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People reading this have likely heard of the Watkins-Johnson HF-1000 with its many DSP filters, and other receivers or transceivers using DSP filtering are appearing, such as the Yaesu FT-1000MP. Although DSP can be performed on any form of data (such as the results of a survey on spending habits), our concern is with a relatively broadband analog signal in time (such as a collection of audio or radio frequencies) which is sampled periodically and converted into a continuing sequence of digital words. Digital Signal Processing (DSP) takes this sequence of digital words and performs computer computations on it, which result in another sequence of digital words, which, for example, might be a filtered version of the input signal, and would be perceived as such when the digital signal is converted back to analog. Although DSP can be performed on a stored set of data using a personal computer, real-time DSP usually takes place in hardware dedicated to those computations.

In the past few years, DSP has been used in commercial units only at audio frequencies or at the low IF frequency of 25 kHz used in the Watkins Johnson HF-1000. This is because the analog to digital (A/D) converters used to provide the digital signal for processing were only capable of handling these low frequencies. However, A/D conversion technology is developing at such a swift rate that digital signal processing at the frequency of reception is already a possibility.

The following article describes these possibilities and was originally published in the EDN Products Edition of September 21, 1995, and is used with permission of the author who works for Pentek, Inc., a company which specializes in producing DSP boards, including receivers.

Digital Receivers Bring DSP to Radio Frequencies

by Rodger H. Hosking, Pentek, Inc.

With the advent of digital receivers and high speed digitizers, the benefits of modern digital signal processing techniques have become available at radio frequencies. Economical, high-speed sampling A/D converters offer sample rates in excess of 50 MHz with 10-bit resolution. Digital receiver chips perform down conversion, lowpass filtering and decimation of the sampled RF signal. The resulting bandwidth and sample rate reduction makes it possible to perform real-time calculations, such as FFT spectrum analysis.

Digital receiver chips are available from manufacturers such as Graychip and Harris. The first one, introduced by Graychip in 1990, was the GC1011 narrowband receiver. Harris introduced the HSP50016, its first single-chip digital receiver in 1992. Graychip followed the GC1011 with the improved GC1011A in 1992 and with its GC1012, a single chip wideband receiver, also introduced in 1992.

In this article we'll present an overview of the classic analog superheterodyne receiver and compare it with its digital receiver counterpart. If you'd rather not assemble your own boards, you'll be happy to know that off-the shelf boards and the software required to implement receivers on the VMEbus are now available from board manufacturers. To this end, we'll give you an example of how to assemble the better part of a digital receiver and signal analysis system with commercially available boards.

The Analog Receiver

Radio receivers have been around for approximately one hundred years. While there have been dramatic advances in component technology since the crystal radio and revolutionary improvements in system architecture such as the superheterodyne circuit, receivers have relied primarily on analog devices for the RF signal path.

During the last 25 years, receivers have been equipped with features such as digital readouts for frequency display, and digitally-controlled phase-locked loop synthesizers to replace the older LC local oscillators. Nevertheless, these receivers still employ analog signal processing and do not meet the definition of "digital receiver" as used in this article.

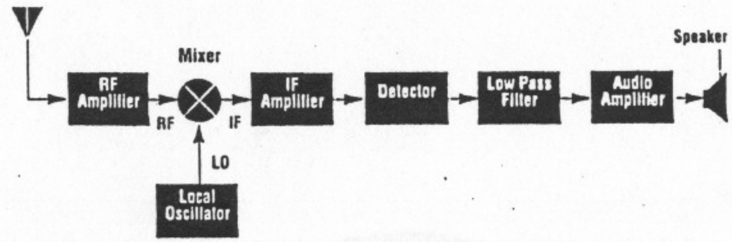

Figure 1. Analog Receiver Block Diagram

To better understand the differences between analog and digital receivers, let's review the typical block diagram of a traditional analog receiver:

As shown in Figure 1, we need an antenna to pick up the signals from the air. Then we need a tuned radio frequency (RF) amplifier to boost the weak signal from the antenna,. Its output is fed into a multiplier, usually referred to as a mixer or down converter. This device has an additional input that comes from an internal variable-frequency local oscillator (LO). When we tune to a station, all we are doing is changing the center frequency of the RF amplifier (F_{IN}) and the frequency of the LO (F_{LO}), so that we can make the difference equal a fixed frequency $F_{IF} = F_{IN} - F_{LO}$.

