Application Note

MSPM0 Enables Cost-Effective Field Transmitter Applications

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ABSTRACT

Sensing signals in the single-digit millivolt range for industrial field transmitters is challenging. This application note highlights a cost-effective, integrated, high-gain sensor front end using the analog peripherals of the MSPM0 and minimal external components. The document presents an example signal chain and resulting measurement outcomes. Additionally, special hardware and software design considerations are examined.

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1 Introduction

Field transmitters are essential devices used in various industries and applications to measure, monitor, and transmit data from sensors located in remote or challenging environments. The importance of these sensors lies in the ability to facilitate accurate and real-time data transmissions, which is crucial for process control and safety.

Field transmitters are located in remote or hard-to-reach areas, such as oil rigs, pipelines, chemical plants, or environmental monitoring sites. Field transmitters allow for monitoring and control of processes and systems without the need for frequent manual intervention.

For real-time data transmission, field transmitters offer different analog and digital interfaces. Typical analog output interfaces consist of a two-wire, loop-powered, 4-20 mA current output or radiometric voltage output. Notably, digital interfaces like IO-Link, SPE, HART and APL are currently available.

Safety approvals are very common in industries like chemical, power generation, and oil and gas, but also in mobile applications. Safety approvals help prevent accidents, protect the environment, and save human lives with high levels of quality and reliability function.

Pressure sensors represent one of the highest volumes in the market. The price target for the active component BOM is very challenging because of this high volume. The sensors are mounted near the process, or in harsh environments, and require wide operation temperature ranges between -40°C up to 125°C. Since pressure changes are dynamic, settling times lower than 1 ms are standard .

A high-gain and low-noise AFE is required to achieve accuracy in the range of 0.01% - 0.1% because the strain gauge (Wheatstone bridge) typically used in a pressure sensor only delivers small voltages in the range of lower than 5 mV full-scale. Typical sensor housings incorporate the form factor of an M17 or M21 screw, which limits the possible PCB size. Achieving a low-power, high-gain front end within reasonable area and cost is challenging and requires a reasonable level of integration.

The MSPM0 MCU is a great design for these challenges with a wealth of integrated flexible analog resources. Leveraging the internal peripherals, such as ADCs, chopper-stabilized operational amplifiers, and DACs can help solve these technical challenges. Section 3 introduces how an MSPM0-based front end can overcome the aforementioned challenges.

2 Technology

2.1 Analog Peripherals in the MSPM0

MSPM0 microcontrollers are rich in analog content. The included peripherals consist of:

- 12-bit 4 MSPS
- ADCs
- Up to two chopper-stabilized operational amplifiers with a programmable gain setting
- A 12-bit DAC with 1 MSPS
- Internal voltage reference

The MSPM0 ADC can average the results in hardware, in addition to the nominal 12-bit resolution. This averaging is accomplished by adding up to 64 samples in the result registers and then right shifting them to calculate the average of these values. Mathematically, this feature allows the ADC to reach a resolution of 14-bit. The maximum effective sample rate in this scenario is 62.5 kSPS (250 kSPS divided by 8). This averaging is supported by the chopper-stabilized OPAs that incorporate a special chopping mode to aid with oversampling and averaging of signals.

Chopping reduces the drift of the OPA to 0.5 µV/°C. The OPA offers a gain factor of up to 32 and the two internal OPAs can cascade to create a difference amplifier that can directly connect to the ADC input. The internal voltage reference is configurable to 1.4 V or 2.5 V and provides an accuracy of 200 ppm/°C to the analog peripherals. These components create a setup that makes sense signals in the single-digit mV range possible using a cost-effective MSPM0 MCU with minimal external components.

The current consumption of these components is excellent for low-power applications. The full application consists of an ADC and two OPAs, while the internal reference and the DAC consumes only 770 uA, on top of the consumption by the controller core at 4 MHz.

2.2 Instrumentation Amplifier - INA350

The INA350 is a cost-competitive, selectable-gain instrumentation amplifier that offers four gain options available in small packages (X2QFN10 in 1.50 mm × 2.00 mm). INA350ABS has gain options of 10 or 20 and INA350CDS has gain options of 30 or 50. These gain options can be selected by toggling the gain select (GS) pin. The INA350 is excellent for bridge-type sensing and for differential to single-ended conversion applications.

