

A Simple Modification To Improve The CW Filter Rejection In The K2 Receiver

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Introduction

KO0B posted a set of modifications to the CW filter in the K2 receiver, which are designed to improve the response of this filter by improving grounding and bypassing. These modifications can be found at <http://www.rt66.com/~hypoxic/K2stuff/ultreject.html>. However, there was no measured data that showed the improvement in the CW filter response. This led me to ask several questions. Does this change really improve the CW filter response? Can I make the measurements of the improvement using Spectrogram and using professional test equipment? Is there a simpler modification that can achieve this improvement?

The answer to all of these questions is yes. Most importantly, a huge improvement in the CW filter can be made with a simple 5-10 minute modification of the K2. The table below shows the before and after response of the CW filter.

	100 Hz Filter		400 Hz Filter		700 Hz Filter	
	Before	After	Before	After	Before	After
6 dB Bandwidth (Hz)	170	180	330	330	340	340
60 dB Bandwidth (Hz)	1210	710	1390	980	1150	1040
Rejection at 1800 Hz (dB)	*	106	*	112	*	111
Insertion Loss (dB)	~5	~11	~5	~8	~5	~7
*Ultimate filter rejection at 1800 Hz not measured before modifications						

This modification greatly improves the rejection of off frequency signals. This results in better single signal reception. The only disadvantage to the change is that it increases the insertion loss, especially at the narrower filter bandwidths. The insertion loss shown here is an estimate based on an indirect measurement, but the relative insertion loss between filters tracks this estimate fairly well.

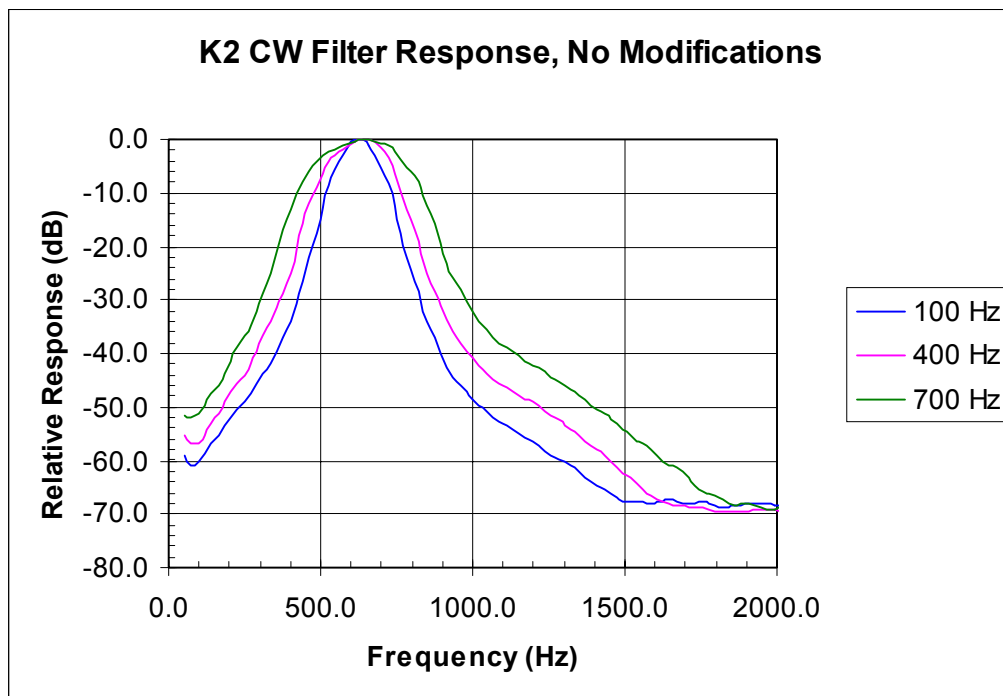
Filter Response Before Modification

Before I did any changes to my K2, I spent several weeks determining exactly the response of the current filter. Most of these measurements were done with Spectrogram, but some data was also taken with a HP-8753C network analyzer. To make your own measurements using Spectrogram, see **Appendix A: Using Spectrogram To Measure The Filter Response Of A High Frequency Receiver**.

