Elecraft K3 Transceiver AGC Parameters and S-Meter Calibration

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This document is a reformatted version, with higher resolution images, of my web page http://www.cliftonlaboratories.com/elecraft_k3_agc_and_s-meter.htm. I've prepared a PDF text version of the page so that it may be printed and more easily circulated than in the web version.

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Revision History
Original page 17 August 2008
Revised 19 August 2008 to include AGC-F, AGC-S and AGC HOLD parameters
Revised 24 August 2008 to correct legend in plot showing fast/slow AGC
Revised 25 August to correct typo on AGC F/S differences; added several paragraphs with practical differences
Revised 13 January 2009 to replace hand-drawn sketch with computer-generated graphic created by Tom, N0SS
Revised 13 January 2009 to reformat into text and PDF.
Revised 15 January 2009 to clarify that AGC Decay time sets the rate of recovery, not fixed time and that AGC Hold is in 10 ms units.

Introduction

Elecraft's K3 transceiver is without question the most complex radio I've owned. Fortunately, the "factory default" settings are intelligently chosen and allow one to obtain more than acceptable performance without tweaking the user-settable parameters at all.

This page explores the effect of adjusting five AGC-related parameters of the K3's dozens of user-settable configuration parameters.

AGC Threshold and Slope are discussed first, followed by AGC decay time (for fast and slow settings) and AGC hold time.

AGC SLP and AGC THR

The K3 Owner's Manual provides a terse description of these two parameters:

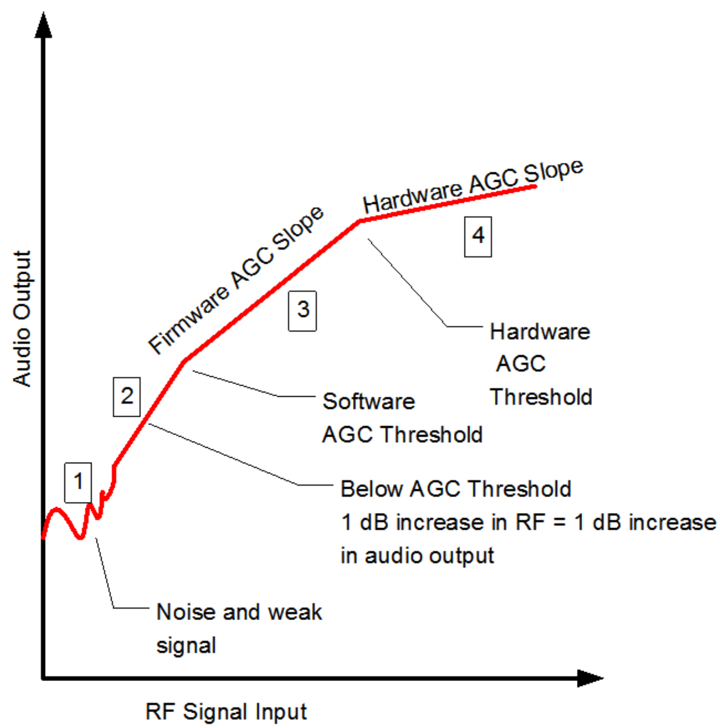
AGC SLP [T]	12	**(Advanced.)** Higher values result in 'flatter' AGC (making signals at all amplitudes closer in AF output level).
AGC THR [T]	5	**(Advanced.)** Sets AGC onset point; a higher number moves the onset up.

The range of possible AGC SLP parameters is 0 to 15, and permitted AGC THR values are 2 to 8.

The data is from my K3, operating with firmware revision 2.22. It's possible, of course, that other firmware releases will alter the behavior of these parameters. My K3 was assembled and calibrated by Elecraft and came with the AGC SLP and AGC THR settings illustrated above, i.e., 12 and 5.

Before looking at the data, it's first useful to see a "notional" view of what we expect to see. You may also wish to read my earlier page on AGC measurements, Receiver AGC Curves in conjunction with this page.

First a definition; AGC means "automatic gain control" and its function is to keep the receiver's audio output more or less constant as the RF input signal changes level. Designing a useful, stable AGC system is a non-trivial task.



It's convenient to divide the K3's AGC characteristics into four regions, as illustrated in the conceptual diagram at the right. The four regions are:

1. For extremely weak

signals, the audio output is mostly determined by noise and hence does not change much as the signal increases.

2. When the signal level is perceptibly greater than the noise, the audio output increases on a 1:1 basis, *i.e.,* a 1 dB increase in input signal level results in a 1 dB increase in audio output. This relationship is more apparent as the signal to signal plus noise ratio increases above 10 dB or so. (The audio output in this regime is S+N/N where S is the signal and N is the noise. As S becomes large with respect to N, the output is, to a good approximation, S/N.)

3. At a point defined by the AGC THR setting, the K3's software AGC begins to operate and increases the audio output at a slower rate than represented by the increase in RF signal level. Increasing the RF signal level 10 dB might, for example, increase the audio output by 2 dB. This input versus output relationship for signals above the threshold point is governed by the AGC SLP setting.

4. Once the input signal level increases above approximately -43 to -48 dBm (with the K3's preamp off; 10 dB weaker levels if the preamp is on) an independent hardware AGC circuit takes effect. The hardware AGC threshold and slope are not user settable, other than by making component changes within the K3. (Earlier K3 production runs had a different hardware AGC threshold and an update kit is available from Elecraft.)