The device interfaces directly to low-speed (10-bit to 14-bit) ADCs and is great for replacing discrete implementations of instrumentation amplifiers built with commodity amplifiers and discrete resistors. INA350 achieves 85 dB of minimum CMRR and 0.6% of maximum gain error, along with 1.2 mV of maximum offset across all gain options, while consuming just 125 μA of maximum quiescent current. The device has an integrated shutdown option for additional power savings in battery or loop powered applications that to turns off the amplifier when idle.

For sensors with higher performance requirements, the INA333 is a low-power (typically 50 μA), zero-drift instrumentation amplifier offering excellent accuracy. The zero-drift chopper circuitry eliminates the 1/f noise and provides a very low offset and drift over temperature, making INA333 appropriate for DC and low frequency, high gain applications. A single external resistor sets any gain from 1 to 10,000. The INA333 is laser trimmed for very high common-mode rejection (100 dB at G ≥ 100).

2.3 Voltage Reference - REF2925

The REF29xx is a precision, low-power, low-voltage dropout voltage reference family available in a tiny 3-pin SOT-23 package. The small size and low power consumption (50 μA maximum) of the REF29xx is an excellent option for portable and sensor applications. The REF29xx is stable with any capacitive load and does not require a load capacitor. The REF29xx is operable unloaded with supplies within 1 mV of output voltage. All models are specified for the wide temperature range of –40°C to 125°C.

2.4 Low-Dropout Regulator - TPS7B6933-Q1

The TPS7B6933-Q1 device is a low-dropout linear regulator designed for up to 40-V input operations. The device is available in a tiny 5-pin SOT-23 package. The device is an excellent option for sensor applications with only 15-μA (typical) quiescent current at light load. The design features an integrated short-circuit and overcurrent protection. Temperature operation range is –40°C to 125°C.

3 Signal Chain

This section presents leveraging the capable analog peripherals of the MSPM0 microcontroller series to adjust for challenges of pressure transmitter designs and other high-gain sensor interfaces. A significant amplification of the signal is necessary to scale a single-digit mV signal from a sensor to the full scale input of an ADC. This amplification is not solely achievable with the internal operational amplifiers of the MSPM0. Therefore, an INA350 instrumentation amplifier, with 50x amplification, is used as the first stage of the signal chain. The following amplification is handled by the internal chopper-stabilized OPA of the MSPM0, which is internally connected to the ADC of the MSPM0. The internal OPA, therefore, allows for flexibility in amplification between 50x (OPA in a buffer configuration without amplification) and 1600x with the internal OPA setting at 32x amplification. The signal chain is visualized in Figure 3-1.

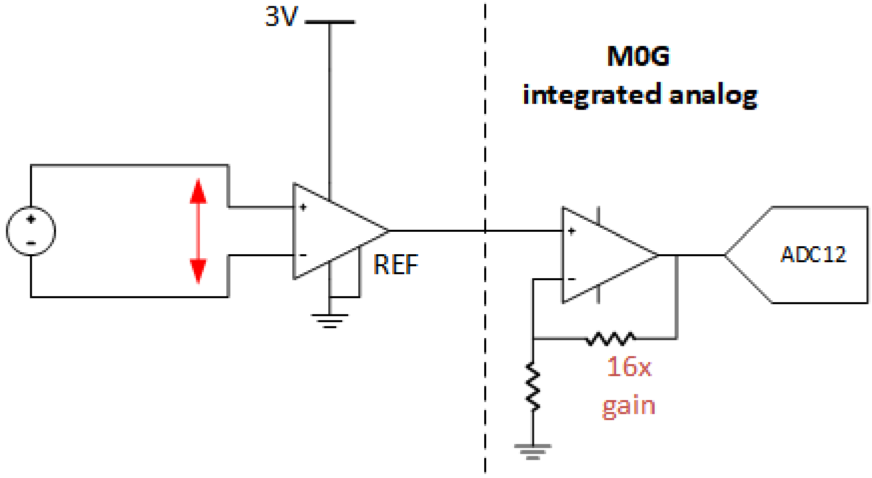

Figure 3-1. Signal Chain Using INA350 and MSPM0 Internal OPA

The ADC is used in oversampling mode to improve the effective resolution by utilizing the hardware assisted averaging feature. The ADC is configured to aggregate 64 samples in the result buffer and then the result is divided by the factor of 8, which is done by right shifting by 3 bits in hardware. This configuration is done directly in the *SysConfig* tool as displayed in Figure 3-2. The total conversion time for a sample is 64 times the sample time, and conversion time, per sample because the sample time configured in *SysConfig* always equates to one single sample. The conversion time is dependent on the clock that the ADC is sourced from. Aggregating 64 samples and dividing the resulting sum by 8 increases the nominal resolution of the ADC by 3 bits when considering Equation 1.

