Simulation and realization of baseband pulse shaping filter for BPSK modulator

This pulse shaping technique reduces side lobe levels of bi-phase shift keying (BPSK) modulation and spectral spike elimination. Useful for space communications, the technique can be implemented in a practical way. This technique will be used in GEO satellites in the near future.

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With the continuing growth of communications and the increasing number of users, frequency bands are becoming more and more congested. To cope with this frequency congestion, many authors have studied methods to increase bandwidth use [1,2].

Significant RF spectrum limiting can be obtained in three ways. Here, the location of filter plays a key role. The various locations include:

- filter after power amplification.
- filter at intermediate frequency (IF).
- filter at baseband.

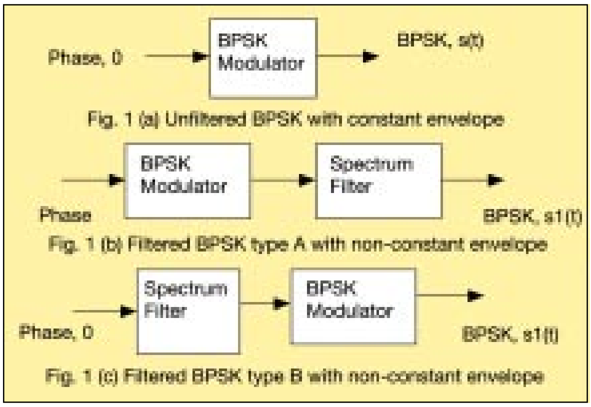

Figure 1. Various filter location configurations for BPSK spectrum .

Post power amplifier (PA) filtering is attractive to spectrum managers because all unwanted emissions, which are outside the filter's passband, are eliminated. Theoretically this filter location provides maximum control over emissions.

For effective spectrum management, the IF filter's bandwidth needs to be adjusted to each mission's maximum telemetry data rate.

However, it would be difficult for post PA filtering to improve RF spectrum use in most space missions. Filters can be either stripline or waveguide bandpass filters, which are generally used in microwave applications. For reasonable insertion losses, such filters are constrained to bandwidths ranging from 1.5% - 2% of the transmitted frequency. It should be noted that the filters that have somewhat lower insertion loss tend to be large and heavy.

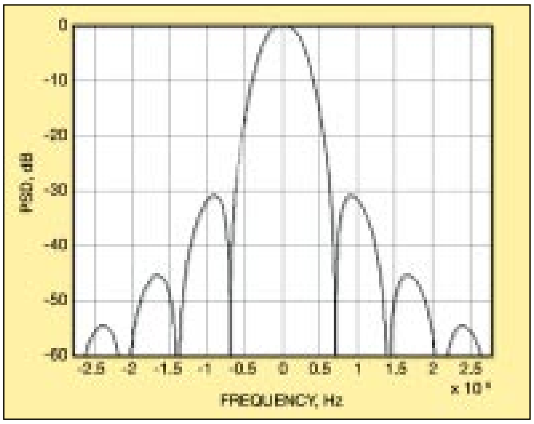

Figure 2. Simulated PSD of BPSK spectrum using new pulse shaping filter.

Filtering at IF is attractive because the filter operates at low power levels and does not reduce transmitted RF power. It is also small and lightweight and does not introduce the spectral spikes inherent in baseband filtering. For effective spectrum management, the IF filter's bandwidth needs to be adjusted to each mission's maximum telemetry data rate.

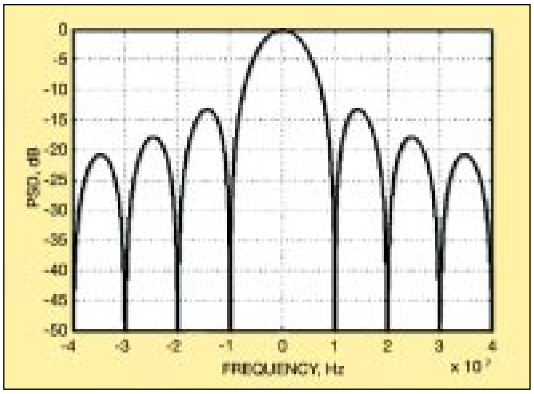

Figure 3. Unfiltered BPSK spectrum.