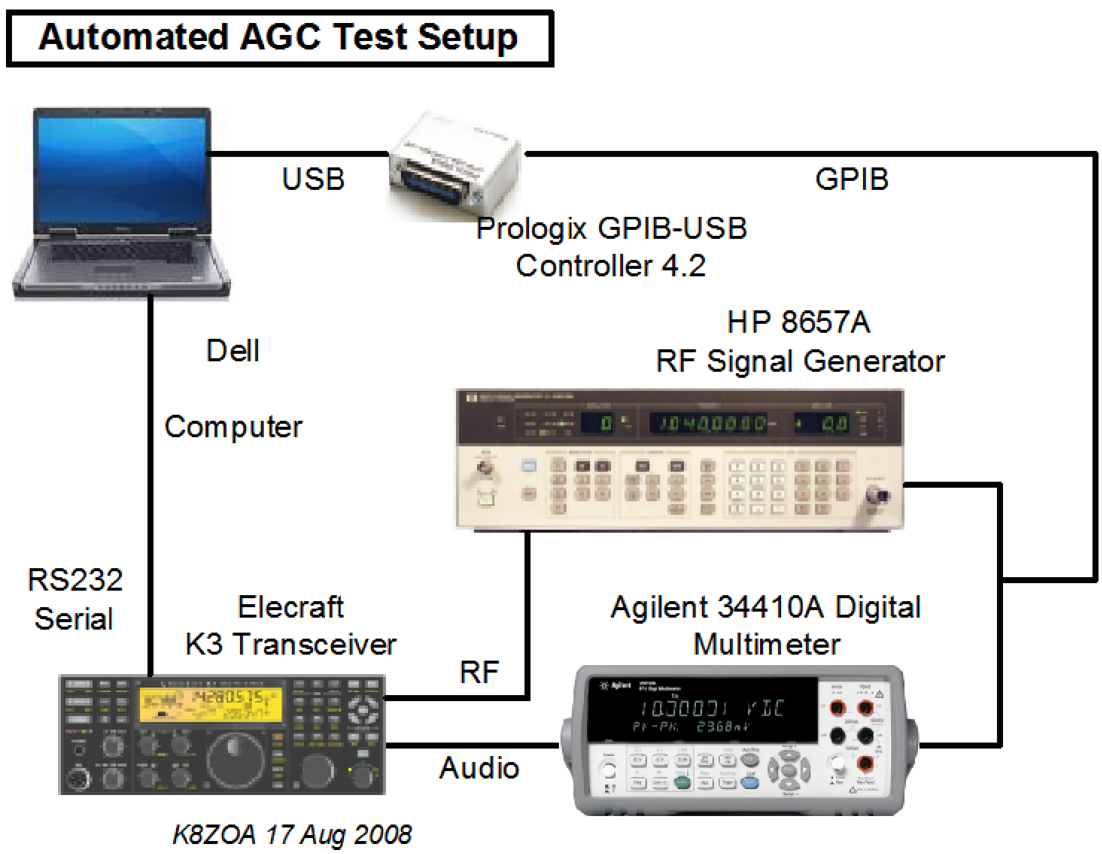
Test Setup

The description of AGC defines how one measures it. Since its function is to adjust the audio output as the RF input varies, we simply apply an RF test signal of known level to the K3 and measure the audio output after a brief pause for levels to stabilize. Increase the signal level and repeat the audio output measurement.

To do this for a couple dozen combinations of AGC SLP and AGC THR, each involving 100 or more individual measurements would be tedious, to say the least.

Fortunately, computer controlled test equipment permits us to automate the process. The figure below shows the arrangement I used to collect the data on this page. The M6300 laptop computer runs software I wrote to control the HP 8657A signal generator and to read the Agilent 34410A digital multimeter. In addition, the software reads the K3 report on the number of signal strength graph segments displayed. The data is saved to disk for post-collection analysis and plotting with [Origin software]() data plotting software.

RF signal levels stepped from -140 dBm to -20 dBm, in 1 dB increments. The K3 is operated in CW mode, AGC at slow, preamplifier off unless otherwise noted. Bandwidth is set at 600 Hz. The 34410A digital multimeter is a true RMS reading meter and was set for AC response.



A typical data file contents are as below (with the file truncated).

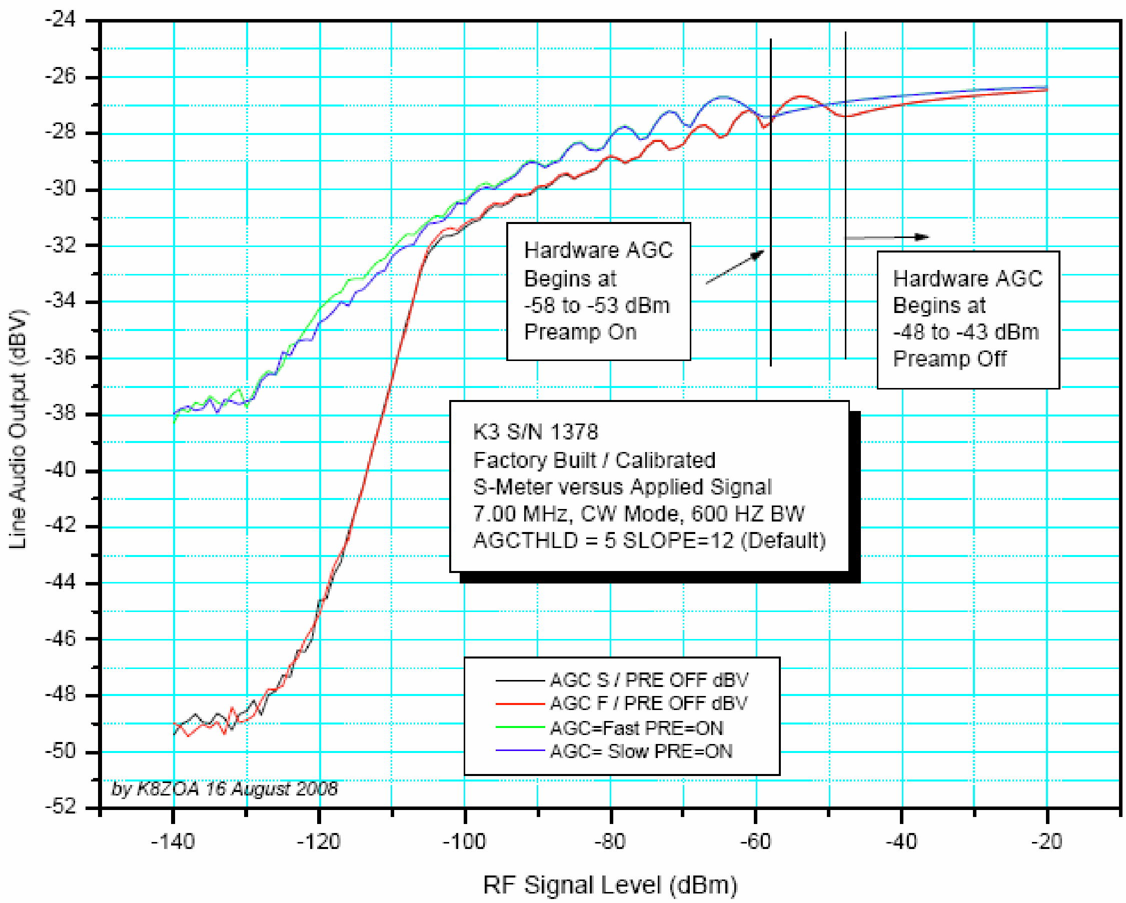
```
K3 Signal Level / S-Meter Check / AGC Audio Out
Run Date/Time: Aug 16, 2008 10:55:40
Transceiver ID ID017;
Transceiver Info IF00007000010 -000000 0003000001 ;
Filter BW Info FW0000;
AGC Speed / Status GT004;
Mode MD3;
Preamp Mode
Attn Mode RA00;
RF Gain RG239;
Prologix Card Ver Prologix GPIB-USB Controller version 5.4

Agilent 34410A ID Agilent Technologies,34410A,MY45000265,2.21-1.10-0.09-46-6
Start Level: -140 dBm
Stop Level: -20 dBm
Step Level: 1 dBm
```

```
Frequency 7 MHz

AGC=SLOW PRE=OFF THRESHOLD=5 SLOPE=09

dBm Bar Graph Audio
--- --------- -----
-140 0 +2.05011334E-03
-139 0 +1.87790216E-03
-138 0 +1.85180895E-03
-137 0 +2.06282250E-03
-136 0 +2.07184504E-03
...
-22 18 +7.74713052E-02
-21 18 +7.75875510E-02
-20 19 +7.76909983E-02
```

Fast and Slow AGC with Preamp On and Off

Before adjusting the AGC SLP and AGC THR, I first measured and plotted the AGC characteristic curves with the default values of 12 and 5, respectively, with AGC fast and AGC slow and the preamp on and off.

The figure below shows the same four regions in our conceptual discussion. It's easier to observe the match between measured and



conceptual looking at the data taken with the preamp off, *i.e.,* the red and black curves. (It's also immediately obvious that there's no real difference between fast and slow AGC speeds for our purposes.)

First, for weak signals, from -140 to -130 dBm, the audio output is relatively constant. That's because the audio is dominated by noise.

We then start to see the signal rise from the noise and maintain a 1:1 relationship to the point of AGC threshold. For example, at -120 dBm input, the audio output -45 dBV (dB with respect to 1 volt RMS). At -110 dBm input, the audio output is -37 dBV, an 8 dB increase, not quite 1:1. (At -120 dBm input, the noise component is contaminating the measured audio to some degree and likely accounts for some of the difference.)