$$\text{additional bits} = \sqrt{\log_2(\text{n})} \text{ with n being the oversampling factor} \tag{1}$$

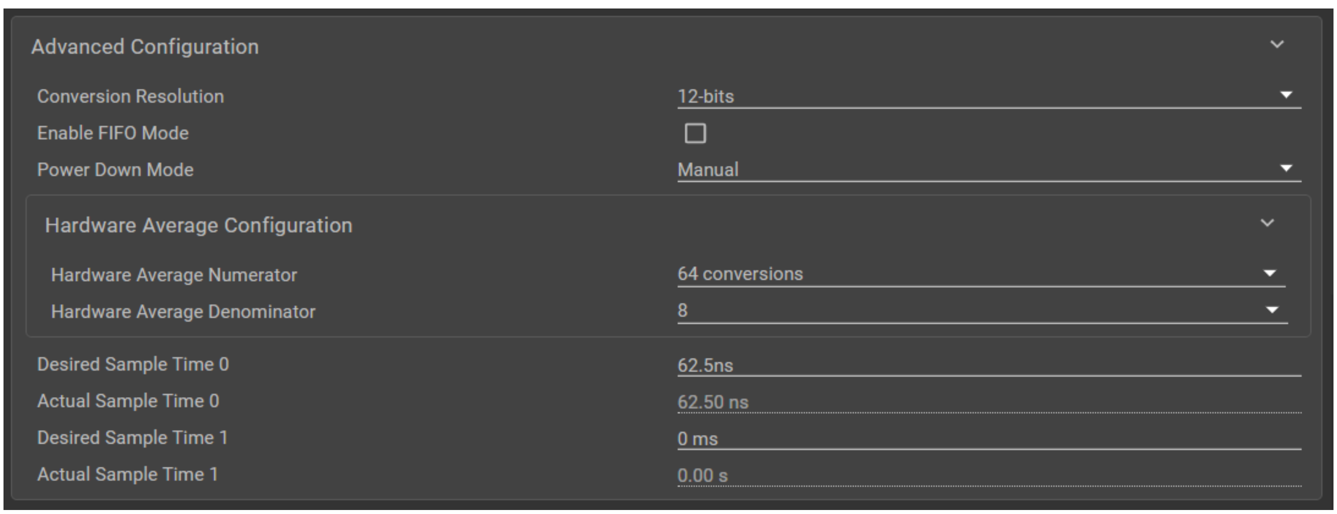

Figure 3-2. SysConfig ADC Configurations Settings for Oversampling

Depending on the size and resolution requirements for a specific application this setup offers the flexibility to use either the internal reference voltage generation of the MSPM0 or an external voltage reference.

Tests results explained in Section 4 were conducted using LP-MSPM0G3507 LaunchPad™ Development Kit and a cost-optimized REF29x voltage reference, which outputs 2.5 V to the MSPM0G3507 and 2.5 V to the INA350.

Figure 3-3 shows the complete option for a bipolar bridge input. Processing a bipolar input using a single-supply signal chain requires a DC shift added to the input, starting with adding *Vcm* to the INA350 output. Once a DC shift is added, the rest of the signal chain needs to take the DC shift into account for further amplification. The next stage is converted from a simple gain stage into a difference amplifier.

The difference amplifier implements using the two amplifiers shown in Figure 3-3. This implementation has multiple advantages. First, the difference amplifier provides high-impedance on both positive and negative inputs. Second, the amplifier allows using the buffered second input (which is the *Vcm*) as an output to feed the INA350 reference node. The negative input for the OPA is generated using the internal low resolution 8-bit DAC or the high resolution DAC12 (Figure 3-3).

Offset calibration is also activated in Figure 3-3. This activation is done by measuring the ADC12, in case of zero input, and then adjusting the DAC12 output, until the ADC12 is reading zero value (the bipolar input is represented by mid-scale reading). This offset calibration compensates for combined offset of the whole signal chain.

