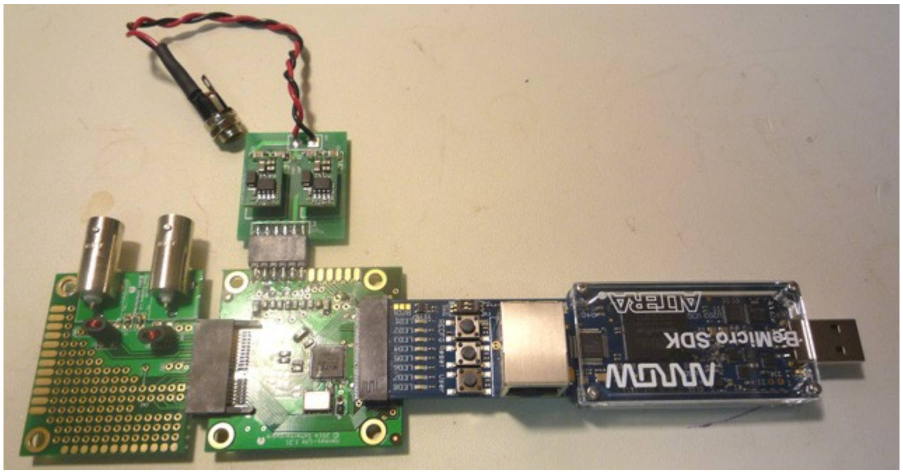
Test Report for Hermes Lite SDR

June 14-17, 2015

by Adam Farson VA7OJ/AB4OJ (Iss. 3)

Figure 1: The Hermes Lite.



Introduction: The following are the results obtained from receiver and transmitter tests which the author conducted on a Hermes Lite direct-sampling/DUC SDR receiver-exciter, kindly loaned by Dave Miller VE7PKE. The DUT was connected via a dedicated Ethernet router to a 2.3 GHz Core i5 laptop running under Win7 Pro 64-bit. As the Hermes Lite does not have an on-board DAC, VAC (Virtual Audio Cable) was enabled in PowerSDR.

Software version: OpenHPSDR mRX PS V3.2.27.

Firmware version: Hermes 3.1.

Initial DUT configuration:

https://github.com/softerhardware/Hermes-Lite/wiki/Software#hpsdr

Note that the Dither and Random checkboxes have been re-purposed. Dither OFF increases LNA gain by 32 dB. Random ON enables a unique AGC function controlled by a clipping detector. For these tests, Enable Attenuator (Options tab) is ON, enabling S-ATT. In the HPSDR tab, Dither is ON and Random OFF (the latter to allow measurement of ADC clip level). S-ATT is set at 0 dB. This sets LNA gain at +19 dB with Dither ON and +48 dB with Dither OFF. The +19 dB LNA gain value was selected because it yields MDS in the -120 dBm range, comparable to other direct-sampling SDR receivers.

A. Receiver Tests:

1. **MDS (Minimum Discernible Signal).** Marconi 2018A signal generator, 20 dB pad, DUT ANT1 input. Ballantine 323 true RMS voltmeter at laptop PHONES jack.

2. **NPR (noise power ratio).** Wandel & Goltermann RS-50 and RS-25 noise generators (fitted with filters per Table 2), MCL 75/50Ω transformer, DUT ANT1 input. DUT set to LSB for all test frequencies except 5340 kHz (USB). 2.4 kHz channel filter selected. NPR read directly from spectrum scope. *(Ref.2).*

3. **RMDR (reciprocal mixing dynamic range).** Marconi 2018A signal generator, 3 dB pad, 9.83 MHz bandstop filter, 0-110 dB step attenuator, DUT ANT1 port. Ballantine 323 true RMS voltmeter at laptop PHONES jack.

4. **2-Tone 3rd-Order IMD (IFSS).** Marconi 2018A and 2019 signal generators, MCL ZHL-32A buffer amplifiers, MCL low-pass filters appropriate for band tested, 20 dB pads, MCL ZSC-2-1W combiner, 0-110 dB step attenuator, 10 dB fixed attenuator at DUT ANT1 input. IMD product levels read from S-meter. Test results presented as curves of IMD level vs. test signal power, with ITU-R P.372-1 band noise levels as datum lines. (*Ref.5*, Slides 23-27.)

5. **DR_2 (IMD_2 dynamic range).** As for **IFSS**.

6. **NR SINAD Improvement.** As for **MDS.** HP 339A distortion meter at laptop PHONES jack.

7. **NB impulse response.** HP 8011A pulse generator connected to DUT ANT1 input. Headphones at laptop PHONES jack.

8. **ANF tone suppression.** As for MDS, HP 3580A spectrum analyser at laptop PHONES jack.

9. **APF passband.** As for MDS, HP 3580A spectrum analyser at laptop PHONES jack.

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1. **MDS (Minimum Discernible Signal** tested in CW mode (B = 500 Hz), S-ATT = 0 dB, LNA gain +19 and +48 dB. The receiver is tuned to each test frequency f_0 in turn and a test signal applied. At each frequency, the input power P_i required to raise audio output noise level by 3 dB is noted. P_i = MDS.

   Test Conditions: NR/NB/ANF off, S-ATT = 0 dB, AGC Slow, AGC Gain at max. AVG on, display refresh rate 60 fps. See Table 1.

Table 1: Minimum Discernible Signal (MDS).

f_0 MHz	MDS dBm	
LNA Gain dB	+19	+48
3.6	-119	-129
14.1	-118	-128
28.1	-116	-126

2. **NPR (Noise Power Ratio)**, tested in SSB mode (B = 2.4 kHz. Receiver tuned to notch center in all cases. Noise loading set to the point where ADC just does not clip for 10 sec. (-1 dBFS). NPR read off spectrum scope (noise level in a channel outside notch minus noise level at bottom of notch.) See Table 2 and Figure 2.

   Test Conditions: Receiver tuned to bandstop filter centre freq. f_0 ± 1.5 kHz, SSB, B = 2.4 kHz, S-ATT = 0 dB, LNA gain +19 dB, NR off, NB off, ANF off, AGC slow, AGC Gain at max., AVG on, Display Refresh Rate 60 fps.

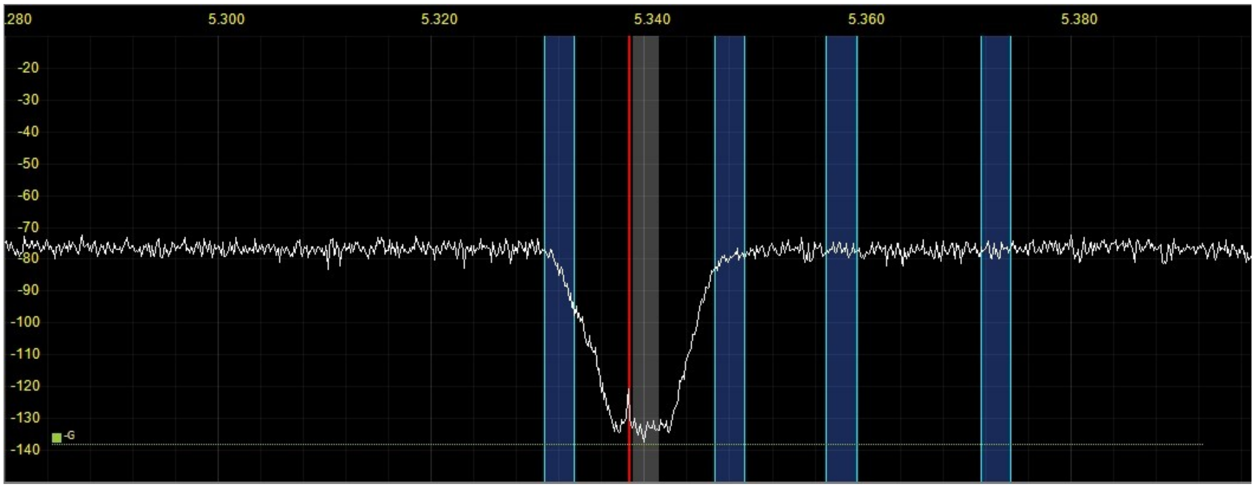
Table 2: NPR Test Results.