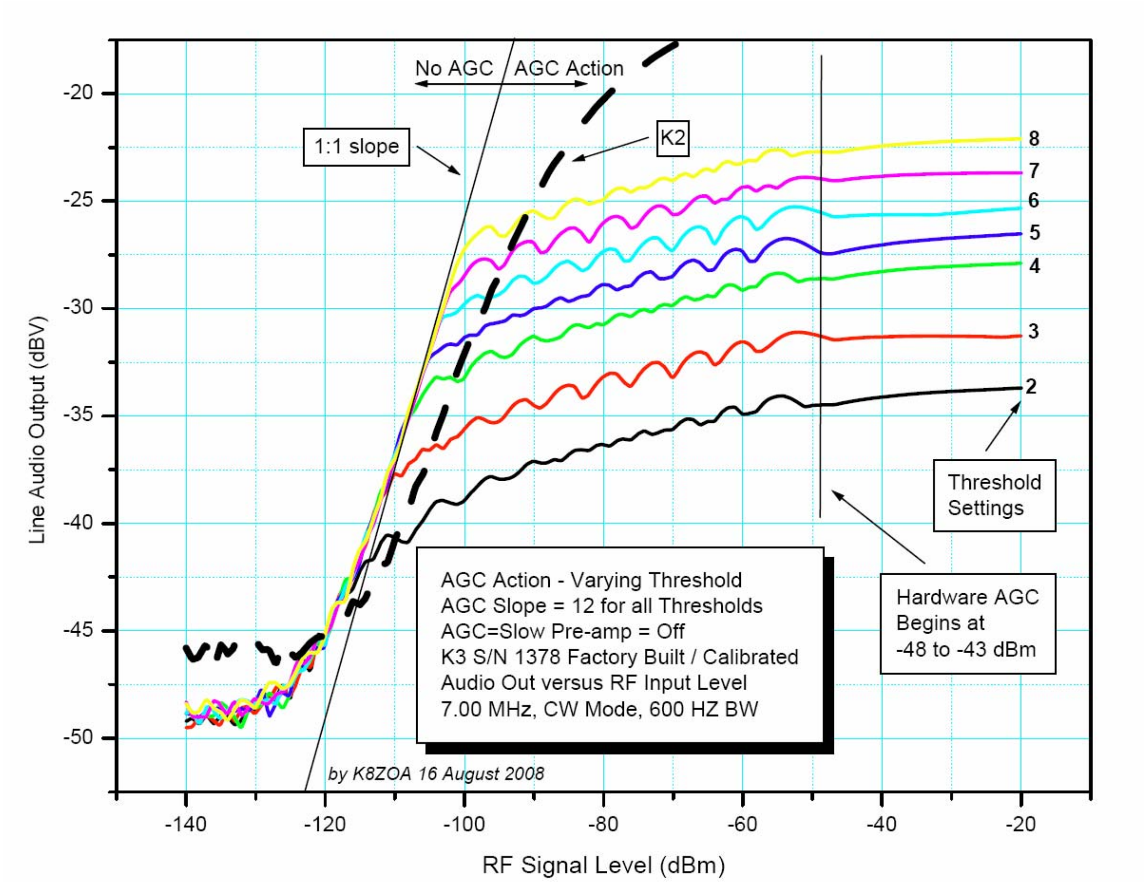
The software AGC threshold is visible at about -104 dBm. For a 20 dB signal increase (from -90 dBm to -70 dBm), the audio output increases 1.5 dB (from -30 to -28.5 dBV) so the slope is 1.5:20, output change : input change, in dB.

At -43 dBm, we see the effect of hardware AGC. The hardware AGC manifests itself not so much in a clear intercept / slope change as it does in removing the ripples in the AGC response. I don't know the source of the ripples, but one possibility is that the K3's DSP uses an approximation to a logarithm function optimized for speed rather than accuracy. In any event, the ripples exhibit relatively small amplitude changes, on the order of 0.5 dB and are likely undetectable when using the K3 for normal purposes.

The effect of the preamp is mostly to shift the curves about 10 dB, the preamp gain. It also increases the noise by 10 db and this is easily seen in the difference in shape of the curves for very weak signals.

Adjusting AGC THR

I ran signal sweep plots for all possible values of AGC THR, while keeping AGC SLP at 12. In addition, I ran a sweep of my K2 as a comparison point.



From the data, my *estimate* of the threshold settings is:

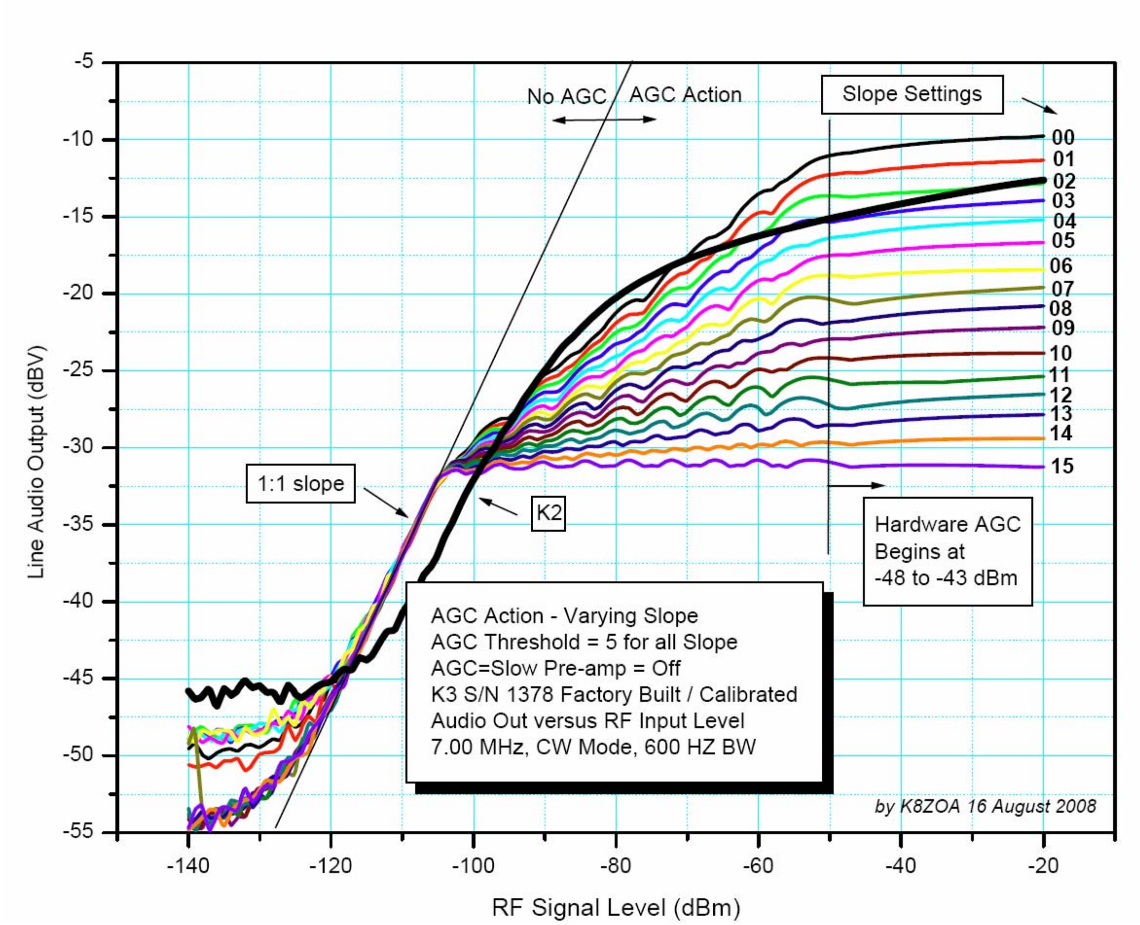
AGC THR	Corresponding Input Signal Level
2	-117 dBm
3	-110.5 dBm
4	-105 dBm
5	-103.5 dBm
6	-102.5 dBm
7	-101 dBm
8	-99 dBm

I've based these values on the point where I see a clear divergence from the 1:1 slope, but reasonable people could read these numbers a couple dB either way.

