Improving the Elecraft Keying Mod

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Introduction

Elecraft recently introduced a modification to improve the keying characteristics of the K2 transceiver. This mod, K2KEYMDKT, and its associated firmware, K2FWMCIO, can be ordered from Elecraft.

Measurements show that the Elecraft Keying Modification does reduce the bandwidth of the keying circuit. However, I felt that the risetime was slower than I would like. I tried some resistor value changes and found that I could reduce the risetime and at the same time reduce the keying bandwidth. This should result in even lower key clicks than the Elecraft mod.

The Elecraft keying circuitry is relatively complex and features two different paths that control the keying waveform. The main path is driven by the signal VPWR, which in the modified circuit passes through a two-pole low pass filter in U10A on the Control Board and then drives the VALC line. This line controls the gain of Q24 on the RF Board. The second path is the VBIAS-XFIL line, which drives Q10 on the RF board to the output amplifier bias circuit. The relative timing of both of these paths affects the overall keying waveform.

The Elecraft mod converted U10A into a two-pole low pass filter. I generally prefer to put the two-poles at the same location because I believe it will minimize the bandwidth for a given risetime. In the K2 keying circuit, you cannot put both poles at the same point because it will result in a mild overshoot at the amplifier output. However, you can move them closer together than in the Elecraft version of the mod.

Modification

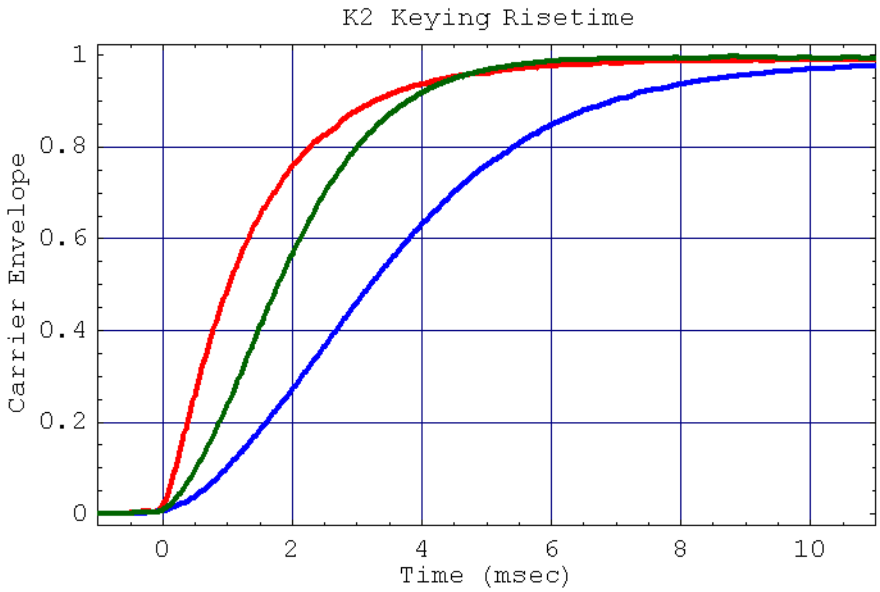
The modification is quite simple. Change the 270K resistor R21 to a 180K resistor. If you want a somewhat slower risetime, you can set R21 to 220K. However, the 220K resistor actually causes a high level of key click energy than the 180K resistor, so I don't recommend that solution. The reason for the higher key click energy with a 220K resistor is that it has a discontinuity in the falling edge near the bottom of the waveform.

Keying Waveform

The figure below shows the risetime of the K2 transmitted signal. All measurements in this note were made at 10 watts output on 20 meters. The keying waveforms will change somewhat depending on power and band of operation.

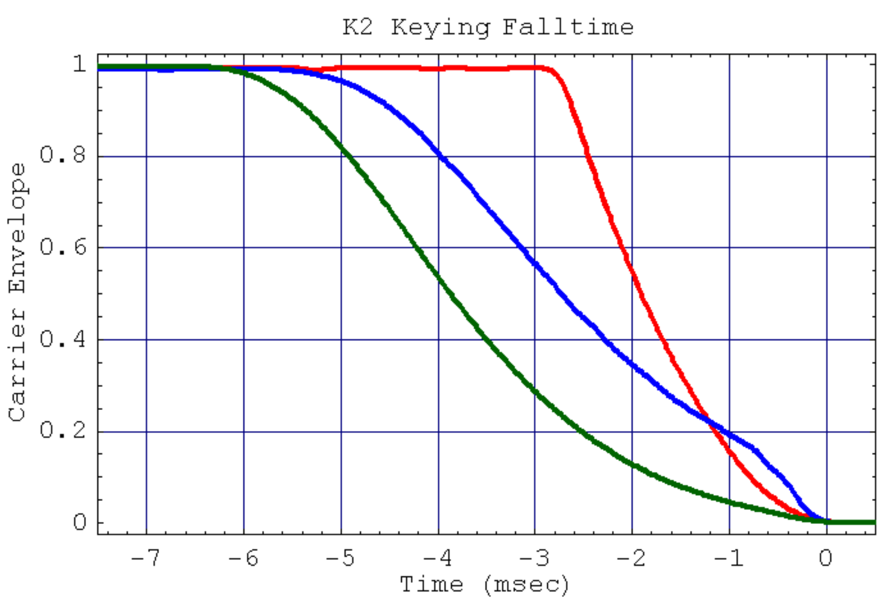
The Red waveform is the keying envelope of the original K2. Note the sharp change at the beginning of the waveform. This type of sudden change may create excessive bandwidth, otherwise known as key clicks. The risetime, measured from 10% to 90% of the rising edge, is 3 milliseconds.

