Vertical Resolution Discussion

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QUALITY = INNOVATION = FORESIGHT

YOKOGAWA

Overview

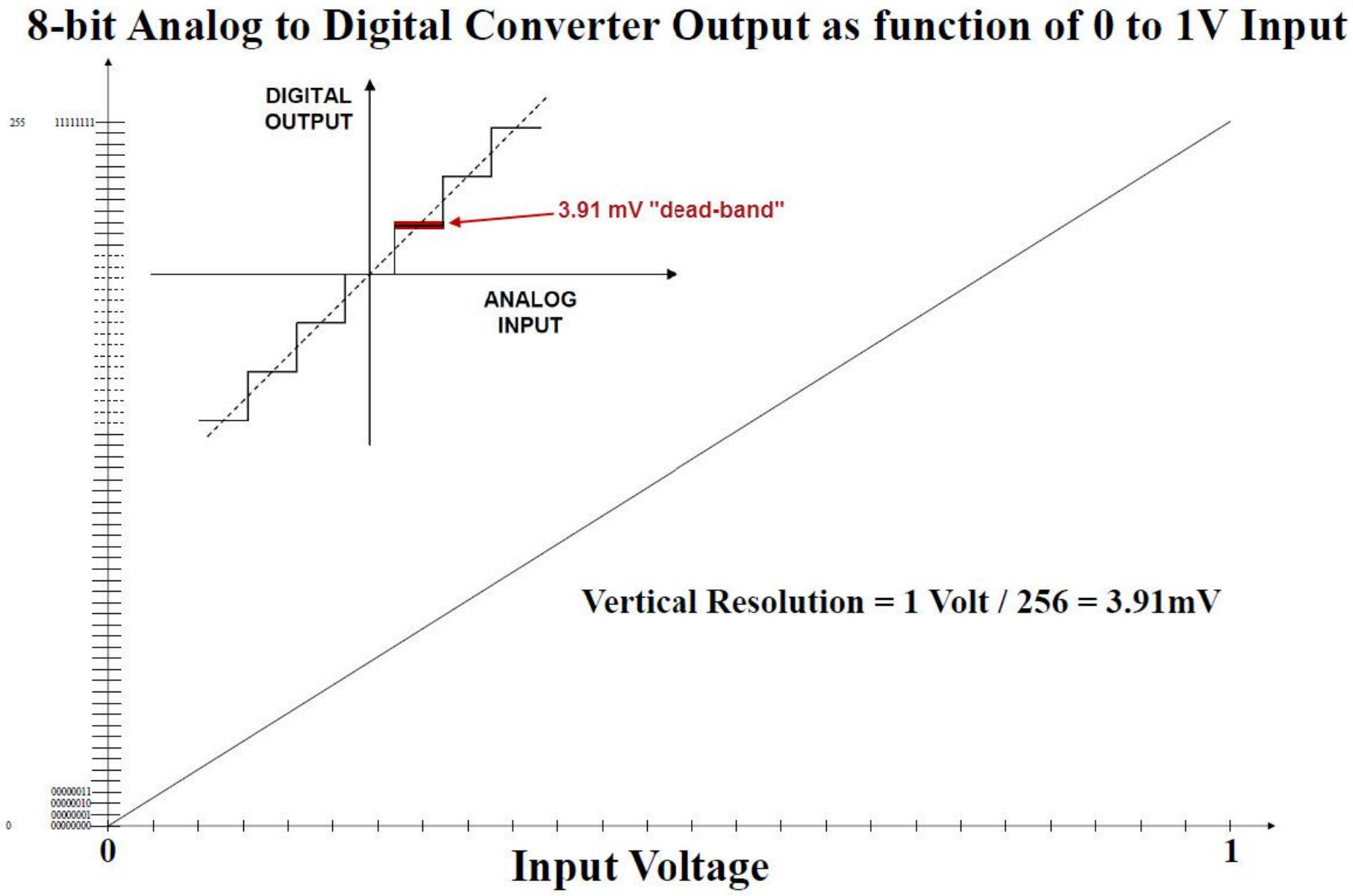
- **OBJECTIVE:** Provide *practical knowledge* and understanding of oscilloscope / recorder *vertical resolution*.

- Points covered will include:
  - What is vertical resolution?
  - Theoretical Examples
  - Real world examples
  - Specific Examples (Yokogawa)
  - System Resolution Calculation ScopeCorder Examplew
  - The ScopeCorder has 20 Divisions …
  - ScopeCorder Examples
  - Tips
  - High Resolution Mode
  - Appendix (time domain examples & FFT examples)

What is Resolution? What is Accuracy?

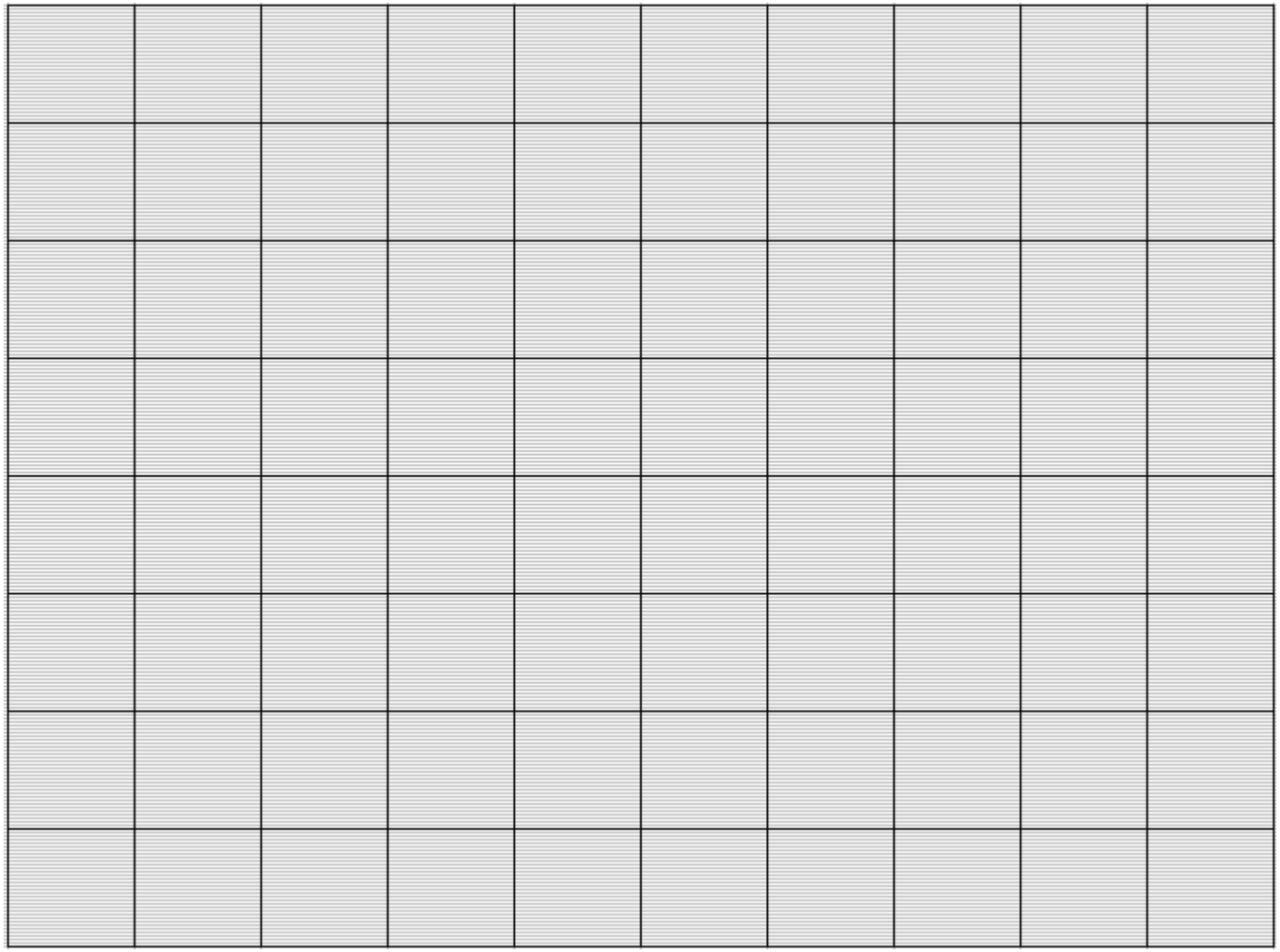
- Resolution - In measurement terms, the resolution of an instrument is the smallest increment that the instrument indicates or displays.
- Resolution is the ability to 'resolve' differences; that is, to draw a distinction between two things.
- Resolution can be expressed a few different ways. Common to data acquisition and oscilloscopes, it is usually expressed as the number of bits – it is the degree to which a change can be detected.
- Resolution is not accuracy.
- Accuracy – In measurement terms, is a measure of the magnitude of error between the result of a measurement and the true value of the parameter being measured.
- The classic 'Target Example' #1 poor resolution & good accuracy, #2 good resolution with poor accuracy, #3 good resolution and good accuracy:

What is *vertical-axis* resolution?



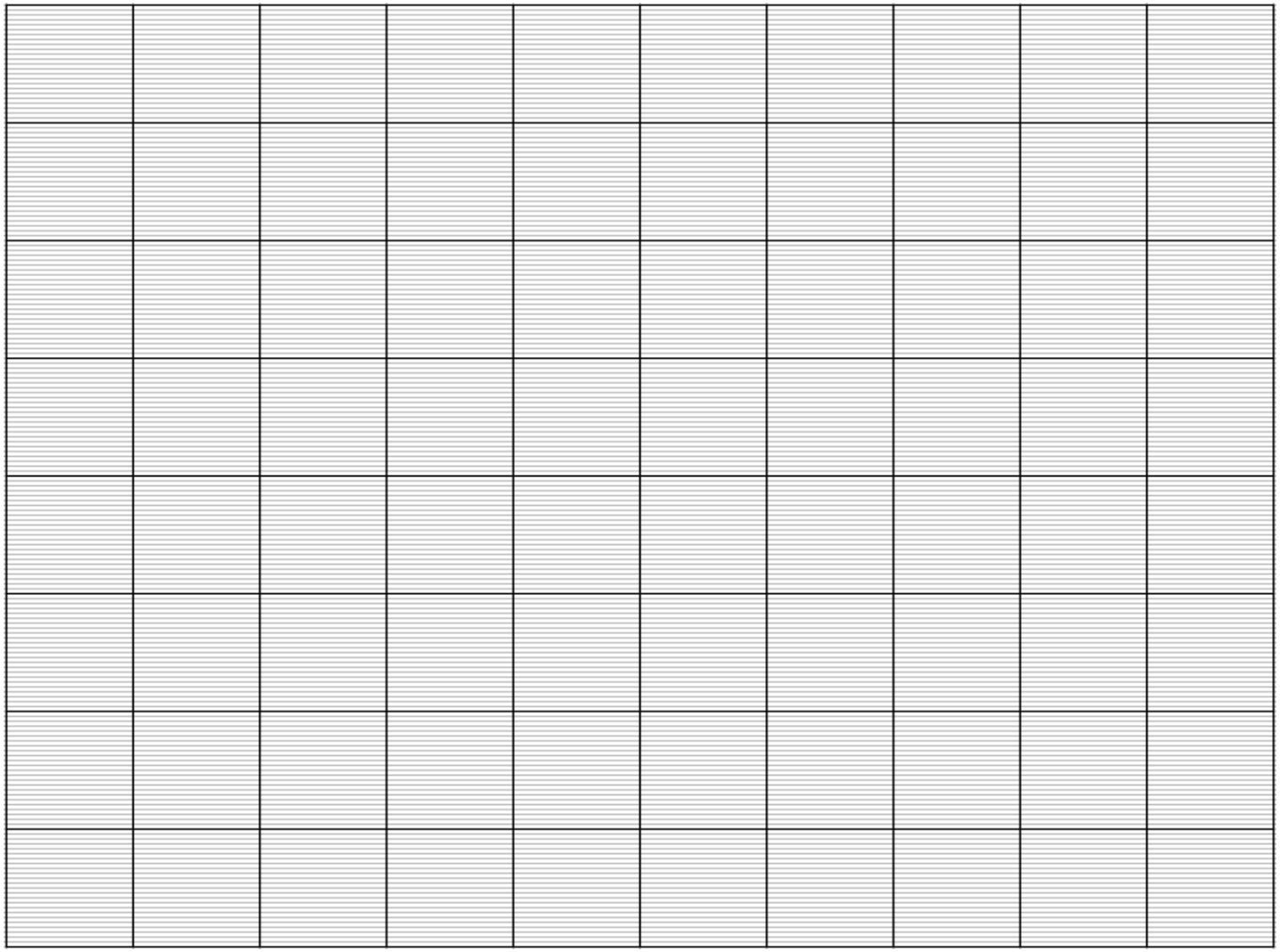
Example: 8-bit oscilloscope – *theoretical*

8 bits, 256 levels, 32 LSB/Div, where (32 X 8Div) = 192



Example: 8-bit oscilloscope – *real world*

7.6 bits, 192 levels, 24 LSB/Div, where (24 X 8Div) = 192



LSB/DIV as a Specification (guaranteed)

Model	Bits	Levels	LSB/Div (spec'd)	Screen Divisions	Total Divisions	Actual Levels
DL1600	8	256	24	8	10.58	253.92
SB5310	8	256	25	8	10.00	250.00
DL9000	8	256	25	8	10.00	250.00
DL7100	8	255	24	8	10.58	253.92
DL7400	8	255	24	8	10.58	253.92
DLM2000	8	255	25	8	10.10	252.50

Frequency characteristics (-3 dB attenuation when inputting a sinewave of amplitude ±3div)*1*2

		DLM202x	DLM203x	DLM205x
1 MΩ(when using passive probe)				
	100 mV to 100 V/div	DC to 200 MHz	DC to 350 MHz	DC to 500 MHz
	20 mV to 50 mV/div	DC to 150 MHz	DC to 300 MHz	DC to 400 MHz
50 Ω				
	10 mV to 10 V/div	DC to 200 MHz	DC to 350 MHz	DC to 500 MHz
	2 mV to 5 mV/div	DC to 150 MHz	DC to 300 MHz	DC to 400 MHz

Isolation between channels: -34 dB@ analog bandwidth (typical value)

Residual noise level*3: The larger of 0.4 mV rms or 0.05 div rms (typical value)

A/D resolution: 8bit (25LSB/div)
Max. 12 bit (in High Resolution mode)

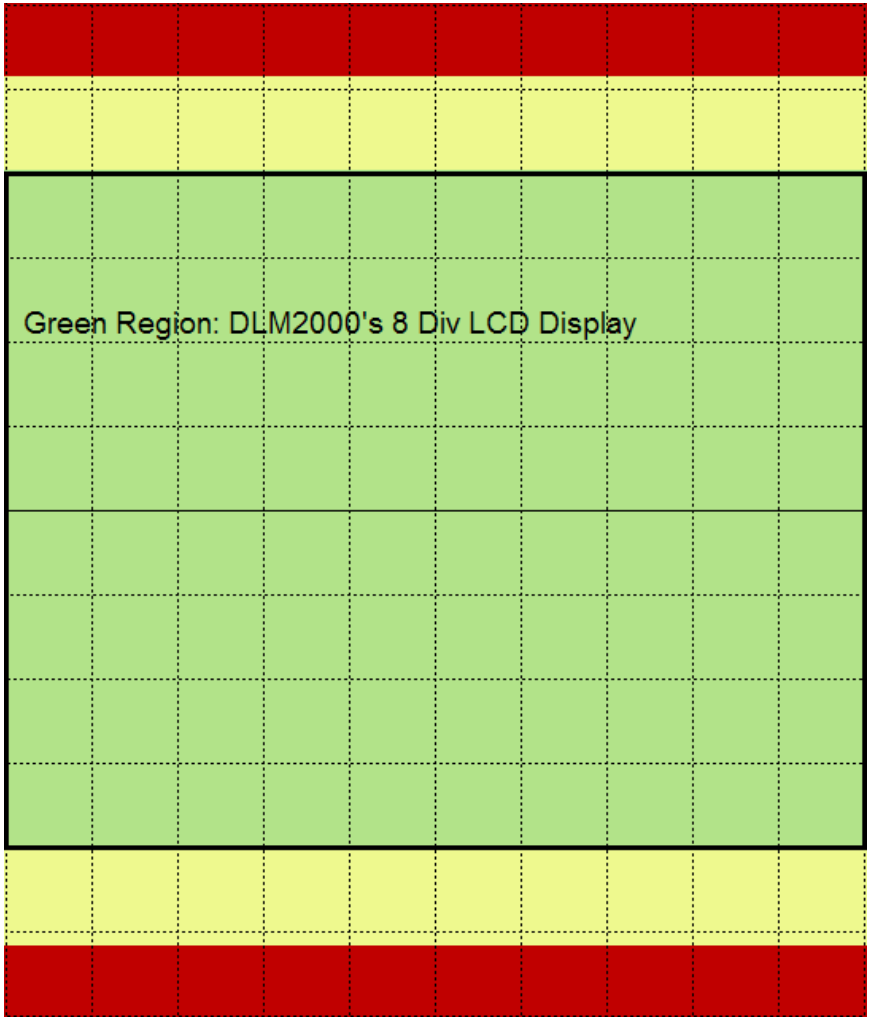
Bandwidth limit: FULL, 200 MHz, 100MHz, 20 MHz, 10 MHz, 5 MHz, 2 MHz, 1 MHz, 500 kHz, 250 kHz, 125 kHz, 62.5 kHz, 32 kHz, 16 kHz, 8 kHz (can be set for each channel)

DLM2000 - 10.5 Divisions

There is ample space to utilize most all of the A/D Converter – by using the *fine* scale Volts/Div. Signal will clip in the red region.