DUT	Det BW kHz	Mode	BSF kHz	BLF kHz	Equiv. J3E chnls.	P_{TOT} dBm[c]	NPR dB[a]	Theor. NPR dB[b]
Hermes Lite	2.4	LSB	1940	60…2044	480	-28	57	60.8
		LSB	3886	60…4100	960	-29	59	57.7
		USB	5340	60…5600	1260	-30	57	56.3
		LSB	7600	316…8160	1800	-31	56	54.8

Notes on NPR test:

a. NPR read directly off spectrum scope.
b. Theoretical NPR is calculated for the 12-bit ADI AD9886 ADC using the method outlined in ***Ref.1,*** normalised to 12 bits. The theoretical NPR value assumes that B_{RF} is not limited by any filtering in the DUT ahead of the ADC, and that the net gain between the antenna port and the ADC is 0 dB.
c. S-ATT = 20 dB increases P_{TOT} for same NPR reading by 20 dB.

Figure 2: NPR at 5340 kHz.



3. **RMDR (Reciprocal mixing dynamic range).** Marconi 2018A signal generator, 3 dB pad, 9.830 MHz 4-pole bandstop filter (> 80 dB notch depth), 0-110 dB step attenuator, DUT (RX port). Noise floor read on S-meter in CW mode (500 Hz bandwidth) with DUT terminated in 50Ω. S-ATT = 0 dB, LNA gain = +19 dB, NB/NR/ANF OFF. Signal generator frequency (f_0) tuned for max. null; DUT tuned to f_0. Signal generator then tuned to f_0 - offset and output P_i increased to raise detected noise by 3 dB. RMDR = P_i – (noise floor with generator off.) See Table 3. ***Note:*** The residual phase noise of the measuring system is the limiting factor in measurement accuracy.

Table 3: Reciprocal Mixing Dynamic Range (RMDR) at 9830.28 kHz.

Δf kHz	P_i dBm	RMDR dB	Phase noise dBc/Hz
1	+4.4	116	-143
2	> +2.4	> 117	-144
3	> +2.4	> 117	-144
5	> +2.4	> 117	-144
10	> +2.4	> 117	-144
Noise Floor = -120 dBm			

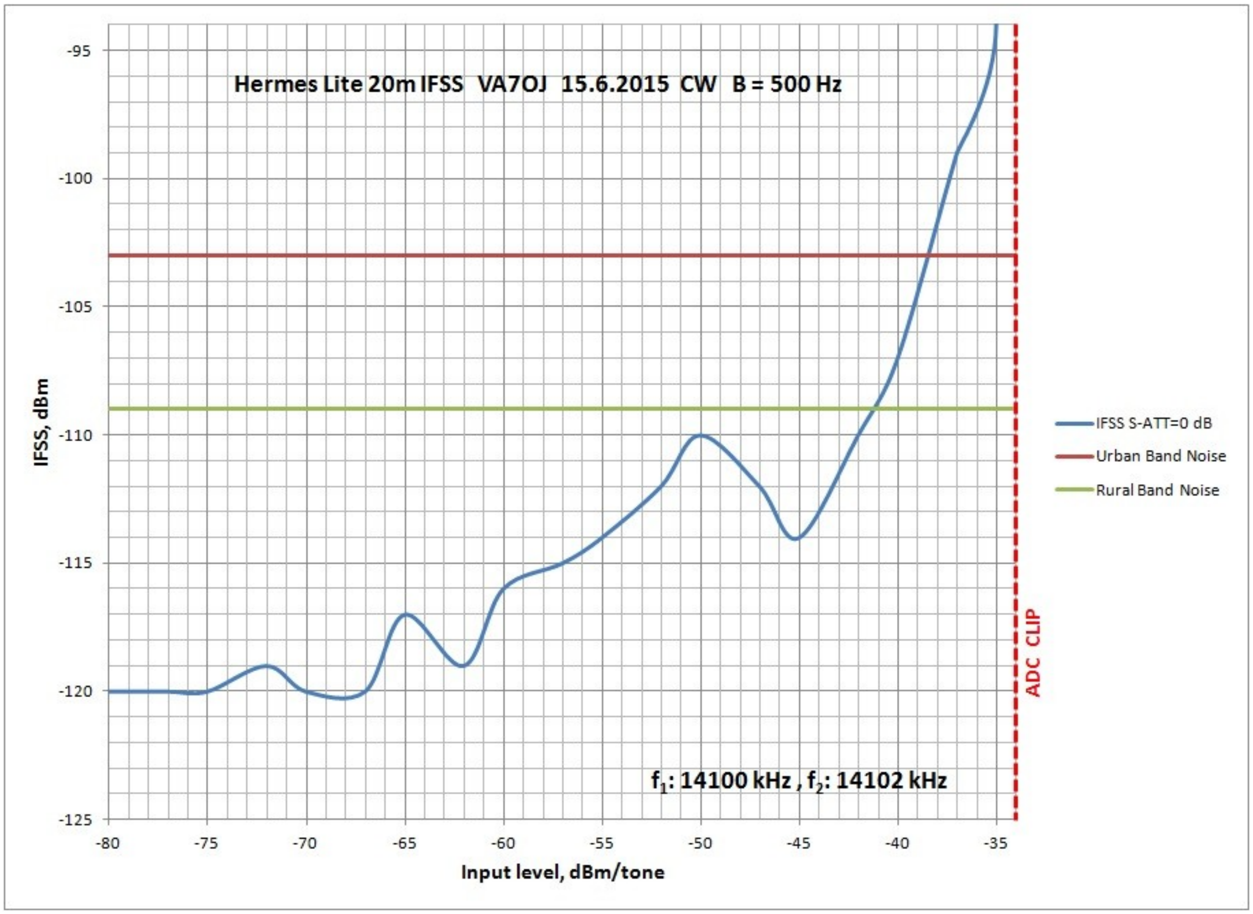
4. **Two-Tone IMD (IFSS, Interference-Free Signal Strength)** tested in CW mode (500 Hz), S-ATT = 0 dB, LNA gain = +19 dB. Test frequencies per Table 4. Absolute IMD product level is read on S-meter in a 500 Hz CW detection bandwidth at various test-signal power levels with S-ATT = 0 dB. The ITU-R P372.1 band noise levels for typical urban and rural environments are shown as datum lines. Figure 2 is a typical screenshot of the IFSS test. The results are given in Figure 4.

Table 4: IFSS Test Frequencies & IMD Products.

Band	f_1 kHz	f_2 kHz	Lower IMP kHz	Upper IMP kHz
20m	14100	14102	14098	14104

Figure 3. Typical IFSS spectrum scope display, showing IMD3 products.