There are two filters in the K2 design. The first, which is the CW or SSB filter, is located between Q22 and U12. This is the primary filter for setting the K2 receiver bandwidth. The

second is located between U12 and U11, and is used to improve the overall filter rejection of unwanted signals. If you want to measure the response of the first filter, you need to remove the second filter from the circuit. This is easily done by placing a 0.01 uF capacitor (exact value not critical) between U12, pin 8, and U11, pin 1. This step is not required; you can still measure the total K2 filter response without bypassing this filter.

The CW filter response of the K2 is shown below. All responses are scaled to 0 dB for each filter's peak response. Bandwidths of 100 Hz, 400 Hz, and 700 Hz were selected, and the second crystal filter is bypassed. There is a very interesting point to note in this plot. When the attenuation is less than 40 dB, the filter response is falling at 100 dB/octave. For attenuations greater than 50 dB, the filter response falls off at less than 40 dB/octave. This modification fixes the higher attenuation filter rejection, and the modified filter falls off at 100 dB/octave down to a rejection of at least 100 dB.



Your K2 will benefit from this modification if it has the two different slopes in the filter response. If it drops directly to greater than a 70 dB attenuation with a slope of ~100 dB/decade, it will not benefit noticeably from this change. The exact way that you installed X7 to X11 and the associated ground wire to the crystal case will determine the filter response. If you don't want to check your K2's filter response, installing the first part of the modification is fairly simple and probably will make a significant improvement your K2's CW filter.

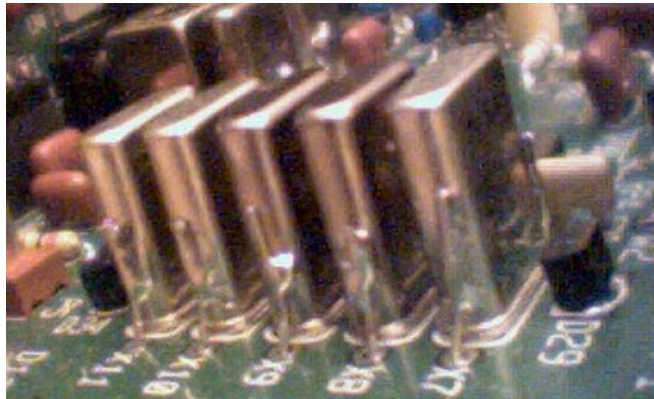
Changing The XTAL Ground

For anyone who has built a K2 transceiver, this part of the modification is fairly simple. The original assembly instructions for the K2 stated that the crystal ground wires should be soldered to the top of the crystals. This results in a higher inductance to ground for the crystal cases and allows them to couple energy to other parts of the K2 circuitry. Even if you soldered your

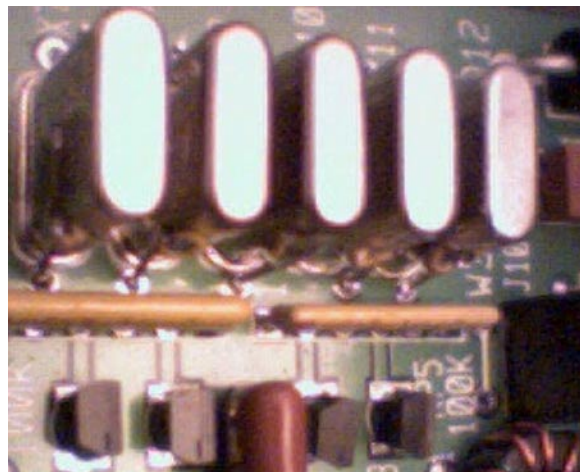
original ground wire to the side of the crystal case, adding the second ground wire will improve the filter response.

This change requires soldering new ground wires to both of the narrow sides of crystals X7 through X11. The change is done in such a way that it will not interfere with SSB board. I have found that a controlled temperature soldering iron with the tip temperature set to 700F works well to solder to the crystal cases. Limit the time that the soldering iron is applied to the crystal case to a few seconds to avoid the risk of damage to them. To make this change, perform the following steps:

1. Remove the K2 top cover, front bottom cover, side cover next to X7 through X11, and the SSB board if present.
2. Cut the ground wire running to the top of crystals X7 through X11 at the top of the crystal. Do not remove this wire from its ground hole in the circuit board.
3. Melt a small blob of solder on the narrow side of each crystal one-quarter to one-half of the way to the top of the case. Do this for both sides of the crystal and all five crystals.
4. Solder the cut wire to the side of each crystal. A picture of what this looks like is shown below.



