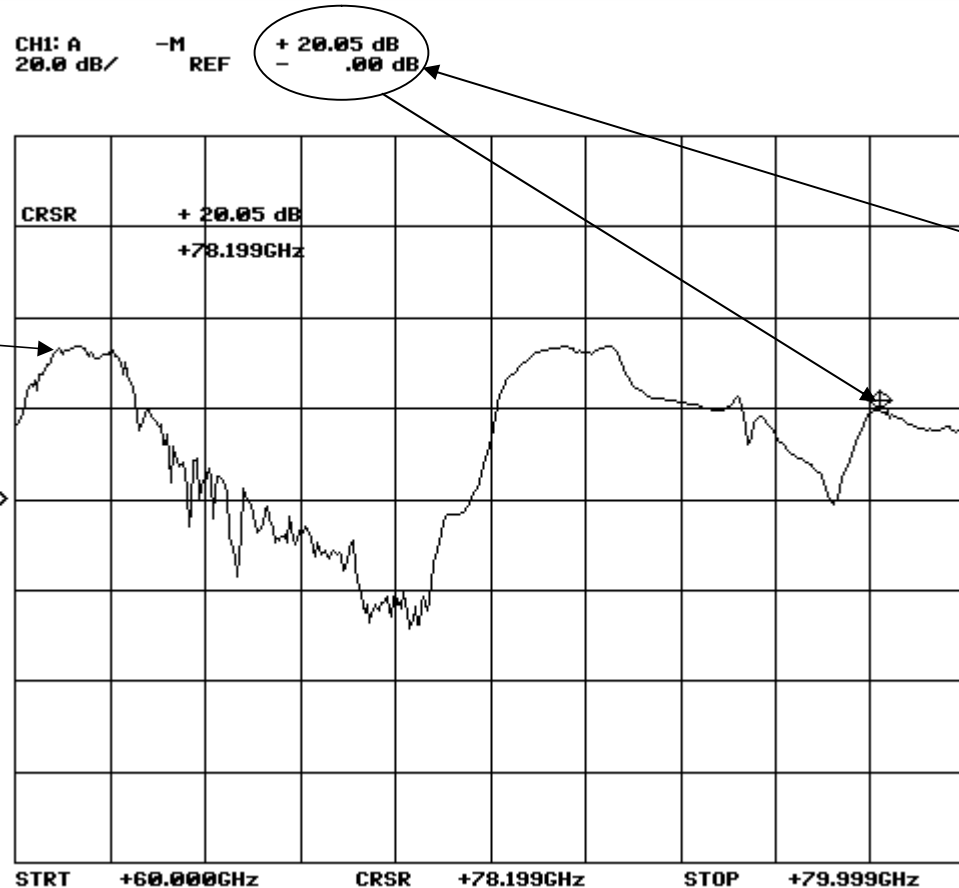
3 0-80 tapped holes on top and 2 on bottom, ones on bottom are offset by .070" from top

Only 2 0-80 screws needed to lower NF from 11.8 dB to 7.7dB ~ 4 dB improvement

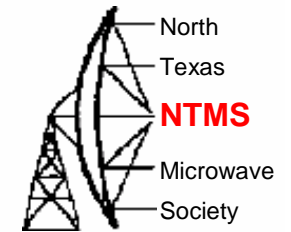
LNA#5 with Input Tuner – 8/29/2010



I don't believe this is real – most likely subharmonics into multiplier since multiplier is most likely responding to a $1/3 f$ signal as opposed to the desired $1/2 f$.

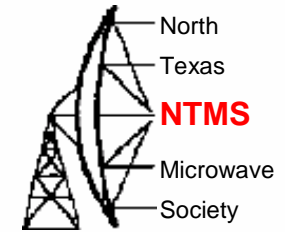


Compares well to 19 plus dB from noise figure meter



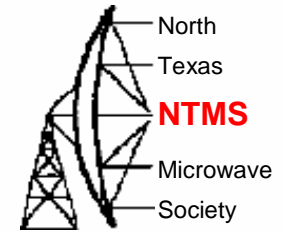
At this point my system noise figure was pretty close to 8.5 dB but I still decided it was time to look for sun and moon noise

GR-1216 & GR-1236 IF Amplifiers



These meters provide a 30 MHz IF amplifier with up to several MHz of bandwidth which makes it easy to measure sun and moon noise – they can be easily retuned for 28 MHz

