LDMOS RF Amplifier Linearization using PowerSDR mRX Pure Signal

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INTRODUCTION

This paper will demonstrate the use of software to improve the IMD performance of a 50 volt LDMOS kW RF amplifier utilizing an NXP BLF-178 device on 6 meters.

The software utilized is PowerSDR mRX Pure Signal. This is specifically written for use with OpenHPSDR hardware.[1,2] For these tests, an OpenHPSDR Hermes board was used.

I highly recommend that you read the latest Pure Signal document that can be found here:

http://users.burlingtontelecom.net/~n1jez@burlingtontelecom.net/images/PureSignal.pdf

This document, written by Warren Pratt, NR0V who is the primary architect of Pure Signal, goes into quite a bit of detail on the system. I won't repeat a lot of it here, but simply offer a synopsis.

In an ideal world, the signal we inject into an RF amplifier would be reproduced with no detrimental changes. In the real world, RF amplifiers suffer from various types of non-linearity. One of the results of this is Inter-Modulation Distortion or IMD. This distortion manifests itself in various ways, but one we're most familiar with is splatter. We've all heard wide signals like this on the bands. So what can we do about it?

On the hardware end, we can design and operate our amplifiers in the most linear fashion possible. This is always desirable but only goes so far. The approach presented here augments the hardware with a software solution.

Pure Signal utilizes a technique known as "*Predistortion*". Essentially, the software "*predistorts*" the input signal to the amplifier to correct for non-linearities in the output. The system continuously monitors output vs input and makes changes based on varying conditions. It uses "*Adaptive Predistortion*".

One of the effects that limit Pure Signal's ability to compensate for non-linearities is what is called "memory effect". The Pure Signal pdf file[3] goes into some detail on this. For solid state amps, tests so far suggest that LDMOS amplifiers using higher voltage supplies produce the best results. That is what is tested here.

HARDWARE

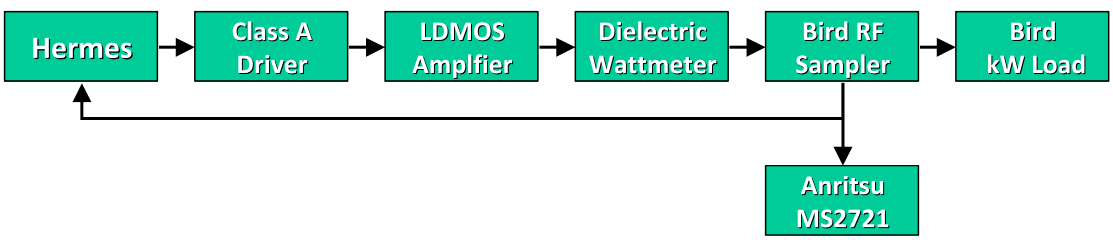
The hardware utilized in this test is as follows:

- OpenHPSDR Hermes board
    - 250 mW output on 50 MHz - DUC/DDC architecture
    - Ability to transmit and receive simultaneously - full duplex mode

- 0.5 watt in to 5 watt out Class A driver amplifier
- LDMOS amplifier using an NXP BLF-178 kW device operating at 48 volts
- Anritsu MS-2721B Spectrum Analyzer
- Dielectric Wattmeter - Average and Peak reading
- Bird 4275s adjustable signal sampler
- Bird kW load
- Various fixed and adjustable pads
- FT-817 receiver with common IF tap at 68.33 MHz[4]
- FUNcube Dongle SDR
- HDSDR software

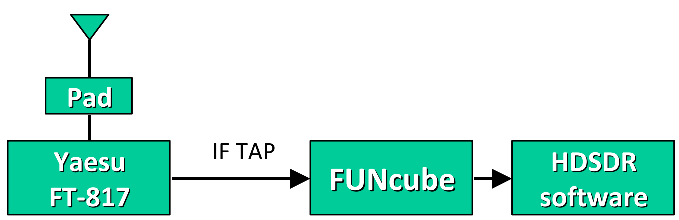
To be able to use Pure Signal, we must provide a 'feedback' path of the actual transmitted signal. This is fed to the Hermes receiver running in duplex mode.

<u>The following is very important!</u> Pure Signal can only correct based on what is fed back to it. It's important to provide the cleanest RF sample from the output of your amplifier as you can. It must be attenuated appropriately so as to provide sufficient amplitude without overloading the Hermes receiver input. Here is a block diagram of my test setup.



Various fixed and adjustable pads are used between the output of the Bird Sniffer and the Spectrum Analyzer and Hermes receiver input.

This is the secondary receiver system setup. This was used for additional audio and spectrum analysis.



SOFTWARE

The PowerSDR mRX Pure Signal software used here was version 3.2.9 with Hermes firmware 2.5b. The software includes a two-tone test generator which was used for these tests. Pure

Signal presents a window from within the software where various parameters can be set. Their use is outlined in the Pure Signal pdf file[3] referenced in the beginning of this paper.

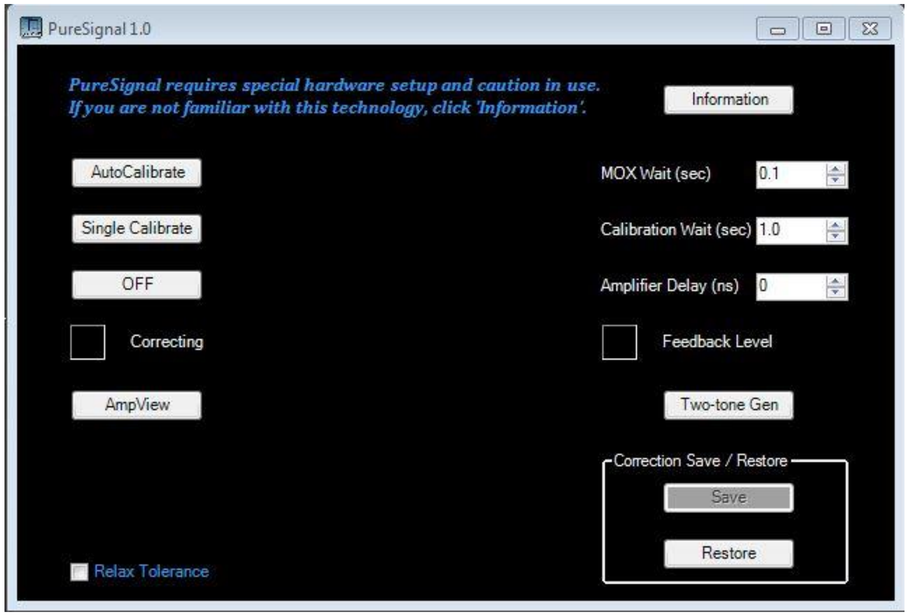


Fig 1 - Pure Signal setup screen

TEST SETUP

For these tests, the LDMOS amplifier was biased for Class AB and driven to 300 watts average power output using the two tone generator in PowerSDR mRX PS. At this power level, drive levels on the Hermes and Class A driver amplifier were quite conservative. Measurements were made through each stage of the system, measuring with both Pure Signal off and then on to compare the effectiveness of the correction.

It should be noted that the Pure Signal system has a finite "correction bandwidth". It only corrects within approximately 40 kHz or +/- 20 kHz from the center transmit frequency. Typically this is where most of the IMD energy is generated.

For each test, the two tone generator was turned on, and attenuation of the feedback signal fed to the Hermes receiver was adjusted, using the built in step attenuator, to a point 1 dB before ADC overload as indicated in the software Panadapter display. The input reference level to the Anritsu Spectrum Analyzer was set to -20 dBm.