5. Place a wire through each hole in the circuit board on the other side of each crystal. Solder the wire to the narrow side of the crystal and to the circuit board as shown below.



This completes the first part of the modification. Measurements with Spectrogram showed that there was no further benefit to the second part of the modification within the measurement limits of Spectrogram. However, I didn't take the pre-modification measurements below the 75 dB dynamic range of Spectrogram, and can't say for sure whether the chip capacitor bypassing provides an improvement beyond a filter rejection of 75 dB. The chip capacitor bypassing will not degrade the performance, but it may not help either.

Add Chip Capacitors For Filter Bias Bypassing

Chip capacitors offer extremely low series inductance, which can be an order of magnitude less than conventional caps with wire leads. This makes them extremely good at providing bypassing where it is needed. However, they are physically small which can make them a challenge to install when doing hand soldering. The picture below shows two chip capacitors; the capacitor on the left is a 0805 size and the other is a 1206 size.



I used six 1206 0.1 uF capacitors to bypass the bias voltage to each of the resistors on RP4 and RP5. Chip capacitors may be obtained from DigiKey and other electronic suppliers at about \$0.30 each in small quantity. The capacitor is soldered between the pad of the resistor pack and the nearby ground connection that was used to ground X7 through X11. Make sure to solder to the bypassed side of the resistor pack, not to the side that connects to the crystals and varactor diodes. To solder a chip capacitor, grasp the center of its body with a needle nose pliers, hold it so that both ends touch the desired pads, and solder it to one of the pads. After the solder sets, you can let go of the cap and solder it to the other pad. This is really all there is to it, and it isn't much harder to do than this. A magnifying glass on a stand can help in performing this operation. The final installed chip capacitor bypassing is shown in the picture below.



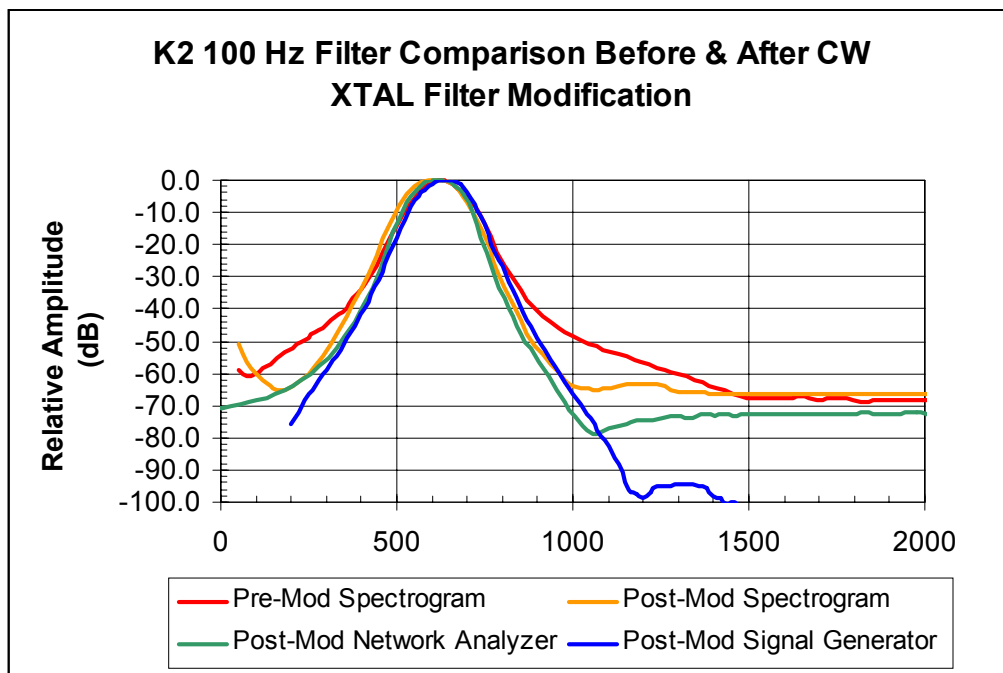
Comparison of Before and After

All of the before measurements were done with Spectrogram, but the after measurements were done by three different methods. All of the after measurements agreed within their dynamic range limits, which leads me to believe that careful use of Spectrogram can measure filter response with a ~75 dB dynamic range.