Measurements



- Sun noise over cold sky
- Moon noise over cold sky
- Ground to cold sky or
- 50Ω to cold sky

$$\text{INV LOG } ((\text{dB})/10) = \frac{Tr + To}{Tr + Tant}$$

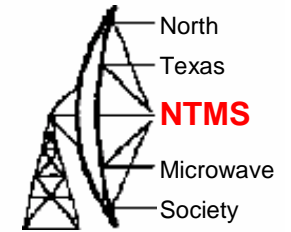
$Tr = 290 \log (NF-1)$ where NF is noise factor (ratio) and NOT noise figure (dB)

Tr = Noise temperature of receiver (Kelvin)

To = temp of 50Ω load (Kelvin)

$Tant$ in Kelvin is a measure of how quiet your antenna is on receive which takes into account feed efficiency and spillover and atmospheric absorption – lower the better

2.4 m Fiberglass Offset Fed Dish with WR-10 Std Gain Horn



NF = 8.5 dB (1763K)

Sun Noise / cold sky =

1.6 to 1.8 dB w / WR-10 Feedhorn

1.2 dB w / WR-15 Feedhorn

1.2 dB w / small WR-15 Feedhorn

1.0 dB w / W2IMU Feedhorn

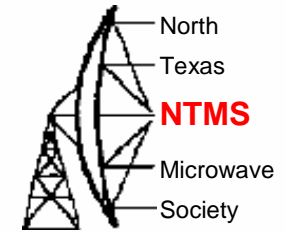
SFI = 75

Moon Noise / cold sky = 0.15 dB
w / WR-10 Horn

50Ω / cold sky = 0.35 dB
w / WR-10 Horn, NF = 8.5 dB,
Ta = 131K

Theoretical 3 dB BW = .11 degree

1 m Winegard Offset Fed Dish with W2IMU Feedhorn built by WA5JAT



NF = 8.5 dB (1763K)

Sun Noise / cold sky =
3.8 dB w / W2IMU Feedhorn
1 dB w / WR-10 Feedhorn
SFI = 82, 1, 1

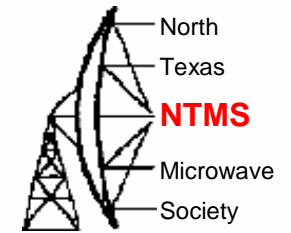
Moon Noise / cold sky =
0.2 dB

50Ω / cold sky = 0.3 dB,
NF = 8.5 dB, $T_a = 153$ K

Not Optimized Yet!

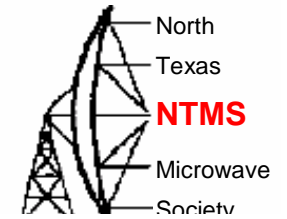
Theoretical 3 dB BW = .3
degree & $G \sim 56$ dBi

Lessons Learned



- This is not going to be easy!
- An isolator on the noise source is a must to reduce measurement error – nothing really new here...we knew that from our low frequency work over the years that an isolator or a 10 dB pad would help improve measurement accuracy
- It appears that the LNA requires an input tuner and maybe even an output tuner – not a big deal, a few screws in a piece of WR-15 and we are ready for tuning.....
- Returned a couple of units to Tom WA1MBA for verification on noise figure.....standing by for a report...

New LNA#6 – Wow!