Screen captures of the Spectrum Analyzer are shown first without Pure Signal activated and then with Pure Signal turned on. There is a marker table that summarizes the IMD levels under "Delta Amp" on the bottom right side. I placed the delta markers on the worse case IMD products. The transmit frequency is 50.140 MHz.

PowerSDR mRX PS can also display the IMD products in its panadapter. This can give a Pure Signal view of the reduction to the IMD products that it has performed. A few screens are included below.

THE MEASUREMENTS

The first tests were on the bare Hermes board with Pure Signal off. For reference, IMD levels are -46.3 and -52.91 below the two tones.

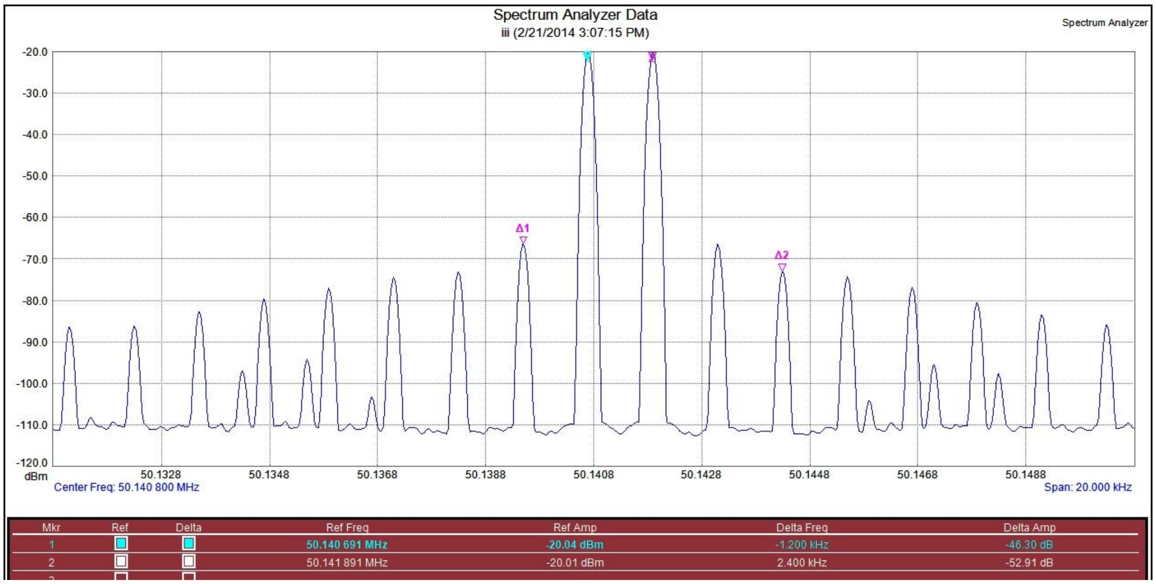


Fig 2 - Bare Hermes - Pure Signal off

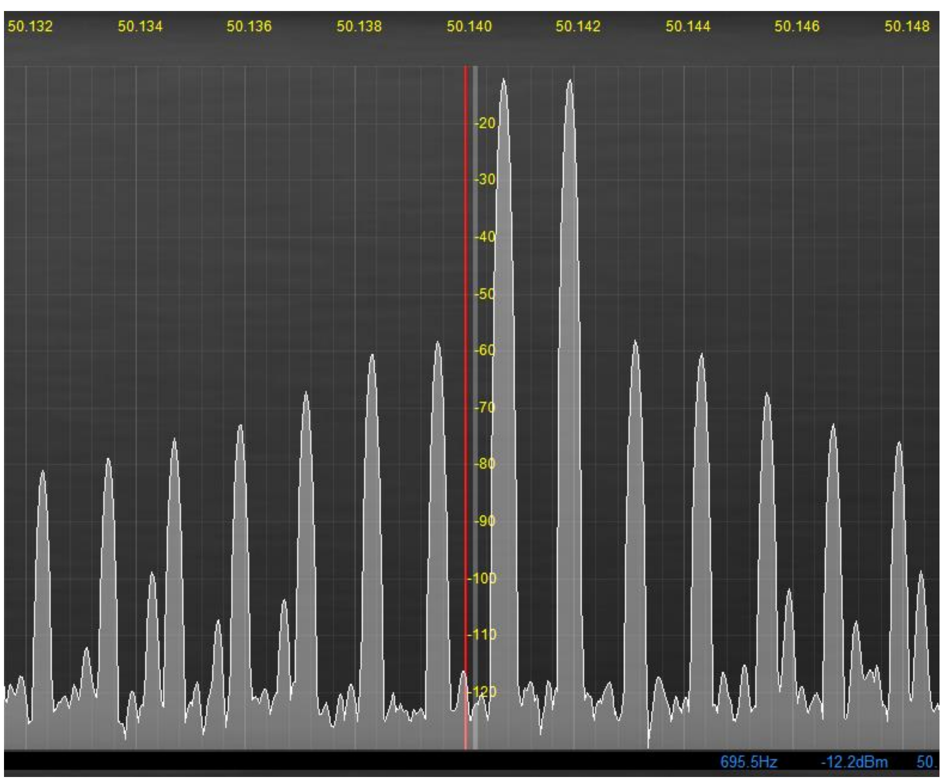


Fig 3 - Bare Hermes - Pure Signal off - as displayed in PowerSDR mRX PS

Here is the Hermes board with Pure Signal on. For reference, IMD levels are -63.93 and -77.71 below the two tones.