Baseband filtering is advantageous because the filters operate at low power levels, are lightweight, do not reduce transmitted RF power and are small and simple (lowpass rather than a bandpass). Baseband filtering of phase-modulated signals suffers from the disadvantage of introducing spikes into the RF spectrum [2]. Despite this limitation, baseband filtering is the only practical method to limit the transmitted RF spectrum for the purpose of improving bandwidth efficiency.

Pulse shaping

In general, the MPSK (M'ary phase shift keying) spectrum consists of a main lobe representing the middle of the spectrum and various side lobes located on either side of the main lobe. Shaping the spectrum should satisfy two criteria: The main lobe should be as narrow as possible, and the maximum side lobe level should be as small as possible relative to the main lobe [3].

In recent years, studies have shown that PSK modulation is particularly suited to digital satellite communications. The power spectra of a PSK signal has a $\left(\frac{\sin x}{x}\right)^2$ characteristic that may interfere with adjacent

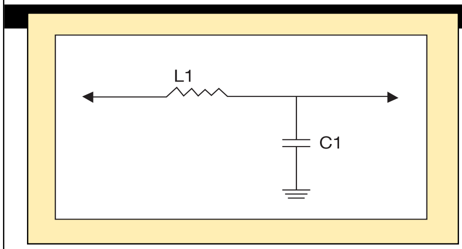

Figure 4. Gaussian filter.

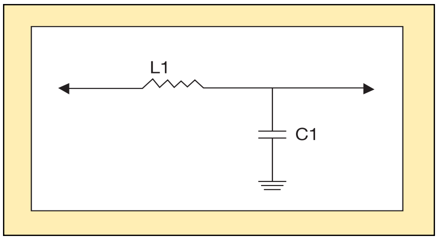

Figure 5. New pulse shaping filter.

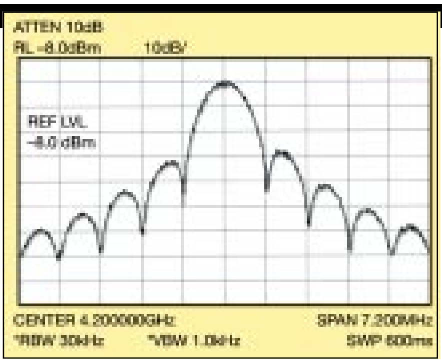

Figure 6. PSD of BPSK spectrum with new pulse shaping filter, BT=0.5.

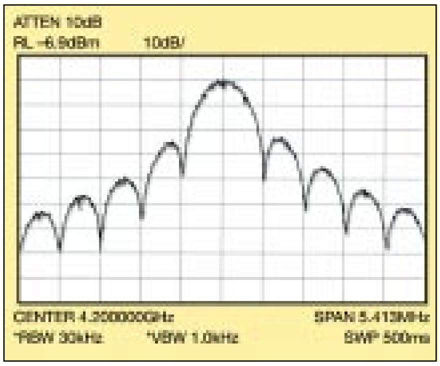

Figure 7. PSD of BPSK spectrum with new pulse shaping filter BT=0.7.

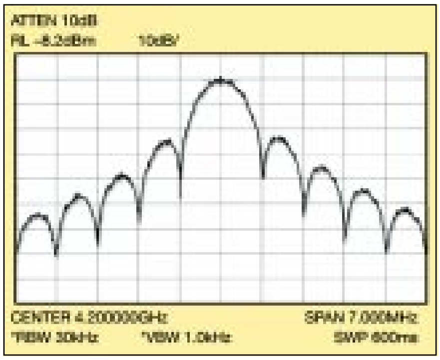

Figure 8. PSD of BPSK spectrum with Gaussian filter with BT=0.5.

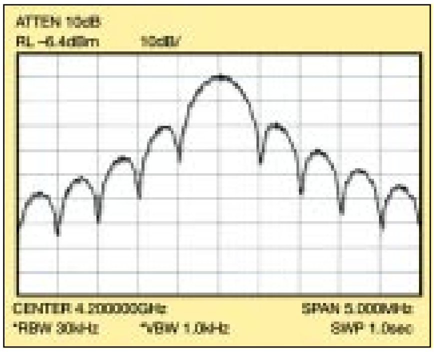

Figure 9. PSD of BPSK spectrum with Gaussian filter with BT=0.7.