256LSB/10.15DIV = 25 LSB/Div

At 25 LSB/Div, 8 Div X 25 LSB/Div = 7.6 bits
And staying on-screen with your waveform

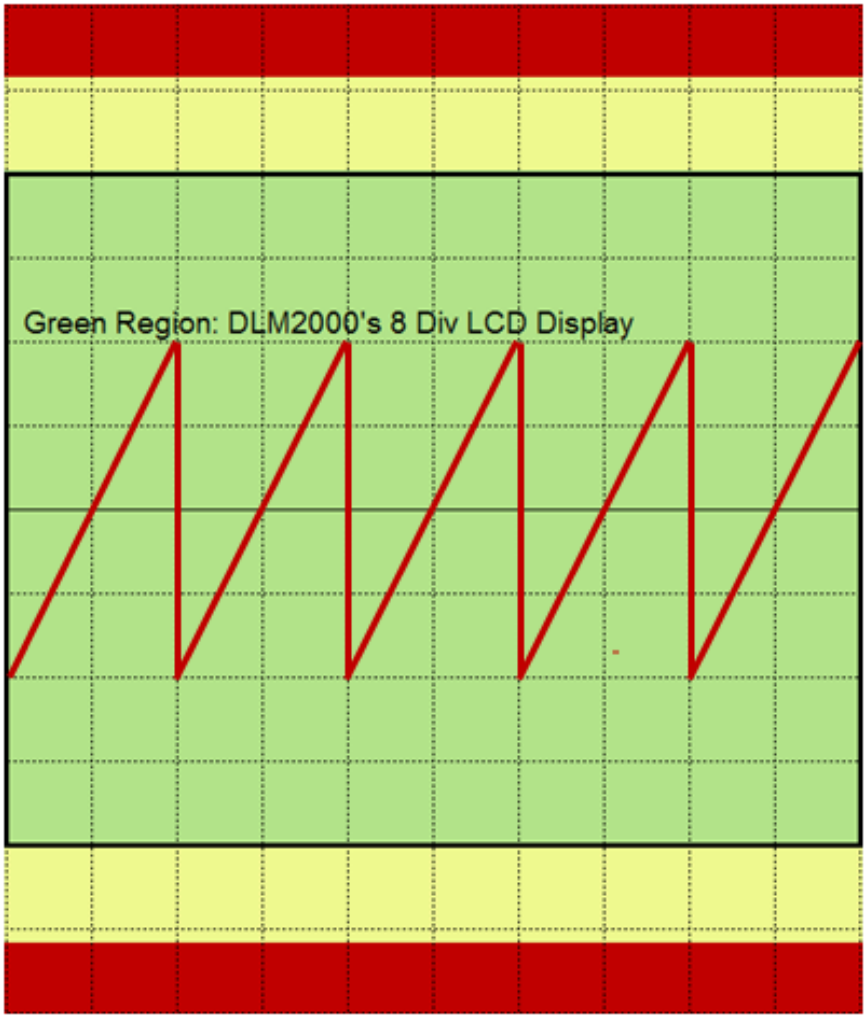


Example: Using 4 Div on the DLM2000

DLM2000 set to 1 V/Div. and the Input Waveform is 4Vpp.
DLM2000 is 25 LSB/Div guaranteed specification.

Vertical Resolution
= V/Div / LSB/DIV
= 1 / 25
= 40mV.

ADC Count
= Log_2(4Vpp / 8Vfull-scale) * 25 LSB/DIV*8 DIV
= Log_2(4/8)*(200)
= Log_2(100)
= 6.6 bits
Each bit halves the resolution (improves)

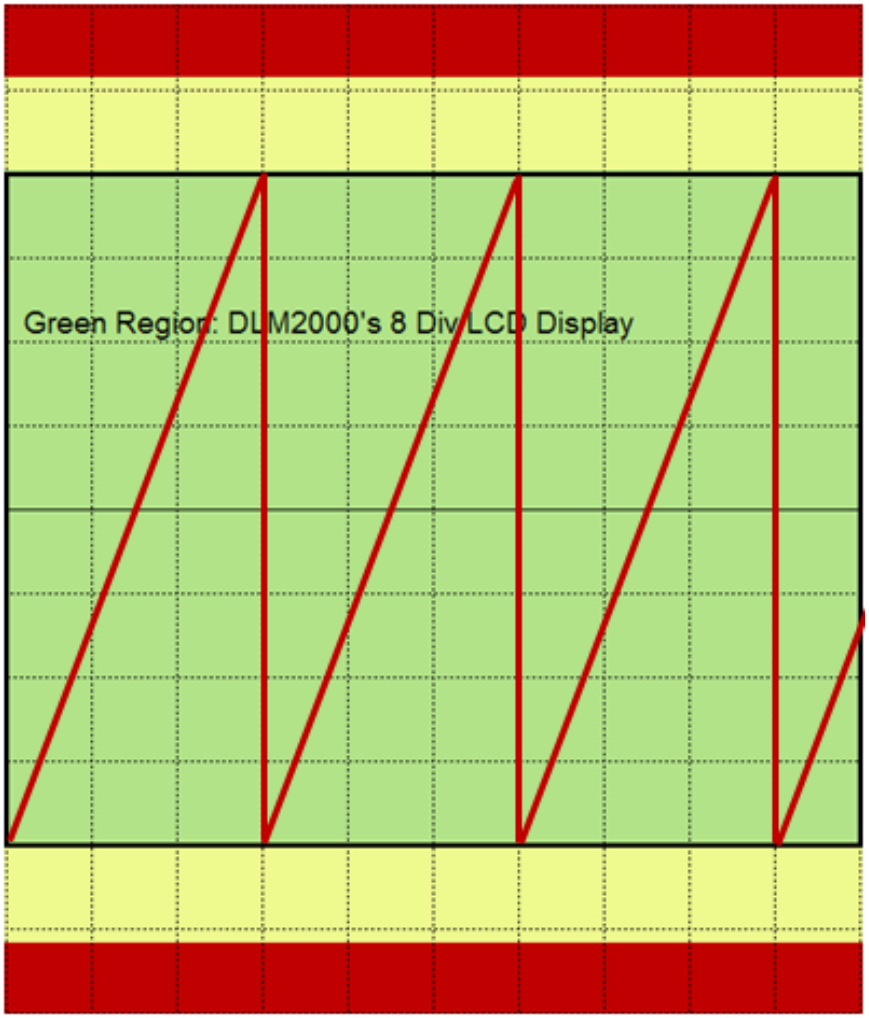


Example: Using 8 Div on the DLM2000

DLM2000 set to 0.5 V/Div. and the Input Waveform is 4Vpp.
DLM2000 is 25 LSB/Div guaranteed specification.

Vertical Resolution
= V/Div / LSB/DIV
= 0.5 / 25
= 20mV.

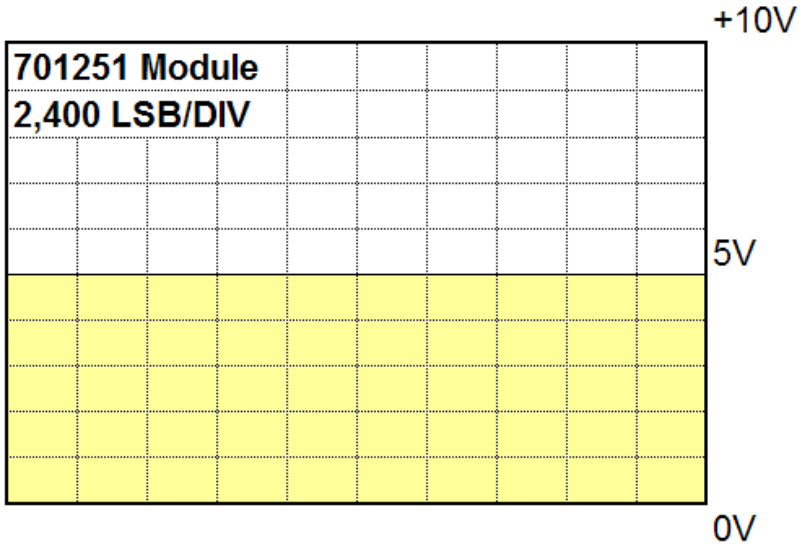
ADC Count
= Log_2(4Vpp / 4Vfull-scale) * 25 LSB/DIV*8 DIV
= Log_2(1)*(200)
= Log_2(200)
= 7.6 bits
Each bit halves the resolution (improves)
So, keep the waveform near or at full-scale.



System Resolution Calculation #1

Uni-Polar Example of a Scale with a 701251 16-bit Module (2,400 LSB/DIV)

Scale
0 to 5V full-scale w/ 100 LB.



ScopeCorder w/ 701251 Module
2,400 LSB/Div
10 Divisions = 0V to +10V = 10V Span

$$\text{Resolution} = \frac{100\ \text{LB.}}{5\text{V}} \times \frac{10\text{V}}{(2{,}400\ \text{LSB/Div} \times 10\ \text{Div})} = 0.0083\ \text{Lbs.}$$

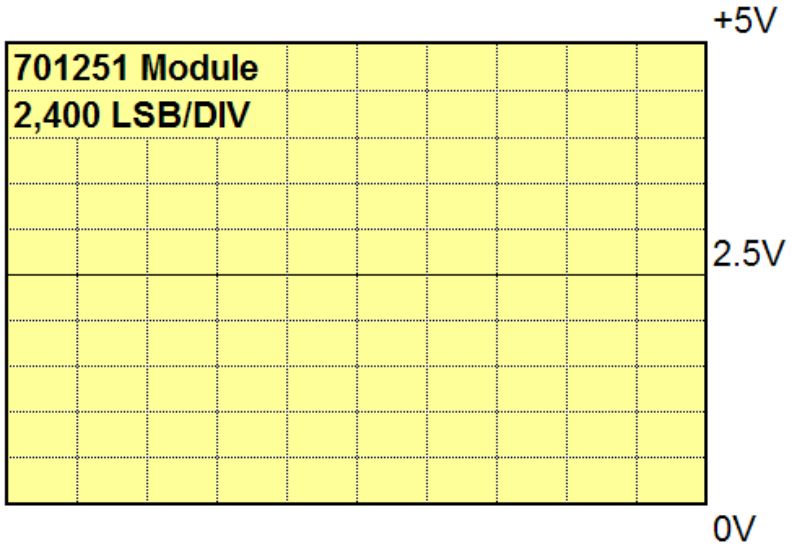
To get the system resolution, simply multiply the resolution of the SCALE by the resolution of the RECORDER:

System Resolution Calculation #2

Uni-Polar Example of a Scale with a 701251 16-bit Module (2,400 LSB/DIV)

Scale

0 to 5V full-scale w/ 100 LB.



ScopeCorder w/ 701251 Module

2,400 LSB/Div

10 Divisions = 0V to +5V = 5V Span

$$\text{Resolution} = \frac{100\ \text{LB.}}{5\text{V}} \times \frac{5\text{V}}{(2{,}400\ \text{LSB/Div} \times 10\ \text{Div})} = 0.0042\ \text{Lbs.}$$

To get the system resolution, simply multiply the resolution of the SCALE by the resolution of the RECORDER:

The ScopeCorder has 20 Divisions …

10 Divisions are on-screen
20 Divisions are specified
25 Divisions in reality – but not specified.
Those extra 5 Divisions should be regarded as “headroom”
We can do even better on resolution, examples follow …

High-Voltage 100 kS/s, 16-Bit Isolation Module (with RMS) (701260) Specifications

Item	Specifications
Standard operating conditions	Temperature: 23°C±5°C Humidity: 20% to 80%RH After a 30-minute warm-up and after calibration
Effective measurement range	20 div (±10 div around 0 V, display range: 10 div, when Variable is OFF)
Number of input channels	2
Input coupling	AC, DC, GND, AC-RMS, and DC-RMS
Maximum sample rate	100 kS/s
Input format	Isolated unbalanced

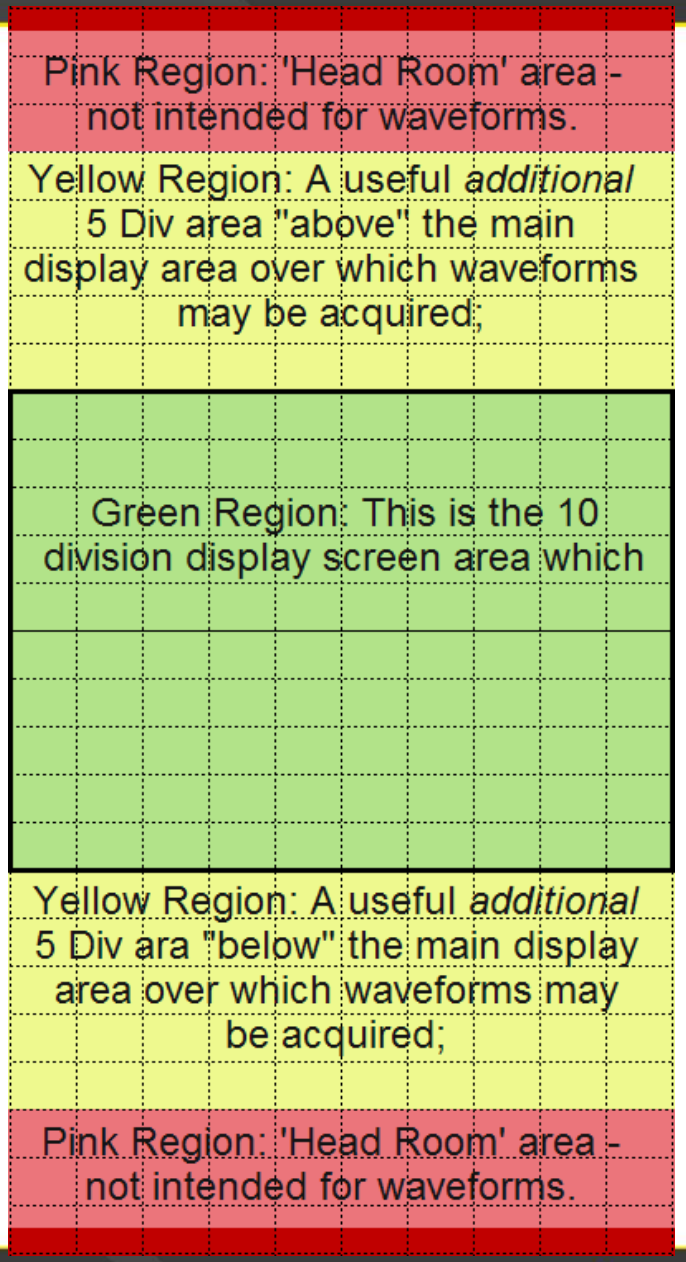
ScopeCorder – Visualize 20 Divisions

- Green Region – This is the LCD, 10 Div
- Yellow Region – 5 additional divisions, both above and below the LCD's 10 divisions, for a total of 20 divisions.
- Pink Region – some "head room".
- Red Region – Waveform will "clip" and cannot enter the red region.