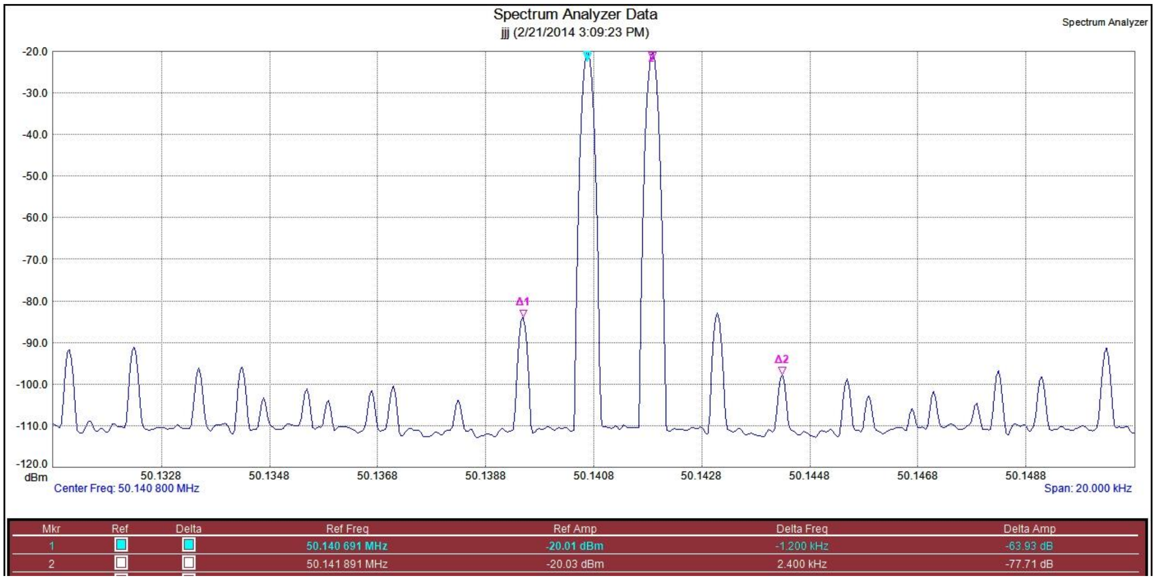


Fig 4 - Bare Hermes - Pure Signal on

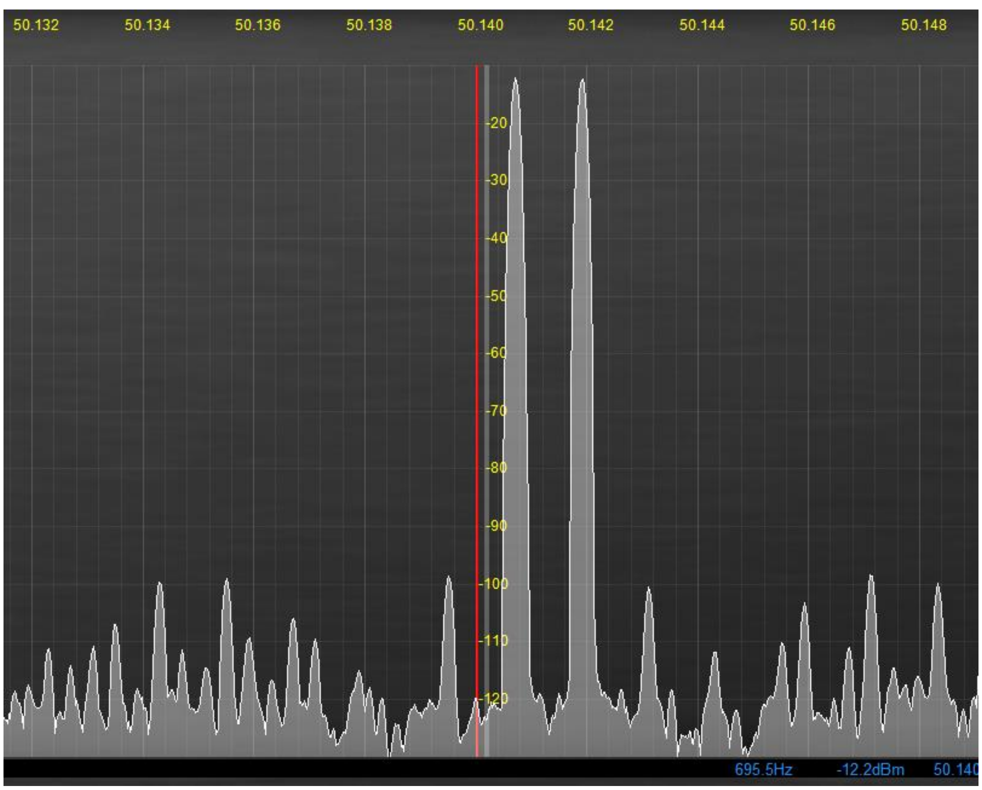


Fig 5 - Bare Hermes - Pure Signal on - as displayed in PowerSDR mRX PS

The next test was on the Hermes and Class A Driver combination with Pure Signal off. IMD levels are -40.16 and -49.82 below the two tones.

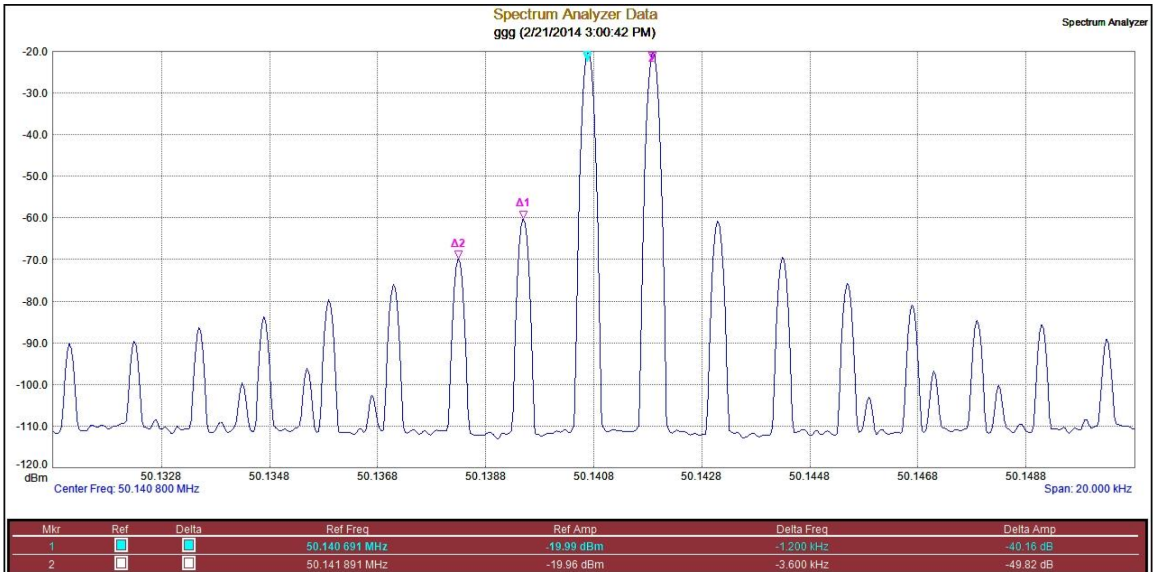


Fig 6 - Hermes and Class A Driver - Pure Signal off

The next test was on the Hermes and Class A Driver combination with Pure Signal on. IMD levels are -61.20 and -75.25 below the two tones.

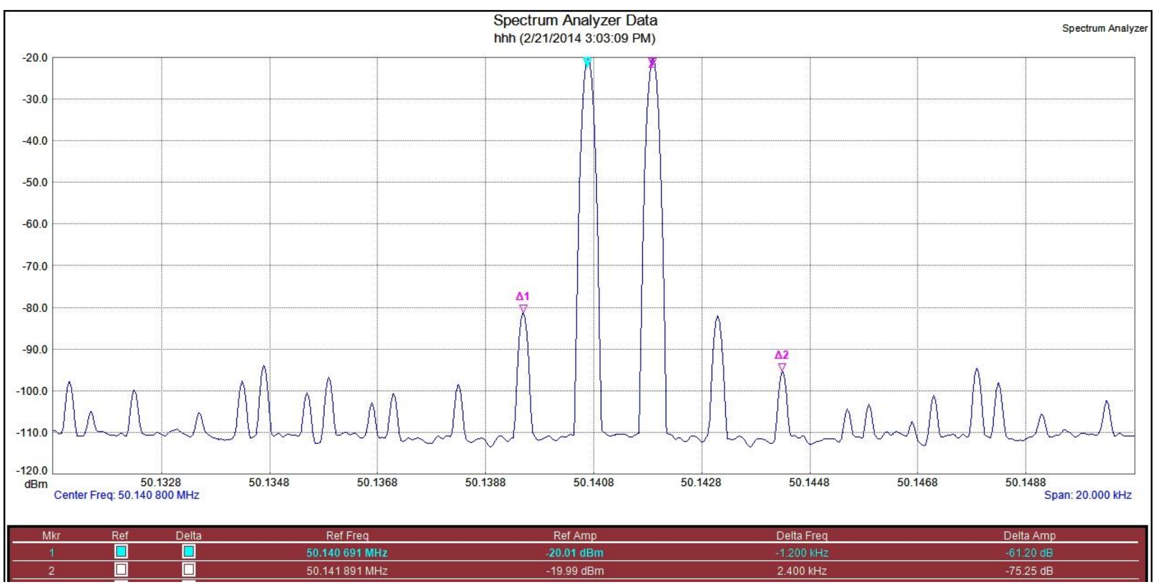


Fig 7 - Hermes and Class A Driver - Pure Signal on

The next test was on the Hermes, Class A Driver and LDMOS amplifier combination with Pure Signal off. IMD levels are -46.11 and -42.42 below the two tones.