The K2's AGC threshold point is between -80 and -90 dBm, but the AGC application is not abrupt, making it difficult to define a single "threshold."

Adjusting AGC SLP

I next looked at varying the AGC slope whist keeping the threshold AGC THR constant at the factory default setting of 5.



Adjusting AGC SLP over its adjustment range reveals quite a difference in slope. At the maximum setting of 15, there's almost no change in audio output between AGC threshold and the onset of hardware AGC. At the minimum setting of 0, in contrast, the slope is relatively gentle. It's also easy to see the hardware AGC onset with slope settings below 10.

Based upon these values, I've prepared a table showing how much the audio changes for a 10 dB change in RF signal level, versus slope setting. I've shown these values to two decimal places, but that does not imply the data is accurate to that degree of precision.

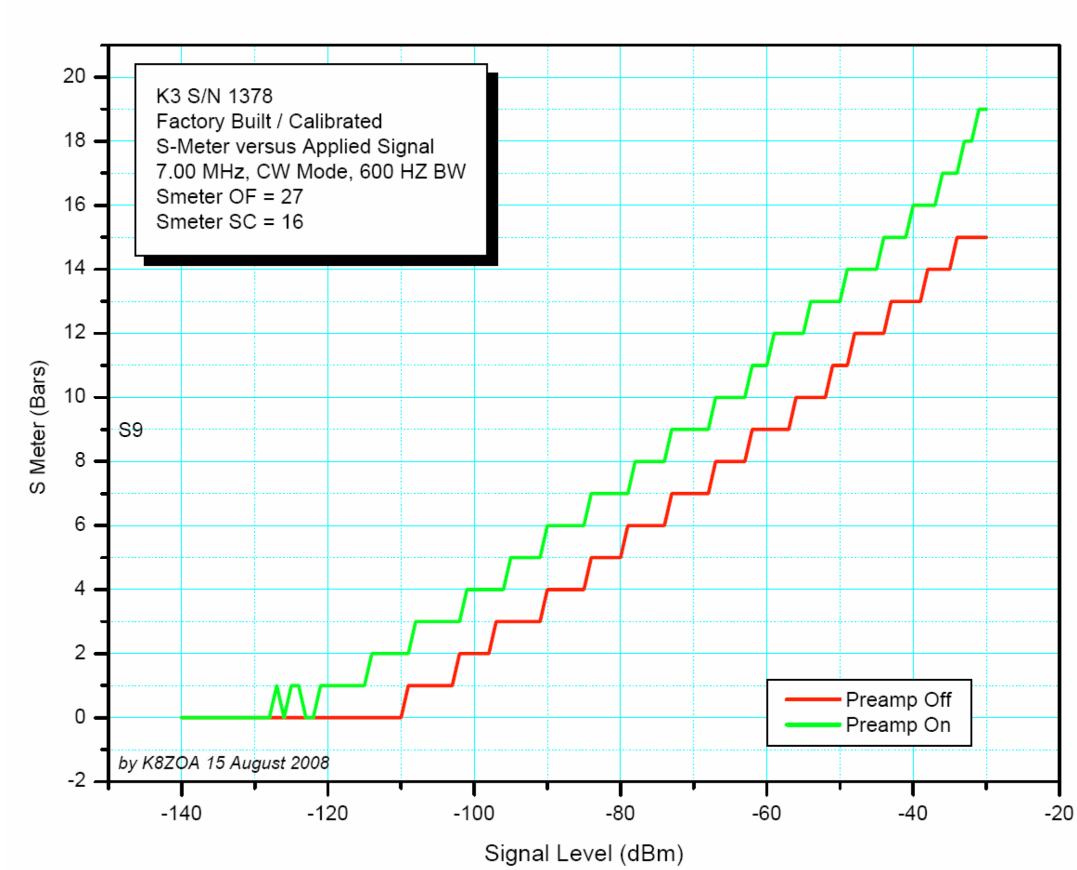
AGC SLP Setting	Change in Audio Level (dB) for 10 dB Change in Signal Level (dB)
0	4.09
1	3.81
2	3.51
3	3.26
4	3.00
5	2.74
6	2.47
7	2.21
8	1.95
9	1.67
10	1.44
11	1.16
12	0.86
13	0.60
14	0.28
15	0.05

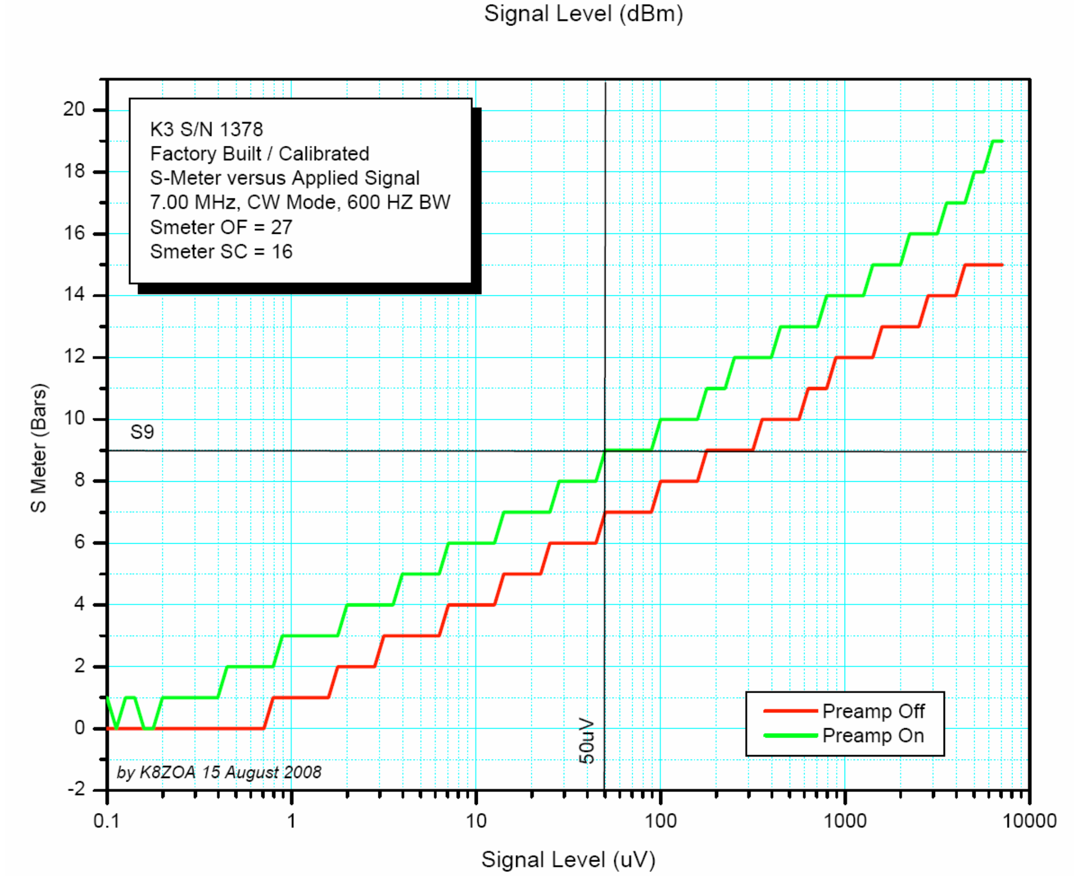
The K2 data shows a 5 dB change in audio for a 50 dB change in RF level (-20 to -70 dBm), for a slope of 0.50 dB for 10 dB change, corresponding most closely to the K3's AGC SLP 13. However, the K3's hardware and software AGC systems make it impossible to duplicate the K2's characteristics.