Figure 4: 20m IFSS (two-tone IMD) curve for S-ATT = 0 dB.



Note on IFSS (2-tone IMD_3) test: This is a new data presentation format in which the amplitude relationship of the actual IMD products to typical band-noise levels *(Ref.3)* is shown, rather than the more traditional DR_3 (3^{rd}-order IMD dynamic range). The reason for this is that for an ADC, SFDR referred to input power rises with increasing input level, reaching a well-defined peak and then falling off. In a conventional receiver, SFDR falls with increasing input power. See also *Ref.5,* Slides 23 – 27.

The SFDR (spurious-free dynamic range) behaviour of an ADC ***invalidates*** the traditional DR3 test for a direct-sampling SDR receiver. Our goal here is to find an approach to SFDR testing which holds equally for SDR and legacy receiver architecture.

It will be seen from the above chart that the IMD curve approximates 1st order until -10 dBFS (10 dB below ADC clip level) is approached; in Figure 4, the curve in the range -10 dBFS to 0 dBFS is closer to 3rd-order. This is due to non-linearity in the LNA.

5. **DR_2 (IMD_2 dynamic range)** tested at 14.200 MHz, WIDE, in CW mode (500 Hz), S-ATT = 0 dB, LNA gain = +19 dB. Test frequencies: f_1 = 6100 kHz, f_2 = 8100 kHz. 2nd-order IMD_2 product: 14200 kHz. Test-signal level is adjusted for a 3 dB increase in audio output, and DR_2 & IP_2 calculated.

   $DR_2 = P_i – MDS$.

   $IP_2 = (2 * DR_2) + MDS$

   Test Results: Refer to Table 5.

Table 5: IMD2 Dynamic Range (DR2).

S-ATT dB	LNA Gain dB	MDS dBm	P_i dBm/tone	DR_2 dB	IP2 dBm
0	+19	-118	-75	43	-32

6. **Noise Reduction (NR) SINAD Improvement** tested in USB mode (2.4 kHz),), S-ATT = 0 dB, LNA gain = +19 dB. Receiver tuned to 14100 kHz. Test signal at 14101 kHz. The distortion meter is connected to the PHONES jack and signal level adjusted for 6 dB SINAD with NR off. NR and NR2 are selected in turn, and SINAD read and noted for each setting. PowerSDR NR parameters are at default values.

   Test Results: Refer to Table 6.

Table 6: NR Improvement.

NR Setting	SINAD dB	SINAD Improvement dB
OFF	6	0
NR	13	7
NR2	18	12

Note: With NR2 on, the recovered audio has a watery, burbling quality.

7. **Noise Blanker (NB) Impulse Suppression** tested in USB mode (2.4 kHz), S-ATT = 0 dB, LNA gain = +19 dB. A pulse train is applied to DUT RX port. Receiver tuned to 3600 kHz. Pulse parameters: V_{pk} = 32 mV, rise-time ≈ 10 ns, PRF = 2 pps.

   Test Results: With NB on, PowerSDR NB parameters at default values, no audible pulse "ticks" with duration ≤ 225 ns. Noise floor decreases slightly with NB on.

8. **Auto-Notch Filter (ANF) Tone Suppression** tested in USB mode (2.4 kHz), S-ATT = 0 dB, LNA gain = +19 dB, PowerSDR NB parameters at default values. The DUT is tuned to 14100 kHz, and a S9 + 20 dB (-50 dBm) test signal at 14101 kHz is applied. The test tone level at the PHONES jack is measured with the HP 8530A spectrum analyser.

   Test Results: ANF reduces the tone level by more than 70 dB.

9. **Audio Peak Filter (APF),** tested in CW mode (B = 500 Hz), S=ATT = 0 dB, LNA gain = +19 dB. The HP 3580A spectrum analyser is connected to the laptop PHONES jack. A test signal at 14.1 MHz and -90 dBm is applied to RX IN. The spectrum analyser is tuned to f_0 = 600 Hz and screenshots taken for various APF settings. See Figures 5, 6 and 7.

HP 3580A settings: 10 Hz RBW, 50Hz/div span, 2s/div sweep time, ref. level 0 dBv.

Figure 5: APF off.

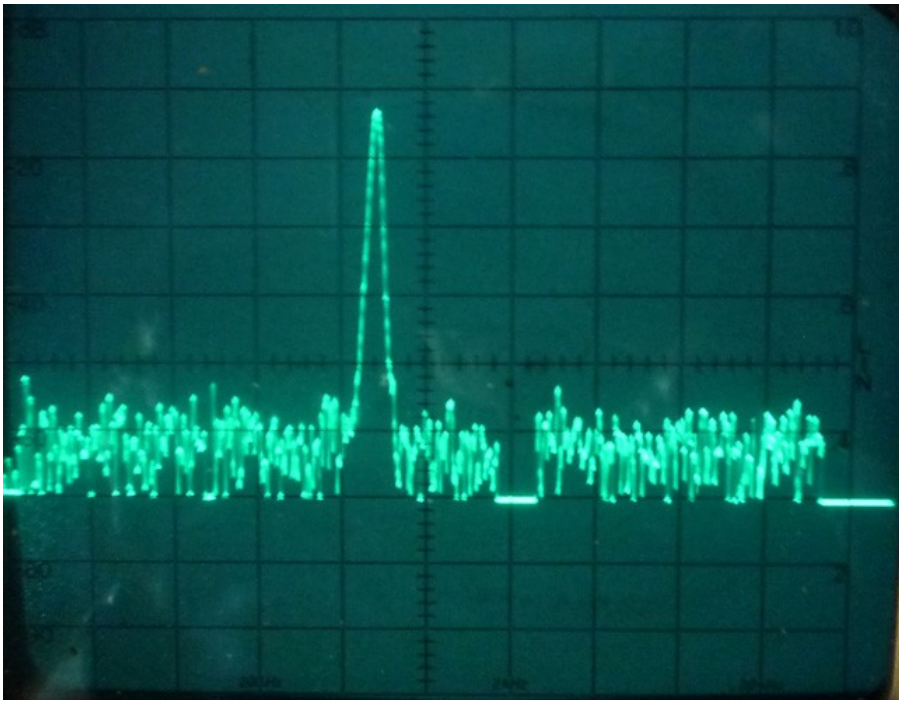


Figure 6: APF 75 Hz, 0 dB.

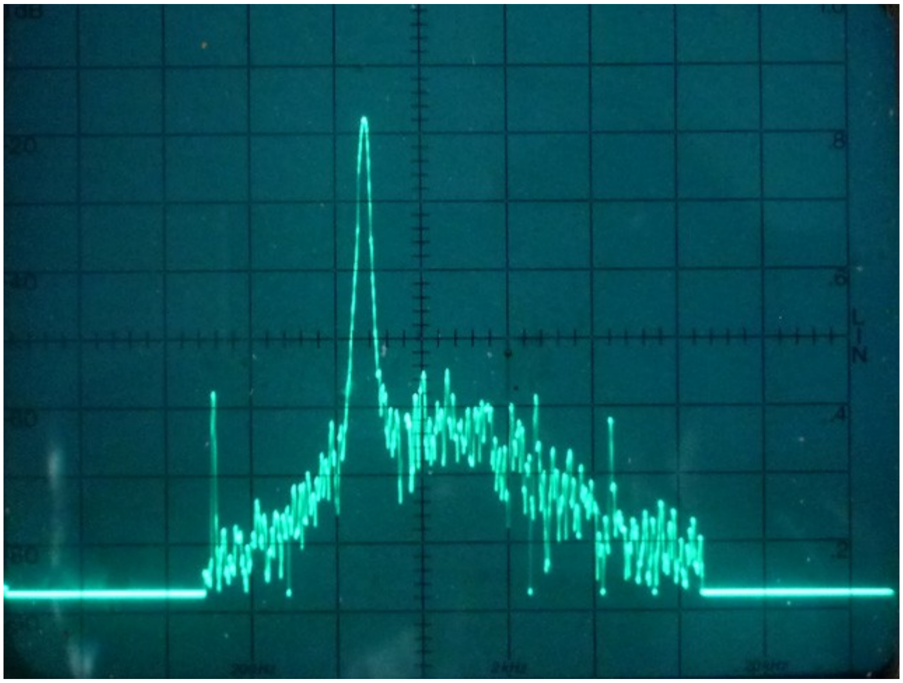


Figure 7: APF 75 Hz, +10 dB.

