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DESIGN AND PERFORMANCE OF A MULTI-MODE RECEIVER CARD

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ABSTRACT

This paper will discuss the design and performance of a multi-mode receiver. The receiver is designed to operate in standard VME and PC environments and will support data rates up to 20 Mbps. The paper will discuss new digital demodulation techniques that support PCM-FM, PCM-PM, FM, PM, BPSK, QPSK and O-QPSK modulation. This new demodulator also includes a built in bit sync with soft decision outputs. This paper will provide an overview on digital filtering used in the second IF filter which provides dynamic changing of the IF bandwidth.

INTRODUCTION

Many changes in today's telemetry environment have affected the use of standard range telemetry receivers. The most prevalent change is the increased data rate requirement for new telemetry missions. The increased data rate demand is requiring new modulation formats. However, legacy projects using low data rate methods will still have to be supported by range operation. Combine this with the decreasing spectrum issues and you have many issues to address. Most of these issues focus on the need to have a telemetry receiver that can be used for both high data rates (20 Mbps) and low data rates (10 kbps) applications. In addition the telemetry receiver will have to support multiple demodulation modes.

In the past designing a receiver that would support high and low data rates was difficult. Techniques used for high data rates required 70 MHz second IF Center Frequencies and Local Oscillators capable of tuning large ranges. These items made it difficult to build narrow filters and demodulators that would perform over many octaves of frequencies. Likewise, narrow band receivers used 20 MHz IF Center Frequencies which would not support wide IF filters. Today these challenges can be solved using digital sampling and filtering techniques.

The need for multi-mode demodulation can be solved using many of the digital techniques available through the advancement of function specific DSP technology. Demodulation mode can be controlled by on the fly programming of complex digital semiconductors. This enables demodulator design that can easily be re-configured and optimized for different modulation formats and rates.

DESIGN IMPLEMENTATION

The receiver design makes use of the latest digital signal processing IC's to facilitate a wide range of intended applications. This approach has merit in that it yields a "soft" radio that can be easily re-configured for changing applications. A block diagram of the receiver is shown below in Figure 1.