The Blue waveform shows the official Elecraft Keying Modification waveform. The edges are now much more rounded, but it takes considerably longer for the output to reach full power. The risetime is 6 milliseconds, which is in the expected range for a CW signal. However, I would prefer a faster risetime.



I changed the Elecraft Keying Modification circuit to produce the Green waveform. This waveform shows a risetime to full power nearly as fast as the original K2 waveform, but it has a much more rounded edge at the start of the waveform compared to the original circuit. The risetime is reduced to 4 milliseconds, which is the same as its falltime.

The following chart shows the falltime for the same three options. The time scale of the falltime plots is different from the risetime plots.



The Red waveform shows a very rapid falltime and sharp breakpoint at the top. The falltime is 2 milliseconds. This is too fast for a CW waveform, and could produce excessive bandwidth on the CW signal.

The Blue waveform is much more rounded at the top and gradually decreases until it reaches about 10% of full power. At this point it takes a rapid decrease to zero output. I suspect that the change at 10% is being caused by the output amplifier bias circuit being turned off. The falltime is 4 milliseconds. This discontinuity in the Blue waveform does increase the bandwidth of the signal.

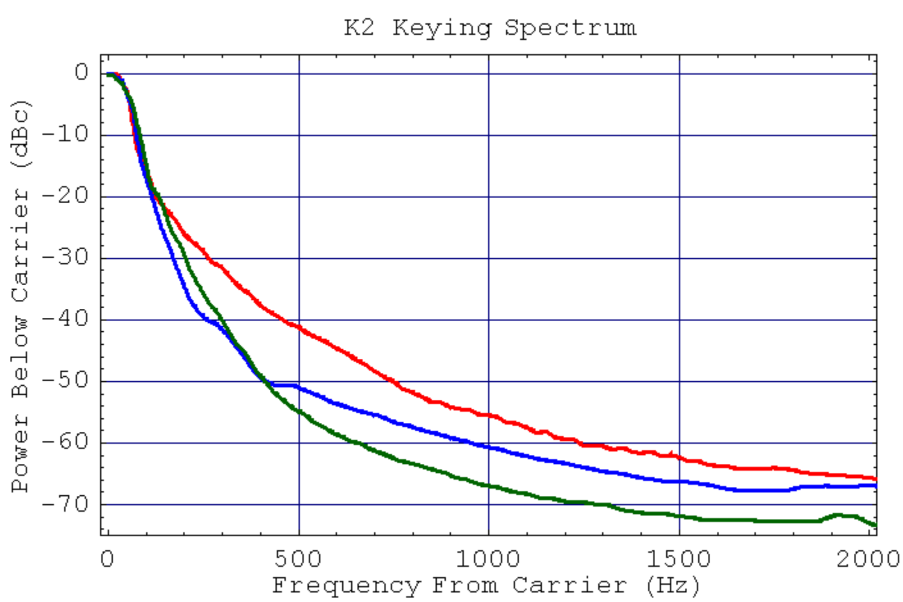
The Green waveform falls off more rapidly than the Blue waveform, but avoids the discontinuity in the last 10%. The falltime is also 4 milliseconds.

Spectrum

Measuring the spectrum of a CW signal is non-trivial. In most of today's transceivers, the CW signal is non-coherent (this is definitely true of the K2). This means that the phase of the RF carrier varies randomly from one CW element to the next. Therefore, you cannot use an arbitrarily narrow bandwidth to make the spectral measurements or else you'll get partial cancellation of the carrier. This statement is true whether you are using a spectrum analyzer or Fourier analysis.

