Frequency Translation Using Decimation

Introduction

Frequency translation is the process of moving a signal from one part of the frequency axis, to another part of the axis. Frequency translation is often done in wireless communications systems to move a pass band signal to base band before demodulation. Complex multipliers can be used to perform frequency translation, but a more efficient method is to use decimation.

Requirements for Frequency Translation Using Decimation

In digital signal processing applications, aliasing is usually avoided at all costs. However, in this application aliasing is the mechanism at work. Care must be taken so the aliasing produces the desired result instead of the usual negative results associated with aliasing.

First, the signal to be translated must be band pass in nature. In general, this means that the signal of interest must occupy a relatively narrow band, and all other frequencies must have significantly less energy. However, this requirement is application specific since there may be applications that perform well, even with a significant amount of aliasing.

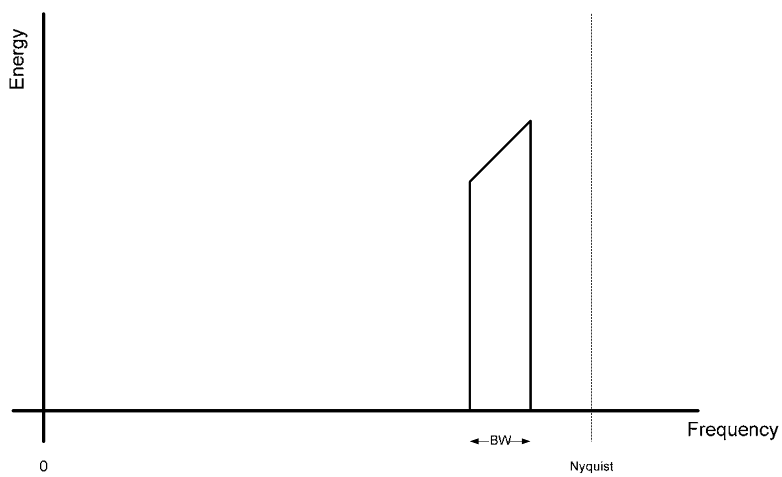

Figure 1 Band pass signal

Figure 1 shows a band pass signal with a bandwidth of BW, centered at a frequency relatively high compared to BW. The energy of the signal of interest is much higher than the energy in the other frequencies. This requirement can be met in one of two ways. In some cases the signal may be band pass in nature to begin with, or the application may call for a signal that is only mildly band pass. In this case the decimation can be done immediately. In most cases the band pass signal will need to be created with a band pass filter before decimation is done.

Second, the bandwidth of the signal of interest, BW, must be less than the original sample rate divided by two times the decimation factor. This requirement is summarized in (1).

$$BW < \frac{f_s}{2D} \qquad (1)$$

The requirement in equation (1) ensures that the final sample rate is high enough for the signal of interest band width.

Aliasing Creates Frequency Translation

The mechanism at work in this technique is aliasing. Aliasing is the phenomenon in digital processing where signals are translated from one location on the frequency axis to another location on the frequency axis. In most application this frequency translation destroys the signals, since multiple signals can be translated to the same new frequency, thus destroying each other and the information they contain. When done correctly the frequency translation can be controlled, and the result is useful.