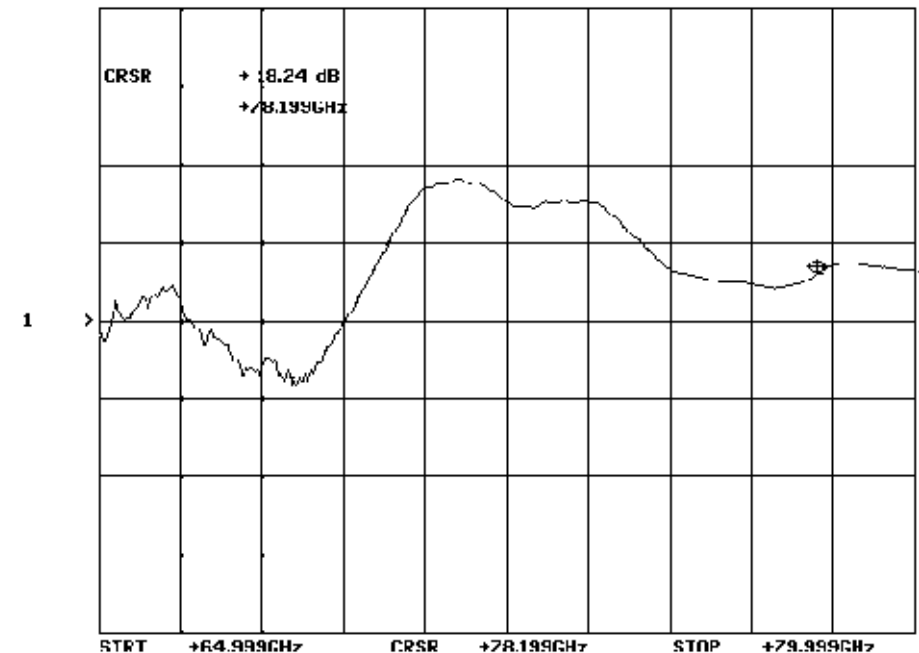
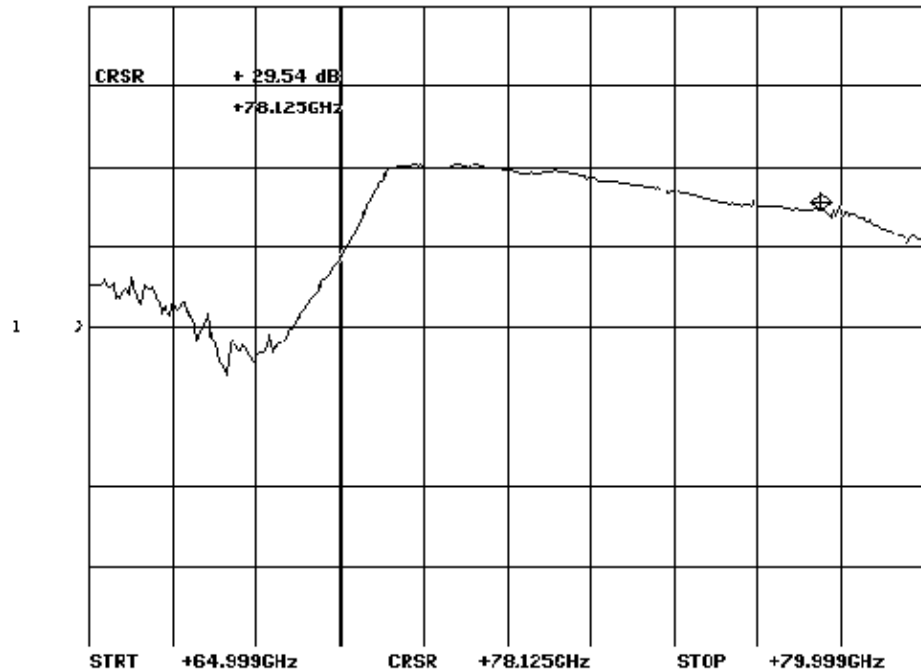


CHI: A -M + 29.54 dB
20.0 dB/ REF - .00 dB

Now

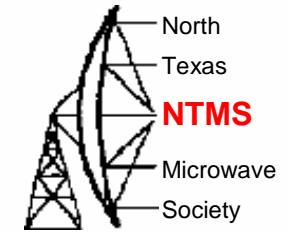
CHI: A -M + 11.99 dB
20.0 dB/ REF - .00 dB