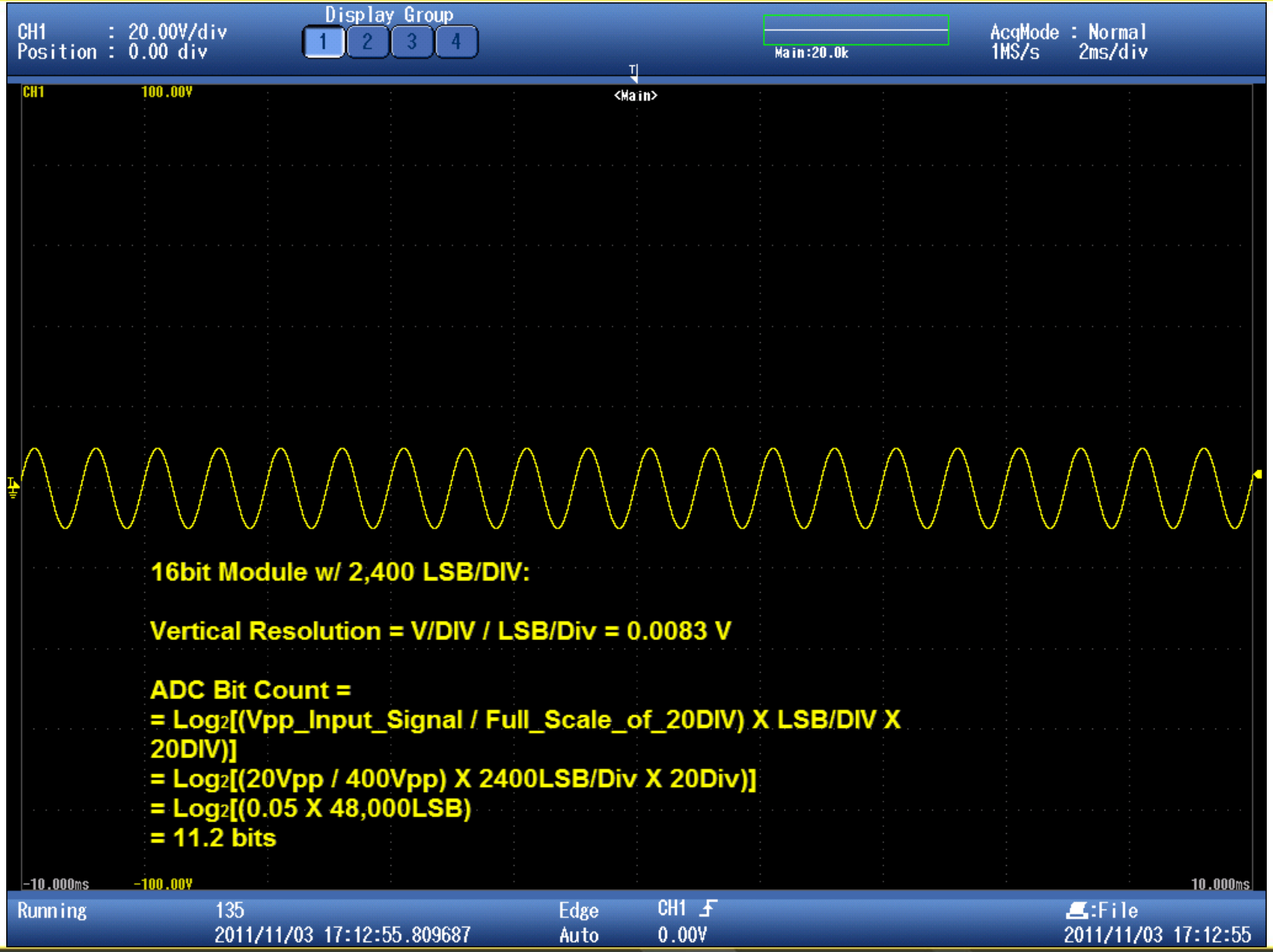
This information describes the DL750/DL750P/SL1400 – not the DL708 / DL716, or any other.

The DL708 / DL716 did not offer this feature.

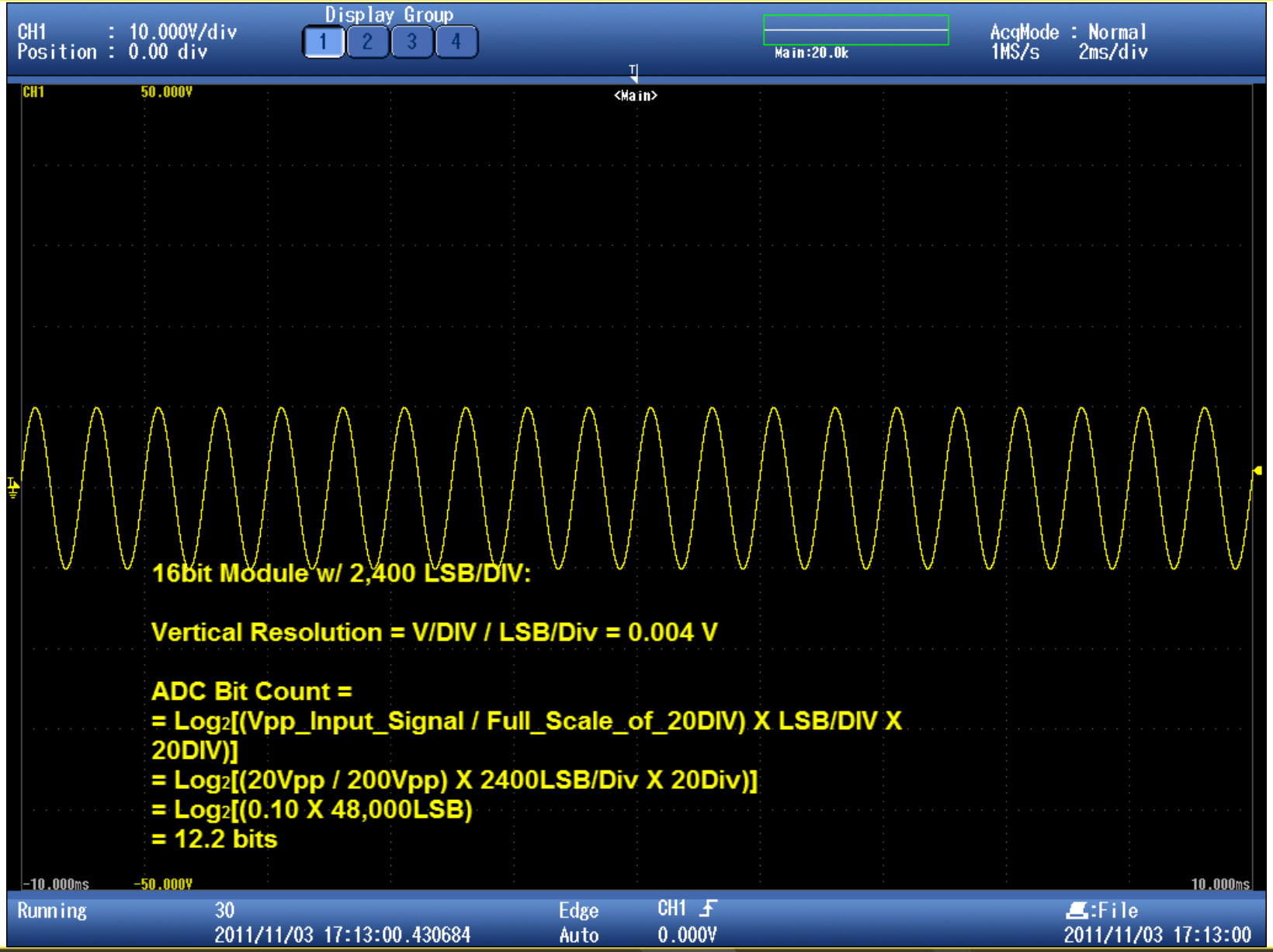
These 20 divisions can be utilized to best advantage and to gain one more bit of resolution (halving the resolution).