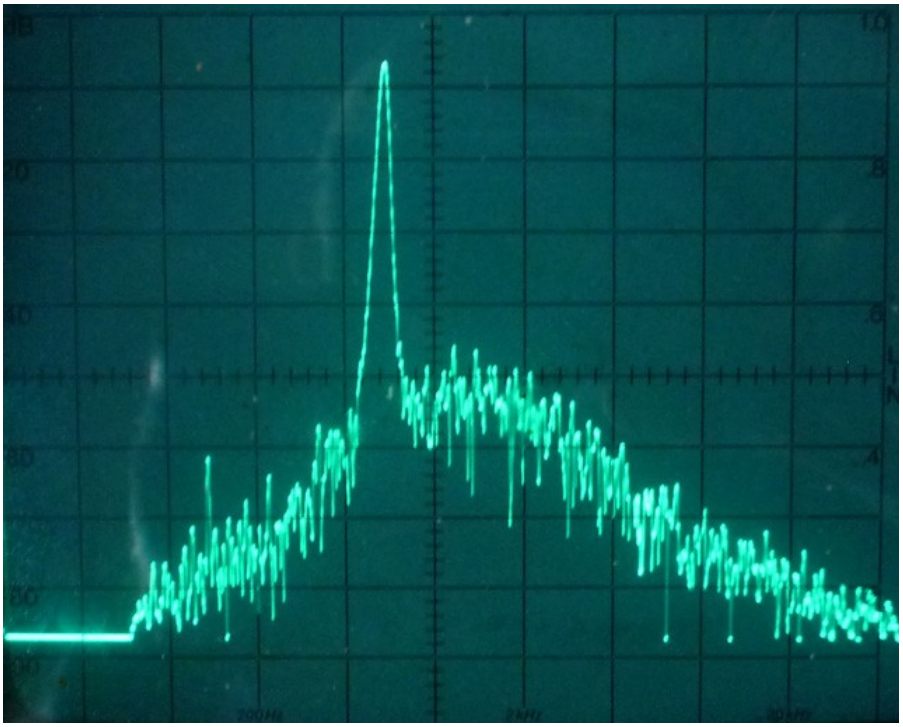


Figure 8: APF 30 Hz +10 dB

B. Transmitter Tests

⚠ Attenuators used in these tests should be rated at 2W or higher.

1. **Maximum RF output.** HP 432A power meter with Harris N6284B sensor connected to DUT TX port via 20 dB attenuator. TUNE mode selected, Drive at 100%. **Test Results:** See Table 7.

Table 7: Max. RF output P_O.

f_0 MHz	Max. P_O dBm
3.6	+12
14.1	+15
28.2	+18.5

Note: P_O checked with SSB, Mode = Radio, Level = 0.0 dB, Freq. = 1000 Hz selected in Transmit. P_0 readings identical to TUNE mode.

2. **SSB 2-Tone Transmitter IMD.** In PowerSDR Tests tab, Freq. 1 = 700 Hz, Freq. 2 = 1700 Hz, Level = 0 dB, RF Power = 100%. HP 8563E spectrum analyser connected to DUT TX port via 30 dB attenuator. IMD measured on 3.6, 14.1 and 28.1 MHz. Refer to Table 9, and Figures 9 - 11.

Table 9: TX IMD in dBc (ref. 1 of 2 equal tones) at 100% RF Power.

Freq. MHz	3.6	14.1	28.1
PEP dBm	+12	+15	+18
IMD3	-54	-48	-52
IMD5	-72	-65	-66
IMD7	-84	-77	-75
IMD9	< -86	< -86	< -90
Subtract 6 dB for IMD ref. 2-tone PEP.			

3. **SSB TX Noise IMD.** As for Test 2, except Mode = Noise, Level = 0.0 dB selected in Transmit. Test run at 14.1 MHz, P_0 = 100%. Power in noise bandwidth ≈ +5 dBm. See Figure 12.

Figure 9.

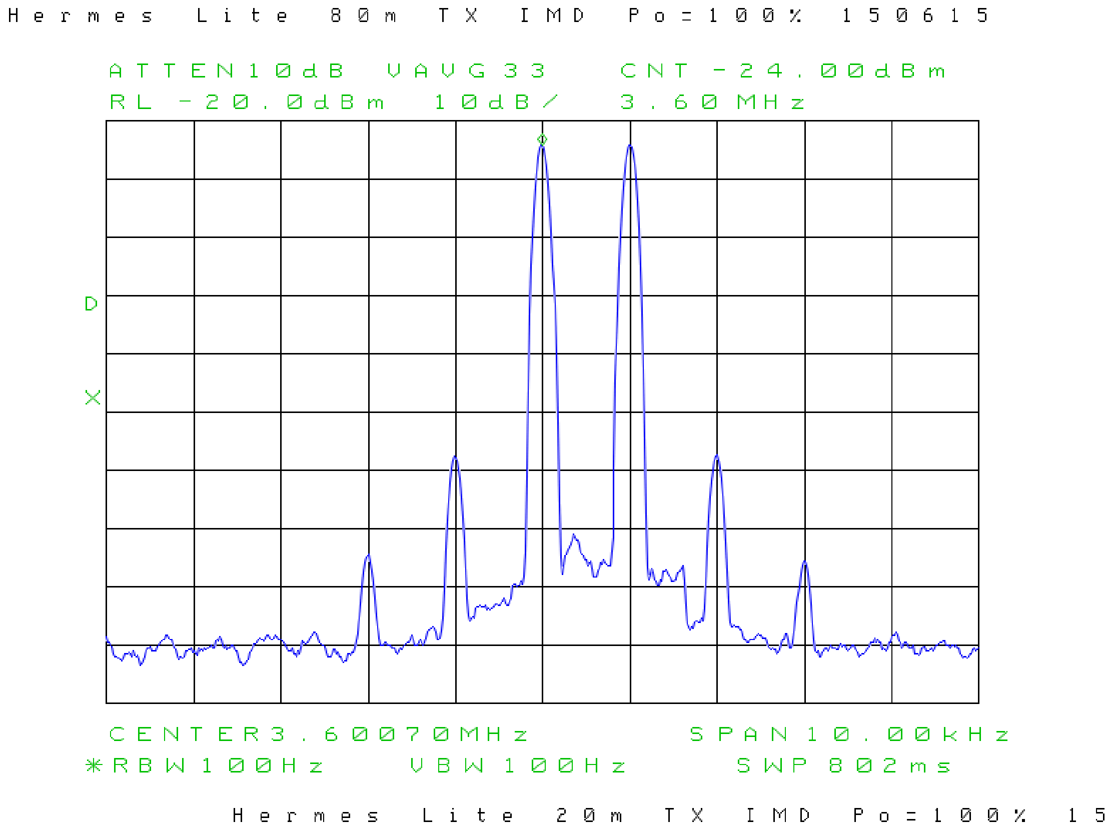


Figure 10.