S-Meter Calibration

The two plots below show how my K3 displays S-meter bars as the RF signal level changes. I've presented the data separately in terms of dBm and µV. The S-meter offset and slope values are the ones my K3 was shipped with.

To the extent there is a standard, S-9 corresponds to 50 µV and one S-unit corresponds to 6 dB change in signal level. With the preamp engaged, at 7 MHz, my K3 ticks over to the S-9 bar exactly at 50 uV and tracks the 6 dB per S-unit objective quite closely. I did not collect data in the "independent" mode where the S-meter reading is independent of preamp or attenuator setting.


K3 S/N 1378
Factory Built / Calibrated
S-Meter versus Applied Signal
7.00 MHz, CW Mode, 600 HZ BW
Smeter OF = 27
Smeter SC = 16
S9
Preamp Off
Preamp On
by K8ZOA 15 August 2008
S Meter (Bars)
Signal Level (dBm)


K3 S/N 1378
Factory Built / Calibrated
S-Meter versus Applied Signal
7.00 MHz, CW Mode, 600 HZ BW
Smeter OF = 27
Smeter SC = 16
S9
50uV
Preamp Off
Preamp On
by K8ZOA 15 August 2008
S Meter (Bars)
Signal Level (uV)

AGC-F, AGC-S and AGC HLD

In addition to the AGC threshold and slope parameters, the K3 has three user-adjustable parameters governing how the AGC releases. As with the earlier AGC parameters, the K3's Owner's Manual provides only a brief discussion of the three parameters:

AGC HLD [T]	0	**(Advanced.)** AGC "hold" time for voice modes. Specifies the number of milliseconds that the SLOW AGC value is held after the signal drops below the level that set the AGC. This is often helpful for SSB voice operation.

AGC-F [T]	120	**(Advanced.)** Sets fast AGC decay rate; a higher number means faster decay.
AGC-S [T]	20	**(Advanced.)** Sets slow AGC decay rate; a higher number means faster decay.

AGC HLD has a range of permitted parameters from 0 to 30. AGC-F is adjustable from 80 to 120, whilst AGC-S runs from 5 to 40.

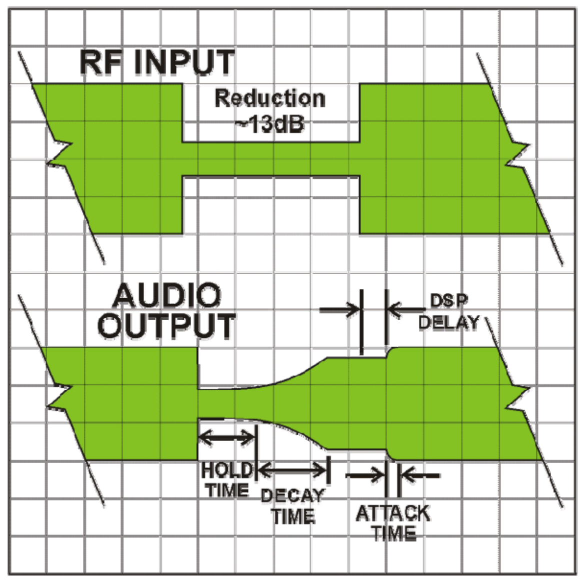
Why have different AGC decay speeds? AGC attempts to preserve the dynamic range of the input signal without overloading the receiver. Consider an SSB signal--the maximum gain possible before receiver overload is determined by the strength of the voice peaks, so the AGC must adjust the overall gain based on the peak signal. In order to react to these peaks, the AGC needs a fast attack time, on the order of a millisecond or two.

Now consider the release or decay time constant. If the AGC has a fast decay time, it will adjust the receiver's audio output upwards on low voice levels and downward on high voice levels. This may be acceptable under certain conditions, but overall it removes dynamic range from the voice audio. The result is similar to the effect of the transmitting station using an aggressive speech compressor and can prove annoying to listen to. In addition, during brief pauses, fast AGC will bring the background noise level up to nearly the peak speech level, not a good thing at all.

A fast attack, slow decay system for SSB will adjust the gain based on peaks, but hold the gain constant for several seconds after the peak. Thus weaker voice sounds produce weaker audio output and stronger voice (but not quite equal to the peak) produce stronger audio, thus preserving the SSB signal's dynamic range. During speech pauses, the background noise is likewise reduced.

AGC operation may be easier to understand if we think of CW mode. During key-down either fast or slow AGC will produce the same result - there's no amplitude variation to speak of in the CW signal during key down, except under rare conditions such as fast polar flutter. However, when the key is up, fast AGC will bring up the background noise but slow AGC will suppress the background noise as it maintains the gain at a level suitable for the signal. One problem with slow AGC is that a noise spike, such as from lightning crashes, will charge up the AGC system and reduce the gain for the decay period. A fast AGC may be desirable for these conditions. (The K3 has a slow AGC mode with spike suppression to avoid these problems.) Slow AGC will make it difficult to copy both a strong and weak signal in fast sequence as the gain will be governed by the stronger signal until the decay period passes.

To observe what happens as we vary the three AGC speed setting parameters, we'll use an AM signal, modulated with a square wave, with a modulation depth of approximately 13 dB. We use a reduced modulation depth because it allows us to easily measure the key parameters with a single test waveform.



The illustration to the right shows the idealized input signal and the K3's audio output in CW mode but the same concepts apply to all modes in which AGC is used. (The artwork is supplied by Tom, N0SS, which replaces my crude hand-drawn sketch.)