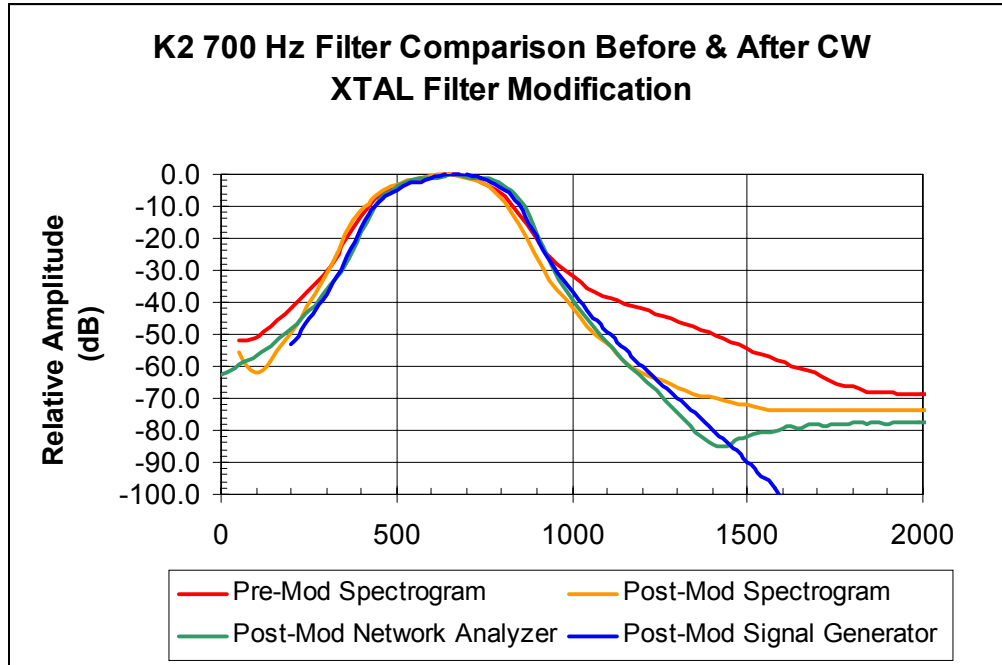
The after modification measurements were done with Spectrogram, a network analyzer, and a signal generator. The HP-8753C network analyzer provides a direct measurement of the filter response. However, to use it, the filter is disconnected from its surrounding circuit and driven directly by the network analyzer. This introduces some error due to eliminating the interactions with the rest of the K2 circuitry. I used the SSB connector to directly access the input and output sides of the CW filter. With my measurements, the dynamic range was limited to ~85 dB.

The HP-8648B signal generator and HP-4195A audio spectrum analyzer provide the most dynamic range of any of the instruments. However, these measurements require intensive manual intervention and take a long time. The measurement setup I used showed a dynamic range of over 110 dB, but the maximum possible dynamic range is much larger. Interestingly, while the filter shape showed rejections in excess of 100 dB, the K2 oscillator phase noise would not allow a real rejection ratio this high. The phase noise could be seen in the filter passband while the actual signal was outside the passband. This is a common limitation of all receivers and is dependent on both the transmitter and receiver oscillator phase noise.

The following plots show the before and after comparisons plotted so that each filter response peaks at 0 dB. The 100 Hz filter passband falls off very rapidly achieving a 60 dB bandwidth of 710 Hz and an ultimate rejection of 106 dB. The slope of the filter is ~100 dB/octave.



The 700 Hz bandwidth filter has a 60 dB bandwidth of 1040 Hz and an ultimate rejection in of 111 dB. Again, the filter slope is falling at a rate of 100 dB/octave down to a 100 dB filter attenuation. It is unlikely that any further design changes could significantly improve the response of the CW filter.



Conclusions

This relatively simple modification can significantly improve the response of the K2's CW filters, particularly at higher attenuation. The first part of the modification, which adds ground wires to the crystal cases, is relatively simple and should be applied to the CW filter on all K2 transceivers. The second part, which adds chip capacitor bypassing to bias network for the crystal filter, is optional and may not provide any benefit.

Changes to the K2 CW filter were originally suggested by KO0B. This work would not have been done without his initial modifications, and he deserves full credit for initiating this set of improvements.

Appendix A

Using Spectrogram To Measure The Filter Response of a High Frequency Receiver

Introduction

Spectrogram is a program that uses a PC sound card to make spectral measurements in the audio range. With an RF noise generator as a source, you can measure the filter frequency response of an HF SSB or CW communications receiver with a dynamic range of over 70 dB. This note is written toward measuring the filter frequency response of an Elecraft K2 receiver, but it can be applied to any HF communications receiver.