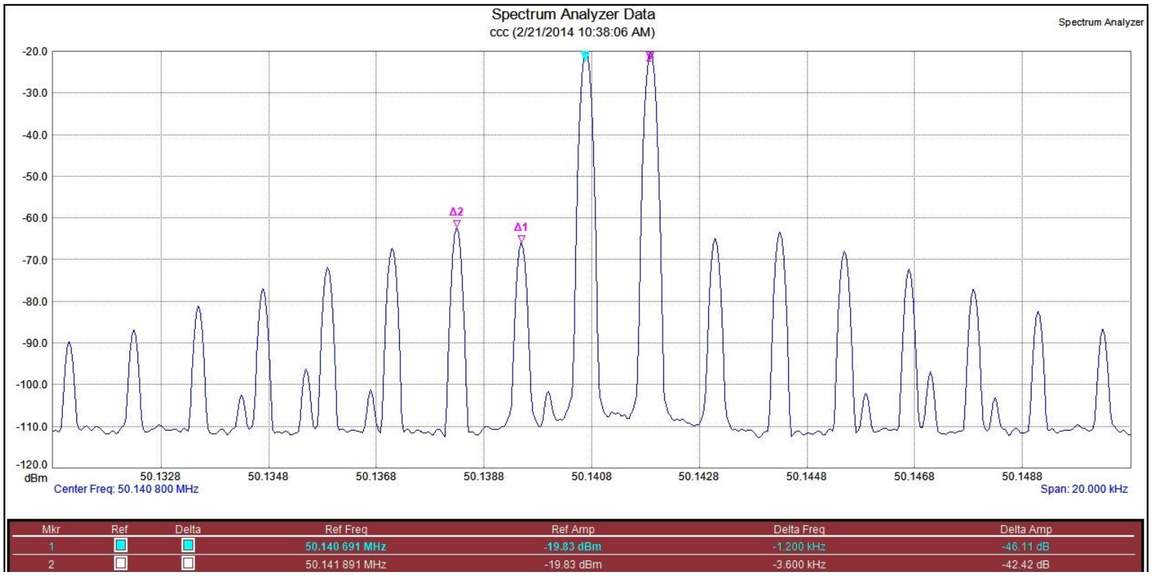


Fig 8 - Hermes, Class A Driver and LDMOS amp - Pure Signal off

Finally, the Hermes, Class A Driver and LDMOS amplifier combination with Pure Signal on. IMD levels are -57.63 and -64.82 below the two tones.

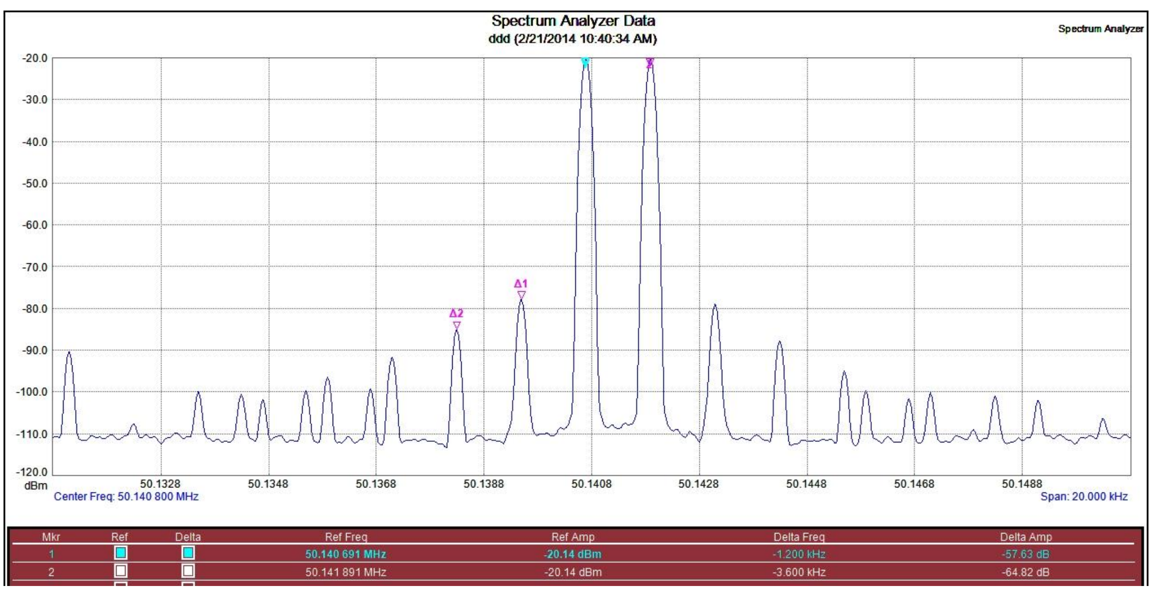


Fig 9 - Hermes, Class A Driver and LDMOS amp - Pure Signal on

AmpView

There is a very interesting information screen that is part of Pure Signal called 'AmpView'.

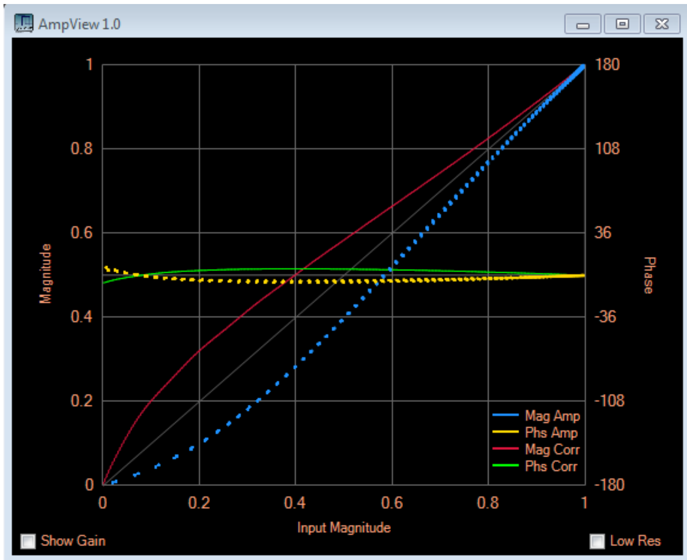


Fig 10 - AmpView 1.0 Magnitude and Phase

To quote Warren Pratt, NR0V from the Pure Signal document:

> *"The blue dots show the output magnitude versus input magnitude of the uncorrected amplifier. Similarly, the yellow dots show the uncorrected phase characteristic versus input magnitude for the amplifier. Note that these are discrete dots at the points of the samples collected to perform the PureSignal calibration. The red and green lines then show the calculated magnitude and phase corrections that are being applied to outgoing transmit samples.*
>
> *Checking the "Show Gain" box changes the left Magnitude Axis to a Gain Axis. Therefore, you have the option of looking at Gain versus Input Magnitude rather than Output Magnitude versus Input Magnitude."*

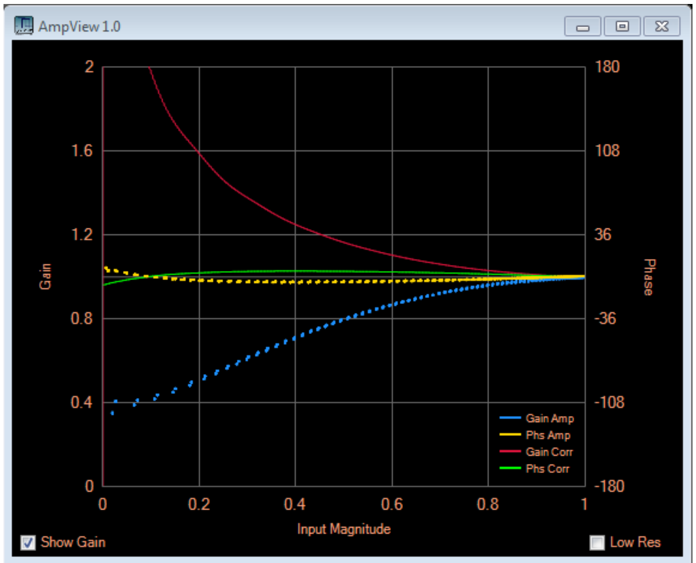


Fig 11 - AmpView 1.0 Gain and Phase

In a perfectly behaved amplifier, there would be linear gain. It would be shown as a straight line from the lower left corner to the upper right corner. There also would be linear phase as shown by a flat horizontal line from left to right in the middle of the screen.