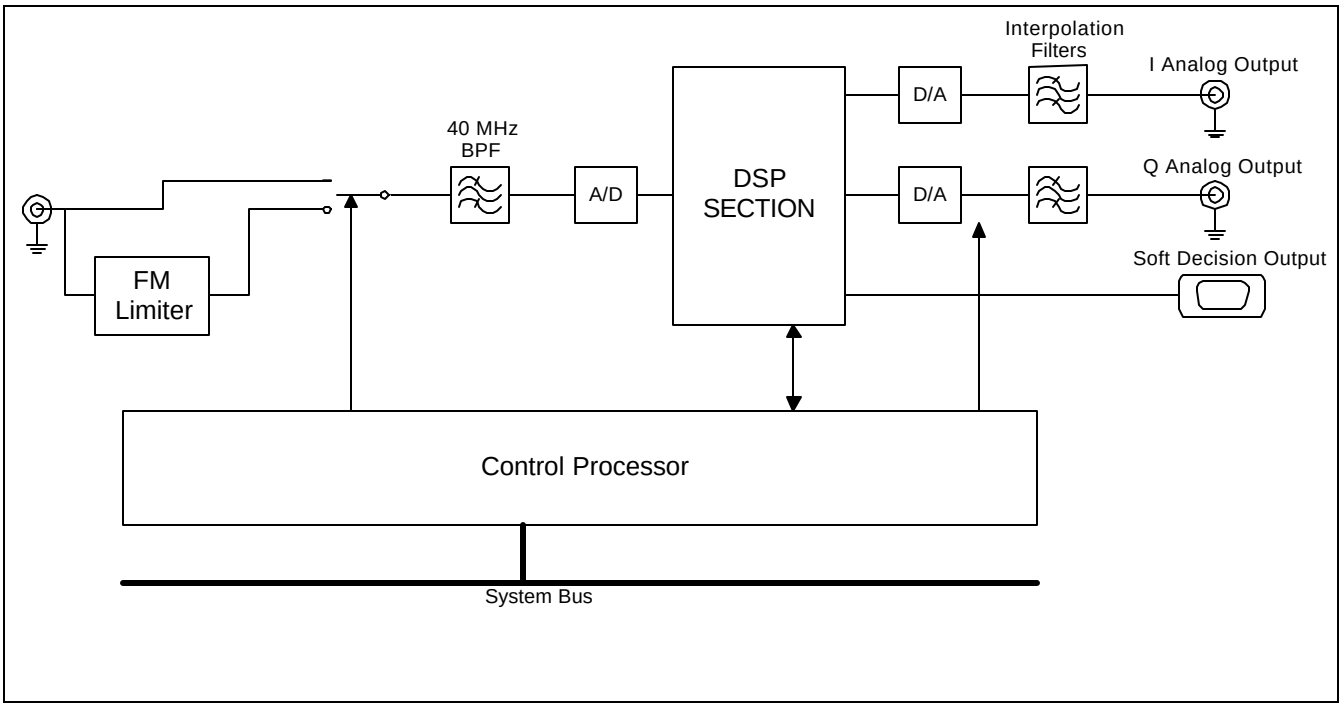


Figure 1 - Receiver Block Diagram

Input Sampling and Anti-Aliasing Filters

The input signal is centered at 70MHz and may be up to 20 MHz wide. The A/D converter has a 10-bit resolution. Wideband signals are sampled at 90 MHz while narrowband signals are sampled at 45 MHz. The distinction between wideband and narrowband is drawn from the partitioning of Digital Signal Processing (DSP) components and analog filters required for such a large range of signal bandwidths. There is some flexibility as to where the crossover occurs. As will be shown, the wideband-processing path is able to cover a range of bandwidths from 75 kHz to 20MHz. The narrowband-processing path is able to process signal bandwidths up to approximately 1 MHz and can easily handle the narrowest signal bandwidth of 10 kHz.

Alias Profile for 90 MHz Sampling

The sampling of the high bandwidth signals at 90 MHz creates replica's of the signal at multiples of the Nyquist (half the sampling) frequency as shown in Figure 2. The input signal is shown crosshatched. Any signals or noise below 45 MHz will alias back into the processing spectrum above 45 MHz. An analog anti-aliasing filter must be used to prevent these aliased components from interfering with the signal of interest.