Getting Started

You will need to download a copy of Spectrogram. These instructions were written for version 5.1.6, but the latest download on the web, version 6, should also work fine. Spectrogram can be downloaded from <http://www.monumental.com/rshorne/gram.html>. Install Spectrogram on your computer and check that you can feed audio into it through your the sound card. This may require configuration of the audio mixer in Windows.

A RF noise source is needed to provide strong broadband noise to the input of the receiver. Noise from the preamp or antenna noise is not strong enough to make measurements over the full dynamic range of the filters. A Noise Bridge works as a source, or the ARRL Handbook for 2001 contains construction details for a noise source and a Noise Bridge.

Finally, you will need a cable to connect from the headphone output of the receiver to the input of the sound card. You may need to use an attenuator between them, especially if you are using the microphone input rather than the line input on the sound card. You can follow the step-by-step instructions to determine if the attenuator is needed. Radio Shack sells a 40 dB audio attenuator (#274-300), or you can construct an attenuator yourself from a pair of resistors.

Step By Step Instructions

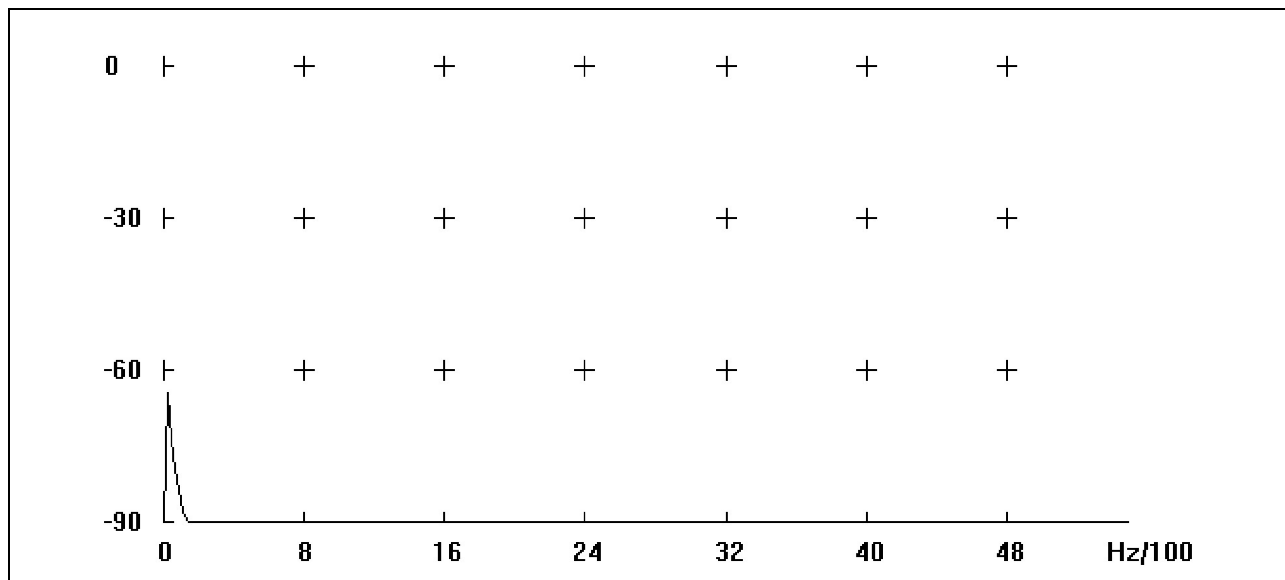
1. Launch Spectrogram

When the display comes up, select **File/F3 – Scan Input**. This will bring up the **Scan Input** dialog box in which you need to select the following options. Most recent computers can use the Preferred Selection; if Spectrogram runs really slow, the Alternative Selection should run faster. Do not vary these settings unless you thoroughly understand Spectrogram and what effect the changes will have. These settings will provide a frequency resolution of 20 Hz, which is more than sufficient to resolve any filters used for CW or SSB reception. All of the following instructions assume that Spectrogram is configured as given in the table below.

