INTRODUCTION:

The Accelerometer FIFO Oversampling Calculator (above) is used to determine the necessary oversampling ratio (OSR) to achieve an increased resolution. Also provided is a brief FIFO configuration to most efficiently retrieve the data from the accelerometer, minimizing interrupts and code complexity. Further information regarding the functionality of the FIFO and configuration can be found in the corresponding data sheets or AN-1025. It is recommended for this application that the FIFO is configured for FIFO mode or Stream mode.

Oversampling can be used to achieve increased system resolution beyond the resolution of the signal digitizer, in this case, the accelerometer. An increased resolution, by definition, allows for a smaller signal step size to be measured.

For example, if an acceleration signal is digitized to 13 bits at 3.9 mg/LSB, oversampling can be used to resolve that signal to 14 bits at 2.0 mg/LSB.

The increase in resolution is achieved by sampling data at a rate greater than the Nyquist rate, and then averaging the data.

Example: If the frequencies of interest in the acceleration signal were up to 100 Hz, the a sufficient sampling rate would be 200 Hz, per the Nyquist theorem. For oversampling, the signal would be sampled at, say 800 Hz and then averaged to yield a new 200 Hz signal. The resulting signal would have a resolution of 2.0 mg/LSB. Note that, to achieve a higher-resolution 200 Hz signal, 800 Hz sampling capability was required.

The built-in first-in first-out (FIFO) buffer of the ADXL345 and ADXL346 assists with oversampling by allowing a large number of samples to be acquired by the accelerometer and then all of the samples transmitted to the controller in quick succession, minimizing how often the controller is interrupted by the accelerometer. Once all of the samples are retrieved from the accelerometer, the data can be filtered and a single, higher resolution sample produced.

OVERSAMPLING THEORY:

Oversampling theory states that to achieve an increase in resolution, the signal of interest must be sampled at some multiple of the Nyquist rate. This multiple is called the oversampling ratio and for an increase in resolution of *n* bits is equal to:

$$OSR = 2^{2n} \tag{1}$$

where OSR is the oversampling ratio. An increase in resolution of *n* bits allows for smaller signal step sizes to be measured.

For example, the ADXL345 and ADXL346 can produce an output signal with 3.9 mg/LSB resolution. Oversampling by a factor of 4 results in a 1 bit increase in resolution and allows measurement of acceleration in step sizes of 2.0 mg. The data rate of the resulting signal will be ¼ of the oversampled data rate.

The theory behind oversampling is that the total quantization noise in an over-sampled signal is the same as the signal sampled at the original rate, but the total quantization noise is spread over a wider bandwidth. The oversampled signal can then be filtered at the original bandwidth and the total quantization noise is reduced. With the total noise reduced, the signal can be resolved into finer steps while maintaining the original signal-to-noise ratio (SNR).

FIFO CONFIGURATION:
To configure the accelerometer to use the FIFO,

1. Configure the FIFO via the FIFO_CTL register (address 0x38):
    a. The FIFO_MODE bits (bits [D7:d6]) should be programmed with either 01 or 10, for FIFO mode or Stream mode respectively.
    b. The Trigger bit (bit [D5]) is not used in either of these modes, so it can be left cleared.
    c. The value recommended by the Set FIFO Samples field under Accelerometer Configuration is the value, in decimal, written to the Samples bits (bits [D4:D0]) of the FIFO_CTL register.

    For example, configuring the FIFO to be in FIFO mode with 16 FIFO samples would result in a value of 0x50 being written to FIFO_CTL.

2. Configure and enable the watermark interrupt:
    a. Map the Watermark interrupt to the correct interrupt pin using the INT_MAP register (address 0x2F, bit [D1]). Write 0 to this bit to map the interrupt to INT1; write 1 to map the interrupt to INT2

    If no additional interrupts are used, this would correspond to a value written into the INT_MAP register of 0x00 for INT1 and 0x01 for INT2.

3. Enable the Watermark interrupt in the INT_ENABLE register (address 0x2E) by setting bit [D0].

    If no additional interrupts are used, this corresponds to writing a value of 0x01 to the INT_ENABLE register.

READING THE FIFO:
With the accelerometer configured, placing the accelerometer into Measurement mode will begin the acquisition of data and filling the FIFO. This can be done by setting the

Measure bit (bit [D3]) in the POWER_CTL register (address 0x2D); This corresponds to writing a value of 0x08 into the POWER_CTL register.