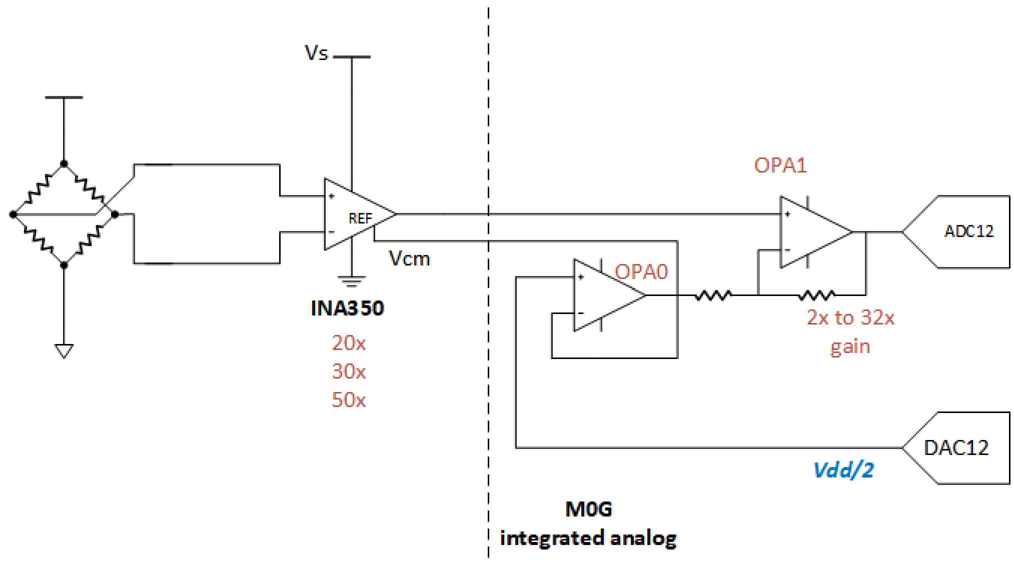

Figure 3-3. Bipolar High-Gain Signal Chain Using the Internal DAC

4 Results

When considering the whole signal chain, multiple factors influence the achievable resolution. These factors include the sampling rate used to capture the signal, the reference voltage used, the chopping method used for the amplifiers, and the amplification factor of the operational amplifiers.

The results consider the effective resolution of the whole signal chain. In the use case of pressure sensors, the pressure changes relatively slowly, therefore, to detect changes in the pressure the sampling speed can be limited. The analysis of the results is limited only to frequencies below 10 kHz and does not account for the factor of harmonics and other distortions in higher frequency signals. Equation 2 and Equation 3 were used to calculate the effective resolution of the signal chain.

$$\text{ENOBs (DC Input)} = \frac{\mu}{\sigma} \text{ with } \mu = \text{average ADC output code and } \sigma = \sqrt{\frac{\sum (x-\mu)^2}{n}} \text{ in LSBs} \quad (2)$$

$$\text{NF bits (for DC input)} = \frac{\mu}{N_{pp}} \text{ with Npp being the peak to peak noise in LSBs} \quad (3)$$

The measurements are carried out by sampling a continuous signal for a fixed number of samples. The level of this continuous signal is selected so that the input to the ADC is always close to the full scale of the VREF.

4.1 Influence of the OPA Chopping Mode

The internal OPA of the MSPM0 has a chopping feature which reduces the drift of the OPA. This chopping is configurable to adapt to different use cases and signal chains. The chopping must be adjusted to the ADC-assisted chopping mode when using the ADC in oversampling and averaging mode. This adjustment prevents the chopping frequency from interfering with the averaging feature of the ADC. Figure 4-1 is a resulting histogram showing two maxima in the distribution of a series of values where the standard chopping mode is used with ADC averaging. Figure 4-1 demonstrates that the effective resolution of the signal chain is significantly reduced.