The output of the mixer is the difference frequency between its two inputs. Actually, when we multiply two frequencies as we just did, we get sum and difference products of the two frequencies and of the harmonics of these frequencies. However, by judicious filtering at the output of this device, we can eliminate all but the lowest frequency, which is the difference frequency of the fundamental components of the input frequencies.

This is the so-called intermediate frequency, or IF. In the FM band, for example, it is equal to 10.7 MHz. This difference signal is further amplified in the IF amplifier, a narrowband amplifier aimed at boosting the IF signal, while rejecting all the undesirable by-products of the mixing process. Again, in the FM example, the bandwidth of the IF amplifier is 200 kHz.

The next essential component of a receiver is the detector, or demodulator. Its function is to extract the information signal such as speech or music from the IF carrier and deliver it to the audio amplifier which drives the loudspeaker. The detection process is always accompanied by a low pass filter, which is required to limit noise bandwidth and to band limit and shape the information spectrum to meet broadcasting requirements.

This the basic block diagram of the classic superheterodyne receiver, so named because it employs this mixing and down conversion process. Why all this fancy analog signal processing? Simply because it improves some important parameters of radio reception such as sensitivity, selectivity, signal/noise ratio and adjacent channel rejection.

Enter the Digital Receiver

Today's digital signal processing technology has made inroads into analog technologies including radio reception. We are now talking about true DSP, not just the buttons and digital readouts of the analog receiver.

Let's take a look at a digital receiver such as shown in Figure 2. A quick overview will readily confirm that its main task is to take a signals sampled at a high rate, down convert it, low pass filter it, T78-2-2

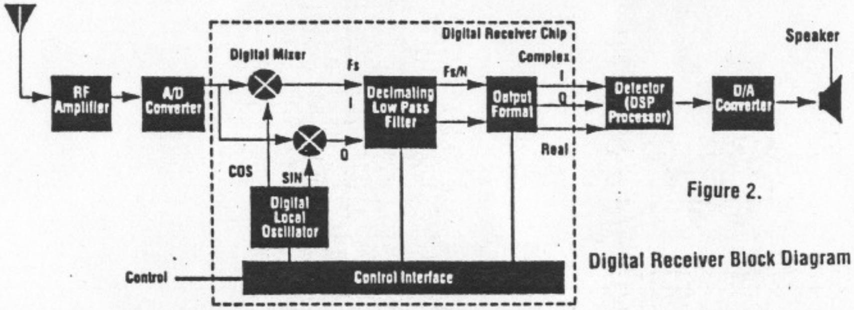

Figure 2.

Digital Receiver Block Diagram

decimate it, and format it into one or more of several forms. After demodulation, we can then convert this signal to analog form and apply it to a power amplifier and loudspeaker, if listening to the news or music is all we want to do.

To pluck a weak signal from the air, we still need an antenna and an RF amplifier. The signal up in the air is still analog, but now we will convert it to digital form with the aid of the A/D converter following the RF amplifier. Next, we take this signal of ones and zeroes and apply it to a digital mixer, just as we did in the analog receiver. Only this time we apply it to two mixers, driven by digital in-phase (I) and quadrate (Q) components of a local oscillator, which in turn is provided by a digital frequency synthesizer. In essence, we are multiplying the input signal with the sine and also with the cosine output of the LO. We need both components. if we want to perform calculations such as computing the complex FFT.