For the Class AB amplifier, here are the displays while using the 2 tone test signal with Pure Signal On.

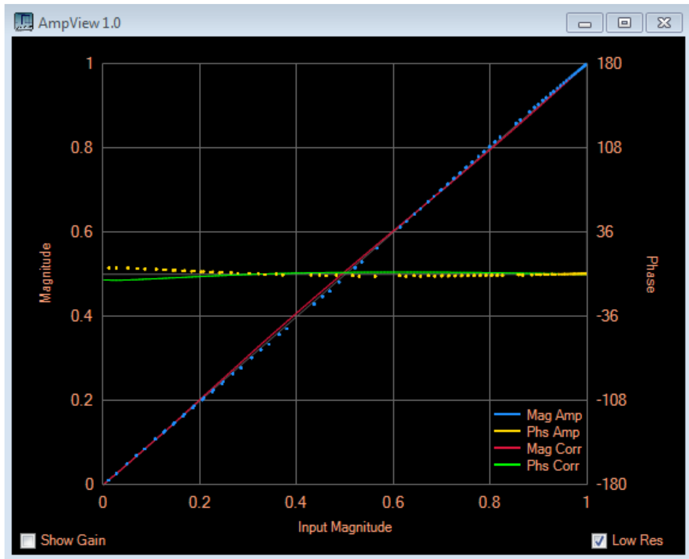


Fig 12 - AmpView 1.0 Class AB IMD test

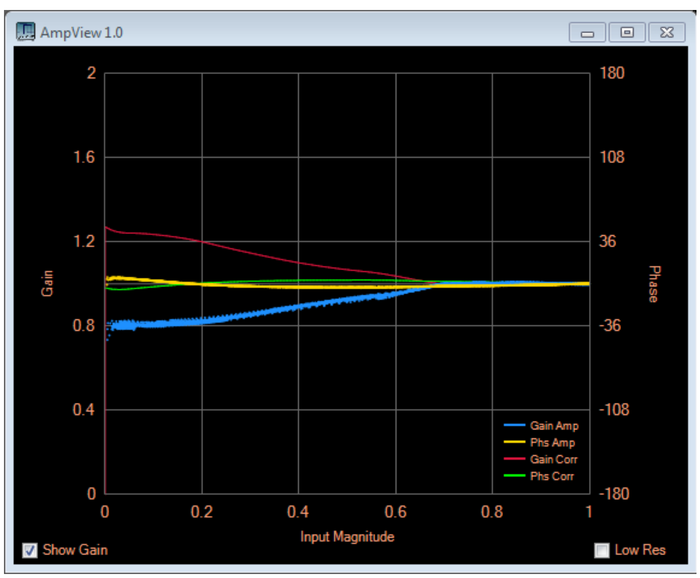


Fig 13 - AmpView 1.0 Class AB IMD test - 1.2A IDQ

As you can see, the amplifier appears fairly well behaved. Pure Signal is not performing a lot of correction. Both magnitude and phase are close to nominal. However, even with the seemingly small corrections, Pure Signal improves the amplifier IMD performance.

The gain screen above shows Pure Signal is performing correction at lower levels. This is with I_{DQ} set at 1.2 amps. To see if I could reduce this effect, I reset the bias for 2 amps I_{DQ}. Here is the change in Pure Signal.

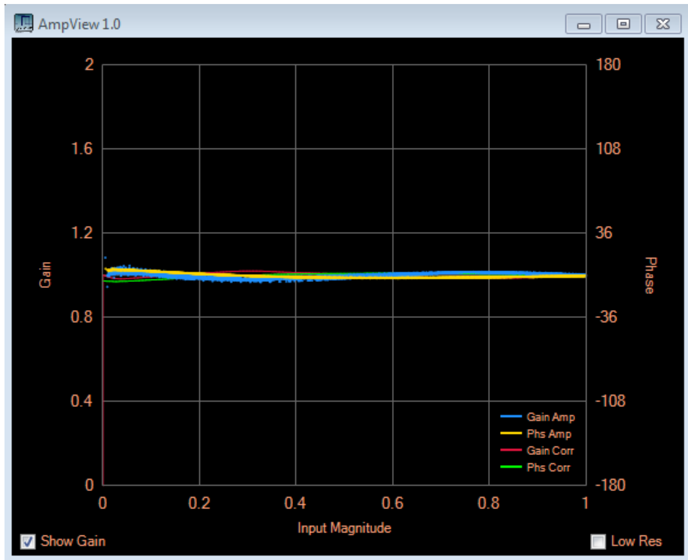


Fig 14 - AmpView 1.0 Class AB IMD test - 2A I_{DQ}

As expected, gain flattens out.

SUMMARY - CLASS AB

It should be noted that no special effort was made to optimize parameters such as amplifier bias, or drive levels. However, all stages were run well below their maximum output.

Several items mentioned in the Pure Signal documentation were observed during the testing.

- You need to provide a good clean feedback signal for Pure Signal.
- Pay close attention to the attenuation of the feedback signal. One would hate to destroy the front end of a receiver.
- There needs to be a high enough feedback signal level to reach the ADC overload point - too little feedback and Pure Signal can't do its job.
- The design of your amplifier has an effect on the amount of correction that can be obtained and maintained. Minimize the "memory" effects.
    - Minimize voltage drop/supply sag. Higher voltage/lower current helps.
    - Heat sinking!
    - Temperature compensating bias - in use on the LDMOS amp tested.

It was found that on 6M, there appears to be a 'sweet spot' for the feedback level for Pure Signal. This was about 5 dB below the ADC overload point. IMD reduction was on the order of

3-4 dB better at that point. I can say that other testers have not seen similar results at HF so it appears to be a 6M effect. More testing is indicated.

Overall IMD reductions were impressive. I have no doubt that with some careful tweaking and tuning, that these levels could be reduced further.

CLASS B TESTING

On the HPSDR reflector, a suggestion was made that a Class B LDMOS amplifier might be "linearized" using Pure Signal. This intrigued me. With the LDMOS amp set for Class AB, it's dissipating ~ 75 watts of heat just sitting idling. Class B bias could drop that to ~ 5 watts. I reset the bias on the BLF-178 to 100 ma I_{DQ} and drove it to 300 watts average power output using the two tone generator in PowerSDR mRX PS. As expected, higher drive power was needed, but the Hermes and Class A driver had no problem developing it. Rather than test all sections again, I just measured the complete system.

THE MEASUREMENTS

Here is the Hermes, Class A driver and LDMOS amp set for Class B with Pure Signal off. IMD is at -22.40 and -28.36 below the two tones.