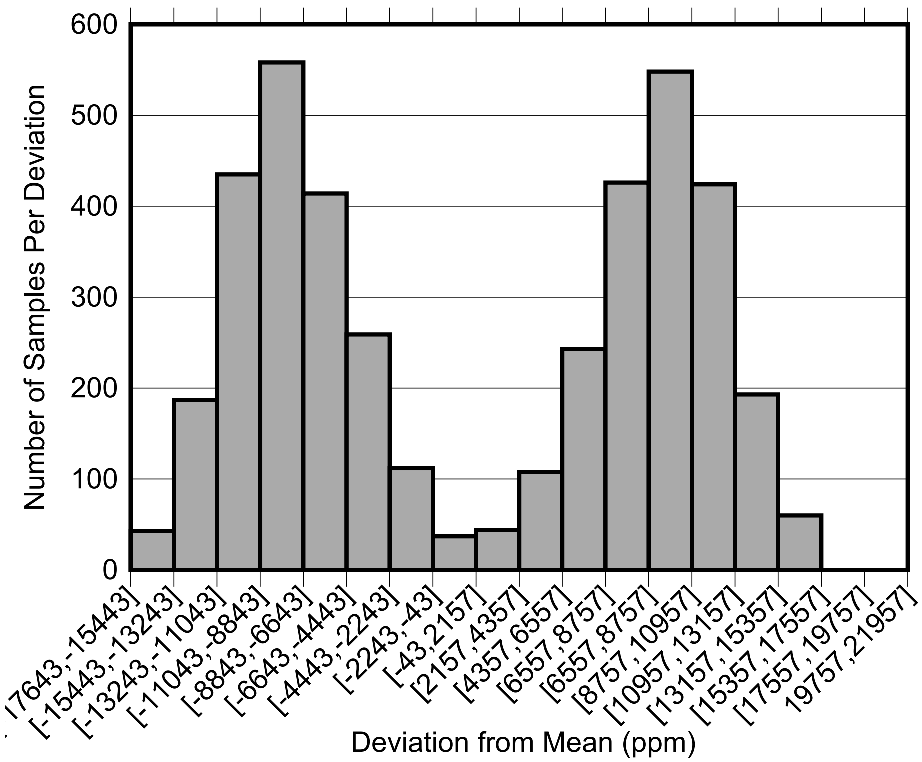

Figure 4-1. Histogram of ADC Samples When Using Standard Chopping While ADC Averaging

4.2 Oversampling and Hardware Averaging

The biggest influence on the effective resolution comes from oversampling the signal and using the integrated hardware averaging feature of MSPM0 to improve the nominal resolution of the ADC. The nominal and effective resolution results increase when comparing the standalone ADC in 12-bit mode against the ADC used with 64 times oversampling, as shown in Table 4-1. The measurements in Table 4-1 use the internal reference at 2.5 V and an input close to full scale. Notably, there is significant deviation between the nominal and effective resolutions in both cases. However, clearly the oversampling improves the effective resolution by almost 3 bits, which is expected with an increase in nominal resolution.

Table 4-1. Effect of Oversampling on Effective Resolution

ADC Mode	Nominal Resolution	Effective Resolution
Standard, no oversampling	12 bit	8.39 bit
64x oversampling	15 bit	11.22 bit

4.3 Effect of Sampling Rate on Effective Resolution

The sampling rate of the ADC has significant influence on the effective resolution of the whole signal chain. Defining the effective sampling rate for this evaluation is necessary since the oversampling and averaging features are used in this test. The effective sampling rate is defined by Equation 4.

$$\text{effective sampling rate} = \frac{\text{nominal sampling rate}}{\text{aggregated samples}} \tag{4}$$

Figure 4-2 shows the dependency of the effective resolution on the effective sampling rate. This test was executed with the complete signal chain shown in Figure 4-2 but with a constant gain setting of 2 resulting in an internal OPA with a total amplification factor of 100.

Figure 4-2 demonstrates that the effective resolution becomes higher as the sampling rate lowers. Figure 4-2 results in 12.88 bits at an effective sampling rate of 1.8 kSPS. Increasing the effective sampling rate up to 62.5 kSPS results in the effective resolution for this configuration remaining at 11.14 bits.