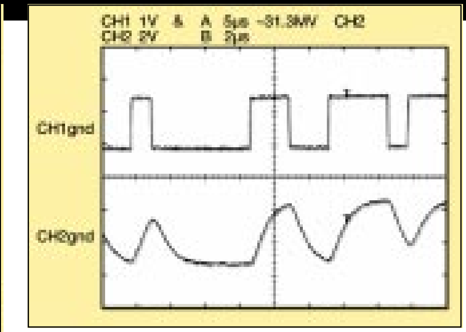

Figure 10. Input data and shaped data for Gaussian filter (BT=0.4).

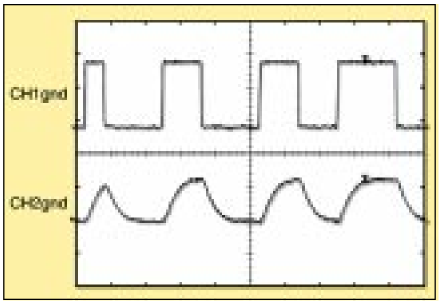

Figure 11. Input data and pulse-shaped input data of new filter.

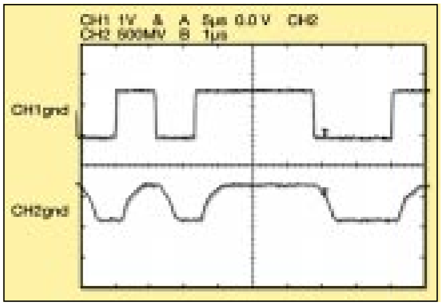

Figure 12. Input data and demodulated data of new pulse shaping filter (BT=0.4).

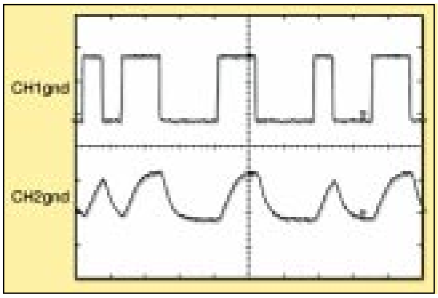

Figure 13. Input data and demodulated data of Gaussian pulse shaping filter (BT=0.4).

channels. To suppress the out-of-band interference, it may be necessary to remove the side lobes by filtering at the transmitter. Here we consider pulse shaping for BPSK spectrum.

The block diagram of the unfiltered BPSK spectrum configuration is shown in Figure 1a. In a similar way, the block diagram of the filtered BPSK configuration is given in Figure 1b. Here, the spectrum filter is placed after the modulator. To realize spectrum shaping, the phase signal goes through a pulse-shaping filter before being modulated as shown in Figure 1c. The change of the position of pulse shaping filters can produce a change of simulation results. Pulse shaping filters are used to narrow bandwidth and improve bandwidth use. However, pulse shaping can introduce distortions and can increase the risk of intersymbol interference (ISI). These distortions make the design of an optimal receiver difficult.

Many designers have tried various pulse-shaping methods [4,5]. Several types of filters such as 5th-order Butterworth, 3rd-order Bessel and square-root-cosine are used. Pre-modulation pulse shaping with different modulation schemes, such as pulse-code modulation (PCM), BPSK, quaternary phase-shift keying (QPSK) and Gaussian filtered minimum shift keying (GMSK) have been studied. In this approach, a simple pre-modulation filter has been employed to achieve low side lobe levels. Here, we considered a Gaussian filter (N=2) and a new pulse shaping filter (N=2) and compared both. In low bit rate applications (500 kbps), pulse-shaped BPSK modulation has been chosen for space communications.

Simulation work

The transfer function of the proposed new pulse-shaping filter is given by

$$H(W) = \frac{1}{1+[0.7067W(L_1C_1)^{0.5}]^{2N}} \qquad (1)$$

where $W= 2pf$, $p=22/7$, N=order of the filter. The simulated spectrum is shown in Figure 2.