To make these measurements, a series of CW dits was transmitted at 50 wpm. Each dit will be roughly 25 ms in width, with a 25 ms space between each dit. If the K2 keying spectrum is measured in a very narrow bandwidth, the carrier would be reduced by 10 dB because of the non-coherent CW. A 100 Hz bandwidth was used to make sure that there wasn't any significant carrier cancellation. This measurement bandwidth is also a better representation of the spectrum that would be encountered with a real CW receiver.

The K2 keying spectrum is shown in the chart below. The spectrum was measured with a 100 Hz bandwidth.



The chart was measured by averaging 1,200 dits at 50 wpm. This removes most of the noise that is present in a single dit measurement, which is an alternative way to measure a non-coherent CW signal. The noise floor of the test setup is about –70 to -80 dBc in a 100 Hz bandwidth. Above 1000 Hertz, the curves are being compressed together by the noise floor, so the actual separation between the Red curve and the Blue and Green curves may be greater than shown.

The Red line shows the unmodified circuit, which clearly generates the highest signal level at all frequencies. The Blue line shows that the signal from the official Elecraft mod is reduced below the signal of the unmodified K2. This is in agreement with the experimental results that indicate that the key clicks are lower with the Elecraft Keying Modification.

The Green curve shows the 180K resistor change to the Elecraft Keying Modification. The signal bandwidth is slightly greater for frequencies less than 250 Hz, but it is less for frequencies greater than 500 Hz. The increased bandwidth less than 250 Hz is an expected consequence of the faster risetime.

Time-Intensity Plots

Traditionally spectral analysis has been used to measure the effect of key clicks. There is one major disadvantage to spectral analysis measurements – they show the average power, not the peak power. The receiver responds to the start and stop of the carrier and produces a click, which is an impulse. We are measuring the average power to determine the effect of key clicks, but it is the peak power that determines their intensity in a receiver.

The following method was developed to better display the effect of the peak power in the rising and falling edge of the waveform. This method is capable of distinguishing the magnitude of the key click from the rising edge and the magnitude from the falling edge. The peak of this intensity plot is a better measure of the effect of a key click on a receiver. This method is independent of the keying speed, which is not true of measurements made with a spectrum analyzer.

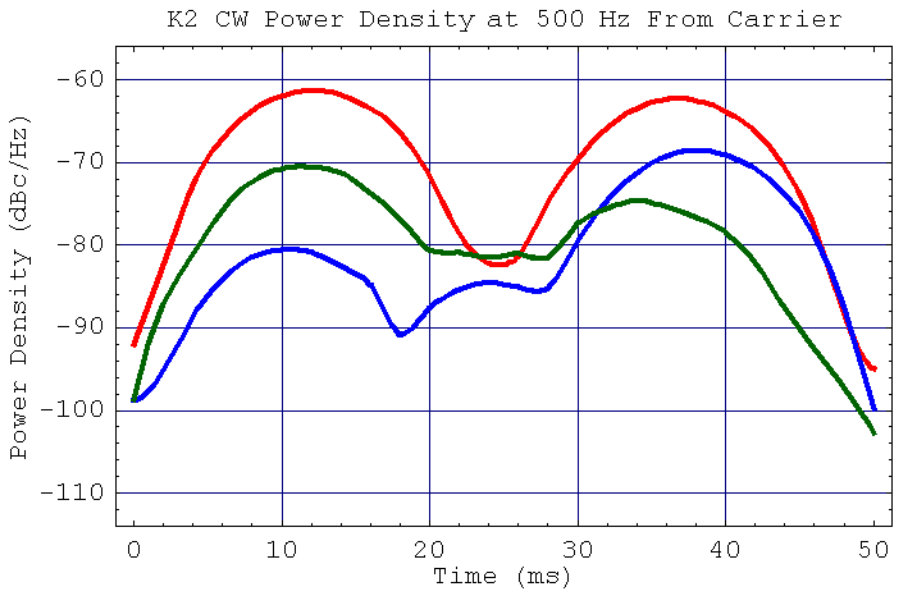
There is a common misconception that a key click is caused by the beginning or end of a rising or falling edge. Discontinuities in the keying envelope are not conducive to a narrow bandwidth, but they don't tell the full story. The spectrum from a rising or falling edge is determined by the entire envelope of that edge. There are cases in which the rising edge generates a higher intensity at some offset frequencies and the falling edge generates a higher intensity at other offset frequencies. This cannot be determined by looking at a keying waveform, but requires measuring the actual waveform.

To generate these plots, a 25 ms wide Hanning Window was applied to the digitized time domain measurements of the carrier keyed at 50 wpm. This Hanning Window was time shifted and Fourier transformed at each time increment into the frequency domain. Plots of the power density versus time were done at offset frequencies of 500 Hz and 1000 Hz.