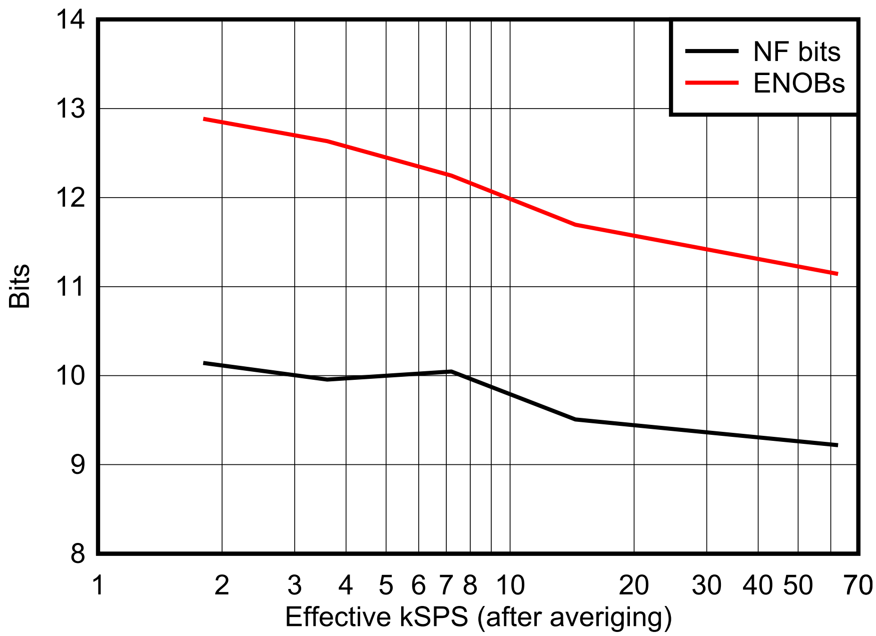

Figure 4-2. Effective Resolution vs the Effective Sampling Rate [kSPS]

4.4 Influence of the Amplification Factor

Amplifying the signal of pressure transmitters, or high-gain sensor interfaces, influences the signal and the noise, therefore, the achievable effective resolution with a signal chain is also influenced. In the case of sensing signals in the single-digit mV region, where the signal has to be multiplied manifold, the noise introduced by the amplification must be monitored closely.

Figure 4-3 shows the dependency of the noise in LSB and the resulting effective resolution versus the amplification factor of the internal OPA of the MSPM0. Notably, the total amplification of the signal is calculated by multiplying the amplification of the external INA350 with this internal gain factor. The measurements are conducted with the 64x averaging and an effective sampling rate of 62.5kSPS.

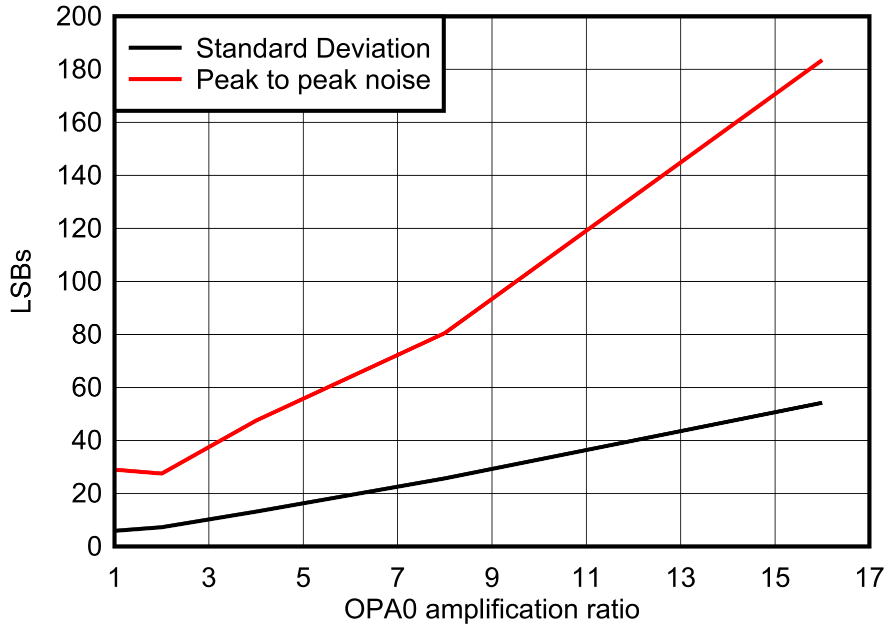

Figure 4-3. Noise and Effective Resolution vs Amplification Factor of the Internal OPA

As shown in Figure 4-3 the noise scales linearly with the amplification factor. The achievable effective resolution for the complete signal chain remains at 8.32 bits when using a 16x amplification factor, which results in a total amplification of 800. This resolution is still usable for detecting jumps in a signal and is capable of reducing the effective sample rate to increase the effective resolution, as described in Section 4.3.

5 Summary

The MSPM0 presents a flexible and affordable design for many high volume sensor transmitters. The device offers features desired in MCU designs like rich analog resources, small packages, and operation over the whole industrial temperature range. High-gain front ends require minimal external components like the high-gain instrumentation amplifier INA350 and the low power voltage reference REF2925. This article highlights performance versus cost considerations and implementations. The results detailed in this section aim at allowing a designer to choose and adjust system configuration parameters properly and quickly for achieving required performance.

6 References

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