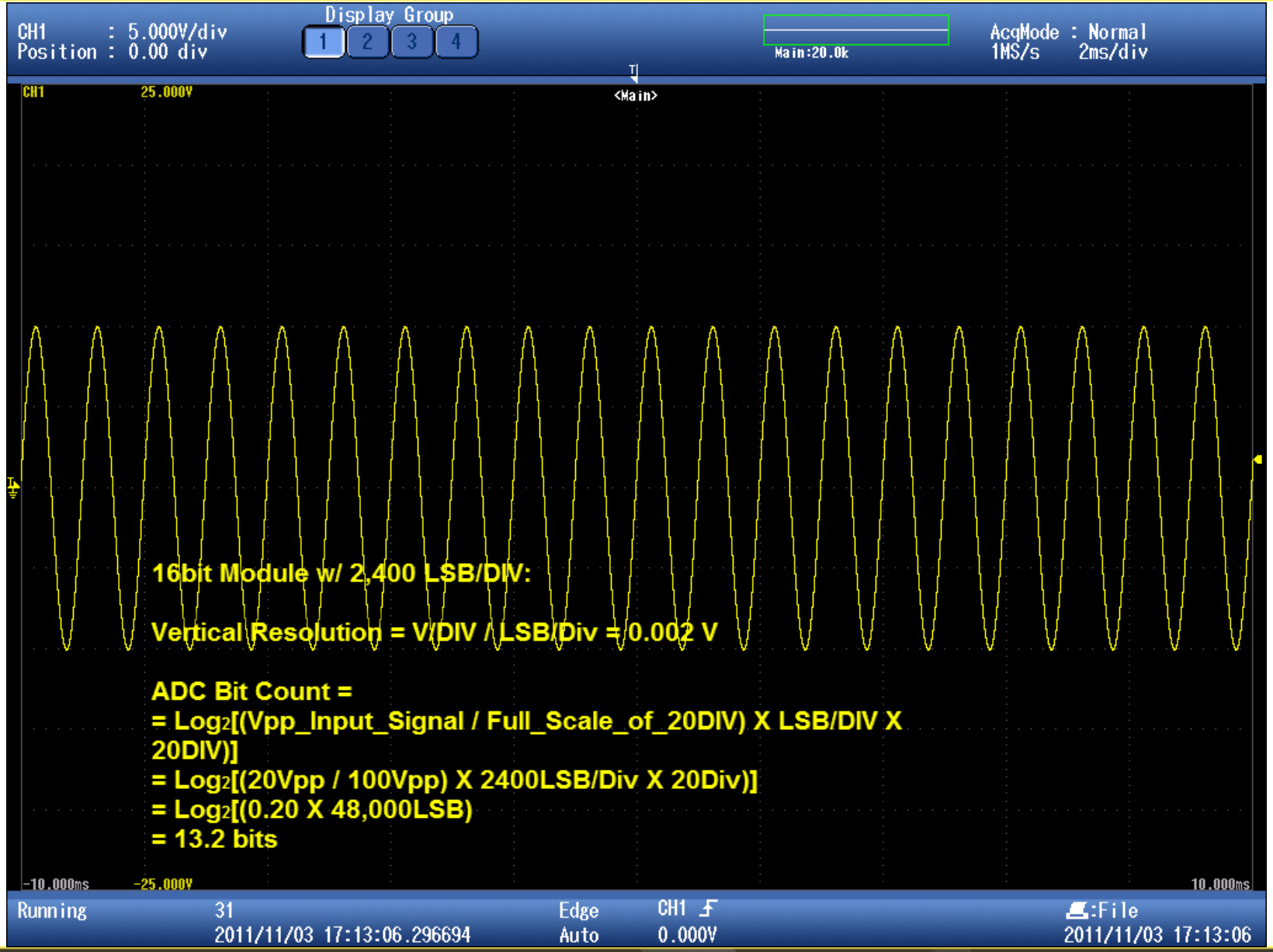
ScopeCorder Vertical Resolution



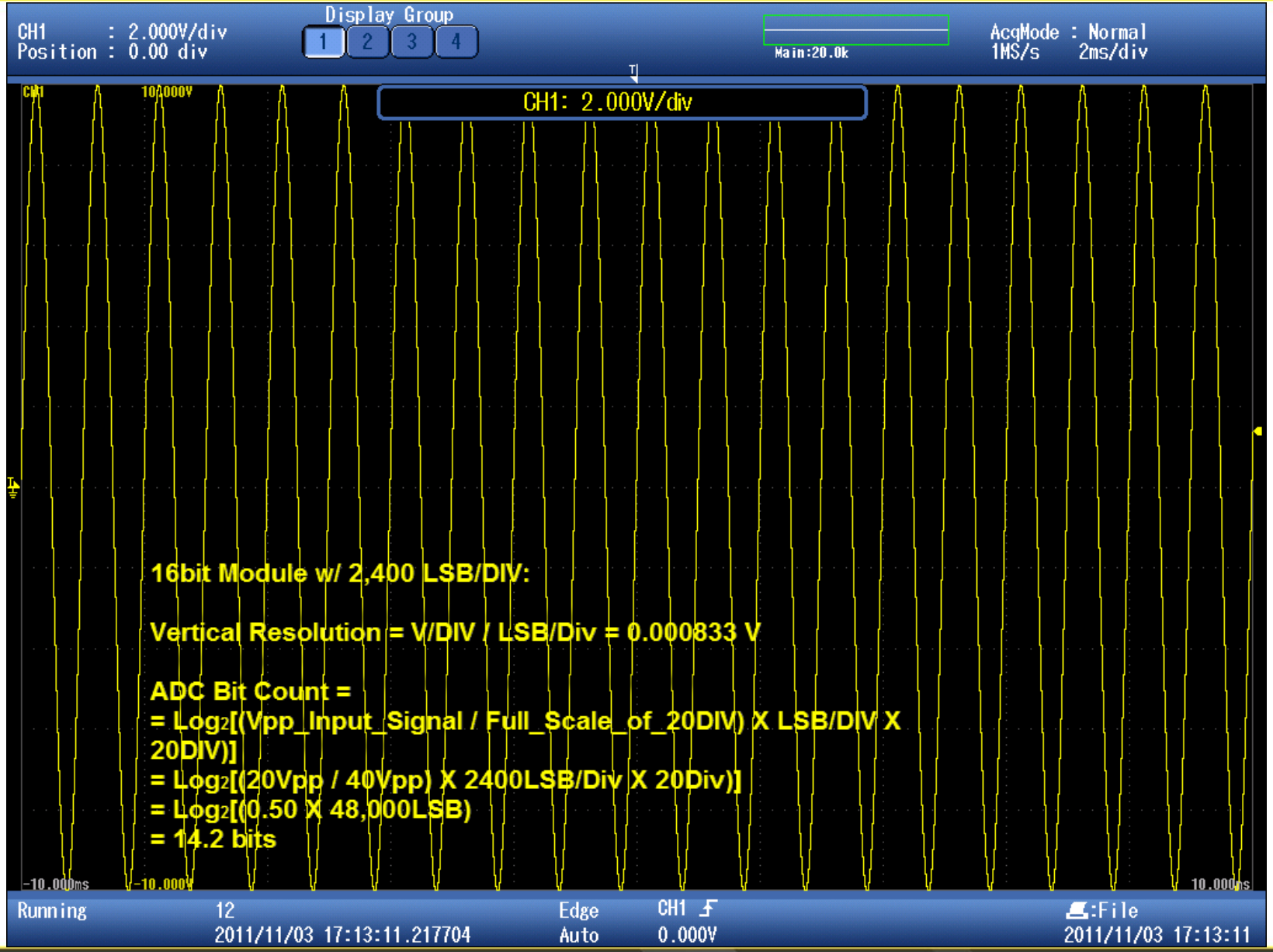
ScopeCorder Vertical Resolution



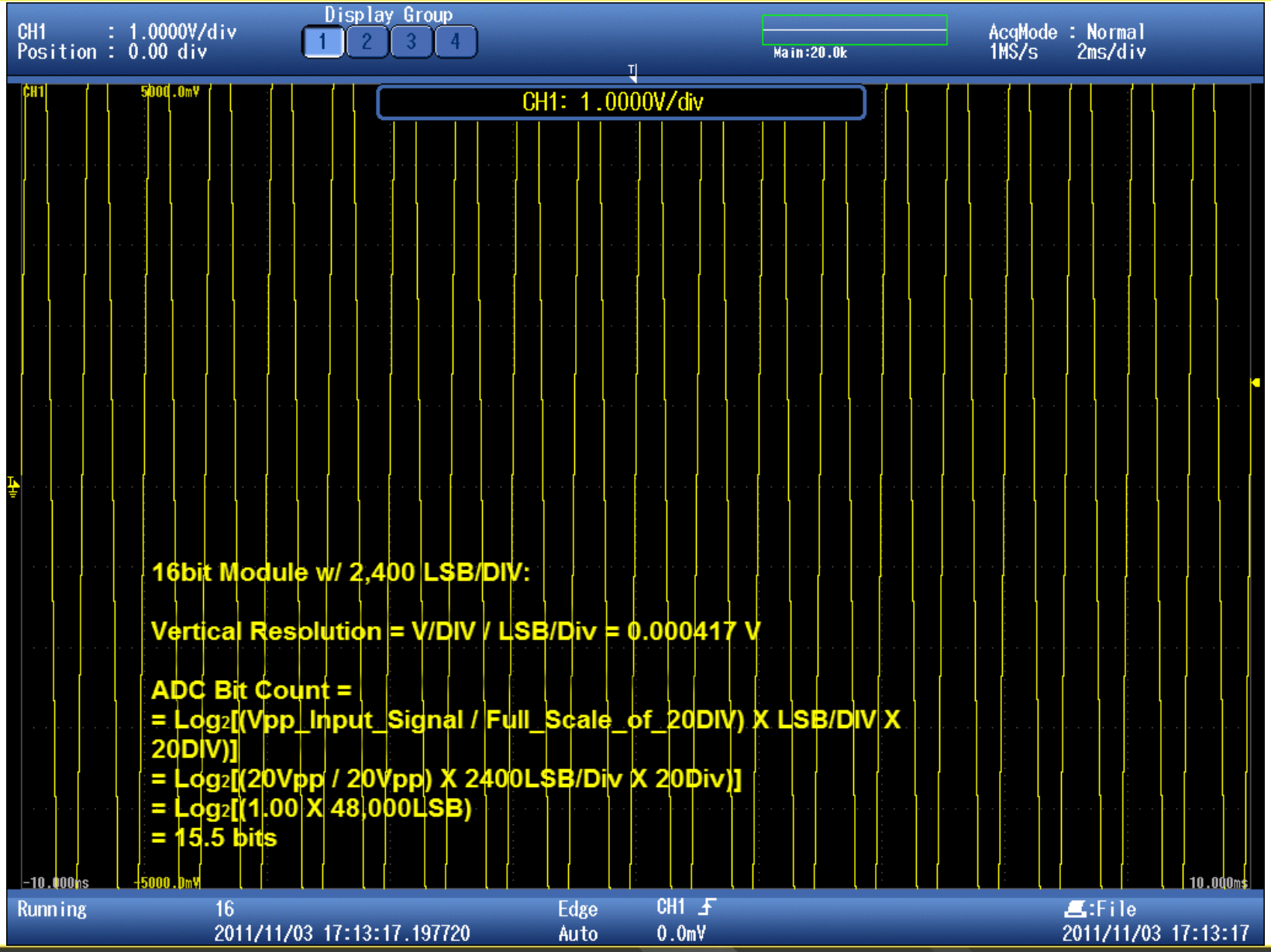
ScopeCorder Vertical Resolution



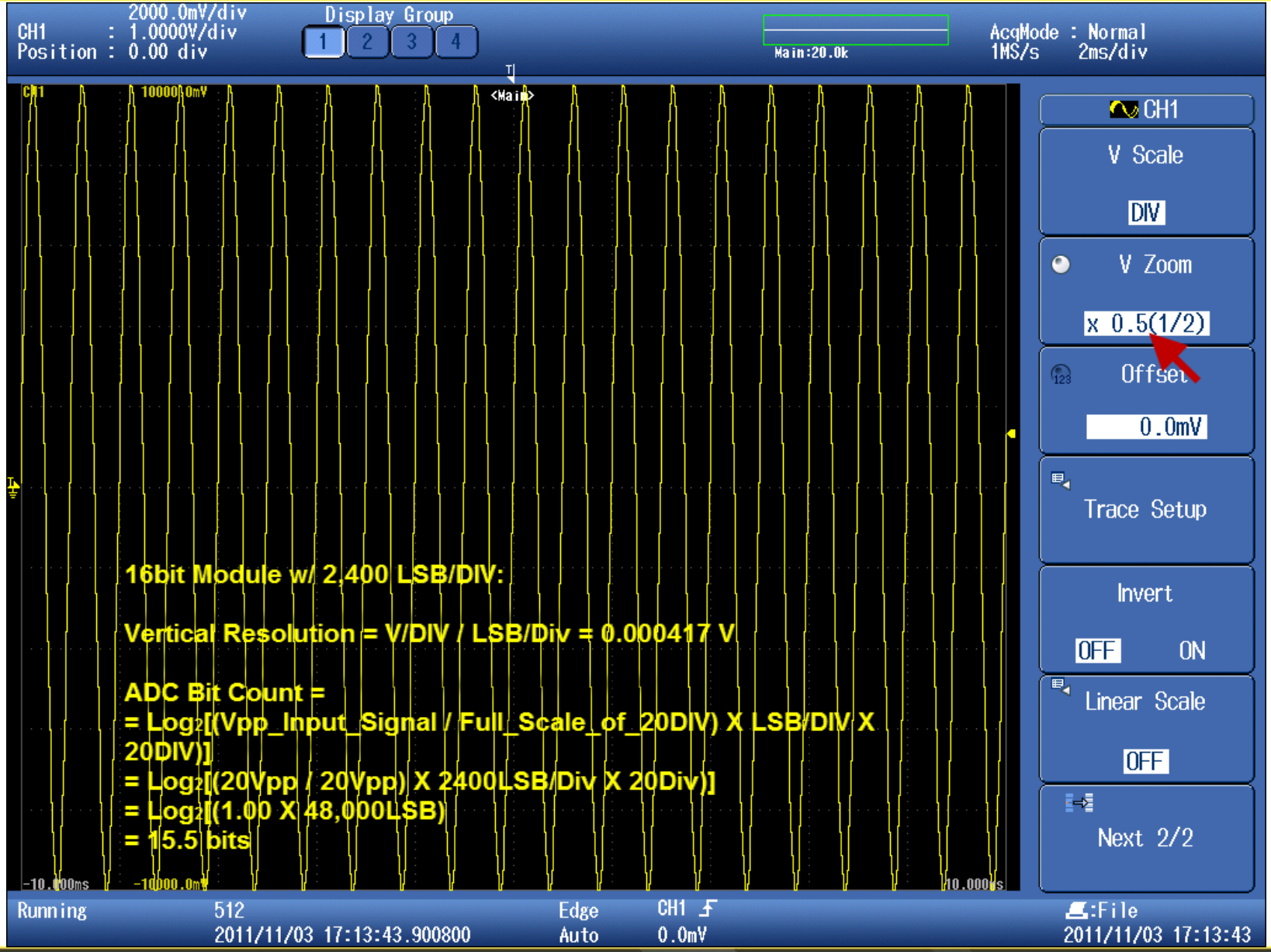
ScopeCorder Vertical Resolution



ScopeCorder Vertical Resolution



ScopeCorder Vertical Resolution



Tips to Optimize Resolution

Tip 1: Use the instrument at or near full-scale.

Tip 2: Use the 'FINE' scale on your instrument's input amplifier.

Tip 3: When measuring small signals, use 1:1 for best SNR.

Tip 4: Calculate and know your ADC count (this is not 'ENOB'), example follows:

You can double your vertical resolution for each bit of improvement to your ADC Count.

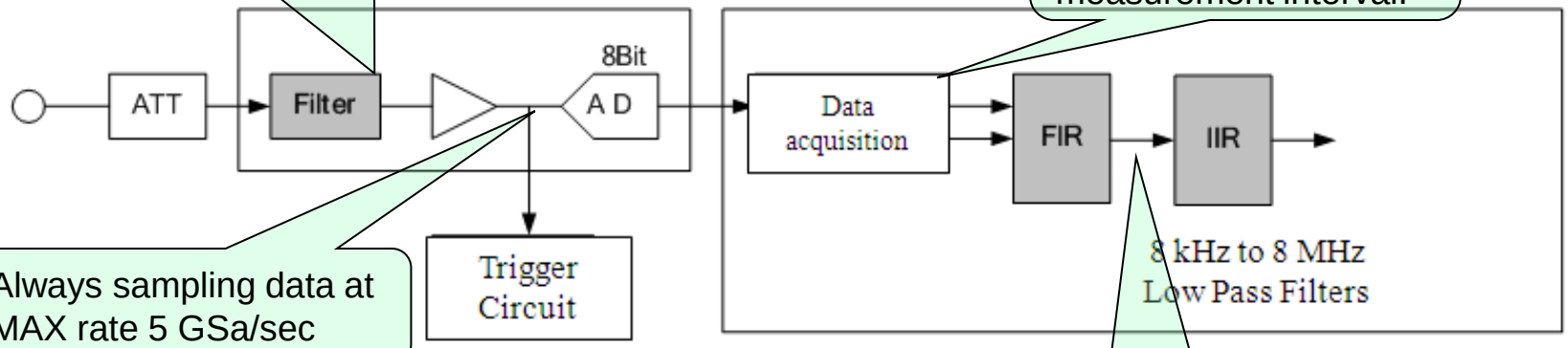
Hi-Resolution Mode

1. These scopes feature Hi-Res mode: DL1600, DL9000, SB5000, DL6000, DLM6000, DLM2000.
2. Hi-Res mode is an industry-standard sequential algorithim:
   Pre-Filter → Over-Sample → Average → Data-Thinning → Filter
3. Hi-Res mode removes HF noise and increases vertical resolution.
4. Hi-Res improves the resolution of small signals in the presence of large signals.
5. Hi-Res increases Dynamic Range; FFTs are improved.
6. Theoretical limit is 13-bits; in-practice, 12-bits; select from 9, 10, 11, 12.
7. Hi-Res DATA is saved as 16-bit format.
8. The record length is reduced: 6.25 Mpts is reduced to 2.5 Mpts on 6000/9000.
9. If the record length is maxed-out, then the displayed sample-rate is halved.
10. The ADC at the front-end is *still running at full-speed*.
11. When Hi-Res is 'ON', the maximum bandwidth of any channel is 200 MHz.
12. Yokogawa's Hi-Res mode compares favorably with the industry:
    The Hi-Res mode works at all Time/Div settings (unlike Tek's Hi-Res mode).
13. It is easy to use; just turn it ON and select a filter. Resolution is increased; Accuracy is un-changed; Hi-Res measurements are *repeatable*.
14. The DLM2000 Hi-Res, *combined with interleave*, can provide -52 dB of noise reduction! As you can see, Yokogawa continues to improve its products.

Hi-Resolution Mode

200MHz and 20MHz filters are analog filters.

Data is thinned out according to the measurement interval.



Always sampling data at MAX rate 5 GSa/sec

Bandwidth	DL9200	
Bandwidth	Noise Suppression	Resolution
200 MHz	1/(2.0)	9.0 bits
20 MHz	1/(4.0)	10.0 bits
8 MHz	1/(14.97)	11.9 bits
4 MHz	1/(21.91)	12.5 --> 12.0 bits
2 MHz	1/(31.5)	13.0 --> 12.0 bits
1 MHz	1/(44.9)	13.5 --> 12.0 bits
500 kHz and	1/(63.75)	14.0 --> 12.0 bits

---> 12 bit : Resolution reduction is due to rounding-error of IIR calculation.

The 8MHz to 8 kHz filters are digital hardware ASIC filters.

Digital filters are composed of FIR and IIR.