Spectrogram Settings	Preferred Selection	Alternative Selection
Sample Rate (Hz)	44k	22k
Resolution	16 bit	16 bit
Type	Mono	Mono
Display Type	Line	Line
Scale (dB)	90	90
Palette	CB or BW	CB or BW
Time Scale (msec)	100	100
Cursor Offset (Hz)	0	0
Freq Scale	Linear	Linear
FFT Size (Points)	2048	1024
Freq Resolution (Hz)	21.5	21.5
Band (Hz)	0 to 5512	0 to 5512
Spectrum Average	128	128
Pitch Detector	Off	Off
Recording Enable	Off	Off

2. Check Soundcard

In the **Scan Input** dialog box, click **OK**. Adjust the slider on the right side of the Spectrogram display to its maximum (top most) setting. The display should show a frequency range from 0 Hz to above 4800 Hz and an amplitude range of -90 to 0 dB. There should be a small blip in the display near 0 Hz, but the rest of the display should show a flat line at -90 dB. The display below is in the BW Palette and the black crosses may be turned on and off with **Toggle Grid**.



If there is noise above the -90 dB line (except the blip at 0 Hz), there is a problem with the sound card and the noise will limit the dynamic range that can be obtained in these measurements.

3. Connect Cable

With the power to the receiver turned off, connect the cable between the headphone output and the sound card input. There should still be no noise on the display. If noise is present, it is probably due to a defective cable or a ground loop in the audio connection. You will need to determine the cause of the noise and eliminate it if possible. You may also try to use an audio attenuator to reduce the noise.

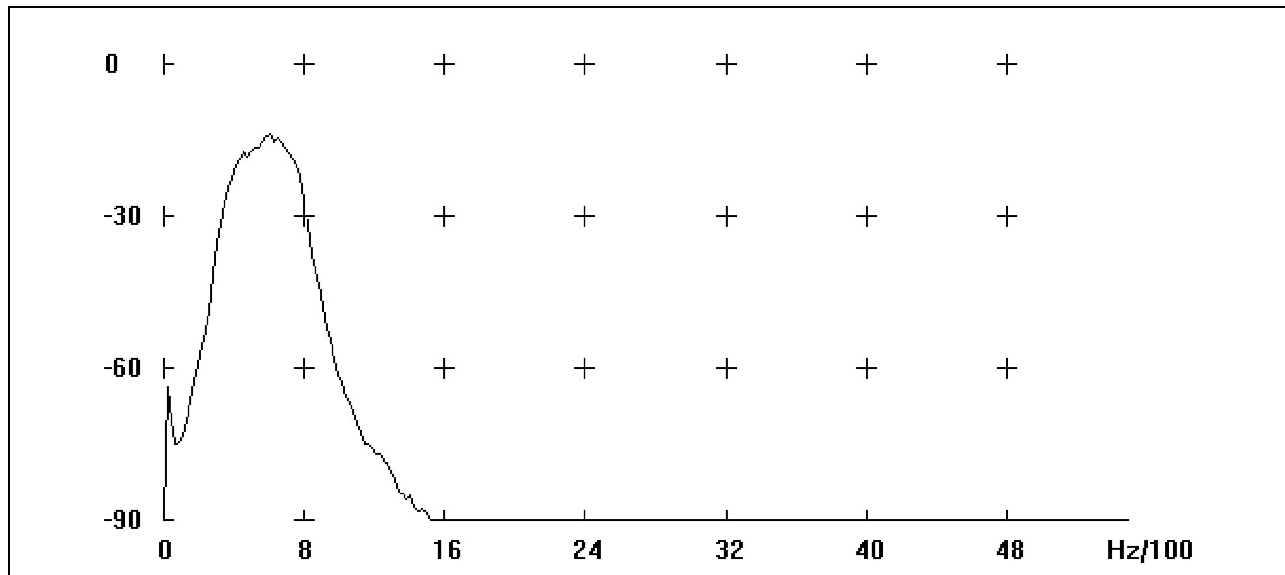
4. Power On Receiver

Turn on the power to the receiver. The audio and RF gain controls should be set to their minimum level and the AGC should be turned off (Hold PRE/ATT and AGC buttons on K2). Disconnect any antenna to the radio. Set the frequency to 80 meters and the mode to CW or SSB. The Spectrogram display should still show no noise other than the 0 Hz blip. If there is noise present, you will need to use an audio attenuator between the headphone output and the sound card input to eliminate this noise.

Slowly turn up the audio level until you can barely see noise at the -90 dB level. This sets the maximum audio level without sampling the internal radio noise in Spectrogram.