Was

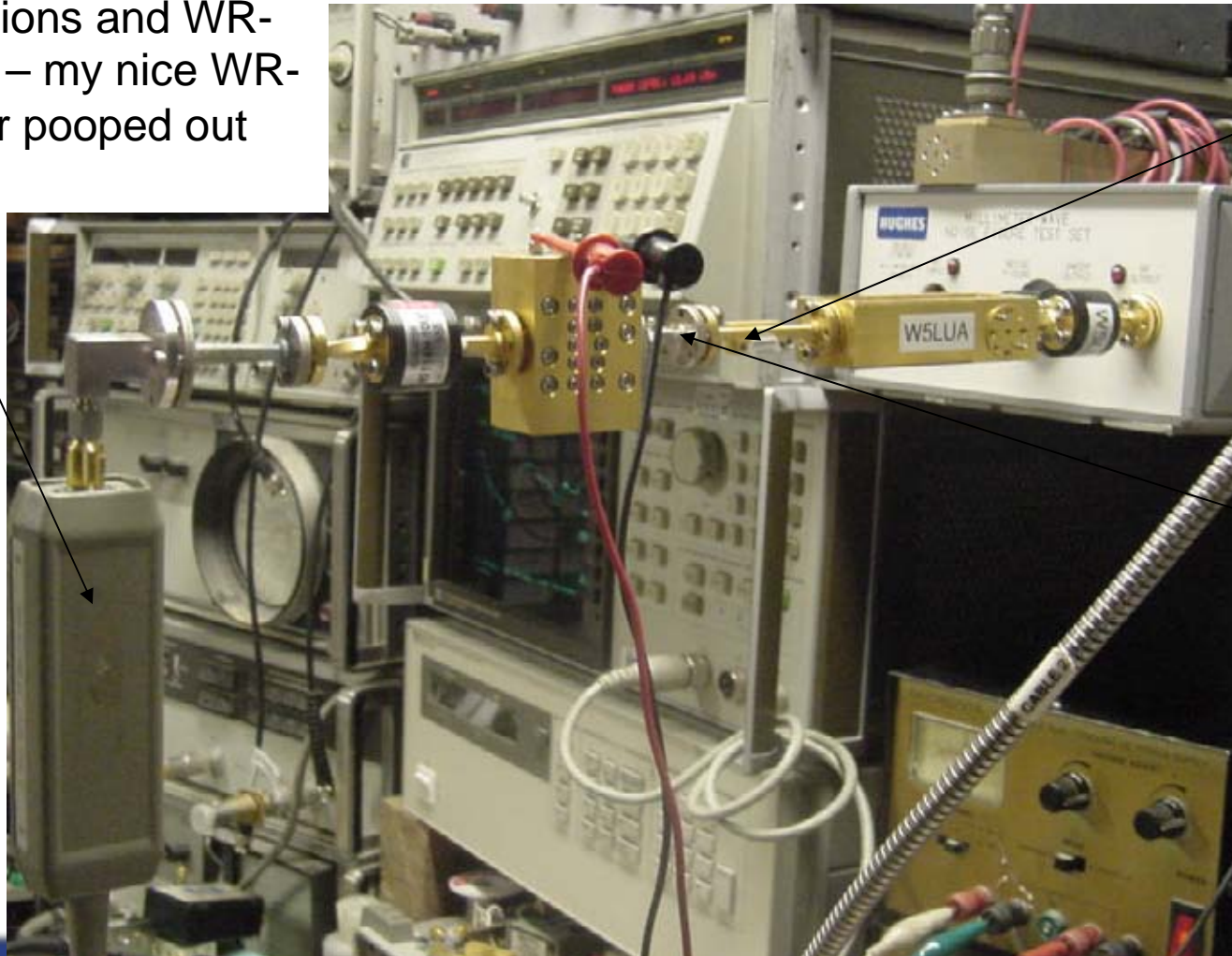


It appears that Tom has performed some magic on the LNA and the gain at 78.2 GHz has gone from 12 dB to 29 dB without the need for a tuner!

