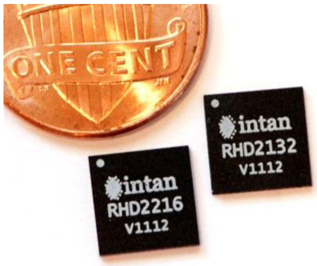
RHD2132
RHD2164
RHD2216



FAQ: Amplifier Gain

3 April 2017

Q:

Why is the gain of the RHD2000 series amplifier chips fixed at 192? Isn't this too low for recording small, microvolt-level neural signals?

A:

The purpose of signal amplification is to boost small signals above the noise levels of successive signal acquisition stages and roughly match the full-scale range of the amplifier with the full-scale range of the analog-to-digital converter (ADC) being used to capture the signals. Too little gain will place a heavy burden on the noise and resolution requirements of the ADC. Too much gain will cause large signals (e.g., LFPs, EMG) to saturate the amplifier or exceed the range of the ADC.

Many traditional electrophysiology recording systems developed in the late 20th century use ADCs with an input range of ±10 V. Boosting a 1 mV signal to a level of 10 V requires a gain of 10,000. This gain was typically accomplished using off-the-shelf operational amplifier integrated circuits (ICs) that operated from a ±12 V dual polarity power supply derived from AC wall power or large battery packs.

Modern ICs used in micropower and battery-powered applications typically operate from single-polarity power supplies of 3.3 V or lower. The Intan RHD2000 series amplifiers operate from a power supply voltage as low as 2.9 V, and produce output signals (internal to the chip) that swing approximately ±1.0 V around a fixed DC offset of 1.225 V. Clearly, this smaller voltage range is not an optimal match for an ADC with a range of ±10 V.

Luckily, ADC technology has improved significantly in the past two decades. Modern successive approximation register (SAR) 16-bit ADCs operate from low single-polarity power supplies. This combination of low voltage range and high resolution greatly reduces the gain requirement on the front-end amplifier.

The 16-bit ADC in the RHD2000 chips operates over a total voltage range of 2.45 V. The smallest voltage step the ADC can resolve – also called the least significant bit (LSB) – is (2.45 V) / (2^{16}) = 37.4 μV. Dividing this LSB level by the RHD2000 amplifier gain of 192, we see that the **electrode-referred LSB level** is 0.195 μV, which is more than ten times below the 2.4 μV rms noise level of the amplifier. Clearly, a larger amplifier gain would not improve our ability to digitize high-fidelity signals in this situation.

By limiting the amplifier gain to 192, we are able to observe electrode-referred signals as large as ±5 mV, which swing from 0.265 V to 2.185 V at the output of the RHD2000 amplifier and still fit within the 0 – 2.45 V range of the on-chip ADC. (The ADC can digitize signals slightly beyond this ±5 mV range, but the amplifiers become somewhat nonlinear outside this range.)

Our experience developing and using the RHD2000 chips has proven that modern high-resolution, low-voltage SAR ADCs work very well with Intan Technologies amplifiers for signals over the entire electrophysiological signal range from microvolts to millivolts. No additional gain is needed in most applications.

Additionally, we do not believe it is necessary to use an ADC with a resolution higher than 16 bits. Although many semiconductor companies advertise "delta-sigma" ADCs with resolutions of 20 bits or more, these types of ADCs are not as well suited for sampling time-multiplexed signals (like the output of the amplifiers on an RHD2000 chip) as a SAR ADC. Also, the **effective** resolution of these converters is typically only in the 16- to 18-bit range.