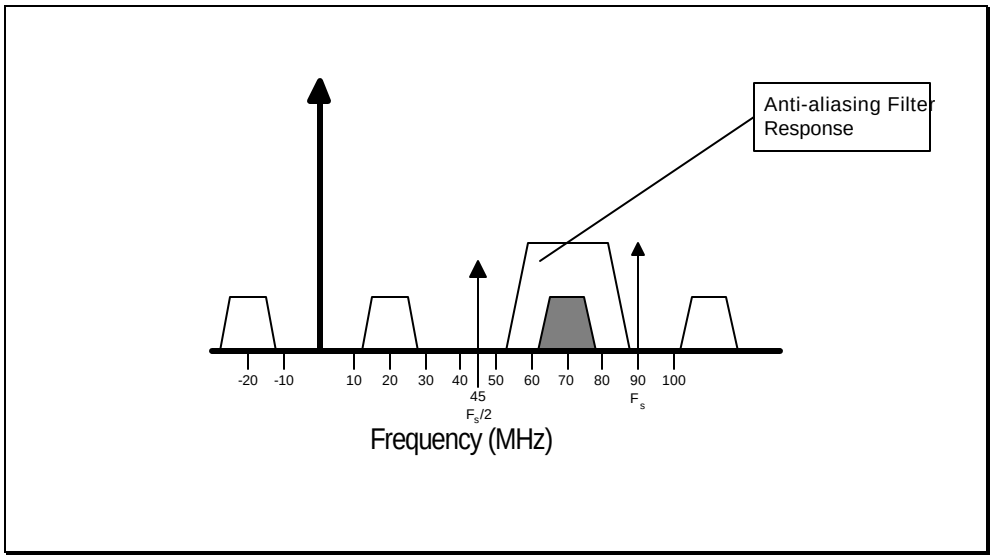


Figure 2 - Sampled Spectra and anti-aliasing filter for 90 MHz sampling

Design of the anti-aliasing filter is a compromise between minimizing group delay distortion (non-flat group delay) in the band of interest and controlling aliasing. Aliased components should be attenuated by 60 dB in the band of interest (50 to 90 MHz) in order to put them below the theoretical dynamic range of the 10-bit A/D (assuming equal spectral density). Signal components between 45 and 60 MHz will alias into the range between 30 and 45 MHz and therefore will not interfere with the band of interest. Signal components at 60 MHz and below will alias into the band of interest and therefore should be attenuated by at least 60 dB.

DSP Section

A block diagram of the DSP section is shown in Figure 3. The path through the Halfband Filter is for the wideband signals. The path through the Programmable Downconvertor is for the narrowband signals.

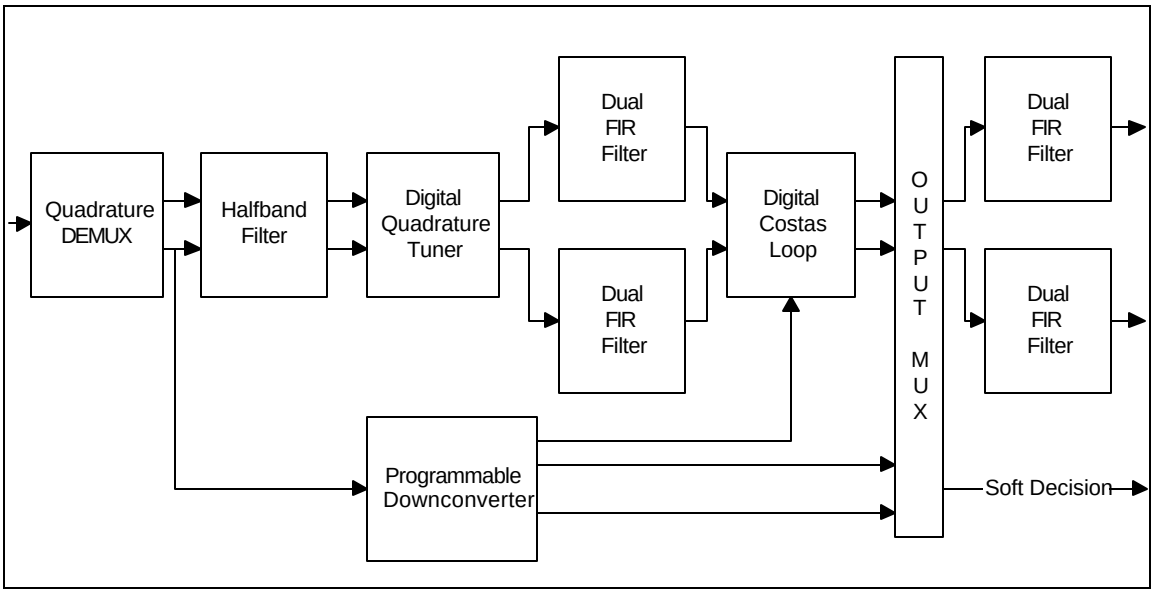


Figure 3 - DSP Section

WIDEBAND SIGNAL PROCESSING

The wideband path uses the Halfband Filter to perform the digital down conversion to a complex lowpass signal. The Halfband Filter also provides a filter which allows the sample rate to be decimated to half the input sample rate or 45 MHz. The quadrature demux logic externally de-multiplexes the two quadrature samples from the A/D and provides them to the Halfband Filter at the 45MHz rate.