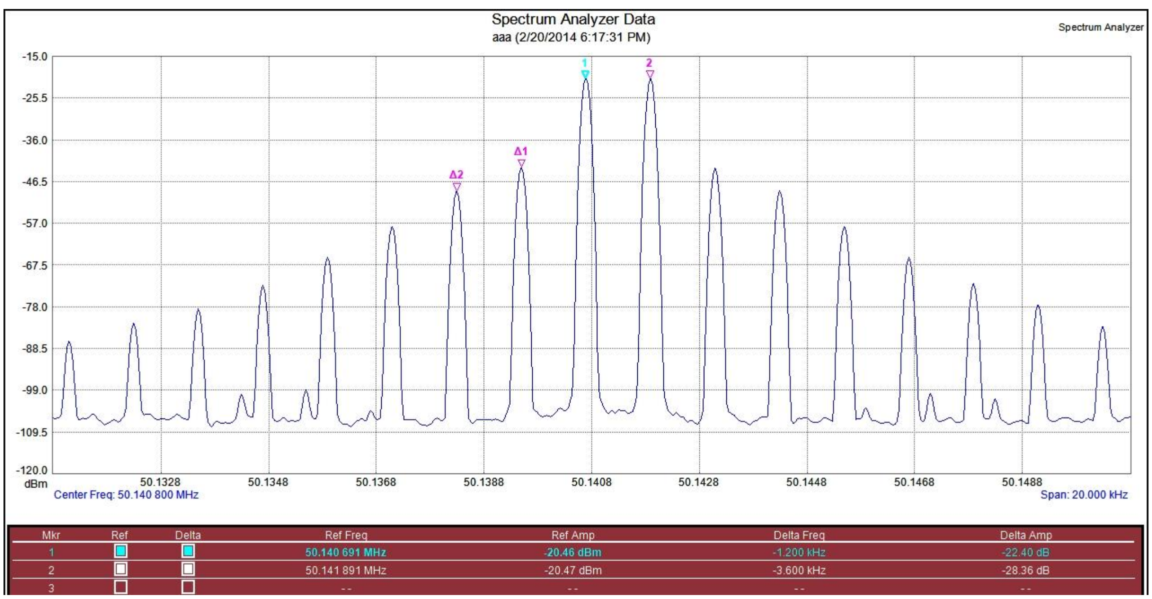
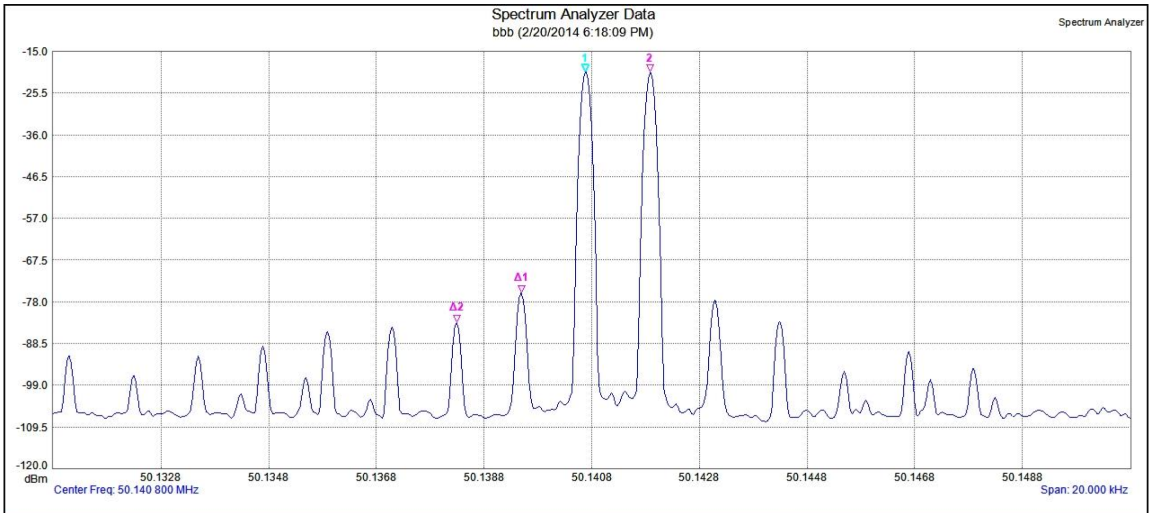


Fig 15 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal off

Here is the Hermes, Class A driver and LDMOS amp set for Class B with Pure Signal on. IMD is at -55.57 and -63.04 below the two tones.



Mkr	Ref	Delta	Ref Freq	Ref Amp	Delta Freq	Delta Amp
1	■	■	50.140 691 MHz	-20.11 dBm	-1.200 kHz	-55.57 dB
2	□	□	50.141 891 MHz	-20.13 dBm	-3.600 kHz	-63.04 dB

Fig 16 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal on

While the Pure Signal correction looks good with two tones, I wanted to see if the spectral output was as good as the numbers indicated. I used the FT-817 receive system and captured the waterfall display. The software was HDSDR. I'm using SSB first with Pure Signal off and then turning it on about half way through. It's pretty evident where I switched it on. You can easily see the sideband reduction.

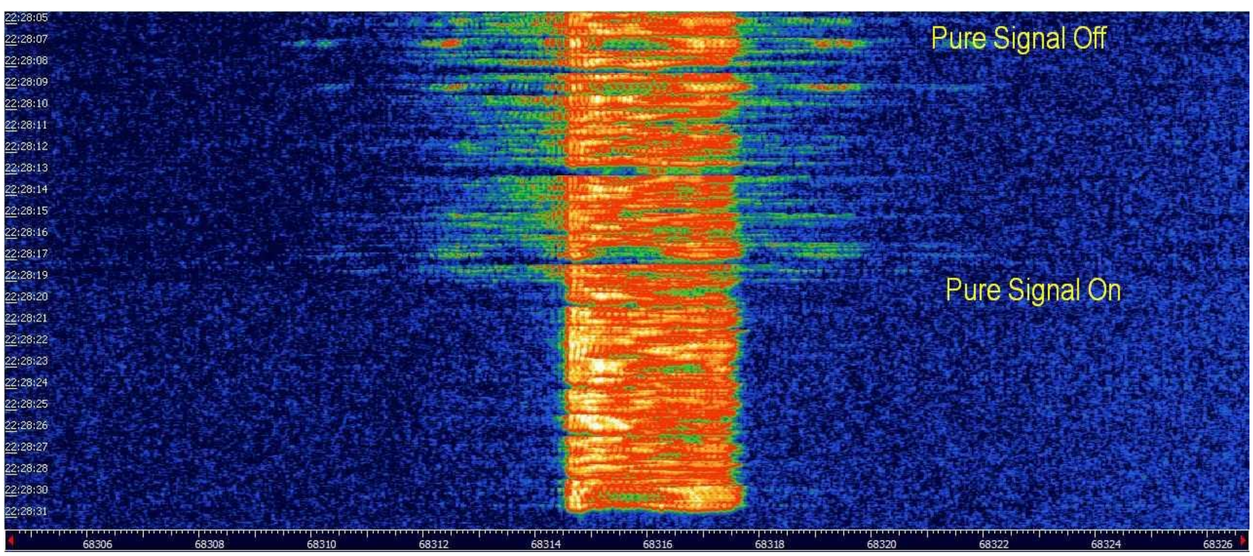


Fig 17 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal off then on

There is an I&Q audio file of this test. See footnote #5 for the URL. You can play it back in any program that can handle I&Q. You will hear the reduction in distortion on my voice as Pure Signal is turned on. I would also suggest tuning +/- 3 kHz and listening to the sideband energy reduction with Pure Signal off/on.