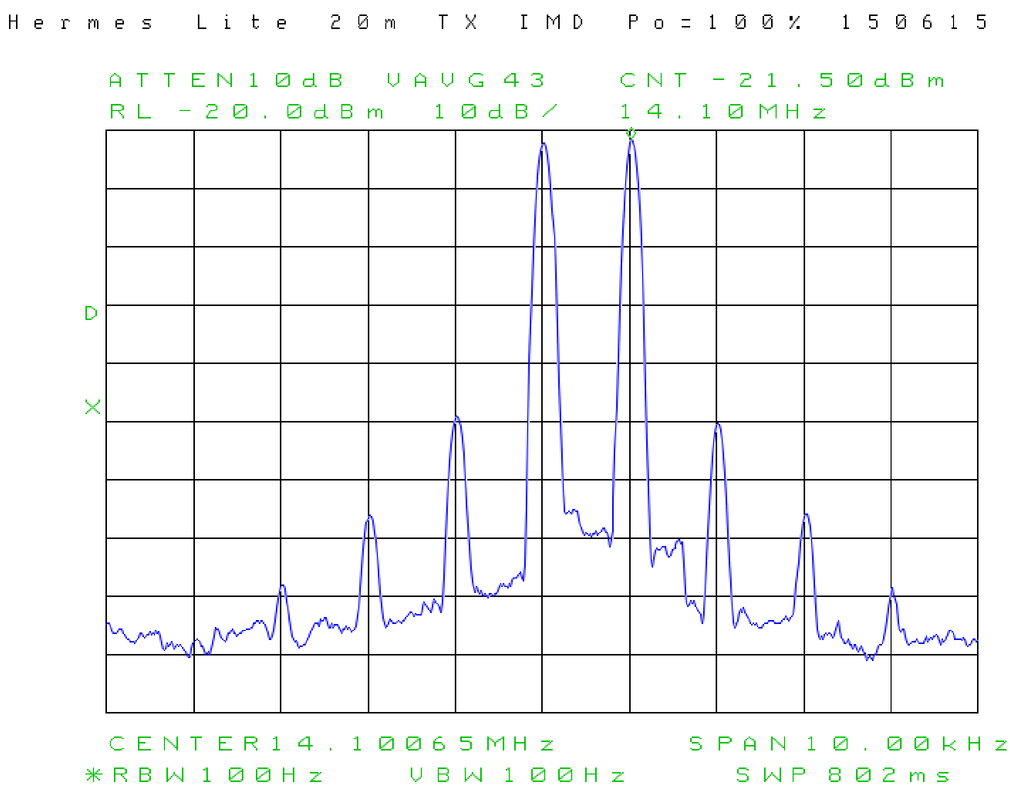


Figure 11.

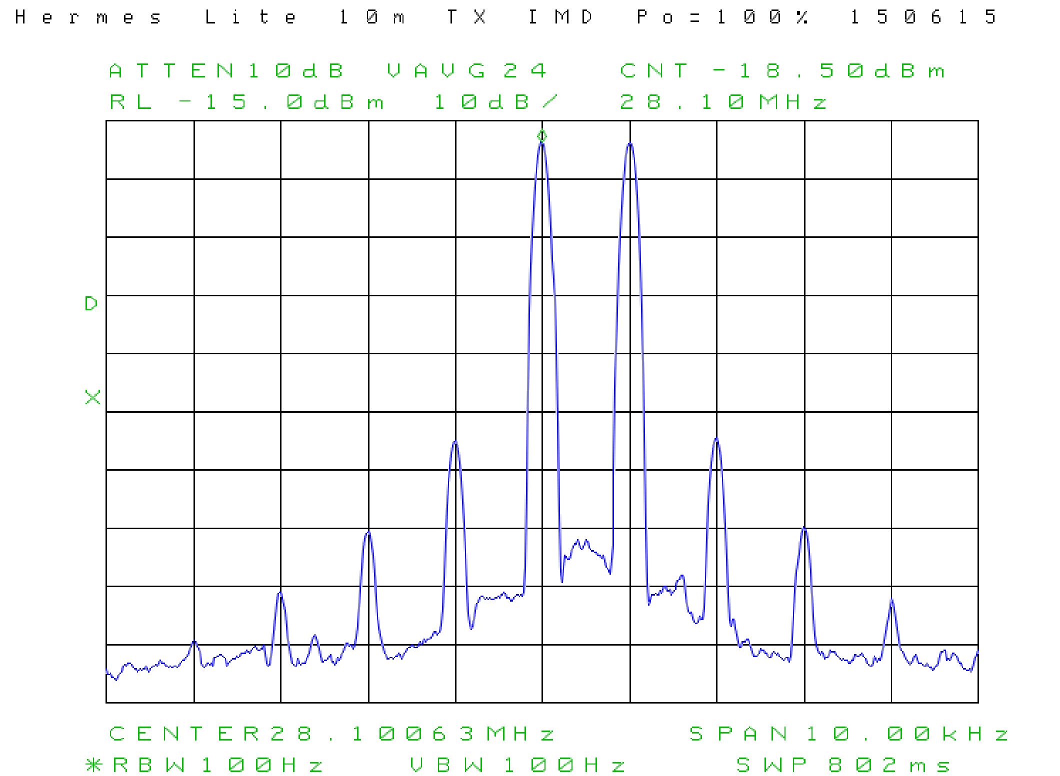
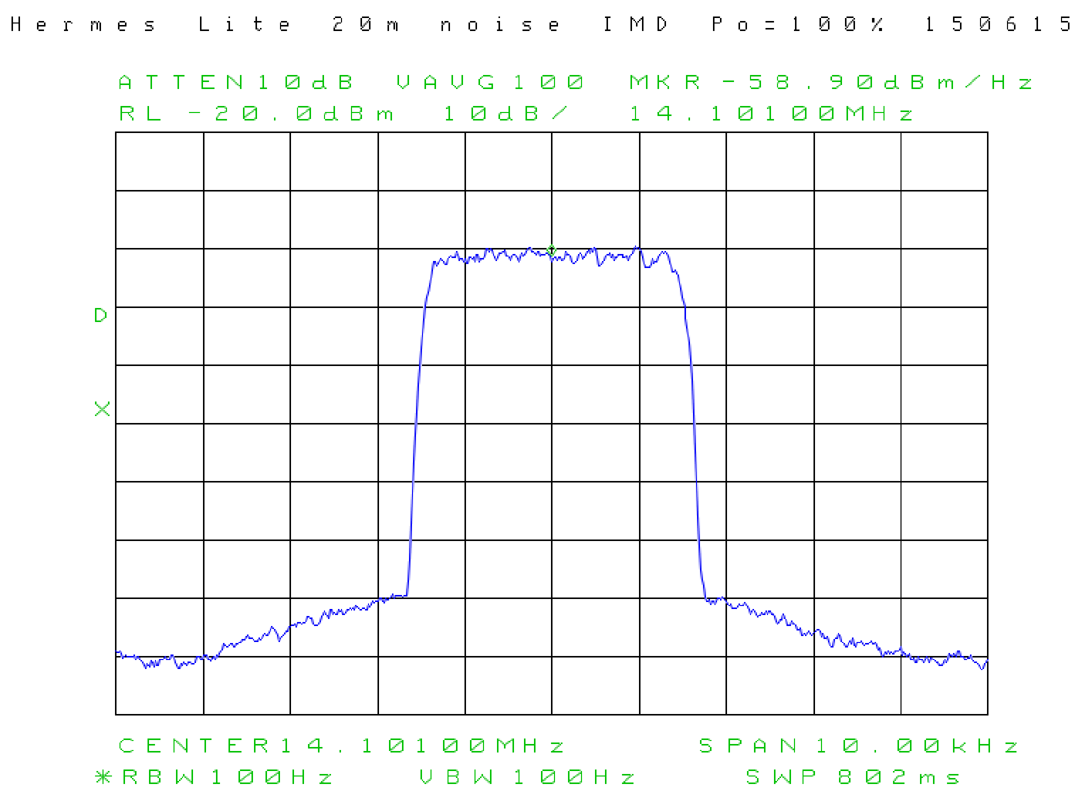