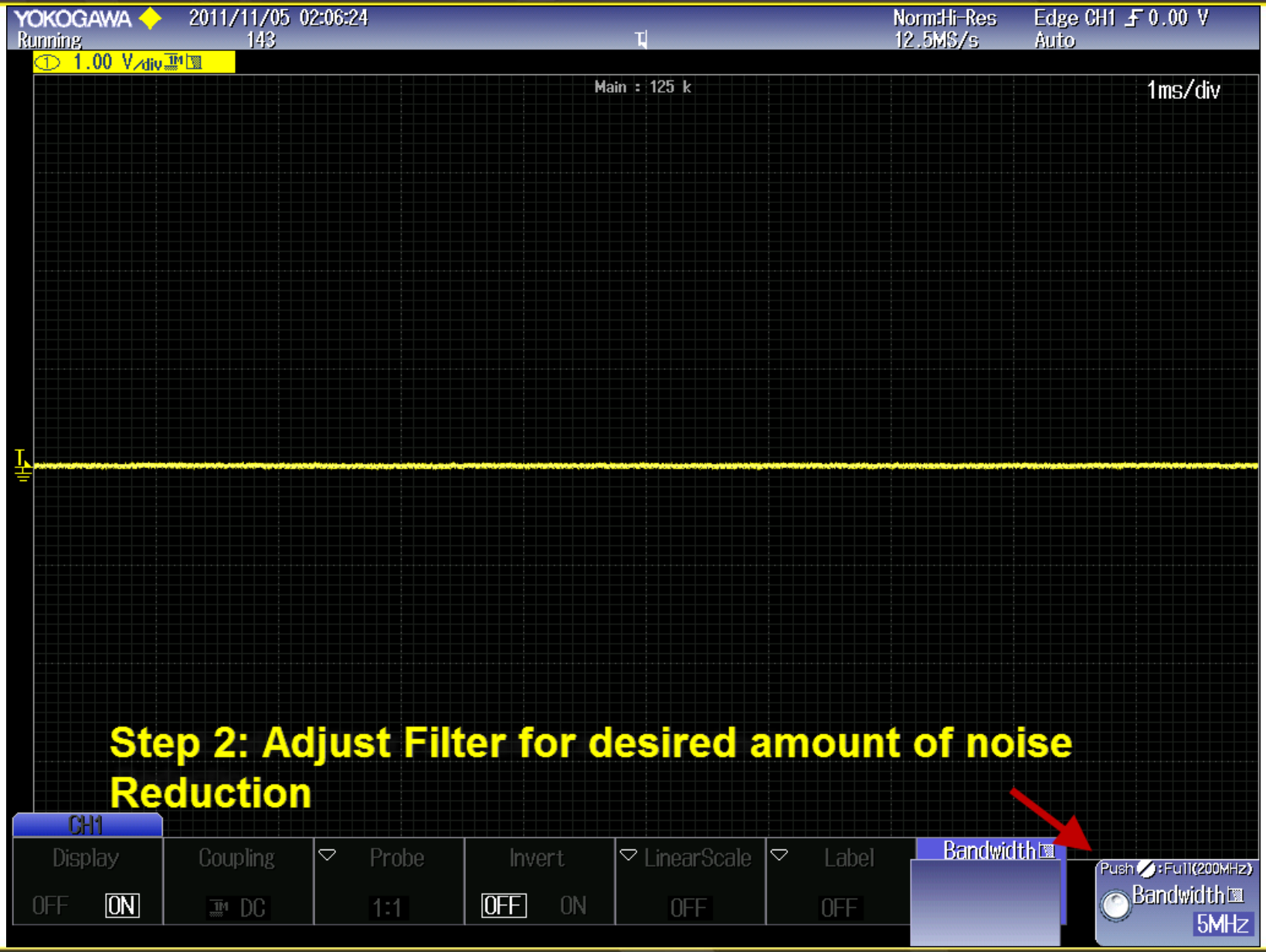
20*LOG(1/63.75) = -36 dB

Hi-Resolution Mode – DLM2000

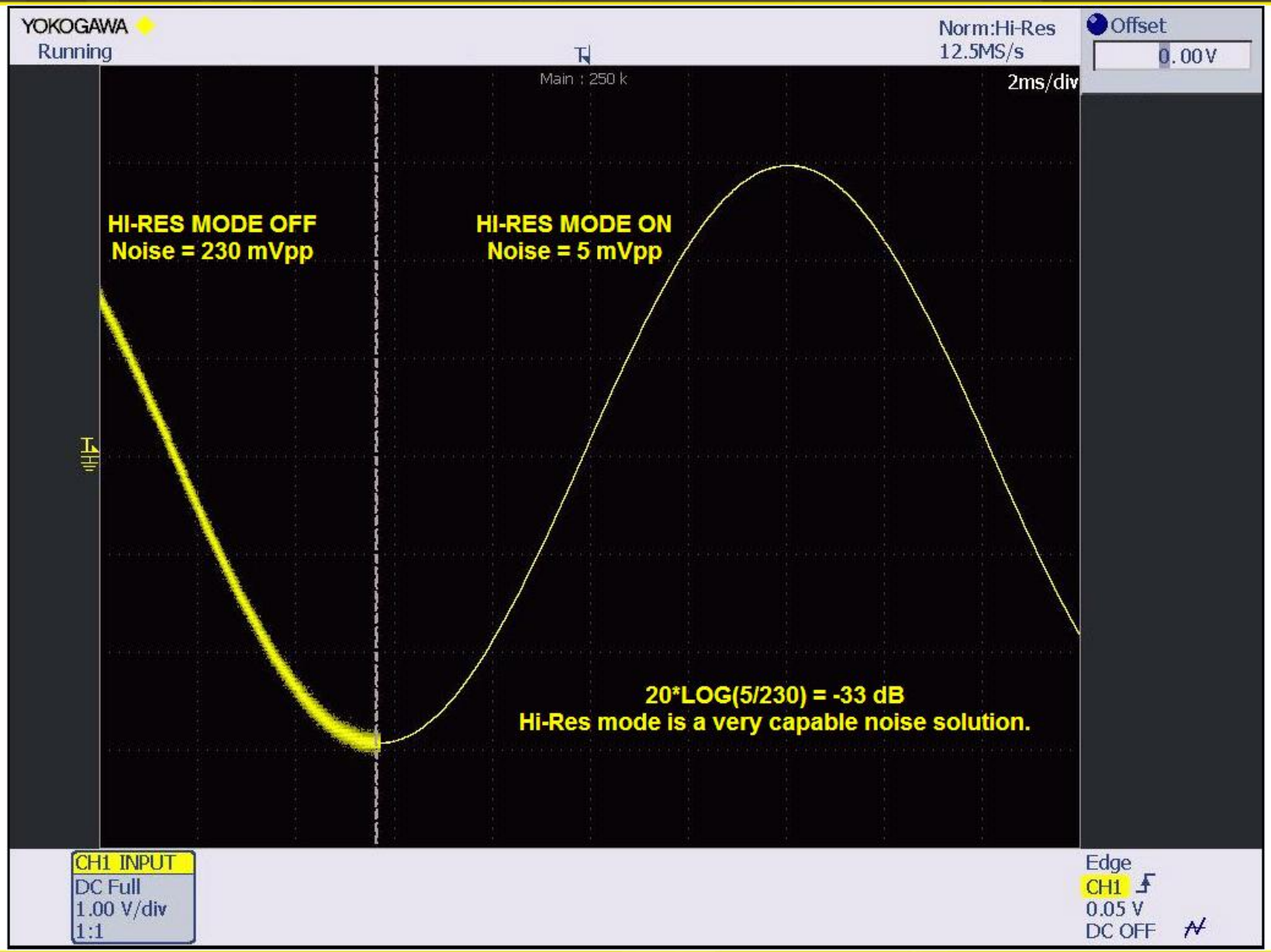
DLM2054	Interleave-OFF		Interleave=ON	
Bandwidth	Noise Suppression	Resolution	Noise Suppression	Resolution
200 MHz	1/(1.6)	8.5 bits	1/(2.0)	9.0 bits
100 MHz	1/(2.4)	9.3 bits	1/(3.4)	9.8 bits
20 MHz	1/(4.9)	10.3 bits	1/(6.9)	10.8 bits
10 MHz	1/(6.9)	10.8 bits	1/(9.8)	11.3 bits
5 MHz	1/(10.6)	11.4 bits	1/(15.0)	11.9 bits
2 MHz	1/(15.5)	12.0 bits	1/(21.9)	12.5 --> 12.0 bits
1 MHz	1/(22.3)	12.5 --> 12.0 bits	1/(31.5)	13.0 --> 12.0 bits
500 kHz	1/(31.7)	13.0 --> 12.0 bits	1/(44.9)	13.5 --> 12.0 bits
250 kHz	1/(45.1)	13.5 --> 12.0 bits	1/(63.7)	14.0 --> 12.0 bits
125 kHz	1/(63.9)	14.0 --> 12.0 bits	1/(90.3)	14.5 --> 12.0 bits
62.5 kHz	1/(90.4)	14.5 --> 12.0 bits	1/(127.9)	15.0 --> 12.0 bits
32 kHz	1/(127.9)	15.0 --> 12.0 bits	1/(180.9)	15.5 --> 12.0 bits
16 kHz	1/(181.0)	15.5 --> 12.0 bits	1/(255.9)	16.0 --> 12.0 bits
8 kHz	1/(256.0)	16.0 --> 12.0 bits	1/(362.0)	16.5 --> 12.0 bits

Hi-Resolution Mode – Step 1 of 2

Hi-Resolution Mode – Step 2 of 2



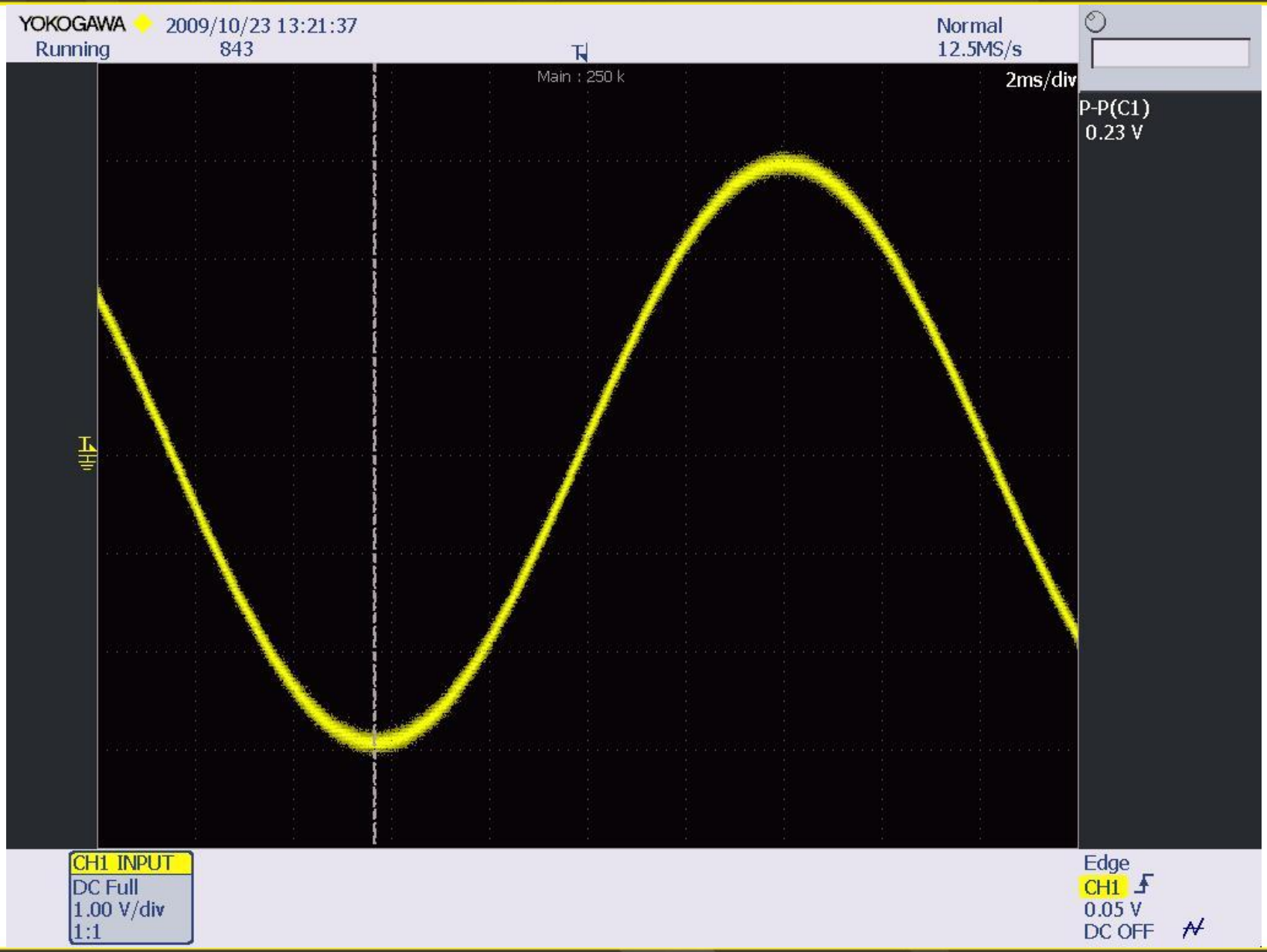
Hi-Resolution Mode Example & Calculation



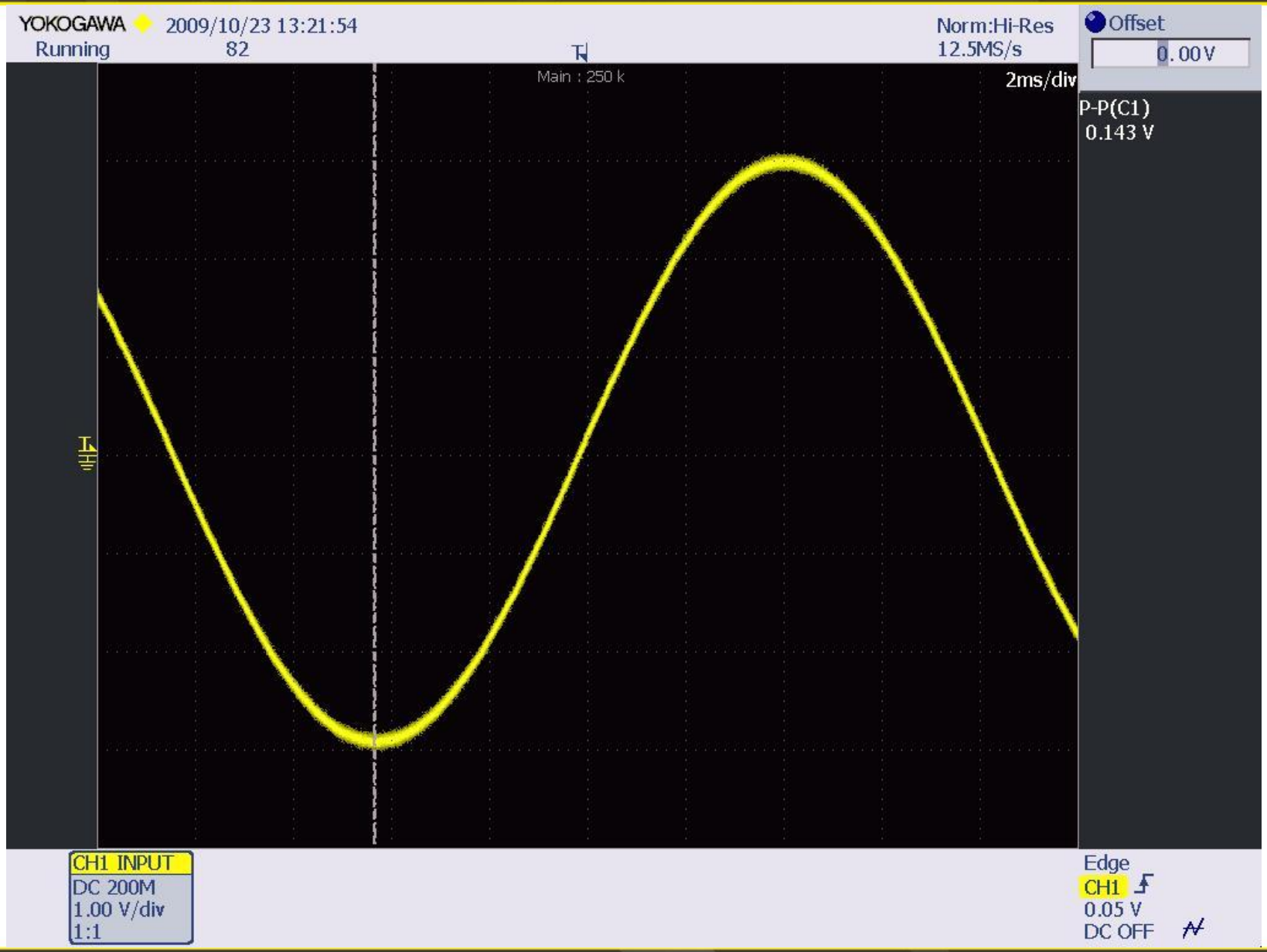
Appendix

- Samples of Hi-Resolution in use
- Samples of Hi-Resolution Mode’s effect on FFT (before and after)
- Graph of Hi-Resolution Performance DLM2000
- Graph of Hi-Resolution Performance DLM2000