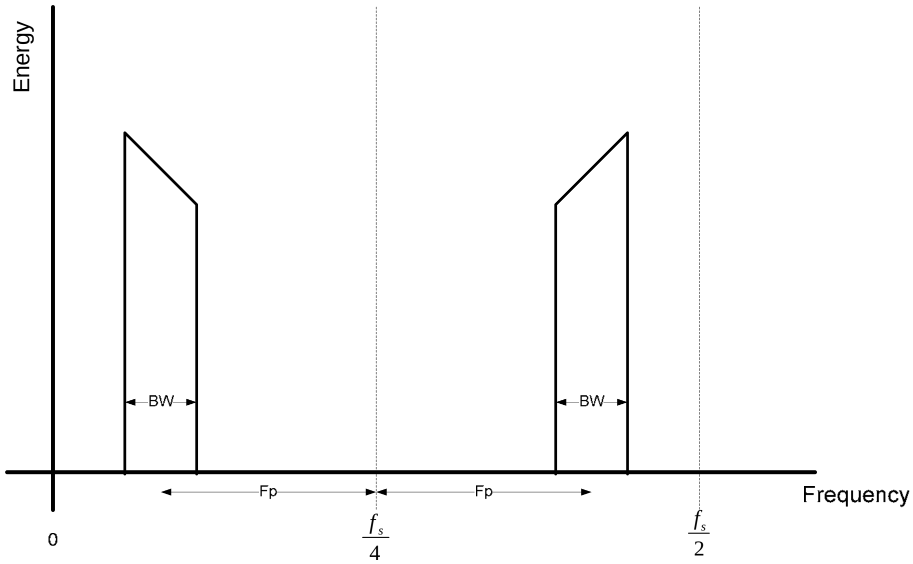

Figure 2 Decimate by two example

In Figure 2 the simple case of decimation by two is shown. The original sample rate is f_s and the new sample rate is $f_s/2$. A band pass signal with bandwidth BW is centered at frequency ($f_s/4 + Fp$). After decimation the signal is centered at ($f_s/4 - Fp$). In this case the spectrum has been inverted. If the spectral inversion is an issue in a specific application, different parameters can be chosen so that the spectrum is not inverted.

The reason for the two requirements mentioned in Section 3 can be seen in Figure 2. If the signal is not band pass in nature and there is significant energy present at ($f_s/4 - Fp$), then the signal of interest at ($f_s/4 + Fp$) will alias into the signal at the lower frequency and will be corrupted. If the new sample rate is not at least twice the bandwidth of the signal, then the signal will not fit into the new frequency space without aliasing.

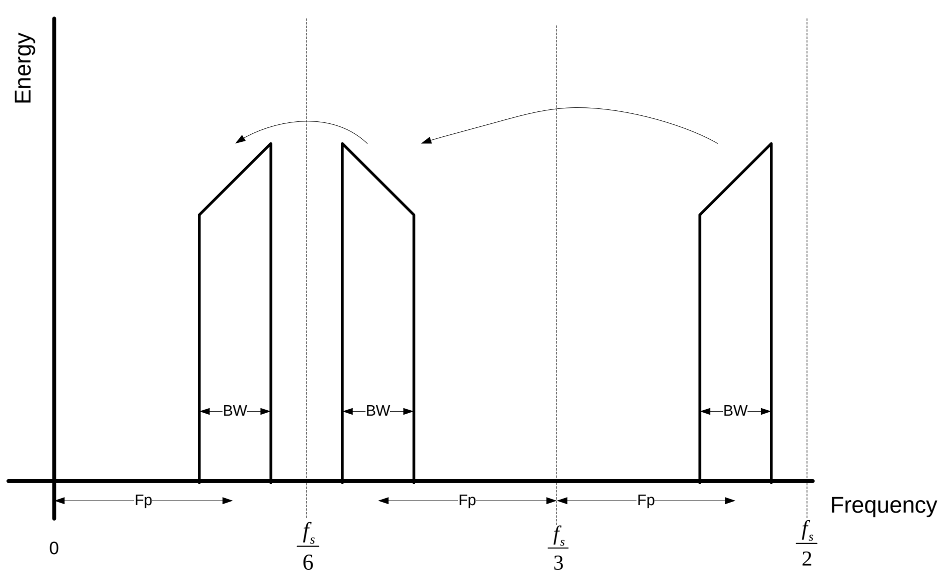

Figure 3 Decimation by three example

In Figure 3 the case of decimation by three is shown. The original sample rate is f_s and the new sample rate is $f_s/3$. The figure shows the conceptual idea of the signal of interest 'flipping' over each multiple of $f_s/3$. If the number of flips is odd, as in Figure 2, the spectral will be inverted. If the number of flips is even, as in Figure 3, the spectrum will not be inverted. This rule can be extended to any value of *D*. To avoid a spectral inversion, choose *D* such that the number of 'flips' is even.