Figure 12.



4. **TX harmonics & spurs.** HP 8563E spectrum analyzer with HP 85672A spurious response utility, connected to DUT ANT1 via 30 dB attenuator. Test run in SSB mode at P_O = 100% on 3.6, 14.1 and 50.1 MHz.

Test Results: Refer to Figures 13 – 15 (harmonic charts) and 16 – 18 (sweeps, showing harmonics and non-harmonic spurs).

Figure 13.

Hermes Lite 80m TX Har Po=100% 150615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 3.601 MHz
-18.0 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-68.3 *	7.202 MHz
3	-46.3	10.80 MHz
4	-76.8	14.40 MHz
5	-53.0	18.01 MHz
6	-98.2 *	21.61 MHz
7	-60.8	25.21 MHz
8	-97.8 *	28.81 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION = .5 %
(OF HARMONICS MEASURED)

Figure 14.

Hermes Lite 20m TX Har Po=100% 150615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 14.10 MHz
-15.2 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-70.8	28.20 MHz
3	-38.2	42.30 MHz
4	-71.8	56.40 MHz
5	-46.0	70.50 MHz
6	-75.0	84.61 MHz
7	-57.2	98.71 MHz
8	-82.2	112.8 MHz

TOTAL HARMONIC DISTORTION= 1.3 %
(OF HARMONICS MEASURED)

Figure 15.

Hermes Lite 10m TX Har Po=100% 150615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 28.10 MHz
-12.0 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-57.3	56.20 MHz
3	-40.8	84.30 MHz
4	-73.8	112.4 MHz
5	-65.2	140.5 MHz
6	-93.2	168.6 MHz
7	-83.7	196.7 MHz
8	-102.8*	224.8 MHz

* MEASURED LEVEL MAY BE
NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION= .9 %
(OF HARMONICS MEASURED)

Figure 16.

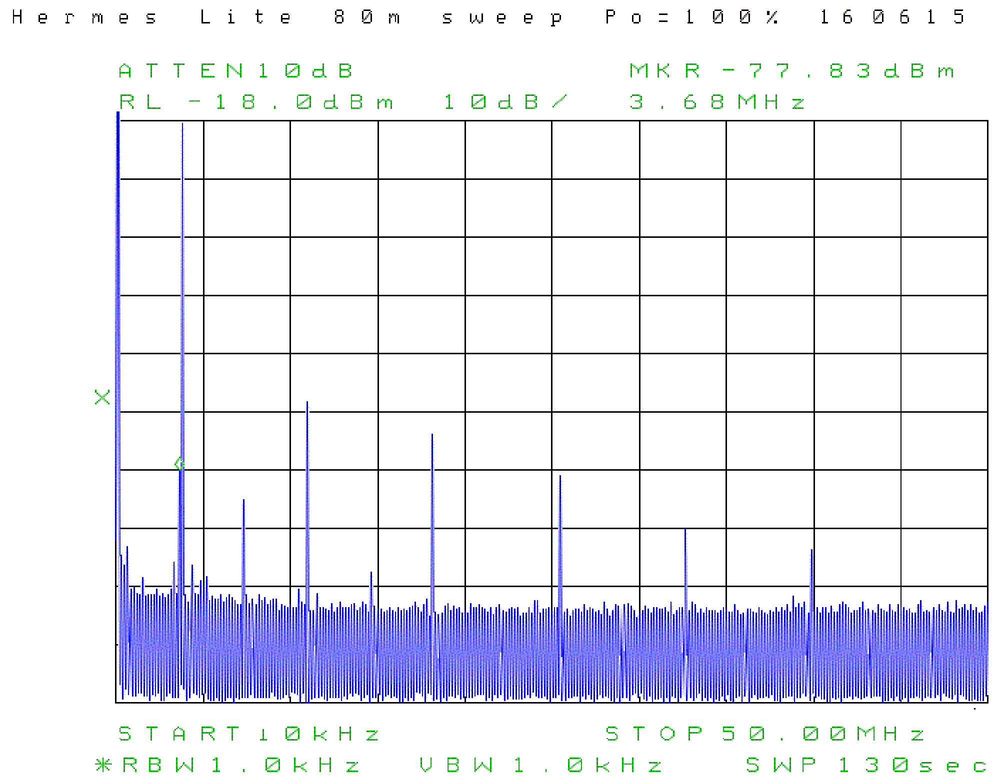


Figure 17.