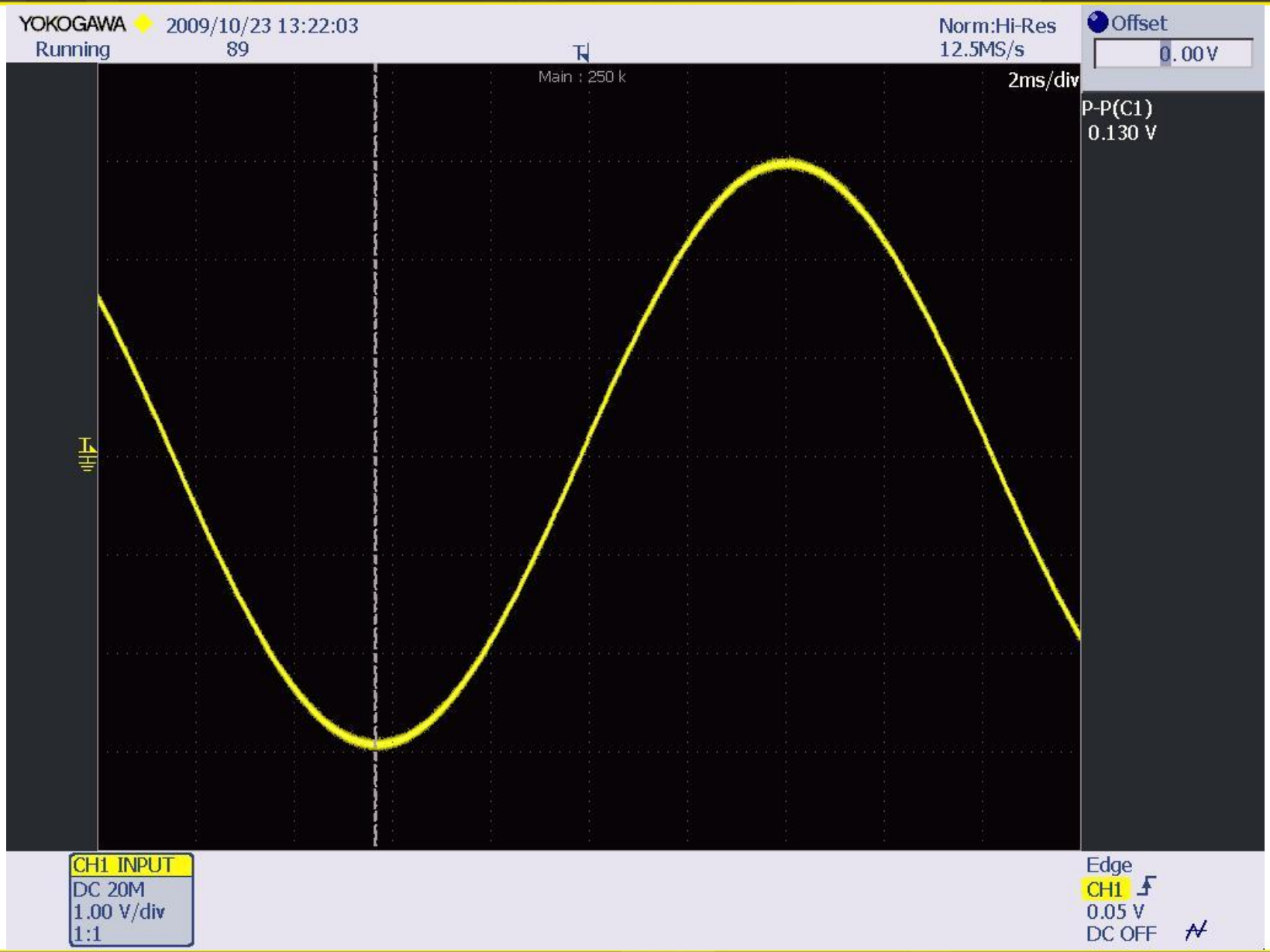
Hi-Res OFF - BW_1GHz_Noise at 0dB



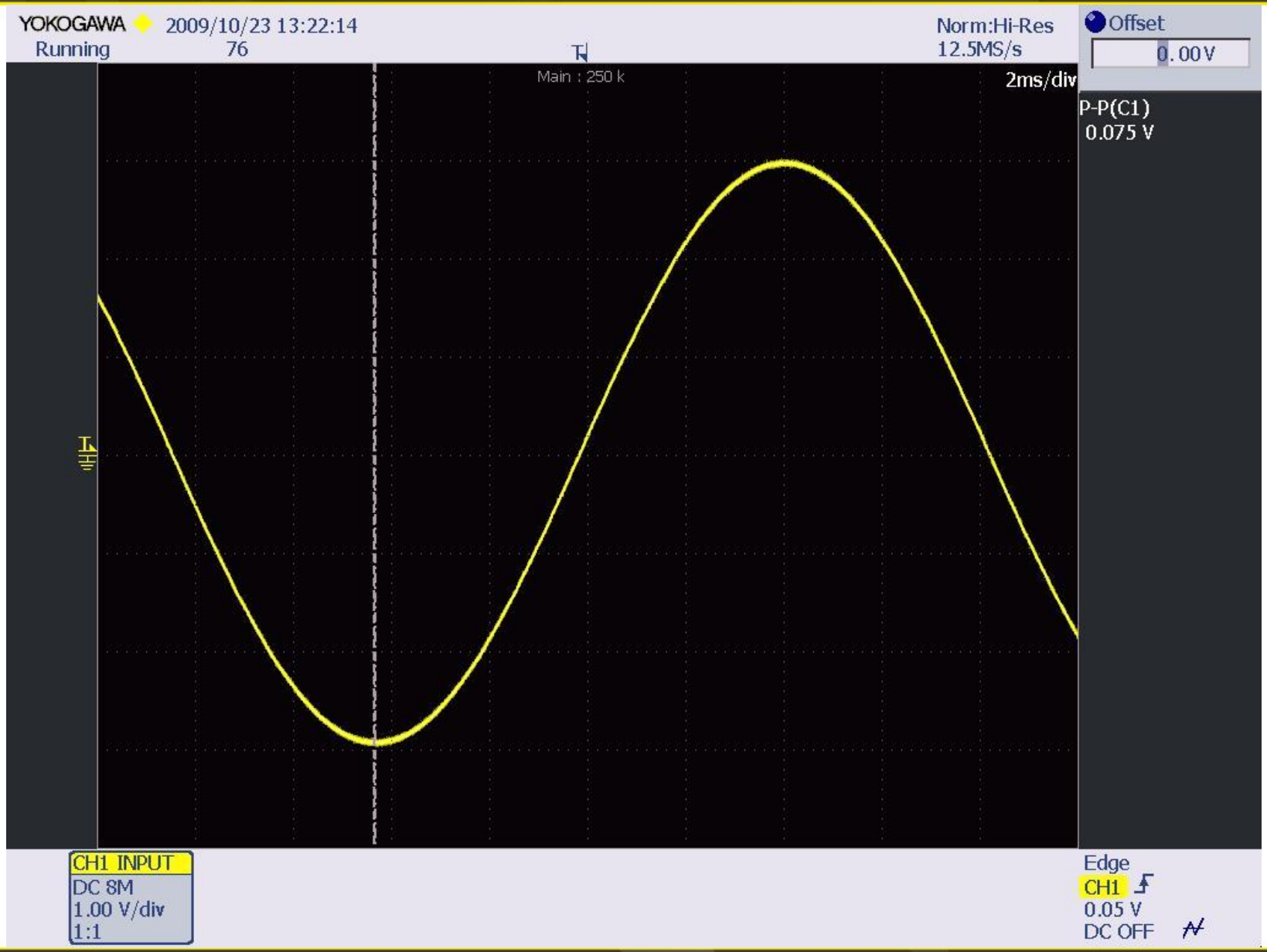
Hi-Res_ON - BW_200MHz_Noise at -4dB



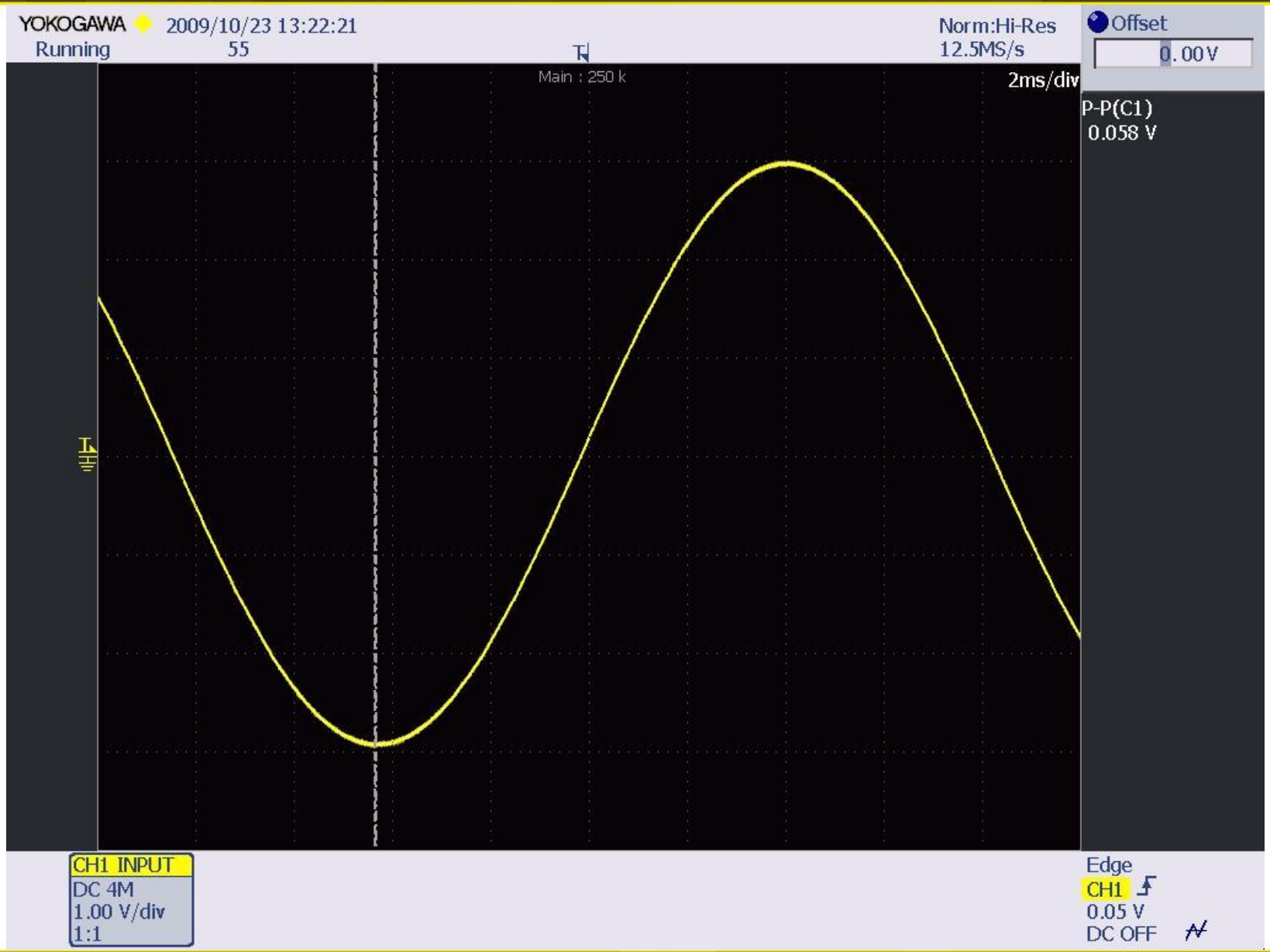
Hi-Res_ON - BW_20MHz_Noise at -5dB



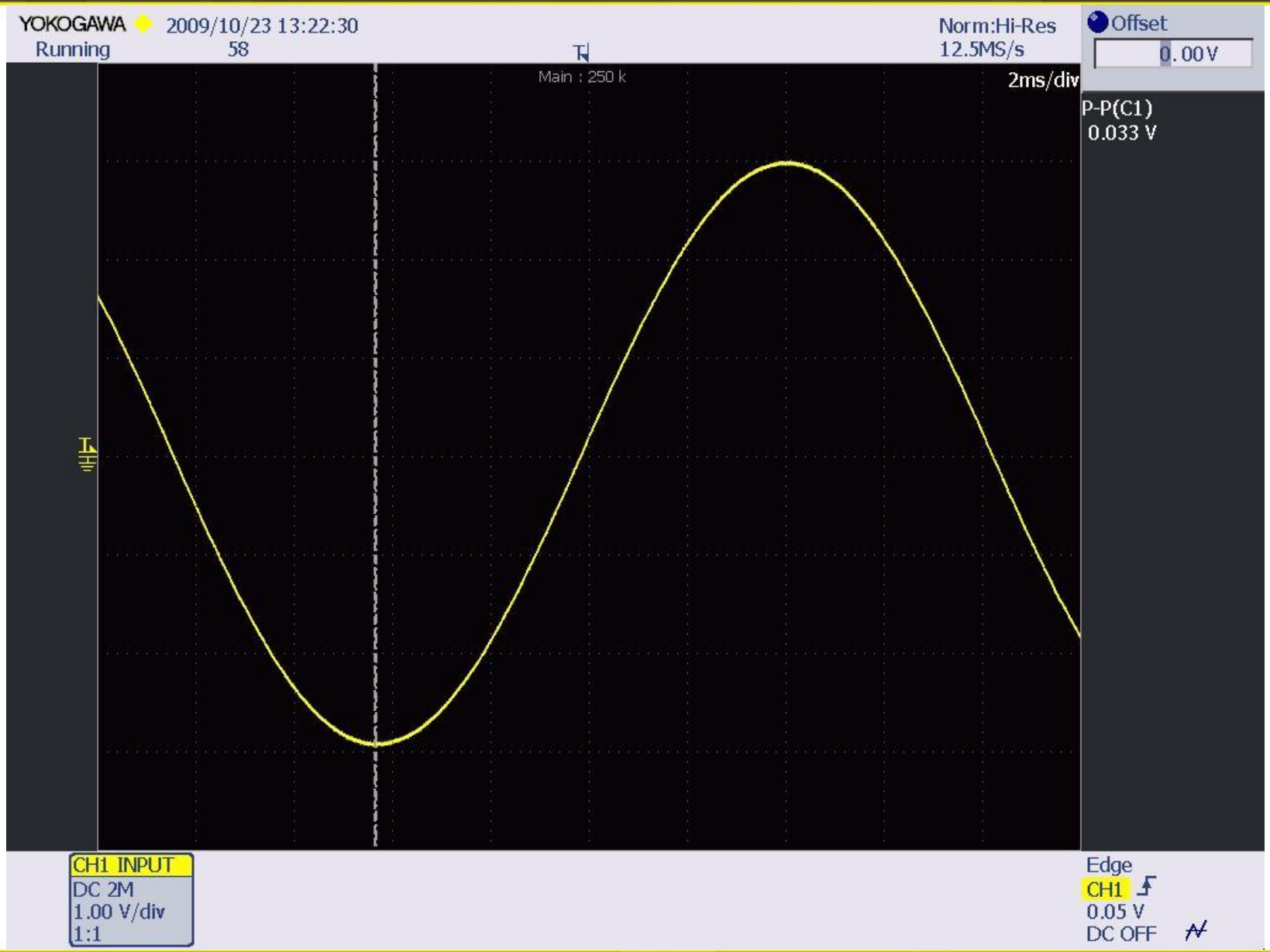
Hi-Res_ON - BW_8MHz_Noise at -10dB



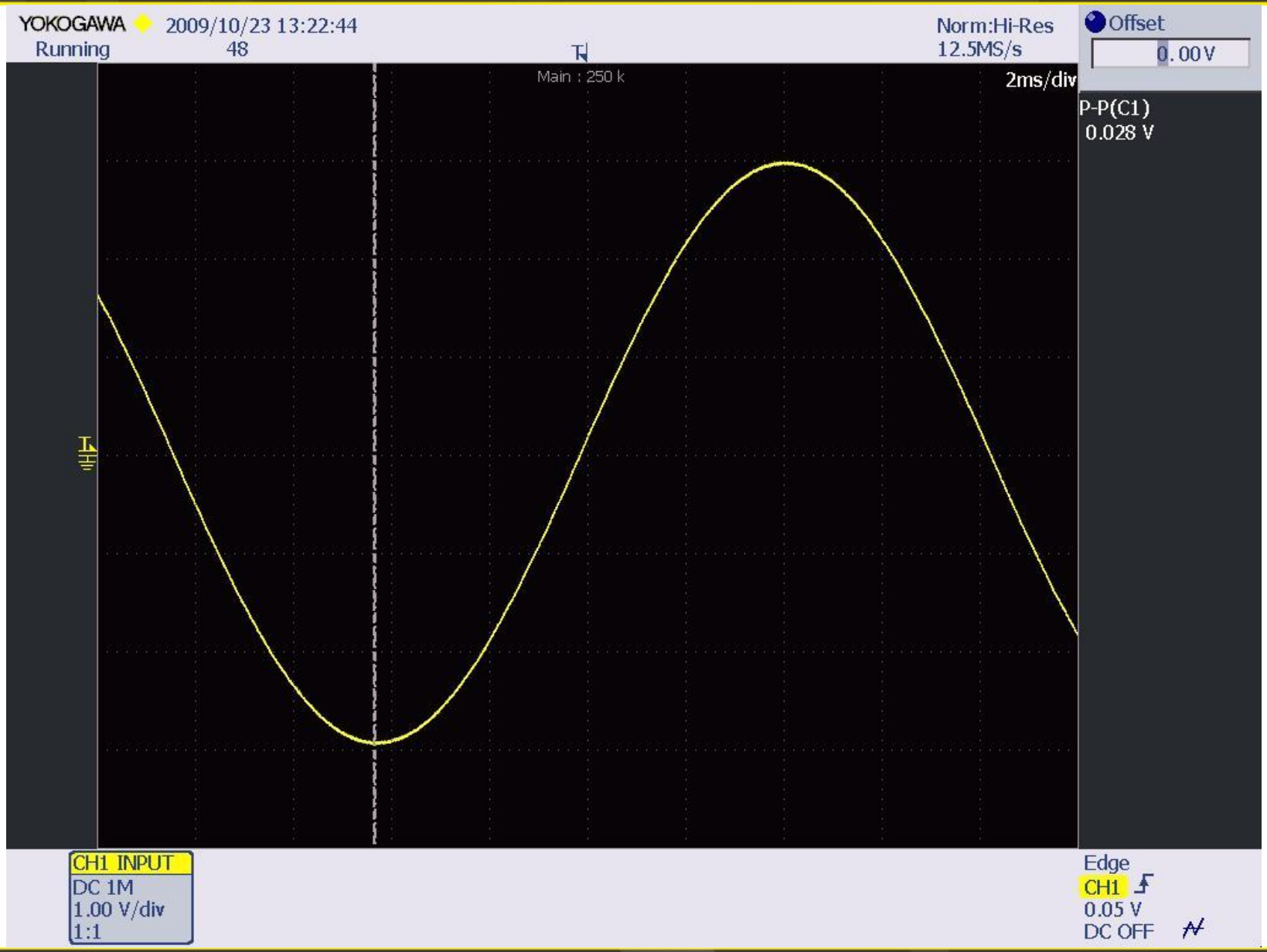
Hi-Res_ON - BW_4MHz_Noise at -12dB