5. Connect The Noise Source

Turn on the receiver preamp. Connect the noise source to the radio input and turn it on. This maximizes the noise injected into the radio and will yield the best dynamic range. Set the receiver to the filter bandwidth that you want to measure. Gradually turn up the RF gain until the maximum reading in Spectrogram is approximately -20 dB. For the K2 in the 700 Hz filter bandwidth, the plot will look similar to the one below.



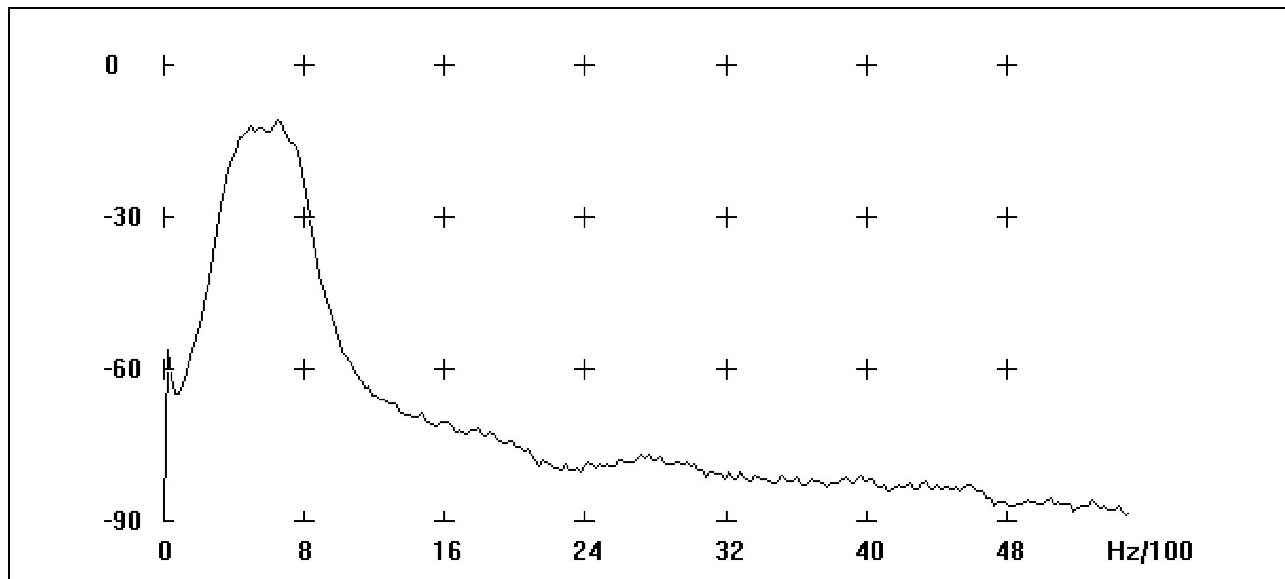
6. Adjust The Displayed Level

The following step is very important to avoid clipping in the sound card and the resulting intermodulation distortion. Gradually increase the RF gain until the noise starts to rapidly

increase at the higher frequencies. Reduce the RF gain from this point by at least 3 dB; a larger reduction won't hurt, but a smaller one could lead to measurement errors in the spectral intensity.

This step sets the input level into the sound card so that we are avoiding any clipping and the resulting distortion; this distortion can be a significant source of errors when measuring the filter response. For filters with a bandwidth of less than 1 kHz, a setting of -15 dB is safe, and for bandwidths equal or greater than 1 kHz a setting of -20 dB is safe. The previous Spectrogram display was taken with a maximum displayed level of -15 dB and a filter bandwidth of 700 Hz.

If your audio level is set too high, the picture below shows what the distortion will look like. Compare this to the previous Spectrogram display. The level at the higher frequencies is very sensitive to changes in the audio input level.



7. Make The Measurement

You are now ready to measure the filter response. It takes at least 15 seconds to read all 128 measurements for the average, and it may take even longer if you have a slower computer. When you are satisfied that you have obtained a good image, click **Stop** on the Spectrogram display. The image may be saved as a display of the Spectrogram window using the **File/Save Image** command or it may be saved as a set of data in text format that can be read into Excel or other graphing programs using the **File/Log Data** command.

Conclusion

Spectrogram can make wide dynamic range measurements of the filter response of HF receivers. It does require some care in its use to obtain accurate measurements, and to utilize the full dynamic range provided by the program.