The Halfband Filter shifts the spectrum by – Fs/4 (–22.5 MHz), which centers the signal just to the left of 0 Hz as shown in Figure 4. The Halfband Filter then provides real and imaginary components at the decimated sample rate of 45 MHz at the outputs. The Halfband filter removes the images created by decimation. Note that the bandwidth of the Halfband filter allows roughly 10 MHz of frequency uncertainty in either direction for the widest signal of interest.

WIDEBAND CARRIER DEMODULATION

Wideband carrier demodulation is performed by the Digital Quadrature Tuner (DQT) and the Digital Costas Loop (DCL). These function specific DSPs form a digital version of the traditional second local oscillator/Costas loop phase coherent demodulator. The DQT is a digital equivalent of a tunable second local oscillator. The DCL receives a digital error word form the DCL and adjust the frequency of a numerical controller oscillator (NCO). This allows the demodulator to form a phase coherent carrier-tracking loop. This will be used for all phase coherent modulation formats such as PSK, BPSK and QPSK. For non-coherent application the DQT can be configured to a fixed frequency.

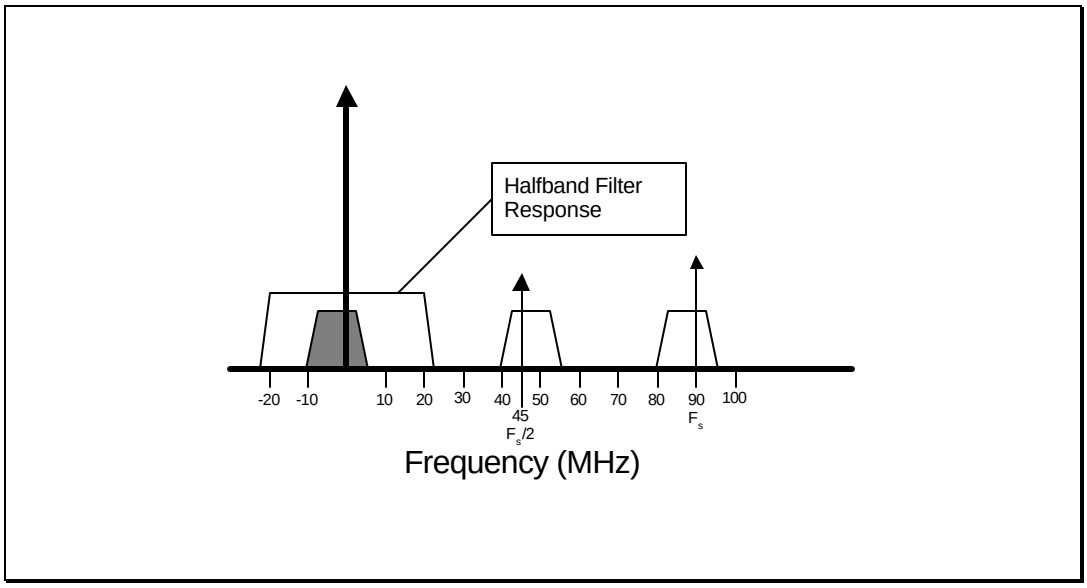


Figure 4 - Down Conversion by Halfband Filter

The Digital Costas Loop contains all the functional blocks of a traditional analog Costas loop. The quadrature signals are routed to quadrature mixers for carrier tracking. The output of the mix operation can be routed to programmable root raised cosine (RRC) filter for optimal performance. Integrate and dump filters are also available. The outputs of the matched filters are routed to symbol tracking devices. This allows the demodulator to include a single channel variable bit synchronizer with soft decision outputs. The final output of the DCL provides both polar output and frequency discriminator outputs. This will allow the demodulator to be configured for many modulation formats including FSK, FM, PSK, PM, BPSK, QPSK and O-QPSK.

WIDEBAND FILTERING

Dual FIR Filters follow the DQT. These filters operate on the complex lowpass output of the DQT providing the equivalent of selectable IF filtering in conventional receivers. This design will use these filters in the single FIR mode allowing for 16 tap symmetric FIR filters at the maximum (non-decimated) output sample rate.