Expanded Discussion of Spectral Inversion

Given the original sample rate, the decimation factor, and where in the frequency spectrum the signal of interest lies, it is easy to know if spectral inversion will occur. First, various parameters are defined below.

f_s - the original sample rate

$\frac{f_s}{2}$ - the original Nyquist frequency

D - the decimation rate

$\frac{f_s}{D}$ - the new sample rate

$\frac{f_s}{2D}$ - the new Nyquist frequency

The frequency axis can then be divided into D sections between 0 Hz and $\frac{f_s}{2}$ Hz. Each section is $\frac{f_s}{2D}$ Hz in length as shown in Figure 4. If the signal of interest falls in an odd-numbered section there will be no spectral inversion. If the signal of interest falls in an even-numbered section, then the spectrum will be inverted. Referring back to Figure 2, the signal of interest is in the second $\frac{f_s}{2D}$ length section, so there is spectral inversion. In Figure 3 the signal of interest is in the third $\frac{f_s}{2D}$ length section, so there is no spectral in version.

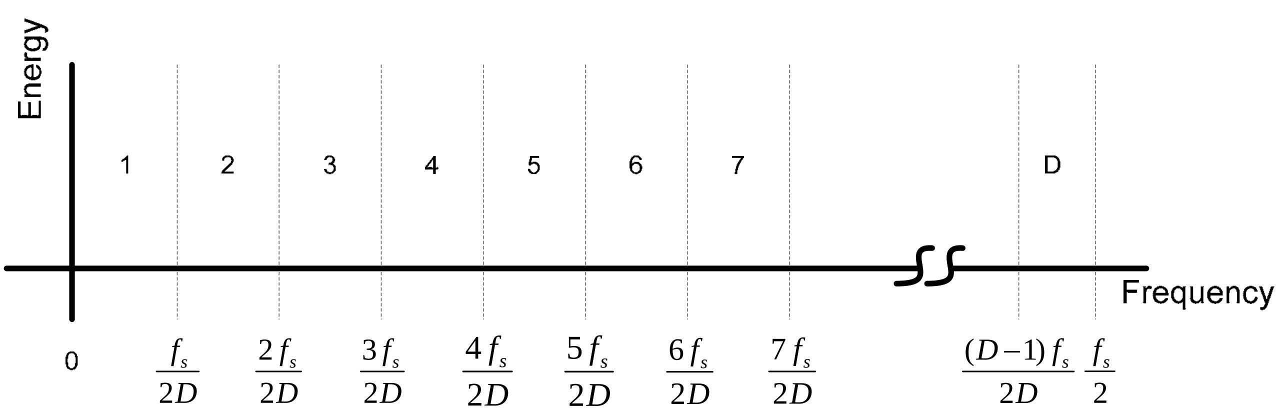

Figure 4 Frequency axis divided into D sections

Applications of Frequency Translation

There are two main applications for frequency translation in the context of the QF4A512 and QF1D512 parts.

a) Moving the signal of interest closer to DC so that the 512 taps of the filter are more effective.

b) Moving the signal of interest below the maximum operating frequency of the parts.

The first application is moving the signal of interest closer to DC to more efficiently use the 512 taps available in the filter. In most applications, a 512 tap filter is more than enough to do the required processing, but occasionally a filter with a smaller transition band or more attenuation is needed. Since the filter properties, such as transition band width, are a function of both the number of taps and the sample rate, lowering the sample rate will increase the effectiveness of a given number of taps. Performing frequency translation using decimation lowers the sample rate and increases the effectiveness of the filter taps.

The seconds application is decreasing the sample rate of a signal so that it is less than the maximum sample rate supported by the part. This process can be useful when using the QF1D512 part to process a signal with a sample rate over 500 kHz, for example.

There are many possible ways to use frequency translation with the QFxx512 parts. Some of the possibilities are shown below.

More Effective Filtering of Non-Band-Pass Signals

The first scenario is when more effective filtering is desired using frequency translation. In this scenario, the signal is not band pass in nature to begin with, so a band pass filter is used before the decimation. Two QF parts are used in this scenario as shown in Figure 5. The first part is used as a band pass filter and the second part is used to decimate and further filter the signal at the lower sample rate.