Testing LNA #5 8/29/2010



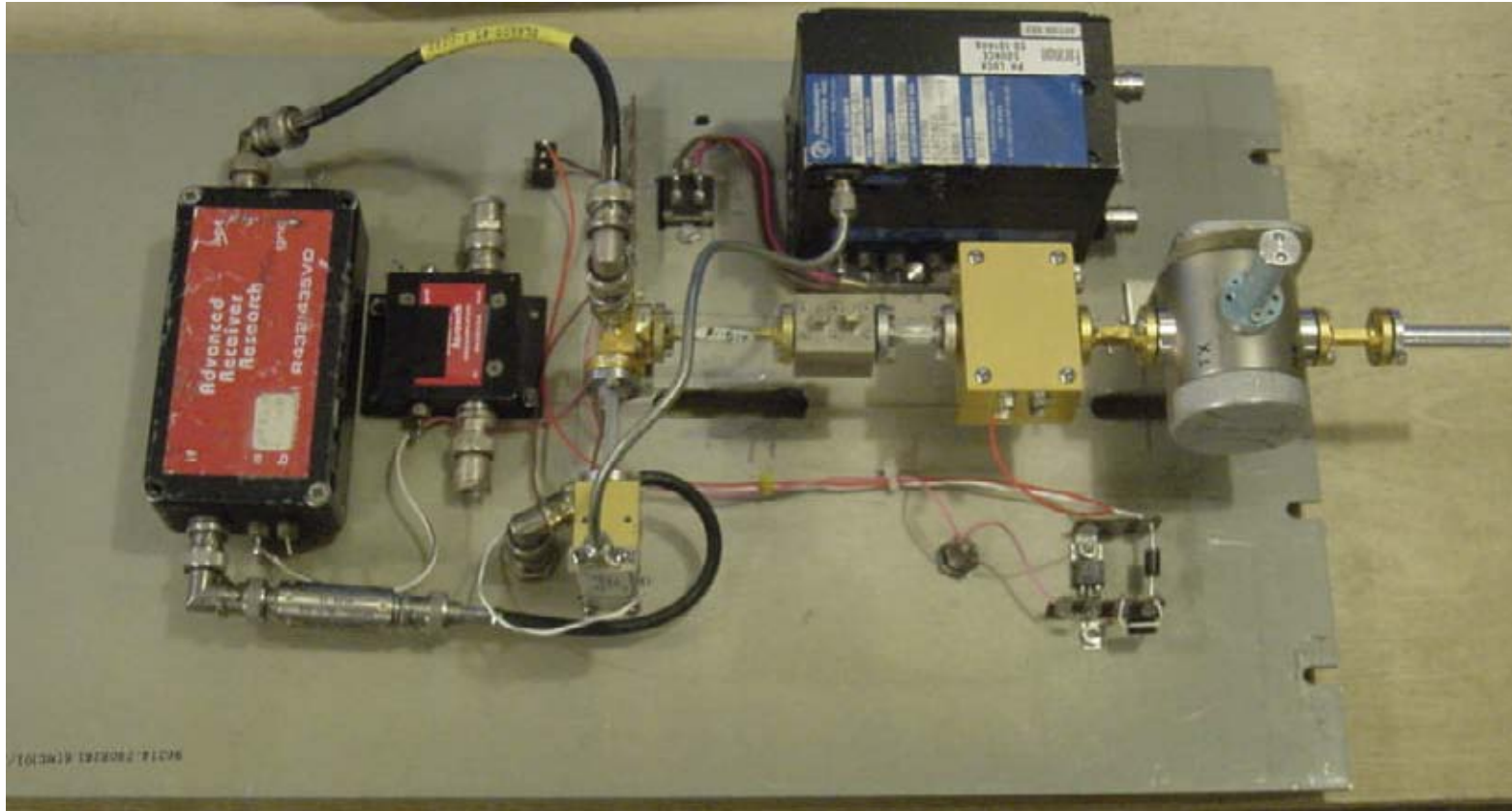
50 GHz 2.4mm detector with transitions and WR-15 isolator – my nice WR-15 detector pooped out on me



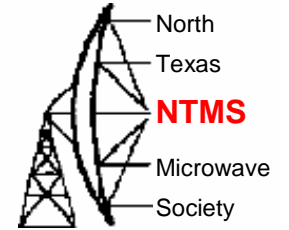
30 dB Attn

-30dBm
Input
power

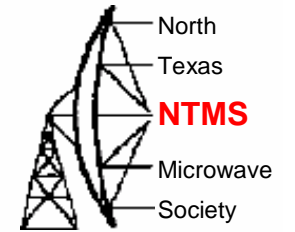
78 GHz Converter



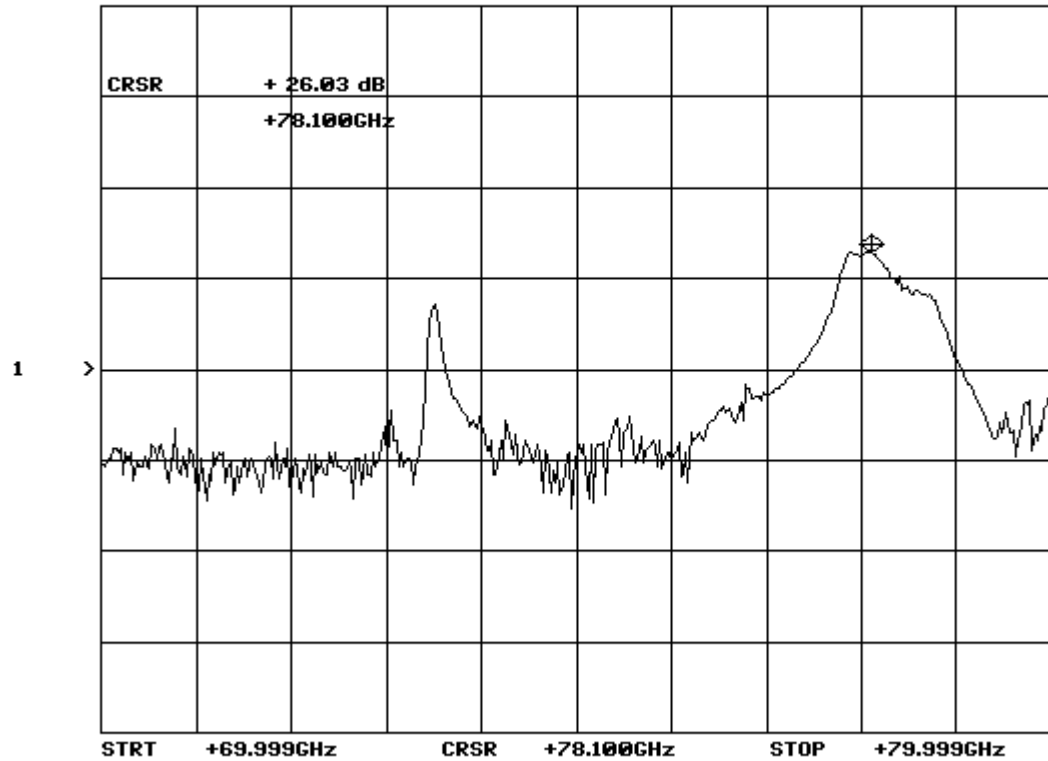
78 GHz XVTR with new LNA !