Once the accelerometer begins to acquire data, the FIFO will begin to fill up at the rate set in the BW_RATE register (address 0x2C). When the number of samples in the FIFO equals the number set by the Samples bits (bits [D4:D0]) in the FIFO_CTL register (address 0x38), as per the Set FIFO Samples recommendation, the Watermark interrupt will trigger. It will remain triggered until the number of samples in the FIFO goes below the number set by the Samples bit. The FIFO is read by reading the data registers (address 0x32 through 0x37). Each time the data registers are read, the FIFO will pop a new sample into each data register. The data registers should be read a number of times equal to the value in the Samples bits each time an interrupt occurs to ensure that no samples are discarded.

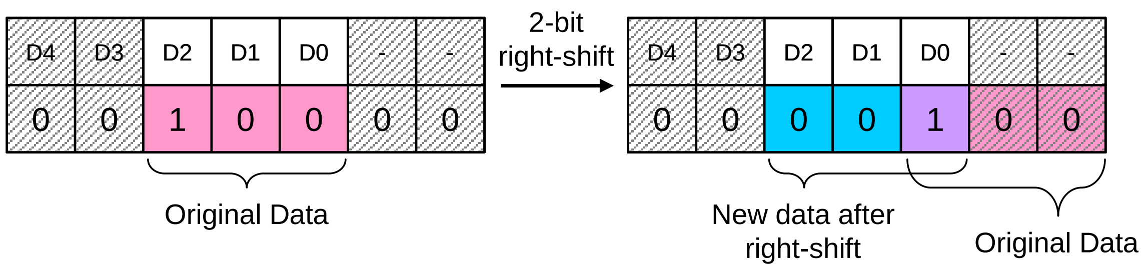
Note: One sample of acceleration data in the ADXL345 or ADXL346 is composed of 6 bytes of data, two bytes for each of the 3 axes. When using the FIFO, a multiple-byte (i.e., 6-byte) read should be performed to prevent sample mixing. The appropriate product data sheet should be reviewed to learn about multiple-byte reads.

For OSR values up to 16, the appropriate number of values should be stored in the FIFO and read in one batch. For OSR values greater than 16, multiple reads of the FIFO will be required. In this case, 16 samples (x-, y-, and z-axis values) would be read at a time from the FIFO (if the Allowable FIFO Samples parameter is greater than 16).
If multiple reads are required, the first 16 samples would be read and stored. The controller would then wait for the next Watermark interrupt, then read 16 more samples and repeat this process until all of the samples have been acquired.

For example, for an OSR of 64, 64 samples would need to be read, requiring four FIFO reads at 16 samples per read. The "Set FIFO Samples" recommendation would be 16. Each batch of 16 samples would be read when the Watermark interrupt is triggered.

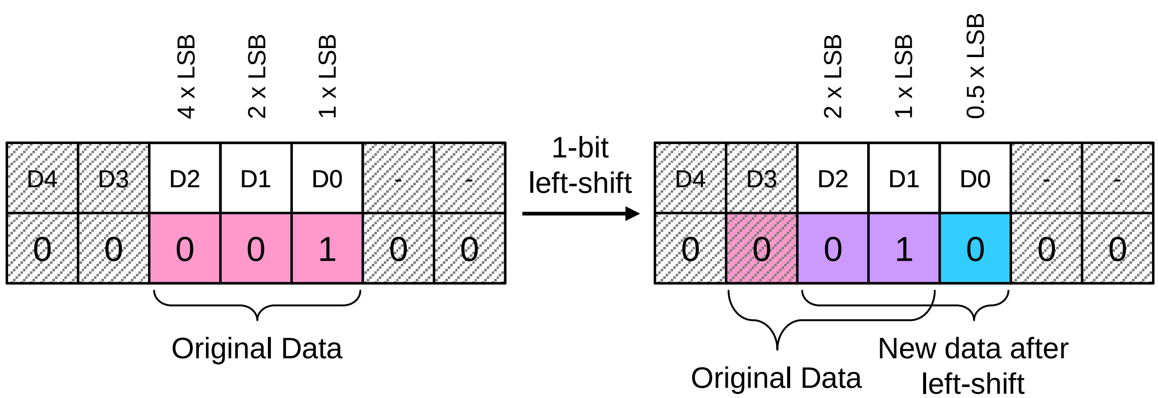
DATA PROCESSING:
The filter commonly used and applicable to this tool is the averaging filter, where samples are summed together and the result is divided by the total number of samples. Since the total number of samples, equal to the OSR, is modulo-2 ($OSR = 2^{2n}$), division can be accomplished by right-shifting by 2n bits.