The important elements are:

1. When the test signal amplitude drops 13 dB, the K3's audio output drops 13 dB (assuming the RF and audio levels are set to be within the K3's software AGC range and out of saturation.)
2. If the AGC is set for slow, with AGC HOLD > 0, the audio output will stay -13 dB from the full amplitude level for the holding time defined by the AGC HOLD parameter.
3. When the AGC HOLD time passes (or immediately if AGC HOLD is 0) the AGC begins to increase the gain so as to increase the -13 dB signal's level. In a vacuum tube analog receiver, the AGC would go less negative, or decay from the negative voltage level established by the full amplitude signal. As the AGC voltage became less negative, the receiver's gain increased. For this reason, the period from the hold interval until the new AGC level is fully

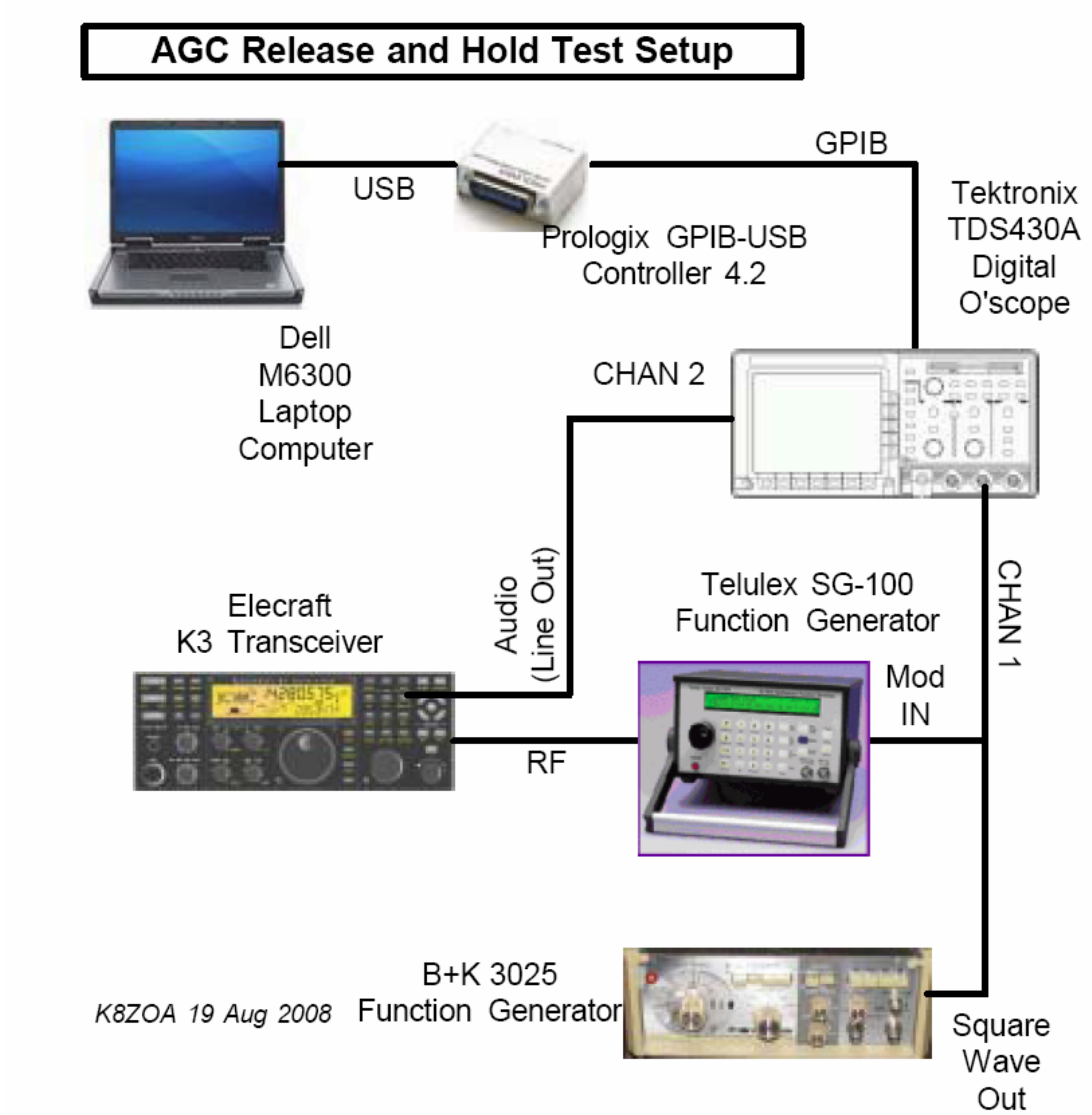
asserted is called the "decay period." (Generally the decay period was based upon an RC time constant, so the shape of the decay was determined by the negative exponential of an RC circuit. Designers are free to use other approaches in the world of digital signal processing, but it seems that Elecraft's K3 emulates an RC network

4. When the new AGC level is fully asserted, the audio output will be a bit less than observed for the 100% signal level because the AGC's sloped response means that a weaker signal will have a slightly weaker audio output even when within the AGC range. (See earlier discussion on this page for more details.)
5. When the signal increases back to 100% amplitude, there is a brief delay due to the digitization and mathematical computations in the K3's DSP. I may measure this at some point but for now we'll take it as a given that a few milliseconds of DSP delay is present.
6. The AGC then will begin to bring the 100% level signal down. The time it takes for the AGC to assert itself when the signal increases is called the "attack time" and in the current K3 firmware the attack time is not a user adjustable parameter.
7. AGC Hold functions only when AGC-Slow mode is engaged.

The test setup for AGC release and hold measurements is shown below. This is not an automated measurement process and the GPIB bus and computer is used only to capture screen images from the TDS 430A digital oscilloscope.

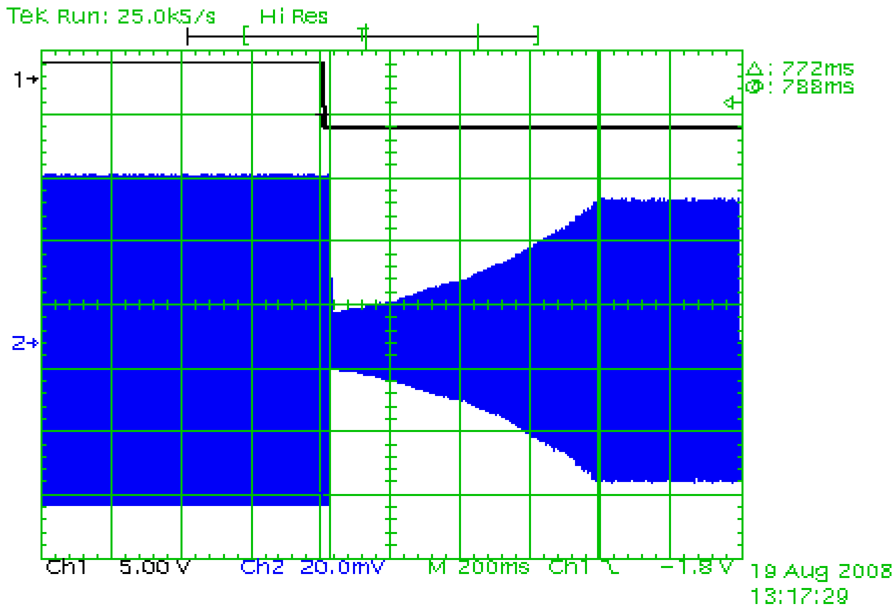
The K3 is set for 7.000 MHz, data mode, with 600 Hz bandwidth. AGC SLP and AGC THR are set at the default values, 12 and 5 respectively.

100% modulation corresponds to -70 dbm. The modulating square wave frequency is around 0.1 Hz for the AGC-S and 1 Hz for AGC-F. The SG-100 has a DC-coupled modulation input so it accepts low frequency modulation signals.