The spectral density of NRZ random data is given by [6]

$$S(f) = 2\,(T_bA)^2\left[\frac{\sin^2(\pi f T_b)}{(\pi f T_b)^2}\right] \qquad (2)$$

where Tb is the bit period, A is the amplitude of the signal and f is the frequency in Hertz. The modulated spectrum is given by

$$S_{TX}(f) = \frac{1}{2}\,[S(f-f_{RF}) + S(f+f_{RF})] \qquad (3)$$

The PSD for an unfiltered BPSK signal is given by [6]

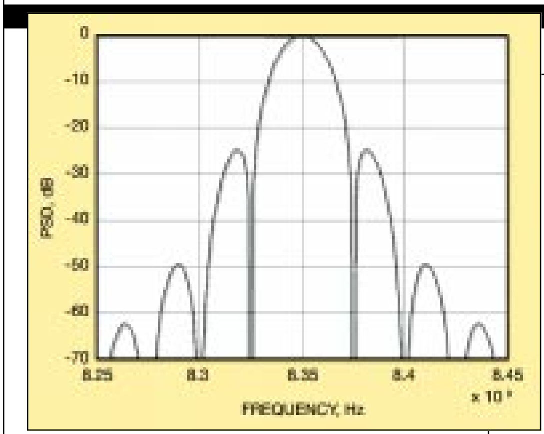

Figure 14. Simulated PSD of proposed window function.

$$S_{TX}(f) = (AT_b)^2 \left[\frac{\sin^2[\pi(f-f_{RF})T_b]}{[\pi(f-f_{RF})T_b]^2} + \frac{\sin^2[\pi(f+f_{RF})T_b]}{[\pi(f+f_{RF})T_b]^2} \right] \quad (4)$$

The theoretical power spectral density (PSD) for an unfiltered BPSK signal is shown in Figure 3. Note that the sharp transitions in the time domain lead to a relatively wide power spectral density that rolls off quite slowly. The first null occurs at a frequency equal to the data rate away from the carrier. The amplitude of the first lobe is only 13 dB down from its value at the carrier frequency, and second side lobe level is at 18 dB.

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Experimental work

In this experiment, a M/s Merrimac BPSK modulator unit has been used to study the modulated spectrum using pulse-shaping techniques. Here, we compared a Gaussian filter (N=2) [Figure 4] and a new pulse-shaping filter (N=2) [Figure 5] designed with a cutoff frequency of 350 kHz. The PSD of BPSK spectrum with new pulse shaping is shown in Figures 6 and 7 for BT= 0.5 and 0.7, respectively. Gaussian pulse shaping filter with bandwidth and time product (BT) = 0.5 and 0.7 is shown in Figures 8 and 9, respectively. One can notice from the above figures that the side lobe levels are less in new pulse shaping filter compared to Gaussian pulse shaping filter.

The shaped NRZ data using Gaussian pulse shaped filter are shown in Figure 10, and shaped NRZ data using new pulse shaping filter are shown in Figure 11. The demodulated data are shown in Figure 12 for a new pulse shaping filter and Figure 13 for a Gaussian filter. The demodulated data quality is good for a new filter as can be observed from demodulated plots. It can be clearly seen that the new pulse-shaping filter has shown advantages over the Gaussian filter for N=2.

New window function

After studying several window functions [7] and modifying their parameters successively by several iterations, a new window function was evolved. This window provides low side lobe levels. The simulated PSD of proposed window is shown in Figure 14.

The proposed window function equation in frequency domain and time domain are given by

$$\omega(f) = \frac{\tau_b}{2}\left[\frac{Sin(\pi f \tau_b}{\pi f \tau_b}\right]^2 \left[\frac{1}{1-(f\tau_b)^2}\right] \qquad (6)$$

$$\mathrm{W1\ (t)} = \frac{1}{2}\left(1+\frac{t}{T}\right) - \frac{SinW_0 t}{4\pi},\ \text{-T} <= t <= 0$$

$$\mathrm{W2\ (t)} = \frac{1}{\ }\left(1-\frac{t}{\ }\right) + \frac{SinW_0 t}{\ },\ 0 < t <= T \qquad (7)$$

where T is equal to tow.

From Figure 15, notice that the first and second side lobe levels are -25dB and -50dB, respectively. This reduction in side lobe levels helps in reducing the interference with other systems.

Conclusion

Test and simulation results indicate that the side lobe levels are less in new pulse shaping filter compared with a Gaussian filter (N=2). Consequently, the new technique can be applied to future GSAT satellite programs. RFD

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