The maximum signal bandwidth required is 20 MHz, which implies 10 MHz lowpass filters for the complex lowpass signal. A 15-tap FIR filter with a 7.5 MHz cutoff designed using the Blackman window is shown in Figure 5. Also shown is a 15 tap filter with a 3.5 MHz cutoff intended to show a reasonable limit for the 15 tap filters while retaining at least a 4:1, 3 dB to 60 dB, shape factor as is specified for the product.

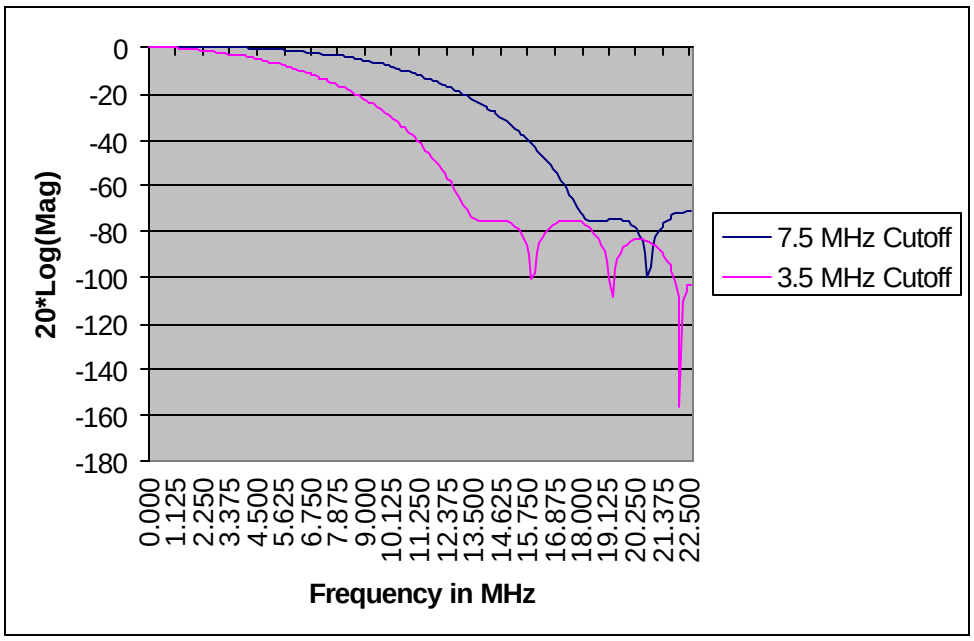


Figure 5 - Filter Response for the 15 tap Blackman FIR Filter

More filter taps are needed to satisfy the shape factor requirement at lower cutoffs. This may be accomplished in the Dual FIR Filter by decimating the output and re-using the multipliers multiple times. Decimation by 16 is possible which yields a maximum 256 tap filter.

In order to show the transition between filters; Figure 6 shows a 3.5 MHz cutoff filter implemented with a 31 tap FIR. The decimation by 2 required to compute 31 taps creates a new Nyquist frequency at 11.25 MHz (note the change of scale on the frequency axis between Figure 5 and Figure 6). In other words, the act of decimation will create a mirror image of the spectrum about 11.25 MHz. The 3.5 MHz filter is down 60 dB by 8 MHz which gives 3.25 MHz of room before the new Nyquist frequency and 6.5 MHz before the mirror image spectrum. Figure 6 also shows a 31 tap filter with a 1.3 MHz cutoff which is the lowest cutoff satisfying the shape factor requirement.