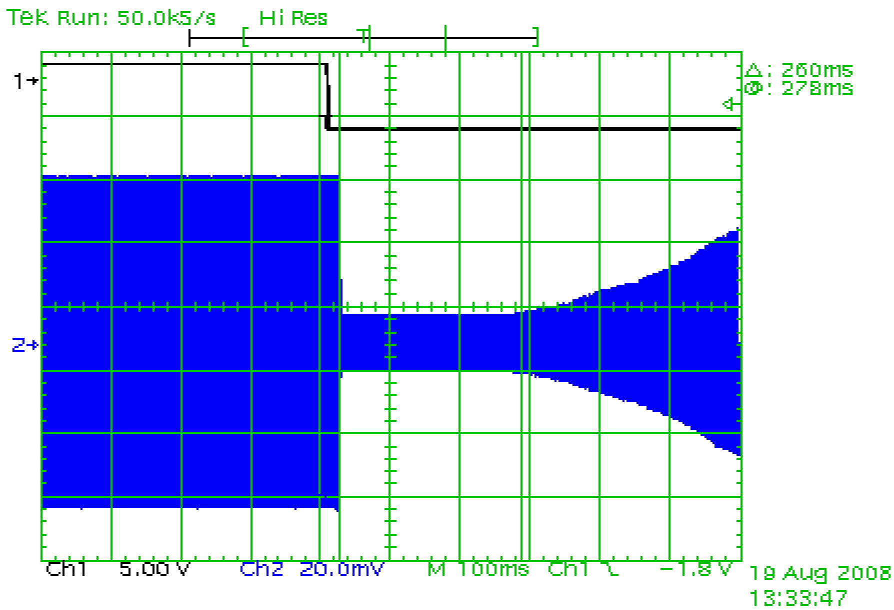


Sample images for the three parameters tested are below.

AGC-S with AGC HOLD = 0. The decay time is measured between the two cursors as 772 ms, measuring from change in signal level to AGC fully stabilized. This corresponds to AGC-S = 20. There's an argument, of course, that the measuring period should be based upon the 10% - 90% envelope. I'll stick with the 0 - 100% points as they are easier to measure.

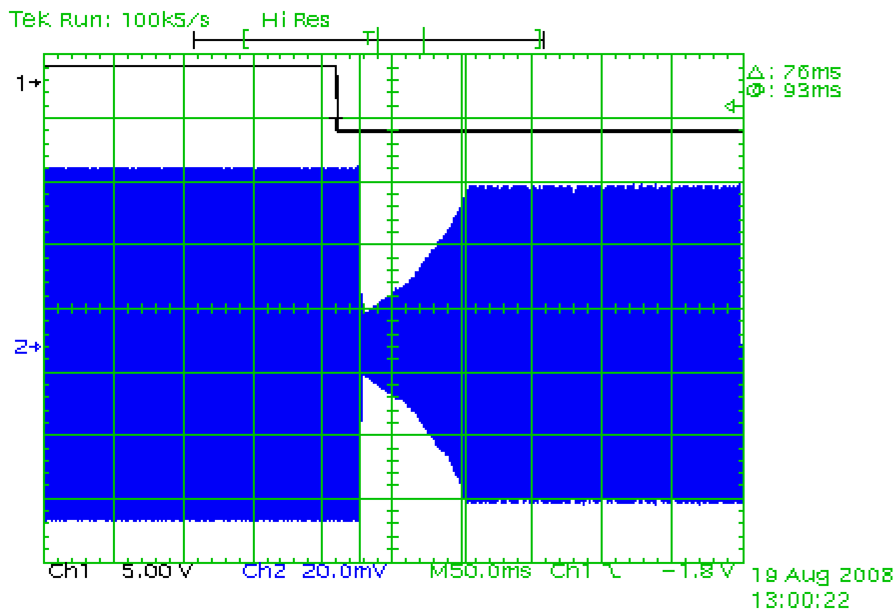


With AGC HOLD = 26. Note that for 260 ms the audio level remains constant. This is because the AGC HOLD function retains the last AGC gain setting (corresponding to 100% amplitude) for the defined hold period. (Hold period in ms = 10x the parameter value.) Since the K3 is not changing the receive path gain during the hold period, the 13 dB reduction in signal strength translates into a 13 dB reduction in audio output. After the hold period times out, the AGC begins to increase the gain and we see the audio output start to climb.



In AGC-F mode, the same interaction occurs, except the time scale is faster. In this case, AGC is fully applied 76 ms after the signal level drops. This corresponds to an AGC-F parameter setting of 200.

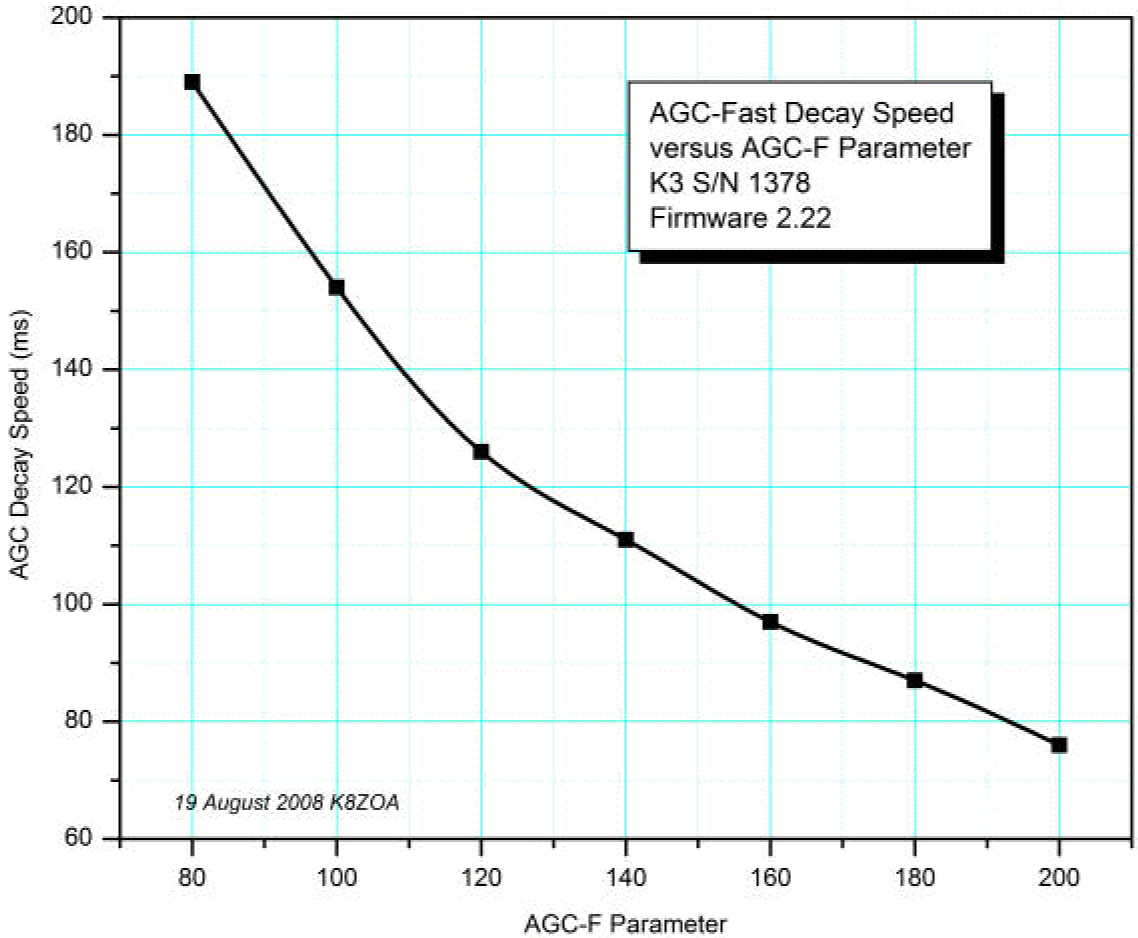
You may also note trace 1, which shows the modulation voltage applied to the SG-100 function generator. The time between trace 1's high-to-low transition represents the K3's DSP delay. It's approximately 18 ms for this particular mode and filter selection.