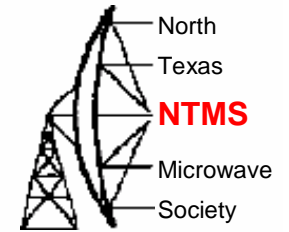
New LNA#6 w/BPF and WR-8



CHI: A -M + 26.03 dB
20.0 dB/ REF - .00 dB

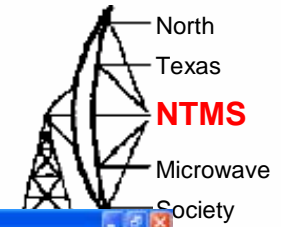


To the Moon, Alice!



- If these noise figure readings are real, then we must be able to verify the measurements by again using the sun and moon and noise sources

VK3UM Software



VK3UM EME Performance Calculator

Two Station EME Receiver Performance Source Positions Planets x 10 Multiplier

Tx A (Home Station)

Frequency: 78.000 GHz, Path Loss: 305.46 dB, T Sky: 200 K, Rx BW: 120 Hz, Diam: Solid, Mesh: Dish, Spacing: -150.0 dBm, Sys Sensitivity: 5.9 dB, Echo SNR: 7.3 dB

Effective ground T_K: 294 °K, C/S - ground → -3.1 dB

7.3 dB (circled), 1.15 dB (circled)

Rx T_K: 359.4 °K = 3.50 dB, Receiver Noise Temperature: 290 °K - 17 °C

Sys T_K: 587.4 °K = 4.81 dB, System Noise Temperature

Dx Station as received at Home Station ... 3.8 dB

Home Station as received at Dx Station ... 3.8 dB

Tx B (Dx Station)

Frequency: 78.000 GHz, Path Loss: 305.46 dB, T Sky: 200 K, Rx BW: 120 Hz, Diam: Solid, Mesh: Dish, Spacing: -150.0 dBm, Sys Sensitivity: 7.8 dB, Echo SNR: 7.8 dB

Effective ground T_K: 284 °K, C/S - ground → -3.1 dB

8.0 dB

Rx T_K: 359.5 °K = 3.50 dB, Receiver Noise Temperature: 290 °K - 17 °C

Sys T_K: 587.5 °K = 4.81 dB, System Noise Temperature

Yagi Array

Single Yagi Gain in dBi: 12.65 dBi, Number of Yagis: 1, Array Gain: 10.50 dBd, 12.65 dBi

Parabolic Reflector

Diameter: 1.00 m, Size: Metric, f/D: 0.55, Efficiency: 65%, Beam Width: 0.27°, Gain: 427397, Dish Gain: 54.16 dBd, 56.31 dBi

258.9 Lambda

Home Station ... Y Factor Calc

Noise Source: Sagittarius, Cassiopeia, Cygnus, Taurus A, Virgo, Termination

Quiet Source: Termination, Aquarius, Leo, Taurus, TSKy, CMB (2.4%)

Noise Flux: 290 °K, Quiet Flux: 200 °K, System T_K: 587.4 °K

Point Source Y Factor: -3.07 dB

Yagi Array

Single Yagi Gain in dBi: 17.30 dBi, Number of Yagis: 4, Array Gain: 20.85 dBd, 23.00 dBi

Parabolic Reflector

Diameter: 1.00 m, Size: Metric, f/D: 0.55, Efficiency: 80%, Beam Width: 0.27°, Gain: 531815, Dish Gain: 55.11 dBd, 57.26 dBi