The 500 Hz plot is shown in the figure below. The peaks around 10 ms are due to the rising edge and the peaks between 30 and 40 ms are due to the falling edge. The power density below the carrier is shown in the vertical axis. As in the earlier plots, the Red curve is for the original

K2, the Blue curve is for the official Elecraft Keying Modification with the 270K resistor, and the Green curve is the modification with R21 replaced by a 180K resistor.

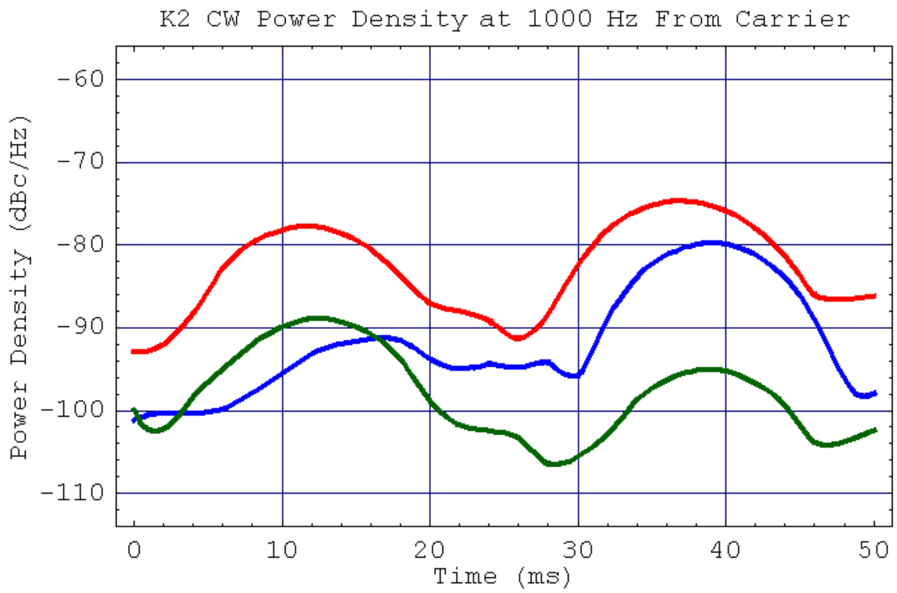
The Red curve shows that the rising and falling edges generate nearly the same intensity. This is in spite of the falling edge having higher levels for both the first and second derivative of the keying envelope. It is a good example of why you have to analyze the entire carrier envelope to understand the bandwidth expansion of a keyed carrier. Simple rules do not lead to correct answers.



The Blue curve shows the intensity with the 270K resistor at R21. The envelope of the Blue waveform, shown in a previous figure, had a slower risetime and that shows up with the lower power density at the risetime. The falltime has a much higher power density and is delayed somewhat from the other plots indicating that the reason for the bandwidth expansion is near the bottom of the power curve. There is a noticeable discontinuity in the Blue envelope falltime near this point.

The risetime of the Green curve shows a power density that is greater than its falltime power density. The peak power density of the Green and Blue curves is nearly identical. Overall, the Blue and Green curves should produce nearly equal levels of key clicks 500 Hz from the carrier.

The time-intensity plots 1000 Hz from the carrier show similar, but in some ways different results. The Red curve now shows a noticeably higher power density for the falling edge. The Blue curve still has a higher peak intensity for the falling edge. The Green curve shows a higher peak intensity for the leading edge, but its peak intensity is much lower than the peak intensity for the Blue curve. The Green curve is clearly much superior at this offset frequency.



In some ways, these results are not too different from the earlier spectral results. The earlier results showed that Red curve is worse at all frequencies. The Blue and Green curves are fairly similar out to 500 Hz, and the Green curve is superior for larger offset frequencies. However, these spectral measurements do not show which edge generates the peak intensity. In some cases the average intensity may give the wrong answer if one of the edges generates a significantly higher level of power density.

Conclusion

The original K2 keying circuit clearly generates a higher level of spectral expansion for a CW signal. This will result in a higher level of key clicks at all offset frequencies. The Elecraft Keying Modification reduces the key click generation. However, there is a better choice for the value of R21.

Changing R21 to 180K is the best overall compromise. The leading and falling edges are now nearly equal in duration, but more importantly, this version generates a lower intensity of key clicks for offset frequencies greater than 500 Hz.

This change has not been tested or approved by Elecraft.

I would like to thank a number of folks who sent me emails off the reflector with helpful questions and comments. These enabled me to re-think this problem from different viewpoints, and eventually led to this new way to view the analysis of key click data.

Everyone who has tried the change has been happy with the results. One person noted that putting a 560K resistor in parallel with the 270K is an alternative way to generate a 180K resistor in case you just want to try out this change without replacing the resistor.