An interesting observation was made while watching the overall power in the 3 kHz receive bandwidth. In HDSDR, once Pure Signal was engaged, there was an increase in the signal within the receive bandwidth according to the S Meter. This was unexpected.

To try and explain this effect, I setup my ANAN-100 (a Hermes based 100 watt radio) in Panadapter view and also setup the Spectrum Analyzer to measure “Channel Power” within the 3 kHz bandwidth. I used a recorded wave file of me calling CQ fed in the line input of the Hermes to provide a consistent and repeatable test signal.

If you play back the I&Q file I mentioned above in HDSDR and watch the S meter, you will see this “power increase” effect when Pure Signal is turned on.

The following screen captures were made with my ANAN-100 using the “peak” function in PowerSDR mRX PS to try and verify that what was observed in HDSDR was actually happening.

Voice CQ – peak level at -31.2 dBm – within the 2.7 kHz filter -31.8 dBm – PS Off

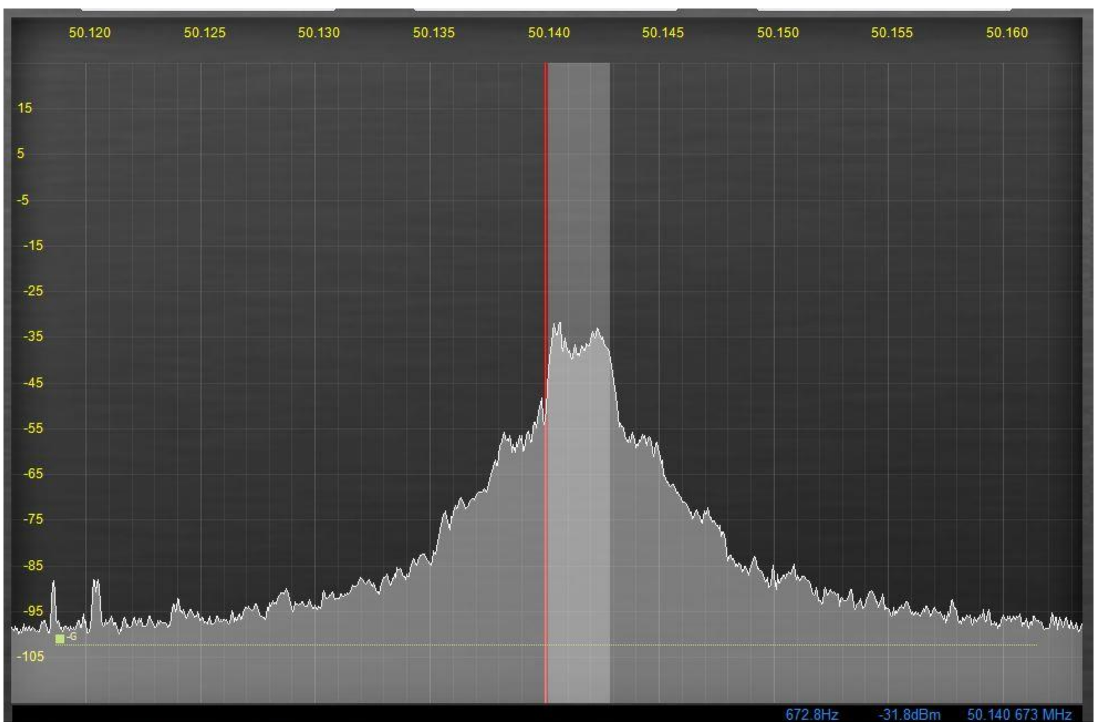


Fig 18 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal off

Voice CQ – peak level at -28 dBm – within the 2.7 kHz filter -28.3 dBm – PS On

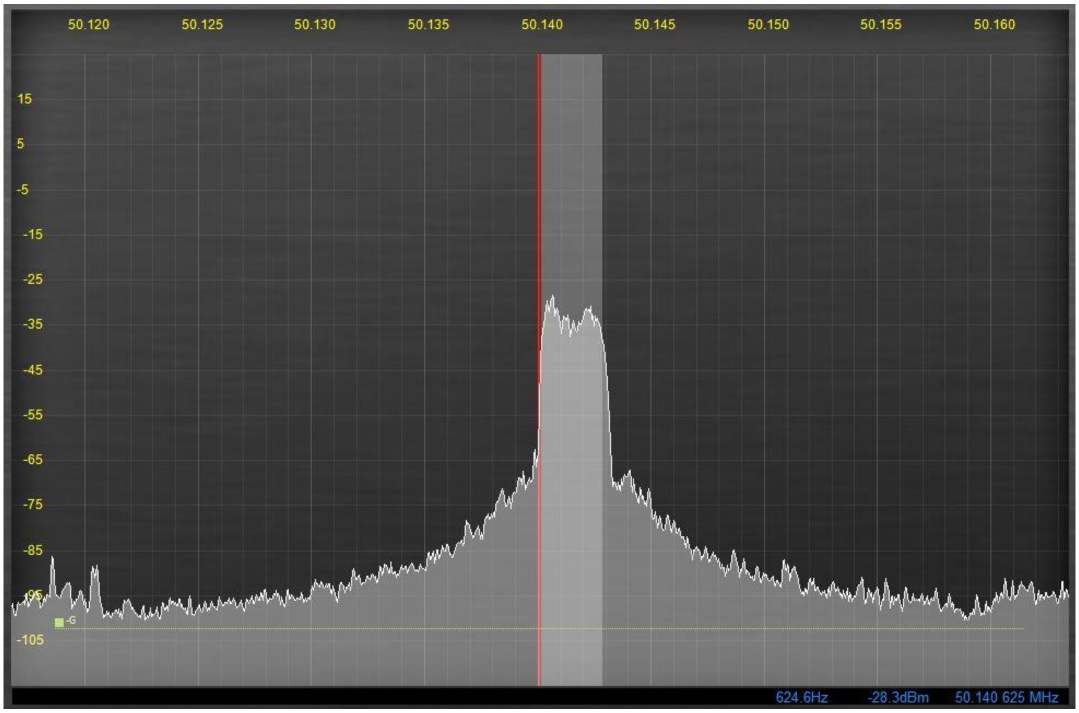


Fig 19 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal on

The following measurements were made using the "Channel Power" function in the Anritsu Spectrum Analyzer as an additional check. Channel width was set to 3 kHz.