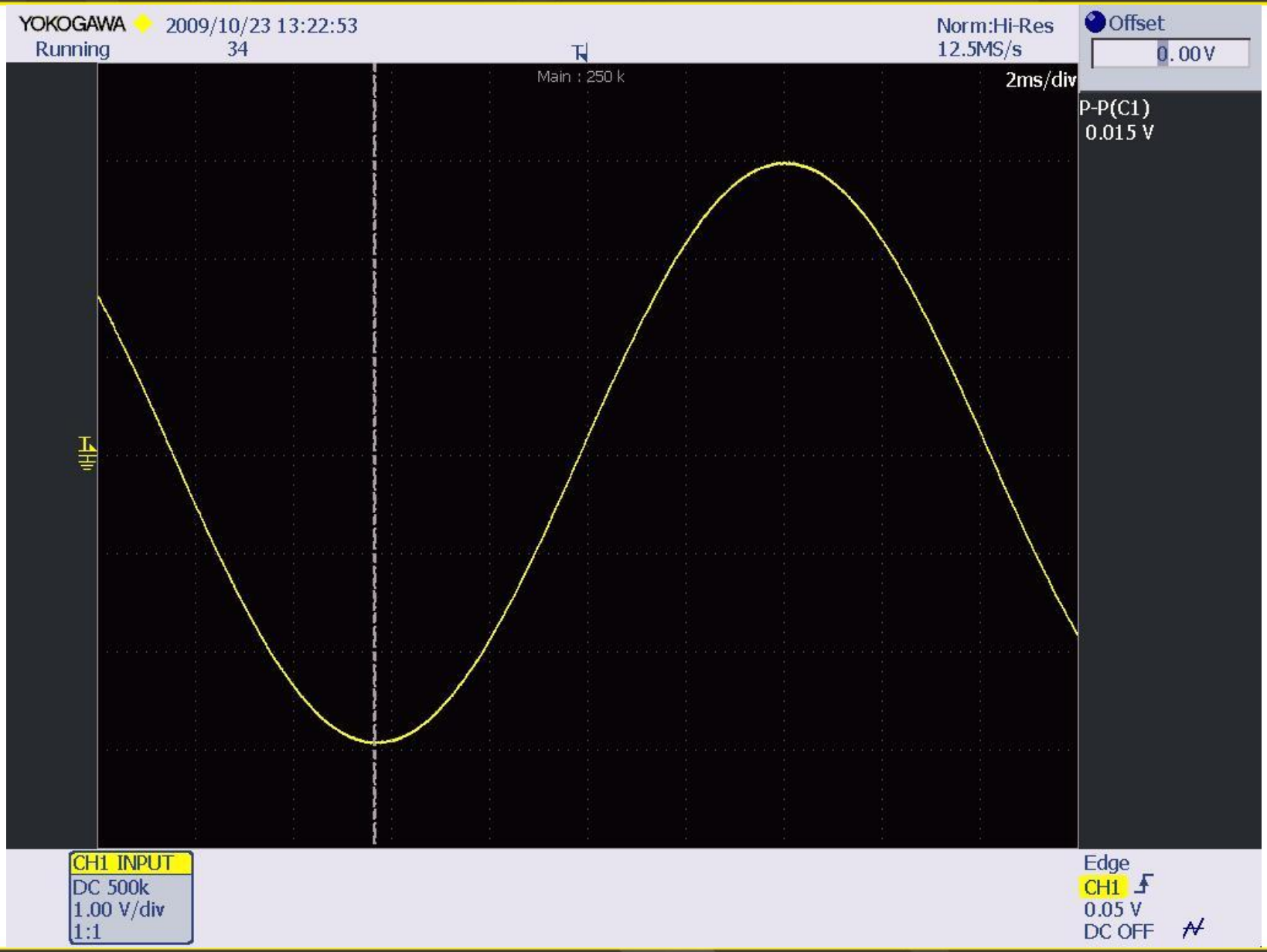
Hi-Res_ON - BW_2MHz_Noise at -17dB



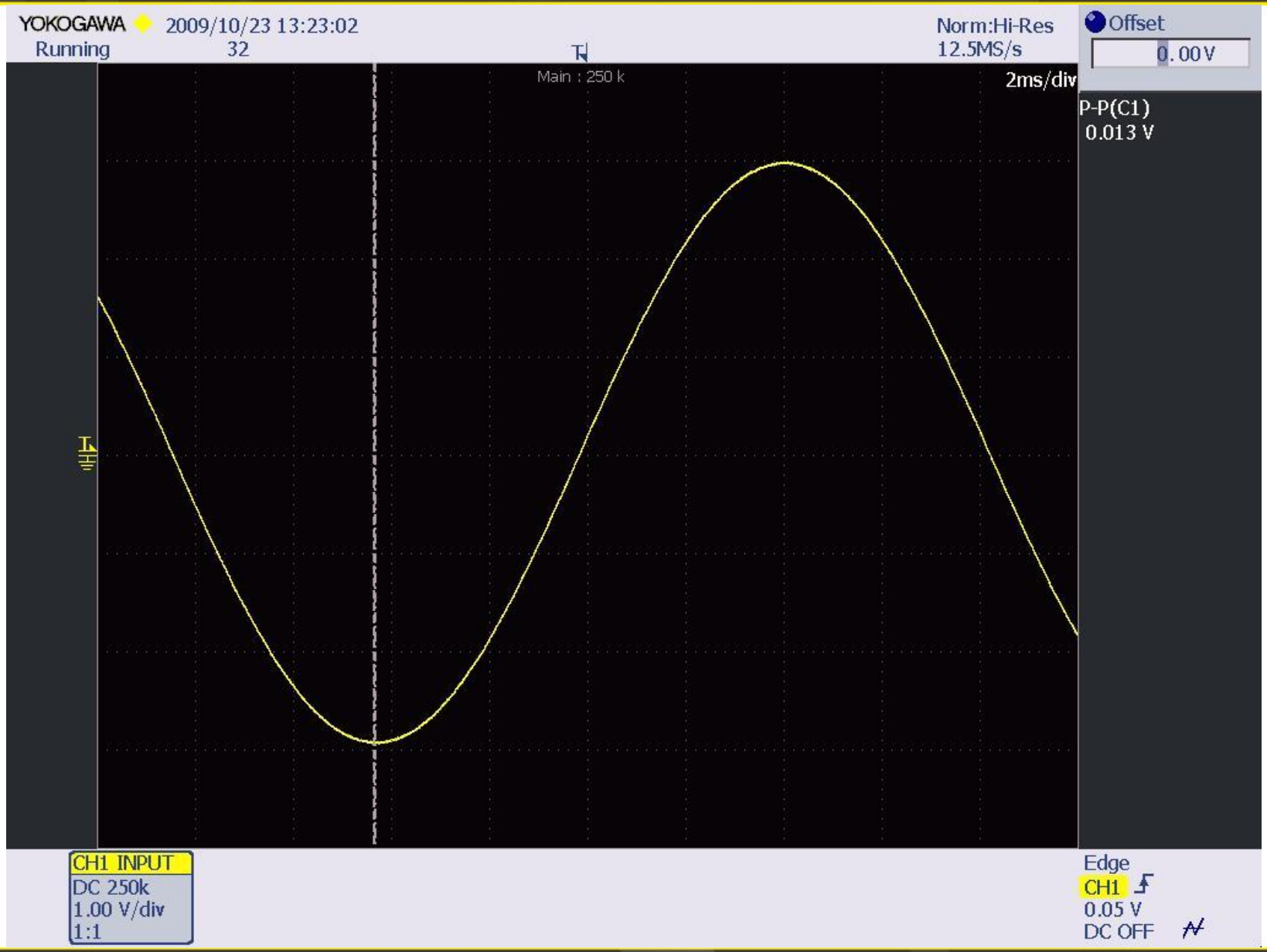
Hi-Res_ON - BW_1MHz_Noise at -18dB



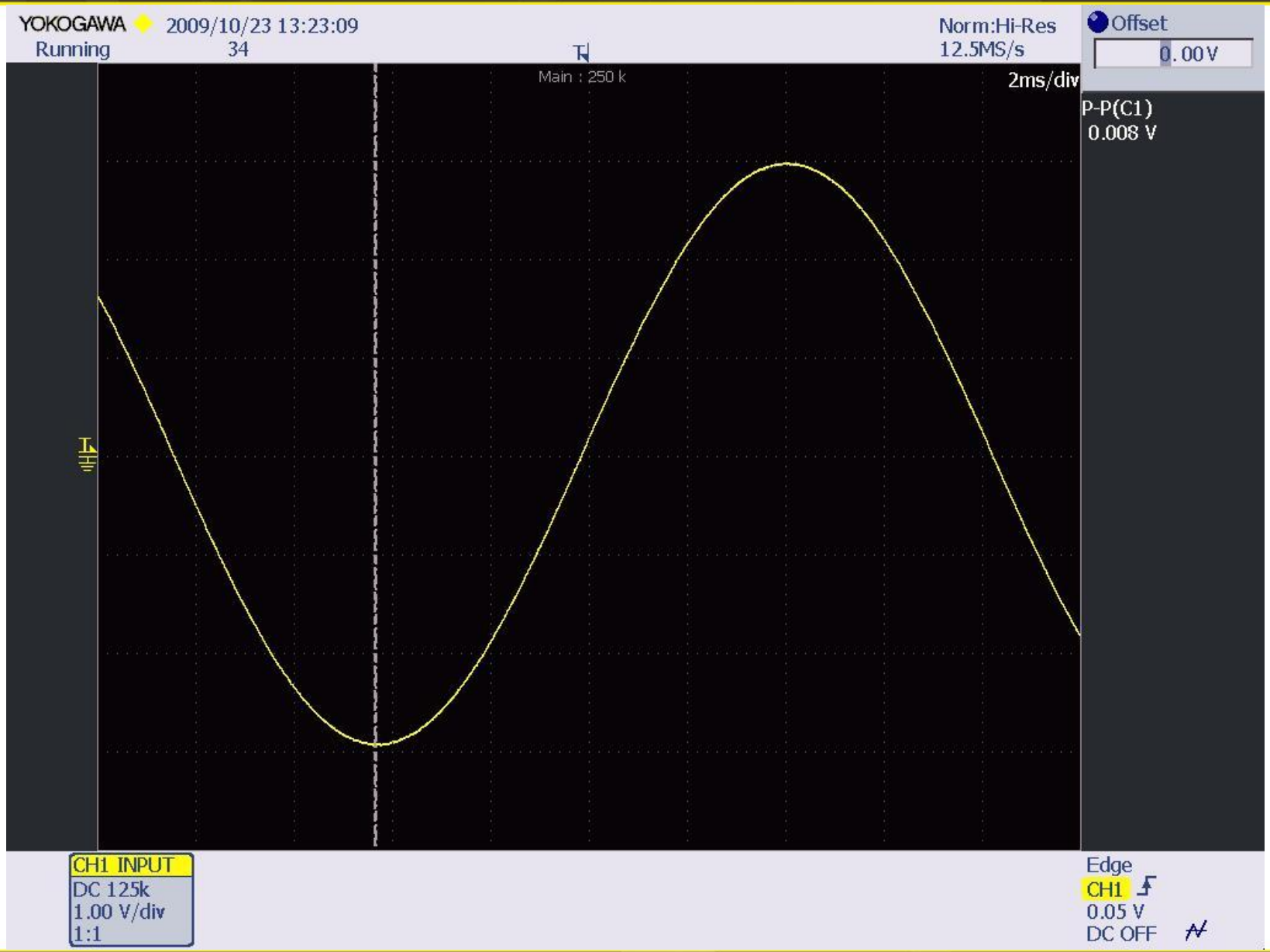
Hi-Res_ON - BW_500kHz_Noise at -24dB



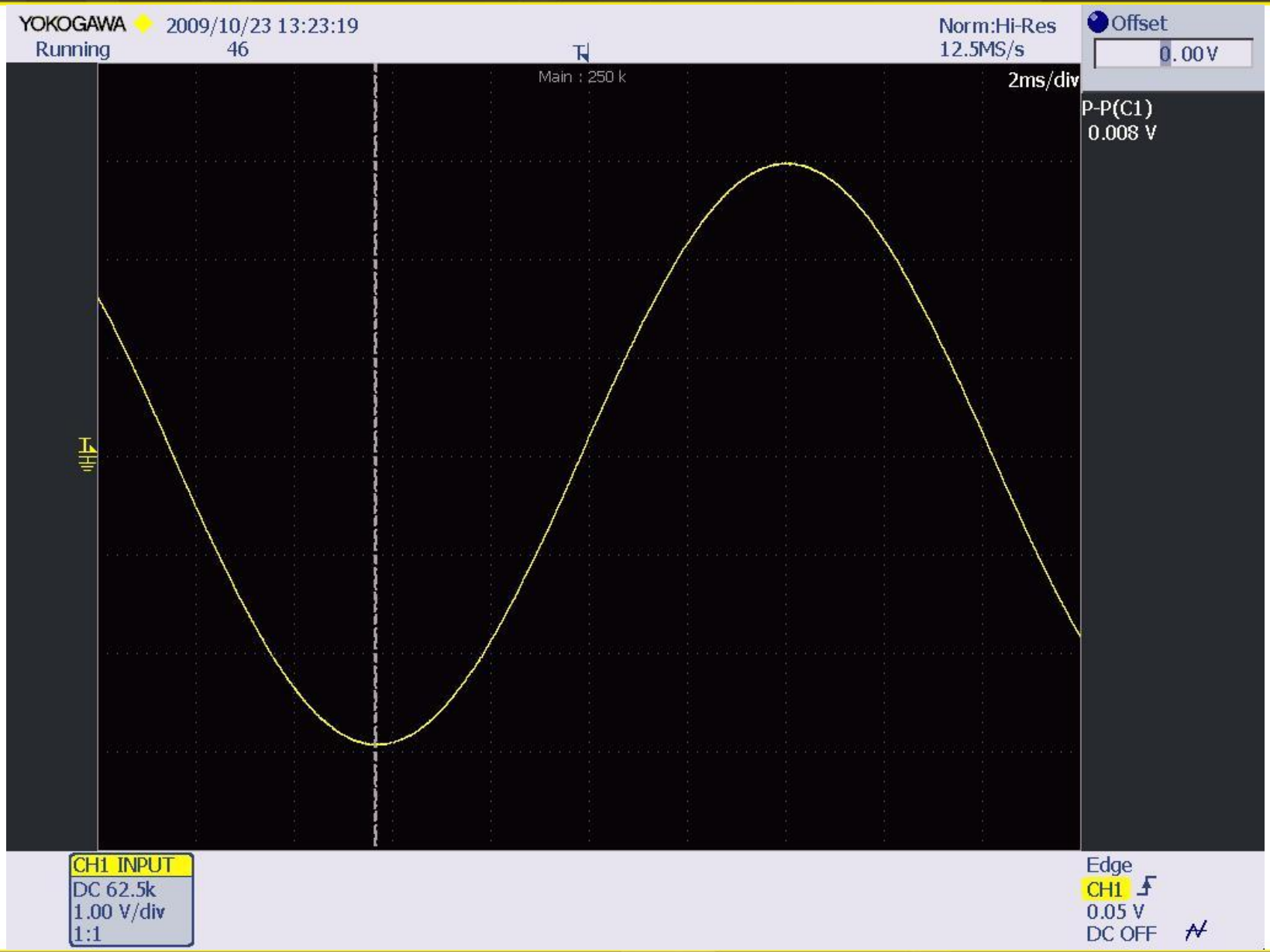
Hi-Res_ON - BW_250kHz_Noise at -25dB



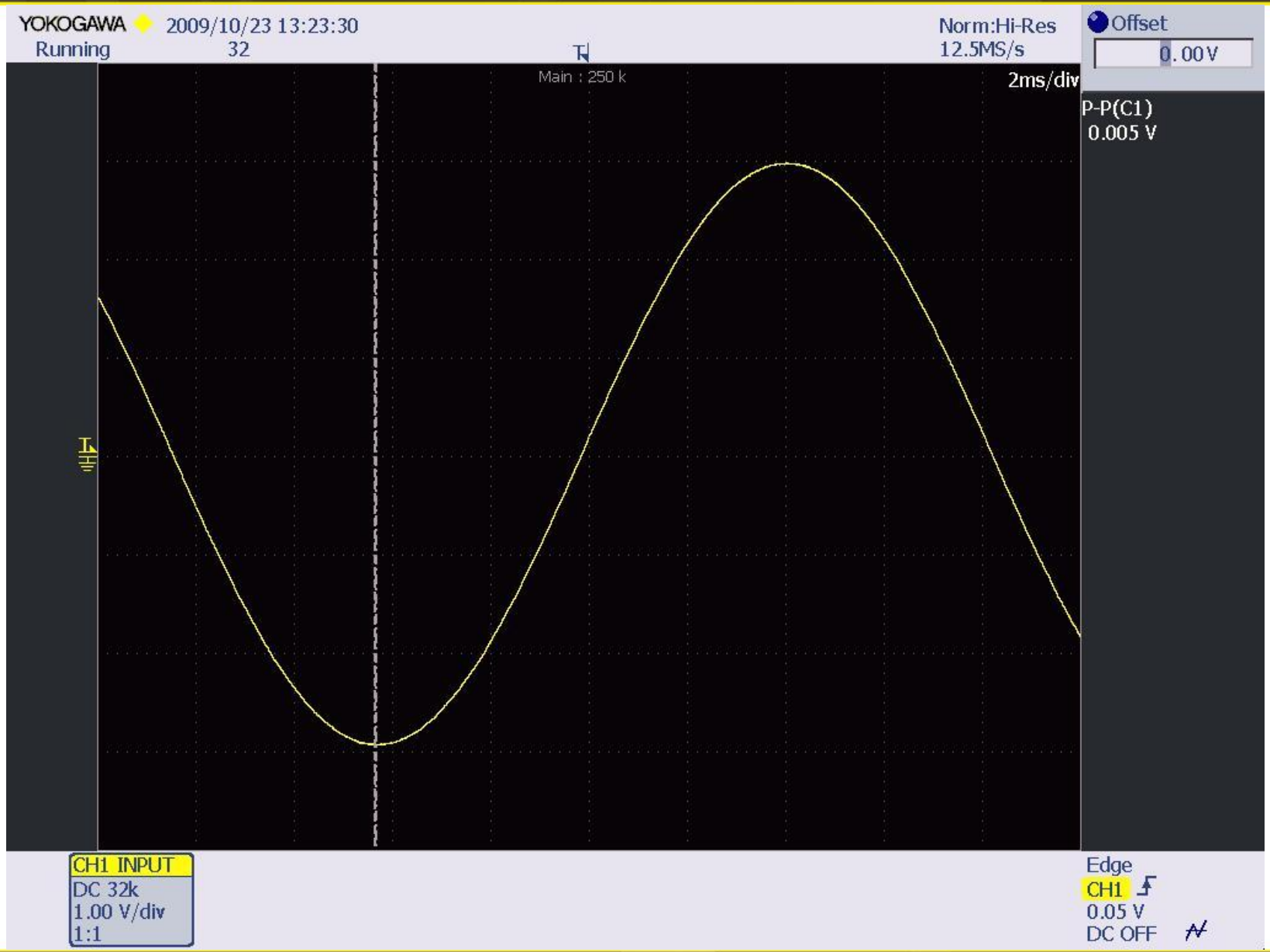