INTERPOLATION FILTERS

The dual FIR filter blocks shown after the output MUX in Figure 3 are used as interpolation (anti-imaging) filters for both the wideband and narrowband processing path. These interpolation filters allow a consistent output rate sample rate to be maintained at the output D/A Converters (DACs) over a wide range of decimation which, in turn, minimizes the number of analog interpolation filters required at the output of the DACs. For the wideband processing path, the signals will be up-sampled to 45 MHz to allow a single analog interpolation filter to be used over the entire wideband range. The widest bandwidth signal required at the output is a 20 Mbps NRZ PCM signal where roughly 95% of the signal

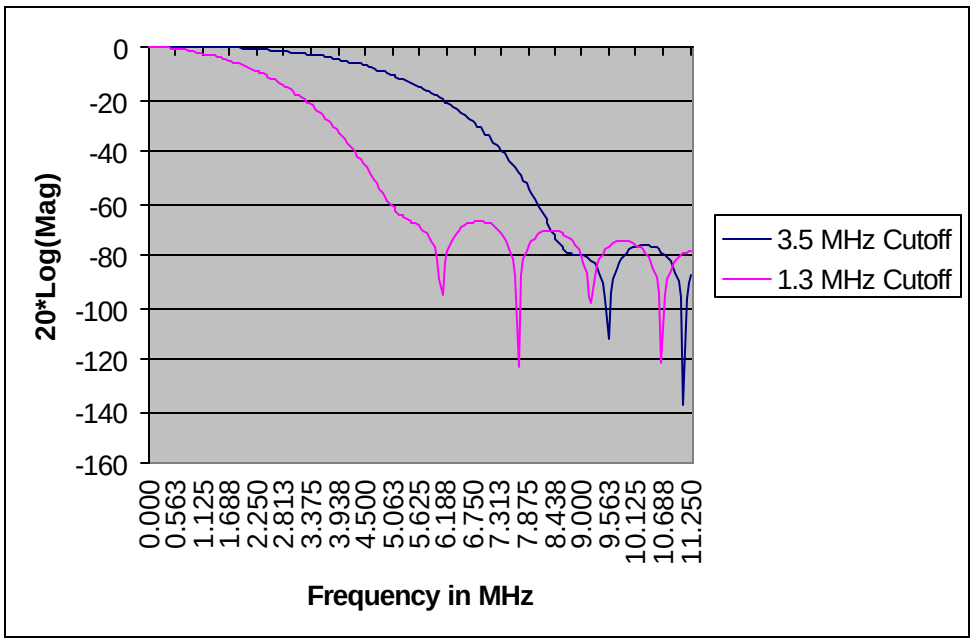


Figure 6 - Filter Response for the 31 tap Blackman FIR Filter

energy occurs below 20 MHz. Therefore, the analog interpolation filter should have its 3 dB cutoff at 20 MHz. The first sampling image will be centered at 45 MHz and have significant energy to 25 MHz (20 MHz below) for the 20 Mbps NRZ signal. The 20 MHz, 7 pole elliptical filter module has a stopband that is 50 dB down and a transition band of roughly 7 MHz. Most of the energy in the image would be attenuated by at least 60 dB.

NARROWBAND SIGNAL PATH

Narrowband signal processing will be performed in the Programmable Downconverter. This functional specific device includes many of the features described early in this paper such as, Digital Costas Loops, FIR Filters, Digital Tuners and matched filters. The programmable downconverter will be sampled at 45 MHz and will enable signal processing under 1.5 Mbps. This will augment to performance of the wideband system. When required to process narrow band signal, the demodulator will switch to this path. This will decrease the sampling rate by a factor of 2 and improve the sensitivity of the demodulator. Using this technique will allow processing signals as low as 10 kbps without changing receiver front end products.

PERFORMANCE

At the time of this writing, testing of this product is just beginning. Simulation and early performance estimate indicate that bit error rate (BER) performance will be within 1 dB of theoretical for both narrowband (10 kbps) and wideband (20 Mbps) applications. Full

test data will be provided at the presentation of this paper or can be obtain by contacting the author.

CONCLUSION

The Microdyne ATR-2700 Multi-Mode Demodulator through the use of functional specific DSPs provides a robust solution for applications requiring both narrowband and wideband data applications. The use of digital techniques in filter and Costas loops allows the demodulator to be used for legacy product testing as well as testing of the latest state of the art testing. These digital techniques allow the user to procure a single receiver for wideband and narrowband applications.

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