260.2 Lambda

Effective Aperture: 0.50 M², **Beam Width Ratio**: 2.07

Moon Beam Fill Factor: 3.05 x, 4.84 dB, Sun Beam Fill Factor: 2.89 x, 4.61 dB, G/T Ratio: 727.64, Moon Temp @ 2.77 cm Phase: 213 °K, 213.0 °K

Moon Radar Eq.: 52.26 dB, Moon Flux 10°-22: 297.6175, Moon Angular Diam: 0.559°, Actual Moon Temp: 213 °K, 213.0 °K

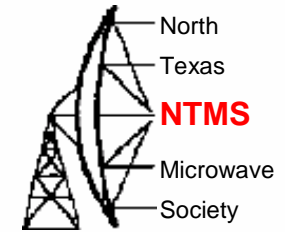
Moon Return Loss: 305.46 dB, 356400 km, 241.33 dB, Connected s/s: 4065

Free Space Loss at 78000 MHz

Buttons: Save Data, Get Data, Default, Print, Exit

VK3UM Ver 7.04

1 m Winegard Offset Fed Dish with W2IMU Feedhorn built by WA5JAT



System NF = 3.5 dB (359K)

Sun Noise / cold sky =
7.2 dB w / W2IMU Feedhorn
SFI = 87, 3, 0

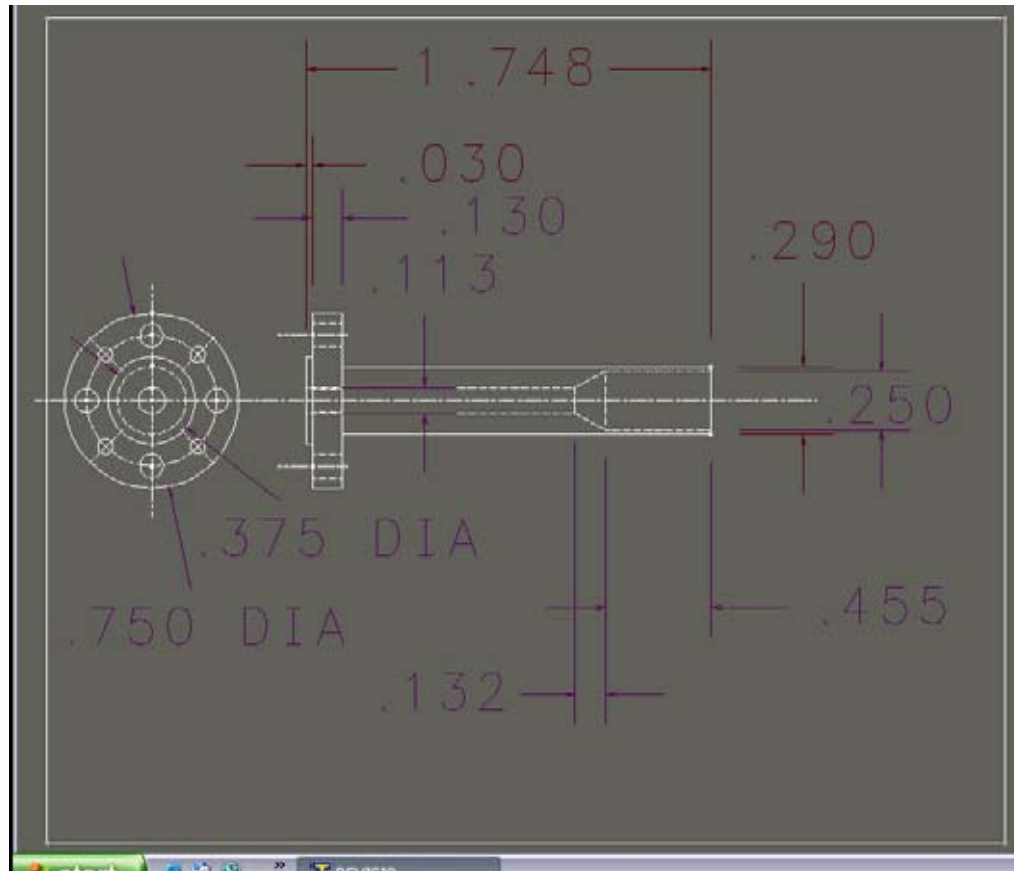
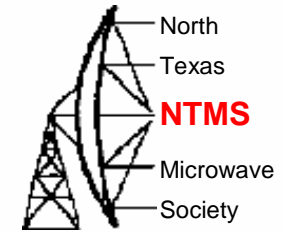
Moon Noise / cold sky =
0.75 dB

50Ω / cold sky = **1.2 dB**,
NF = 3.5 dB, Ta = 133 K

Feed position still not
optimized!