Just as in the case of the analog receiver, the output of the mixer consists of sum and difference frequencies extending way up in the sampled data spectrum. We need to remove the higher order components so that we may recover the baseband signal. We do this by passing the signal through a decimating low pass filter. This digital filter has the property of reducing the bandwidth and sample rate of the input signal by some factor which can be programmed to be as low as one or as high as 131,072 (2^{17}). Since this filter is digital, it has very low bandpass ripple, extremely sharp bandpass characteristic and linear phase, something not possible in the analog world.

The final block in this diagram formats the output signal and makes it available in one or more of several forms, such as complex, i.e. consisting of I and Q components separately available from the two outputs, real only, or interleaved I and Q components in serial form. Depending on the digital receiver chip used, the formatter can also be programmed to provide 16, 24 or 32 bit 2's complement output or IEEE floating point data.

As far as the demodulator function is concerned, it is best performed digitally in a DSP processor outside the digital receiver chip. The processor offers the flexibility of implementing different demodulation algorithms by simply downloading the appropriate software code.

We can now follow the demodulator with a D/A converter and speaker, to complete the analogy between the analog and digital receiver.

A Digital Receiver and Signal Analysis System

Except for the antenna, the RF amplifier, and the VGA display, a multi-channel receiver and signal analysis system can be put together with off-the-shelf boards.

Pentek offers two such digital receiver boards called the 4271 and 4272. The 4271 has four identical narrowband receiver channels, while the 4272 has one wideband and two narrow-band receivers.

The bandwidth of the narrowband receivers can be programmed from less than 1 kHz to over 1 MHz, while that of the wideband receiver can be set from less than 1 MHz to more than 20 MHz.

Pentek also offers a variety of A/D boards, including the Model 6472, which is a dual channel high-speed 10-bit A/D capable of operating at sampling rates of up to 70 MHz.

We can use the two-channel 6472 A/D and one 4271 to construct a multichannel receiver with different center frequencies that could be used for continuous monitoring of select frequencies in, say, the short-wave band.

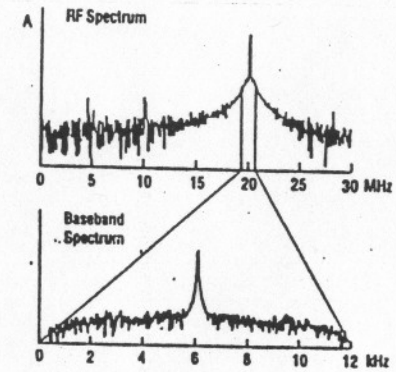

Figure 3. Down Conversion To Baseband

We can take the outputs of the receivers and apply them to a Model 4270 Quad 'C40 DSP processor board, perform the demodulation function, and also calculate and display the real-time spectra of each band under observation.

As stated before, the advantage of using a digital receiver is the down conversion and resulting bandwidth and sample rate reduction, which makes it possible to perform real-time calculations. As shown in Figure 3, an FFT calculation of the receiver output signal is an actual "zoomed-in" view of the selected slice of the input RF spectrum. The position and bandwidth of the slice are programmed by setting the LO frequency and decimation factor of the digital receiver.

Digital Receiver Applications

These new digital receivers offer an excellent solution when DSP is required for signals contained in a certain frequency band of a wideband RF signal. This is typical of many frequency-division multiplexed communications systems, modem modulation schemes and many forms of radar signals. By taking advantage of the receiver hardware to selectively remove out-of-band data, the signal processing demands of more expensive DSP hardware can be dramatically reduced.

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(ed. note: The above should provide some food for thought. A complete DSP glossary would be a good idea, but I'm not the person to do it. However, an FFT is a "Fast Fourier Transform", which is a computation which can take a series of samples of a waveform in time, and delivers a representation of the frequency spectrum of that waveform. And decimation is a process which takes a sequence of samples, and breaks it down to subsets which can be manipulated more easily and/or quickly, but I believe that there is more to it than that. DSP is not a trivial subject!)