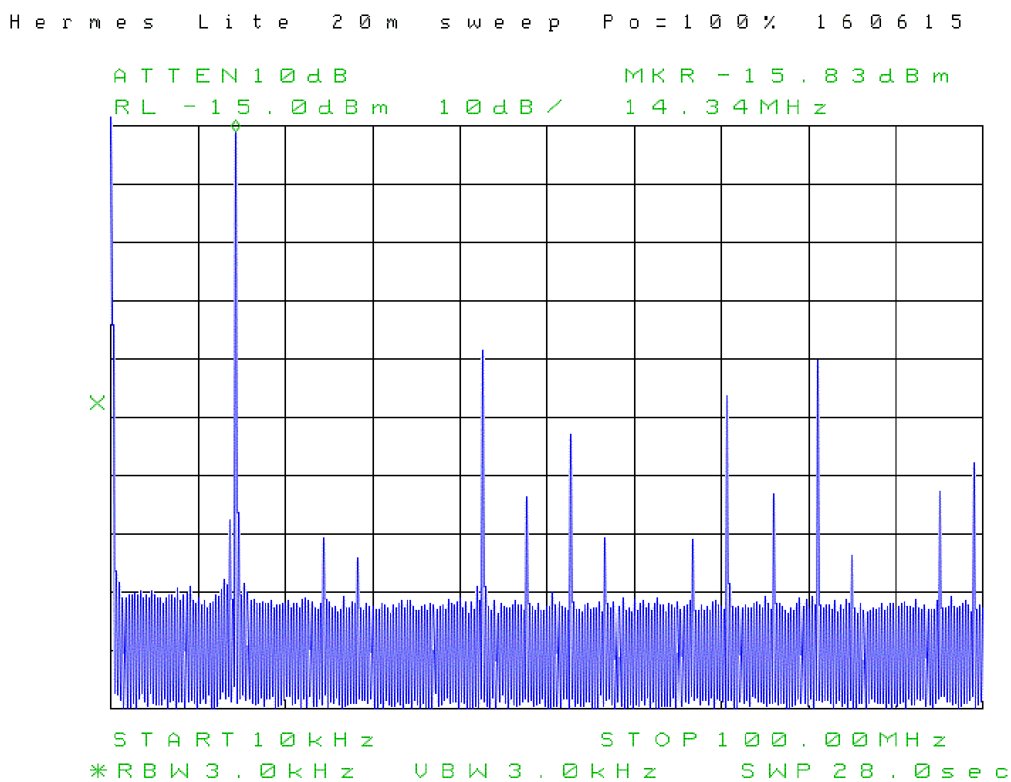
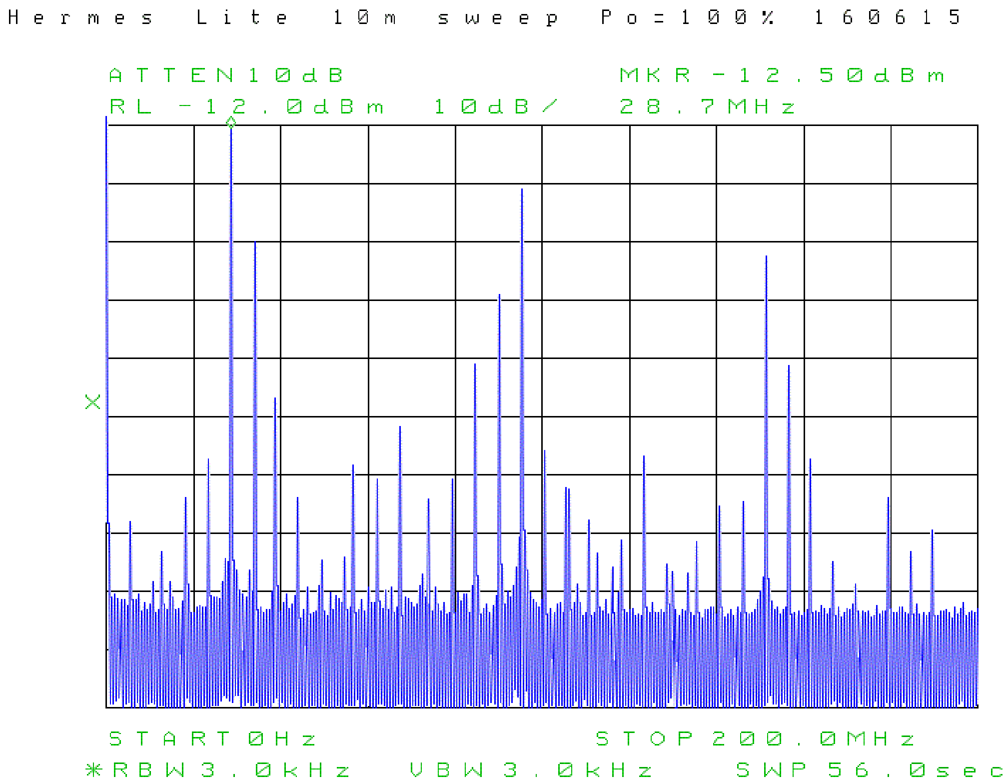


Figure 18.



5. **TX harmonics & spurs with harmonic filters.** At the suggestion of Steve Haynal KF7O, the author repeated Test 4 with a Mini-Circuits (MCL) LPF inserted between DUT TX OUT and the attenuator ahead of the spectrum analyser. The appropriate filter was selected for each band in turn.

HP 8563E spectrum analyzer with HP 85672A spurious response utility, connected to DUT ANT1 via 30 dB attenuator. Test run in SSB mode at P_O = 100% on 3.6, 14.1 and 50.1 MHz.

Test Results: Refer to Figures 19 – 21 (harmonic charts) and 22 – 24 (sweeps, showing harmonics and non-harmonic spurs). Table 10 gives the LPF part number for each band tested.

Table 10: MCL LPF Part Numbers

Band m	TX Freq. MHz	MCL LPF Part No.
80	3.6	BLP-5
20	14.1	BLP-15
10	28.1	BLP-30

Figure 19.

Hermes Lite 80m har BLP-5 Po=100% 170615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 3.600 MHz
-18.2 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-75.5*	7.200 MHz
3	-88.0*	10.80 MHz
4	-99.5*	14.40 MHz
5	-100.0*	18.00 MHz
6	-99.5*	21.60 MHz
7	-99.0*	25.20 MHz
8	-98.5*	28.80 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION= 0 %
(OF HARMONICS MEASURED)

Figure 20.

Hermes Lite 20m har BLP-15 Po=100% 170615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 14.10 MHz
-14.5 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-84.2*	28.20 MHz
3	-92.2*	42.30 MHz
4	-103.3*	56.40 MHz
5	-103.7*	70.50 MHz
6	-102.2*	84.60 MHz
7	-102.2*	98.70 MHz
8	-102.8*	112.8 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION= 0 %
(OF HARMONICS MEASURED)

Figure 21.

Hermes Lite 10m har BLP-30 Po=100% 170615

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 28.10 MHz
-12.7 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-82.3 *	56.20 MHz
3	-95.2 *	84.30 MHz
4	-102.7 *	112.4 MHz
5	-102.8 *	140.5 MHz
6	-103.7 *	168.6 MHz
7	-104.3 *	196.7 MHz
8	-105.2 *	224.8 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION = 0 %
(OF HARMONICS MEASURED)

Figure 21.

Hermes Lite 80m sweep BLP-5 Po=100% 170615

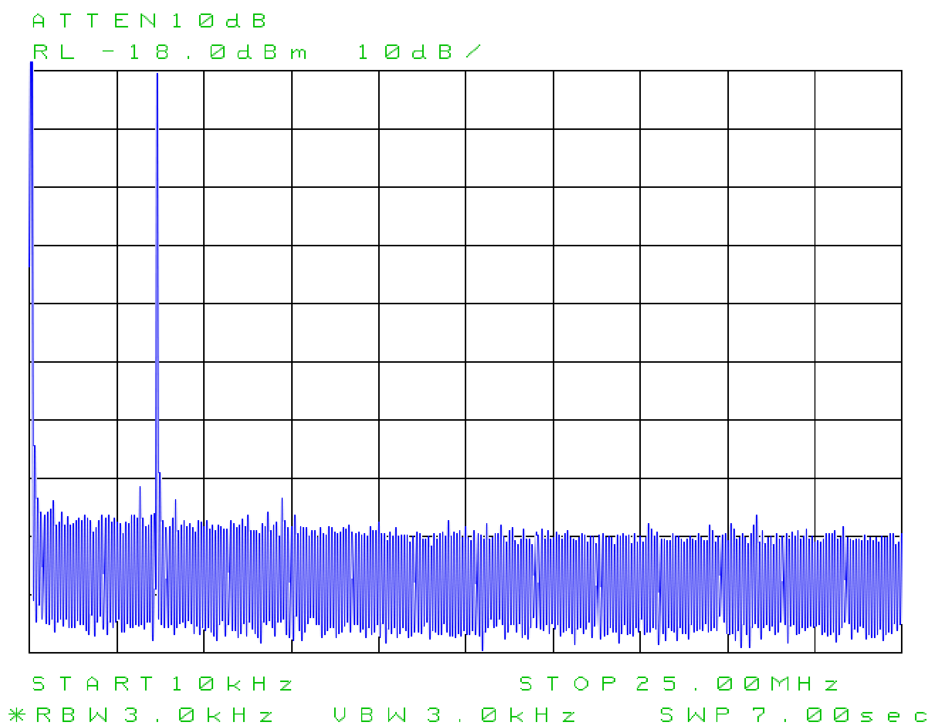


Figure 22.