Dew point is quite a factor in
the measurements = moisture
and oxygen absorption!

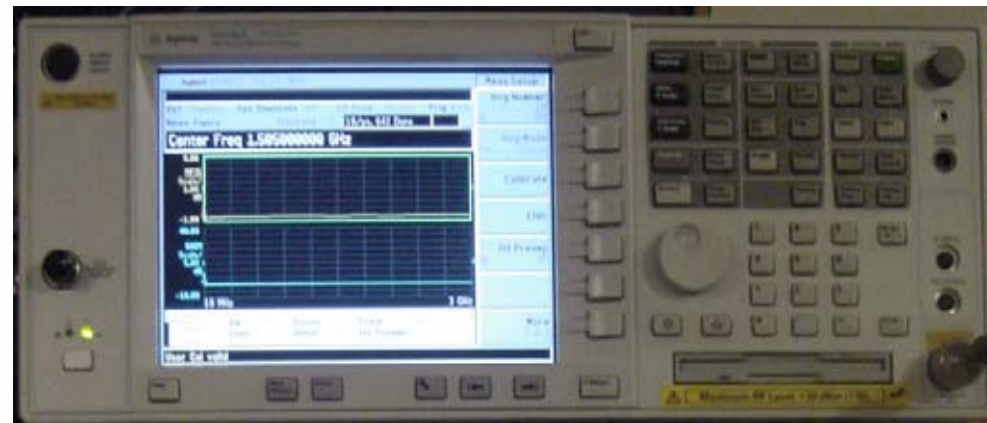
78 GHz W2IMU Feedhorn built by WA5JAT



W2IMU Dual Mode "Scaled" Feed Dimensions

Noise Figure Comparison of ATF-36077 1.3 GHz LNA from Ap Note 1128 as tested on 3 different NF Test Setups

E4440



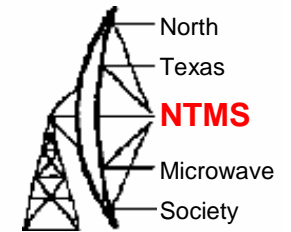
8970



8973



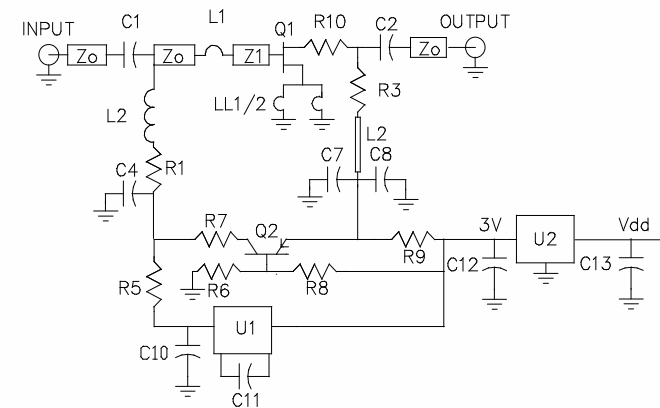
Noise Figure Comparison of ATF-36077 1.3 GHz LNA from Ap Note 1128 as tested on 3 different NF Test Setups

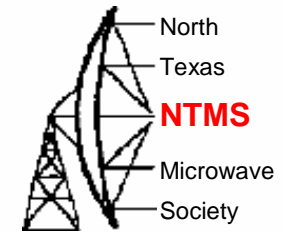


Equipment	NF of NFM – cal'ed out	BW	NF (dB)	Gain (dB)
8970B	6 dB	4 MHz	0.35	15.8
8973A	5.5 dB	4 MHz	0.43	15.9
		100 kHz	0.44	16.0
E4440*	7 to 8 dB up to 3 GHz	4 MHz	0.37	15.8
Spec Anal	With extra internal preamp	1 MHz	0.37	15.9

* With Noise Figure Personality Module

All measured with the same 346A noise source. All meters corrected for noise source T_{cold} . Interesting that the E4440 spectrum analyzer with noise figure personality module gives numbers closer to the old standard 8970 than the 8973 does





- Any Questions?
- My presentation will be available at www.ntms.org after the conference.
- Thank You
- See you on the moon!