AGC-F Changes

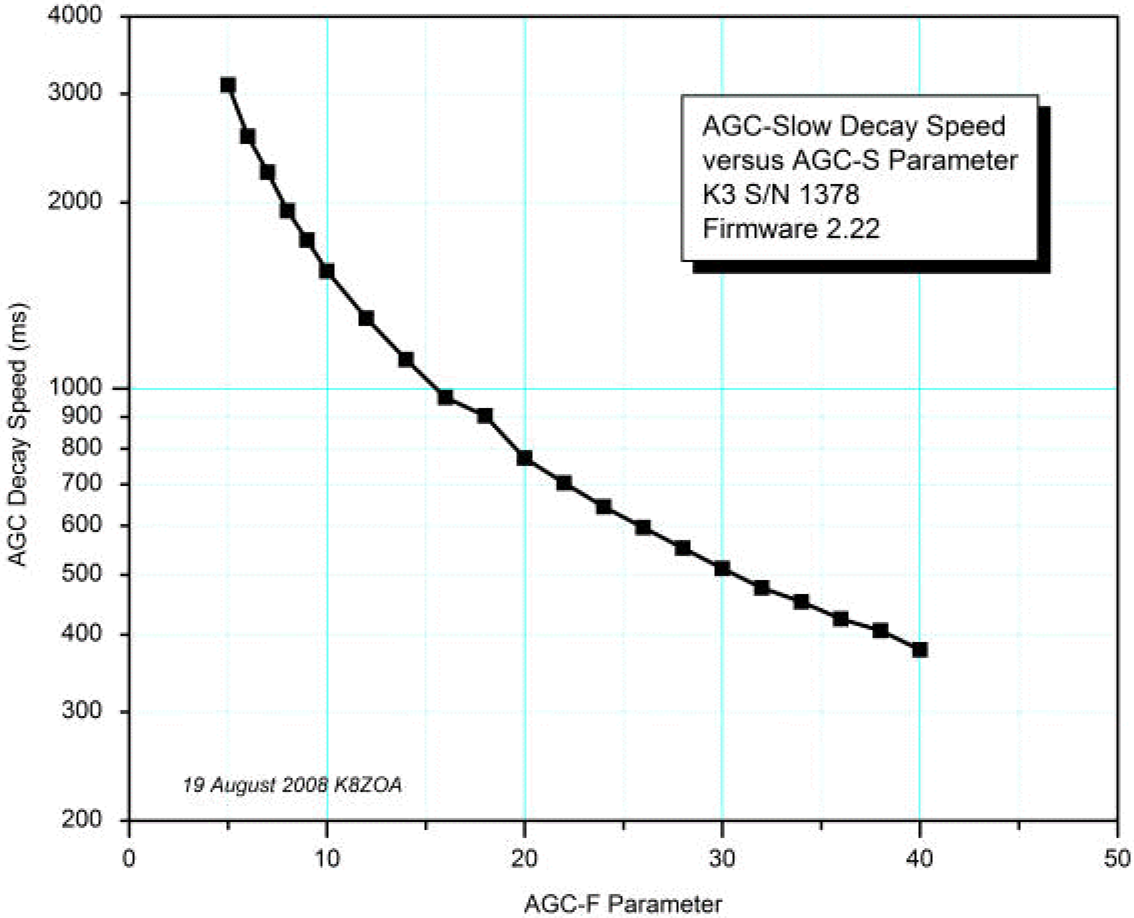
Rather than present a series of oscilloscope captures, I've plotted the measured AGC decay speed versus AGC-F parameter settings.

Note that the AGC Decay parameter does not set a specific time period, but rather defines the rate of change of gain with time, *i.e.,* the gain changes X dB/millisecond. Hence, the times presented in the plots below are valid only for the test signal with 13 dB signal reduction.



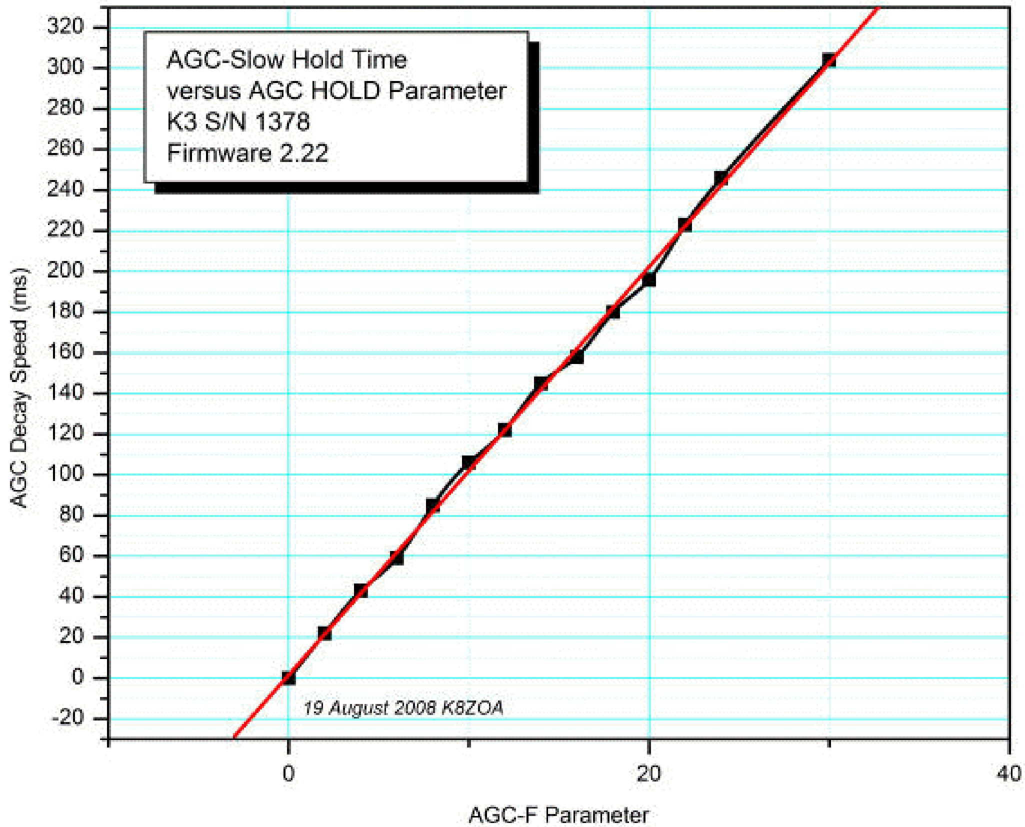
AGC-S Changes

Likewise, the plot below shows the AGC decay time associated with the range of permitted AGC-S parameters.



AGC HOLD Changes

The final plot in this series shows how the AGC Hold time varies with the AGC HOLD parameter. As the Owner's Manual states, the hold time in milliseconds equals the AGC HOLD parameter times 10. (The manual actually says the hold time equals the parameter. It's really 10x the parameter. In other words, the menu item is presented in terms of 10 ms units.)


AGC-Slow Hold Time
versus AGC HOLD Parameter
K3 S/N 1378
Firmware 2.22
19 August 2008 K8ZOA
AGC Decay Speed (ms)
AGC-F Parameter
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
0
20
40