For example, if the sum of four values was 4, the binary representation would be 100_2. In this case, $OSR = 4 = {}^{2n}$, therefore n = 1. The value 100_2 is right-shifted by two bits (2n), resulting in 001_2 or a decimal value of 1. This is indeed the average of four samples whose sum is 4.



Additionally, left-shifting the data by 1 bit would increase the resolution of the data and result in the LSB of the new data being equal to one-half of an LSB of the original data.

For example, if the value of a sample was 001_2 *and the LSB was 3.9* mg*, left-shifting the data by 1 bit would result in a value of* 010_2*, which should still equal 3.9* mg*. The only way* 010_2 *equals 3.9* mg *is if the LSB of the new value is half the original, or roughly 2.0* mg.



If the sum of the samples was first left-shifted by *n*, to increase the resolution, and then right-shifted by 2*n*, the result would be the average value of the samples with an increase in resolution by *n* bits. This process is simplified by summing the samples from the accelerometer and then right-shifting the sum by *n* bits.

The pseudo-code below demonstrates the process of averaging samples, as described above:

```
int8    rshift;             // The number of right-shifts, depends on OSR
int8    osr;                // OSR, equal to number of samples to sum
int8    sample_num;         // Counter for summing loop
int16   accel_data[256];    // Data from accelerometer, separate set of data for
                            // each axis
int16   output_sample;      // Filtered output sample
int32   sum;                // Sum for this particular axis

// User-generated routine to set rshift and osr
```

```
SetParameters(rshift, osr);

// User-generated routine to retrieve data from accelerometer
GetData(*accel_data);

// Compute sum
sum = 0;
for( sample_num = 0; sample_num < osr; sample_num++){
        sum += accel_data[sample_num];
}

// Resolution increase and divide
output_sample = (int16)((sum >> rshift)&0xFFFF);
```

INPUT PARAMETERS:

Accelerometer – Select either the ADXL345 or ADXL346.
The tool estimates accelerometer current consumption and resulting RMS noise after oversampling. Values are typical and based on the nominal operating voltages (ADXL345 V_S = 2.5 V, $V_{DD\ I/O}$ = 1.8 V; ADXL346 V_S = 2.6 V, $V_{DD\ I/O}$ = 1.8 V).

Bandwidth selection – used to select which bandwidth parameter is fixed. The tool will calculate the resulting system bandwidth if the accelerometer bandwidth is inputted and will calculate the required accelerometer bandwidth if the system bandwidth is fixed.

Bandwidth – select the accelerometer or system bandwidth (as appropriate per the Bandwidth Selection choice).

Desired Resolution – select the desired system resolution. Tool will calculate necessary OSR to achieve this resolution.

Allowable FIFO Samples – enter the largest number of samples that can be batch-read from the FIFO without data loss. (If data loss is not a concern for the application, use the default value of 31.)
The built-in FIFO in the ADXL345 or ADXL346 is 32 samples deep. Acceleration is sampled into the FIFO and can be read in batches. An interrupt, referred to in the datasheet as Watermark, is triggered when a certain number of samples has been written into the FIFO. The number of samples that triggers a Watermark interrupt is adjustable via a register setting. If there is overhead or system latency that prevents the controller from servicing the Watermark interrupt when it occurs, data may be lost.

For example, if four new samples could be acquired in the time it takes to service the interrupt, the Allowable FIFO Samples should be set to 28. If the system latency is less than the time it takes to acquire one sample (the inverse of the accelerometer output data *rate) or if losing data is not a concern for the application, this value can be left at its default of 32.*

TOOL RECOMMENDATIONS:

ACCELEROMETER CONFIGURATIONS:
Set FIFO Samples:
Sets the number of samples in FIFO at which a Watermark interrupt is triggered. Configured by writing the recommended value to the FIFO_CTL register (address 0x38).

Set Accelerometer Bandwidth:
The bandwidth is set by adjusting the output data rate (ODR), which is equal to twice the bandwidth (by the Nyquist condition). ODR is configured by writing the recommended value to the BW_RATE register (address 0x2C). By default, the ODR is set to 100 Hz, or a 50 Hz bandwidth, with a value of 0x0A.

OUTPUTS:
System Bandwidth – Displays the resulting system bandwidth to achieve the desired resolution after oversampling.

RMS Noise – Estimated output noise performance after oversampling. Typical value based on product performance at nominal voltage settings. Value is based on the x/y-axis performance; z-axis noise performance is typically 50% higher.

Accelerometer Current – Typical current consumption of accelerometer, based on necessary accelerometer bandwidth and typical parameters at nominal voltage settings.

Oversampling Ratio – Necessary oversampling ratio to achieve the desired resolution.