Voice CQ – Channel Power -28.49 dBm – Channel Power Density -63.27 dBm/Hz - PS Off

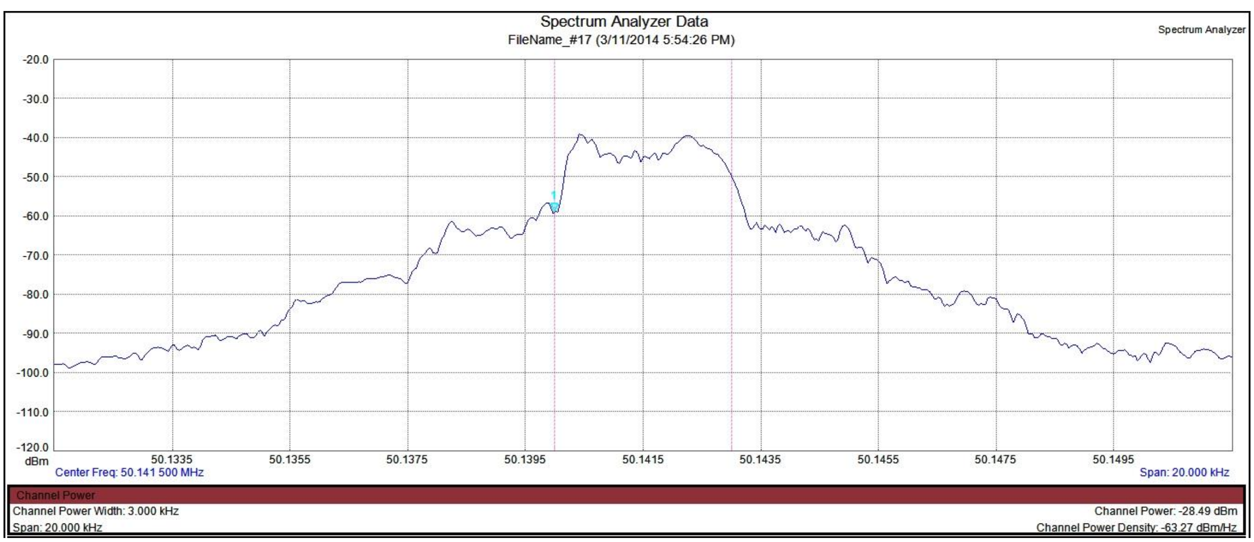


Fig 20 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal off

Voice CQ – Channel Power -25.2 dBm – Channel Power Density -59.97 dBm/Hz - PS On

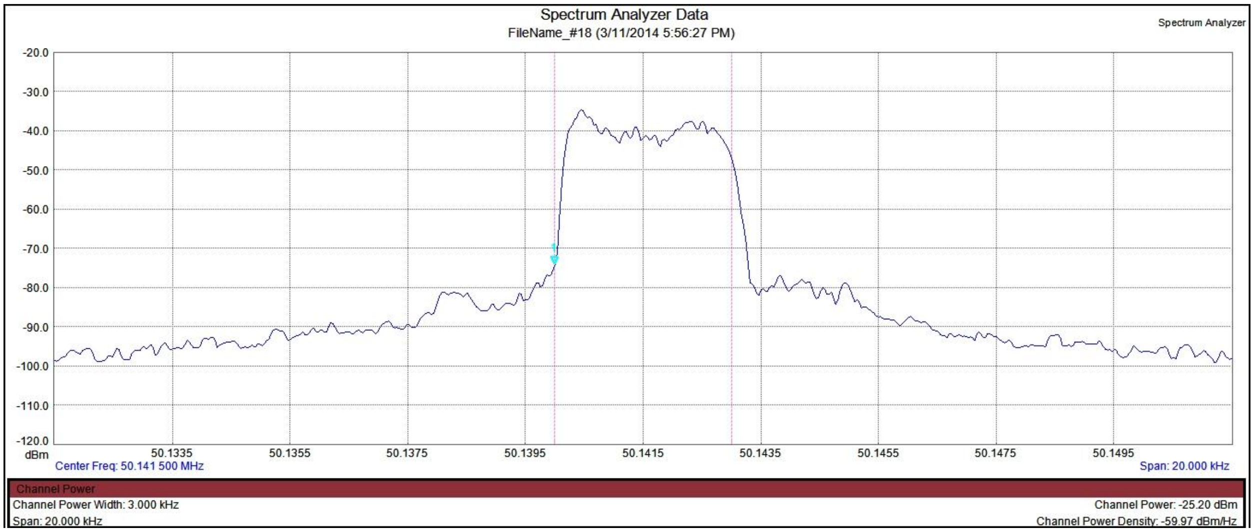


Fig 21 - Hermes, Class A Driver and LDMOS amp Class B - Pure Signal on

SUMMARY - CLASS B

All the measurements made indicate the signal increase effect is real. It is on the order of 3 dB. At this time, the exact cause is not known, but empirically, one could surmise that the energy wasted in the sidebands is now being concentrated in the main channel. Pure Signal also clears up the distortion in the main channel. During these tests I did not see an increase in peak power as indicated on the Wattmeter so this would tend to rule out an increase in drive. The test with HDSDR and the ANAN-100 were 'over the air'. The Spectrum Analyzer was directly connected via the Bird sniffer. Whatever the cause, the result is a positive one!

AmpView

AmpView is much more interesting to look at while correcting the amplifier in Class B.

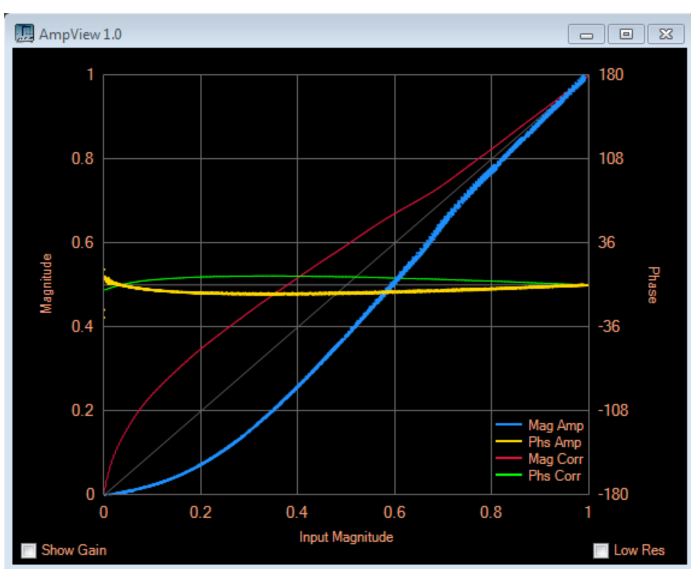


Fig 22 - AmpView 1.0 Class B USB test - Magnitude and Phase

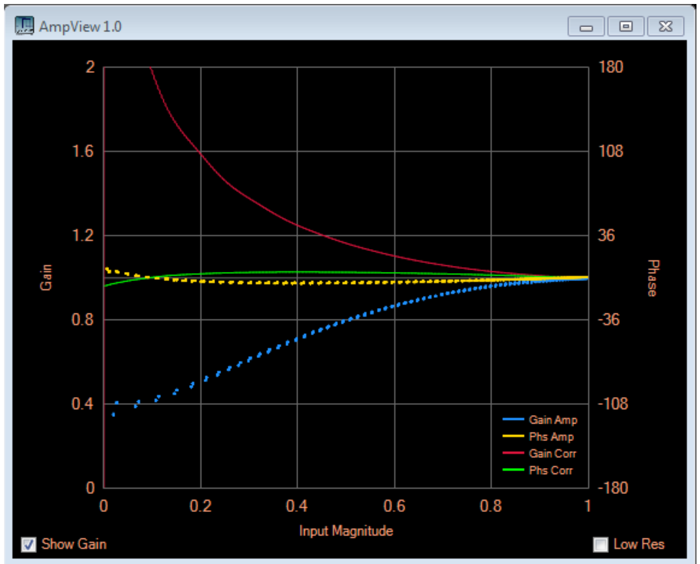


Fig 23 - AmpView 1.0 Class B USB test - Gain and Phase

As was shown in the Class AB testing, Pure Signal can have a positive effect on the purity of our transmitted signals.

Footnotes:

1.) http://openhpsdr.org/
2.) https://apache-labs.com
3.) http://users.burlingtontelecom.net/~n1jez@burlingtontelecom.net/images/PureSignal.pdf
4.) N1JEZ Panadapter -- http://www.w1ghz.org/small_proj/small_proj.htm
5.) http://users.burlingtontelecom.net/~n1jez@burlingtontelecom.net/images/ClassB.zip