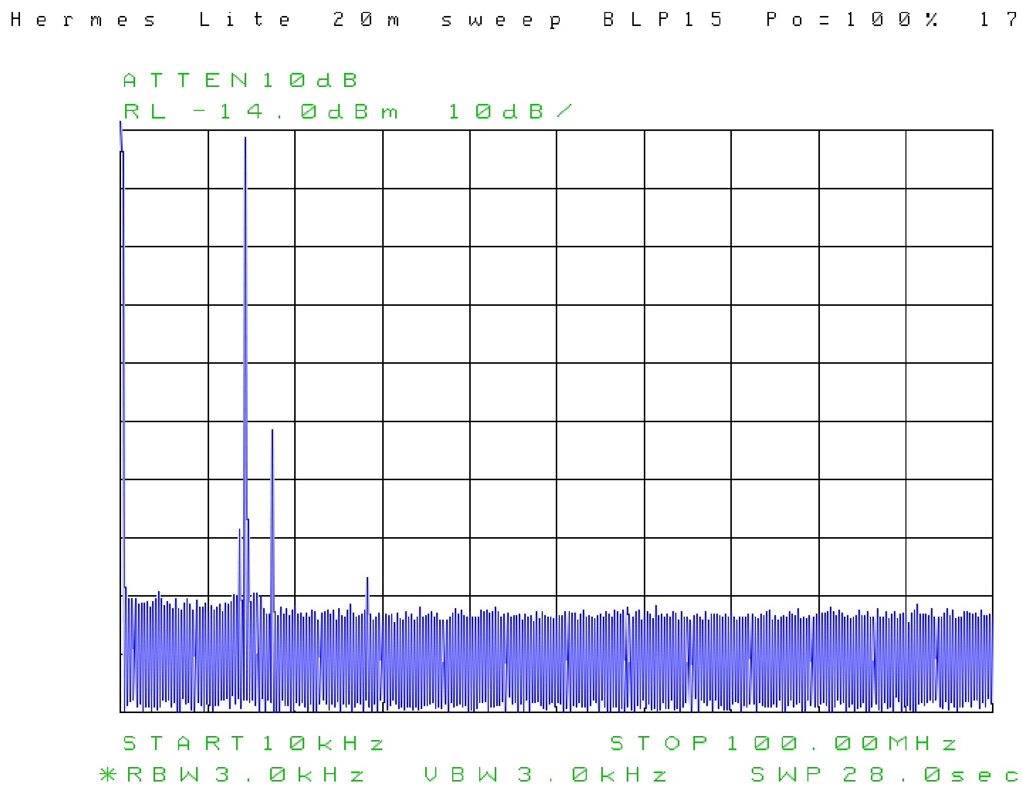
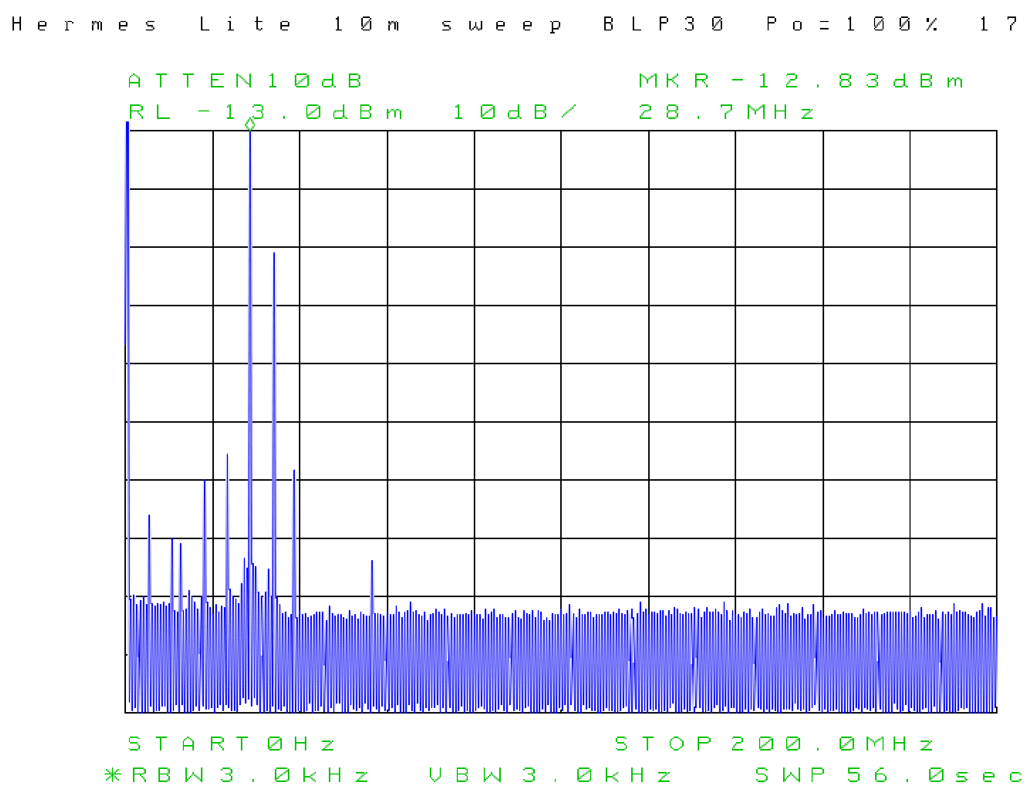


Figure 23.



C. Comments:

1. The receiver's DR2/IP2 (2nd-order IMD) performance is inadequate for use without a good preselector in Region 1 or in other areas where high-power HFBC transmitters are present.

2. As the Hermes Lite FPGA code does not support CW generation, no CW tests were conducted.

3. The default receiver front-end configuration (Dither ON, Random OFF, S-ATT = 0 dB, yielding +19 dB LNA gain) was used in all receiver tests unless otherwise specified, so as to ensure maximum usable dynamic range. In addition, the NPR and IFSS tests require that the onset of ADC clipping will not alter RF gain.

4. The transmitter's excellent linearity makes it suitable as an exciter for a wide variety of PA chains. It should be noted though, that harmonic filters are required to meet regulatory requirements. This is especially true on 10m, where spurs at -10 and -20 dBc were observed.

5. The additional tests with harmonic filters at the DUT TX OUT port show excellent harmonic suppression, although on the 10m band a significant spur (-20 dBc) at 35 MHz is still visible.

D. Acknowledgements:

I would like to thank my friend Dave Miller VE7PKE for the loan of the Hermes Lite DUT, and also for guiding me through the on-line Hermes Lite literature.

E. References:

1. http://www.ab4oj.com/test/docs/16bit_npr.pdf (theoretical maximum NPR)
2. http://www.ab4oj.com/test/docs/npr_test.pdf (NPR testing)
3. http://www.ab4oj.com/icom/nf.html (antenna & receiver NF)
4. http://www.nsarc.ca/hf/arrl_test.pdf (brief tutorial on radio testing)
5. http://www.nsarc.ca/hf/rcvrtest.pdf (IFSS: Slides 23 – 27)

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