Hi-Res_ON - BW_125kHz_Noise at -29dB



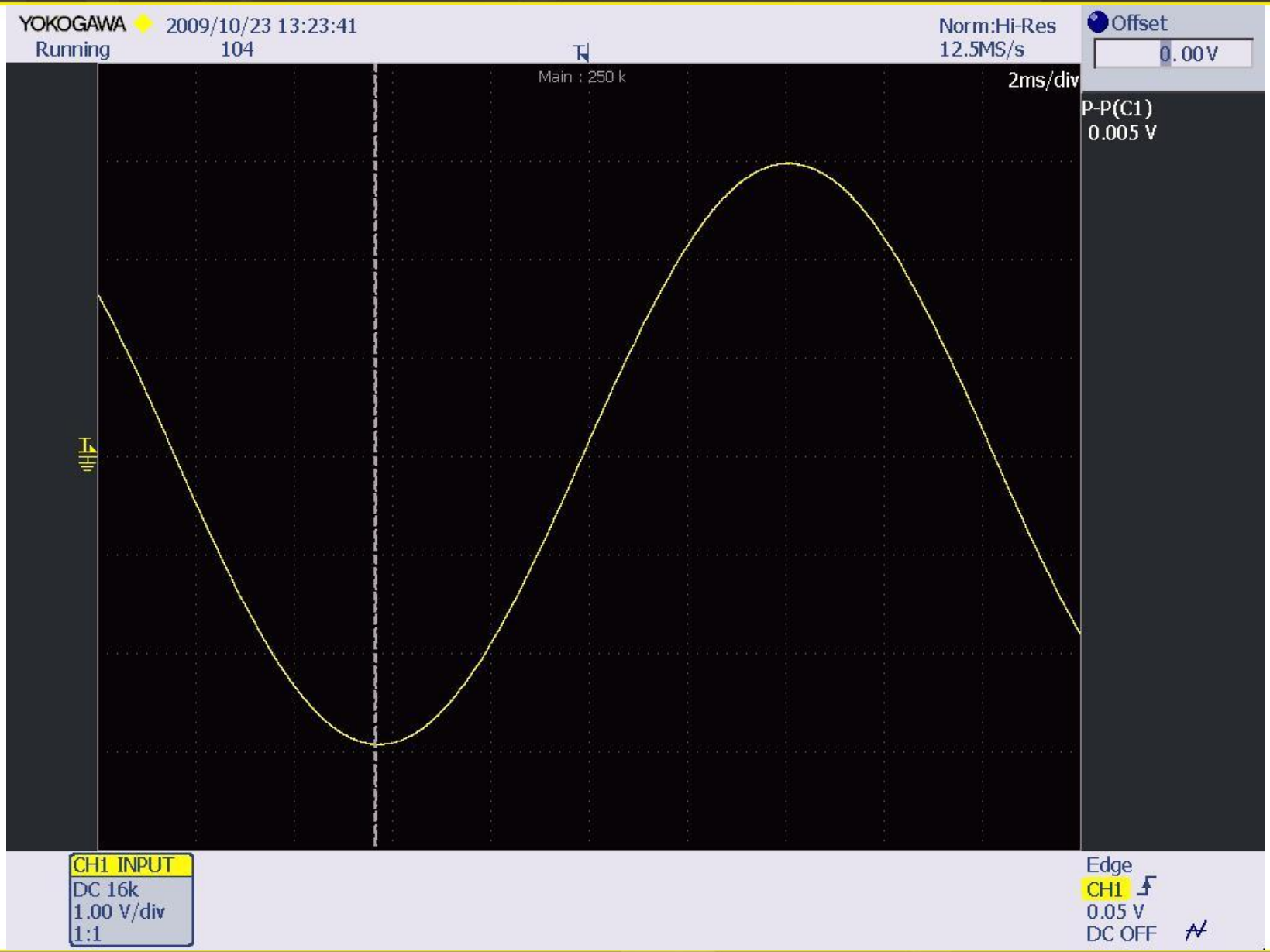
Hi-Res_ON - BW_62.5kHz_Noise at -29dB



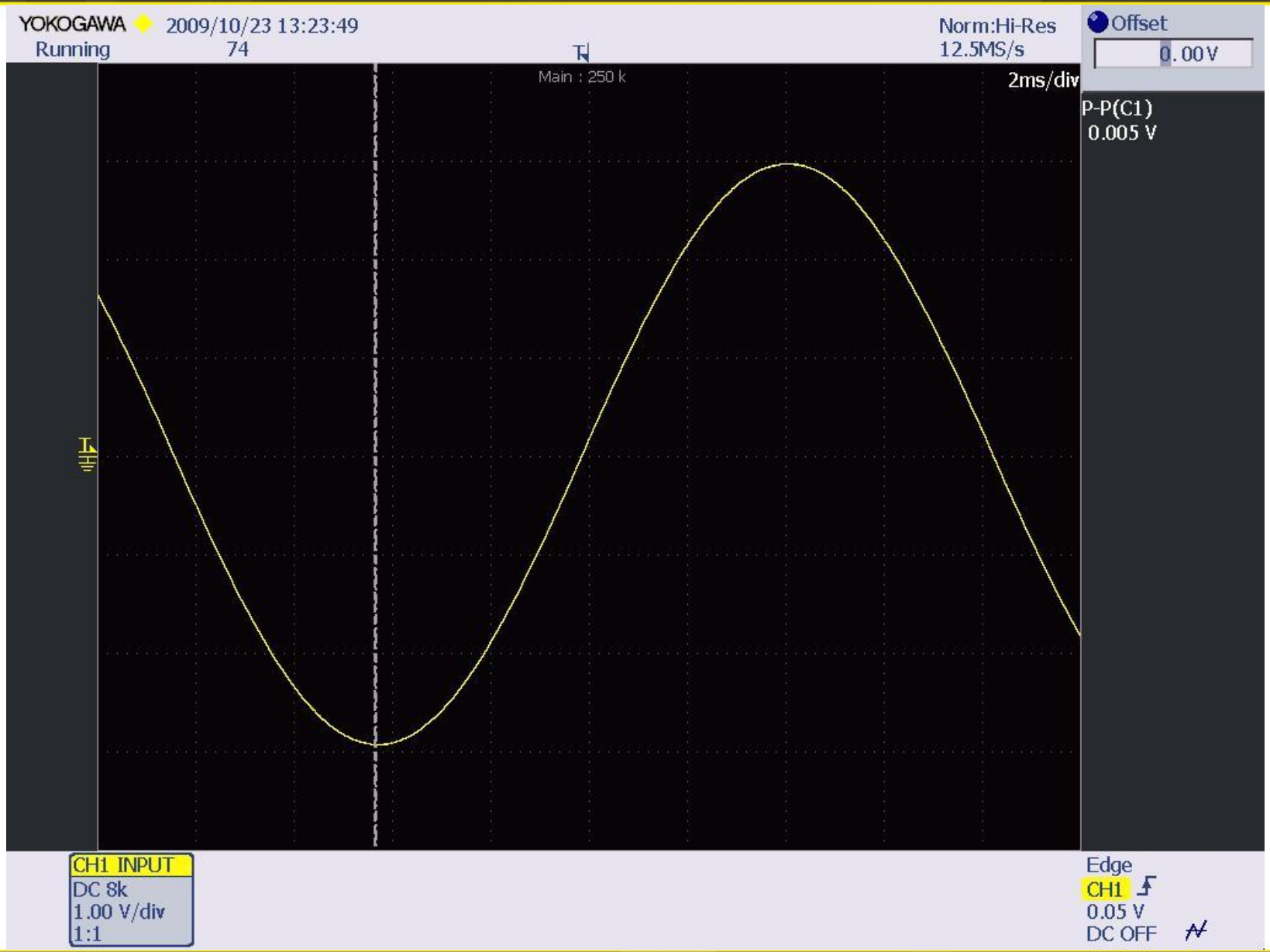
Hi-Res_ON - BW_32kHz_Noise at -33dB



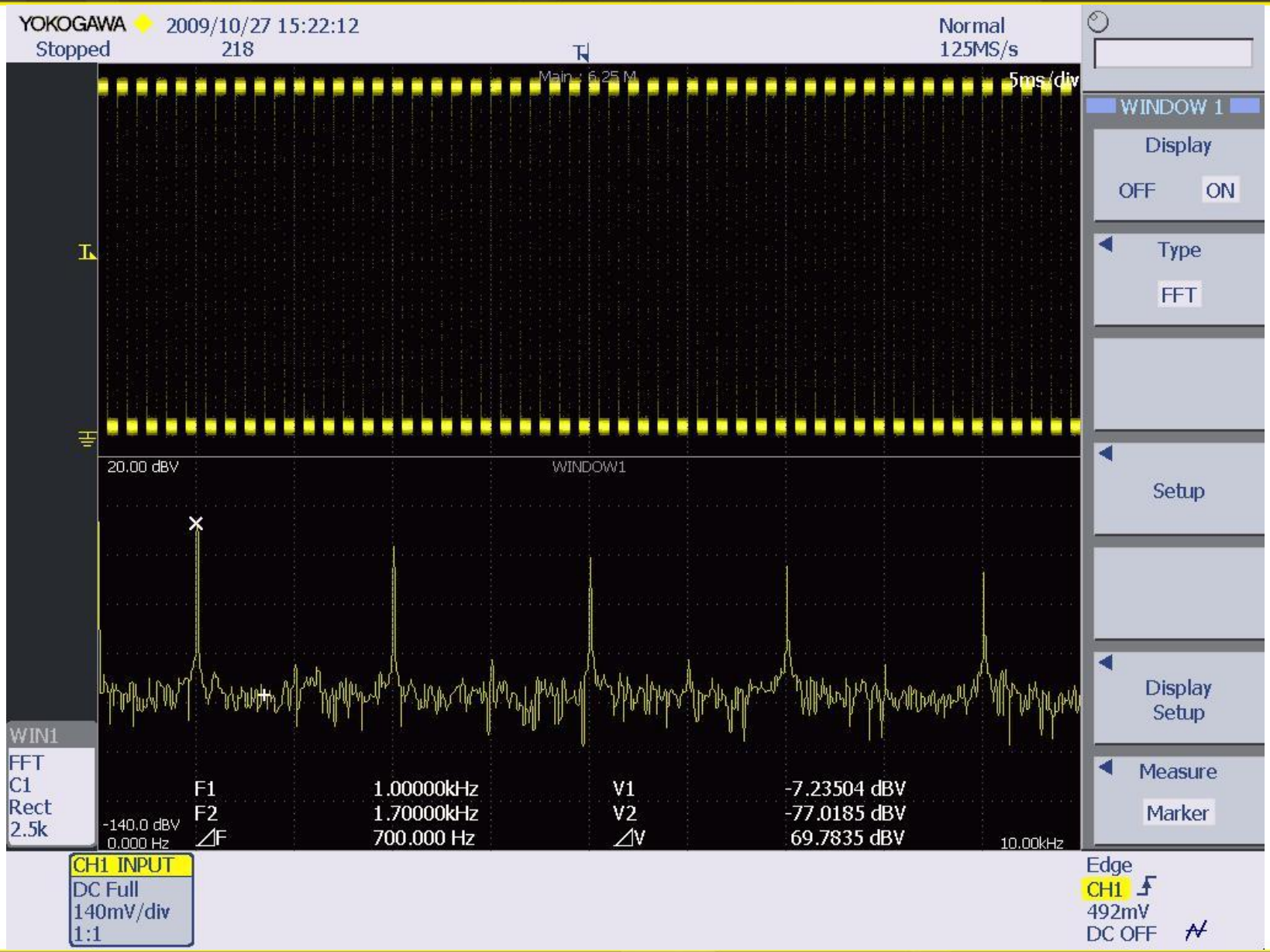
Hi-Res_ON - BW_16kHz_Noise at -33dB



Hi-Res_ON - BW_8kHz_Noise at -33dB



FFT w/o Hi-Res Mode - “Before”



FFT w/ Hi-Res Mode - “After”