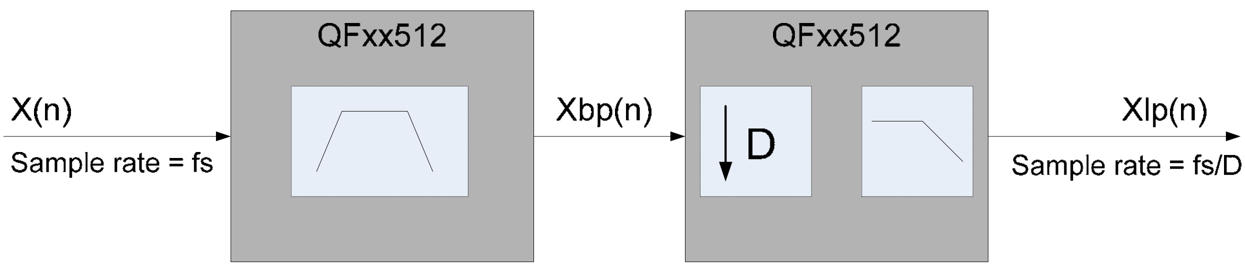

Figure 5 More effective filtering using two QF parts

More Effective Filtering of Band-Pass Signals

The second scenario is when more effective filtering is desired using frequency translation. In this scenario, the signal is band pass in nature to begin with, so a band pass filter is not needed before the decimation. One QF part is used in this scenario as shown in Figure 6. The part is used to decimate and further filter the signal at the lower sample rate.

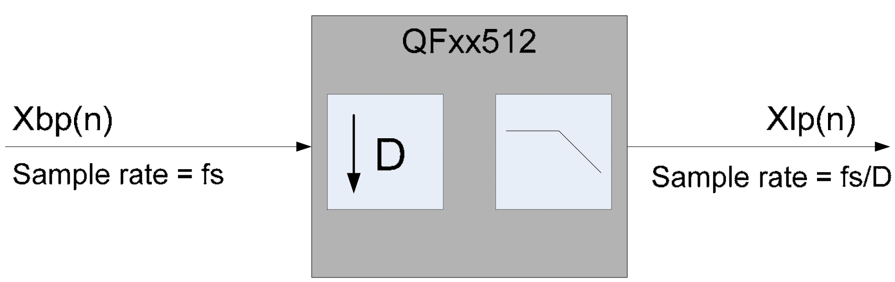

Figure 6 More effective filtering using one QF part

Signals Above the Maximum Operating Sample Rate

The final scenario is when the original signal has a sample rate higher than the maximum allowed by the QF1D512 part. In this case the signal must be band pass filtered and decimated before it enters the part. One possible scenario is the signal is already band pass in nature, and the QF1D512 is fed with digital samples by a microcontroller. If these conditions are met, the microcontroller can decimate the signal by sending every D^{th} sample to the QF1D512 part, instead of sending every sample. This scenario is shown in Figure 7.

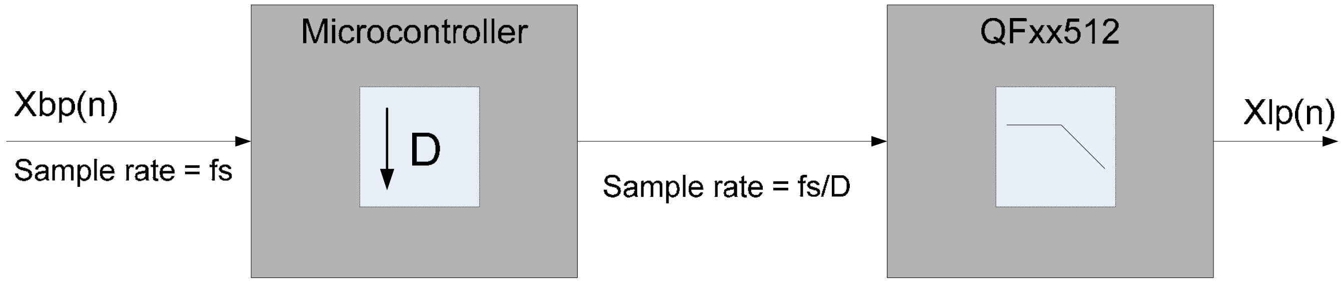

Figure 7 Signal above the maximum sample rate

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