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ADS-B UAT MOPS

Meeting 8

Brief Analysis of Raised Cosine Transmit Filtering

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SUMMARY
This paper presents a brief analysis of the use of Raised Cosine filtering on the baseband transmitted signal prior to FM modulation. The analysis contains material on both the time and frequency domains. Added in Rev A is an additional figure depicting transmitted modulation with only RC filtering.

Introduction

The following paper presents some evaluation of the use of Raised Cosine filtering on the transmitted UAT signal. Historically, all UAT modulation in the SF21, Capstone, and Pre-MOPS units has been via unfiltered continuous-phase binary FSK, relying on the transmit IF SAW filter to provide the band limiting. The original MITRE prototype UATs used a table driven Raised Cosine transmit filter, which was not carried over in UPS AT's first-generation UAT product.

The Raised Cosine (RC) filter evaluated has a roll-off factor of 0.5, and was implemented by a lookup-table implementation of a 37-tap FIR filter (+/- 3 bit filter length, odd order).

The significant issues are whether there are any benefits, or any detrimental effects, from specifying RC filtering in the UAT MOPS.

Transmitted Spectrum

The following figures illustrate the differences in the transmitted spectrum from the BFSK w/ SAW filtering method, vs. the addition of RC filtering.

Please note and ignore the spectral burst effects at the lower frequencies. In both cases, the transmit SAW filter bandwidth is the 1.2 MHz filter. The measurement bandwidth is 100 KHz.

Figure 1 - BFSK w/ SAW filter only

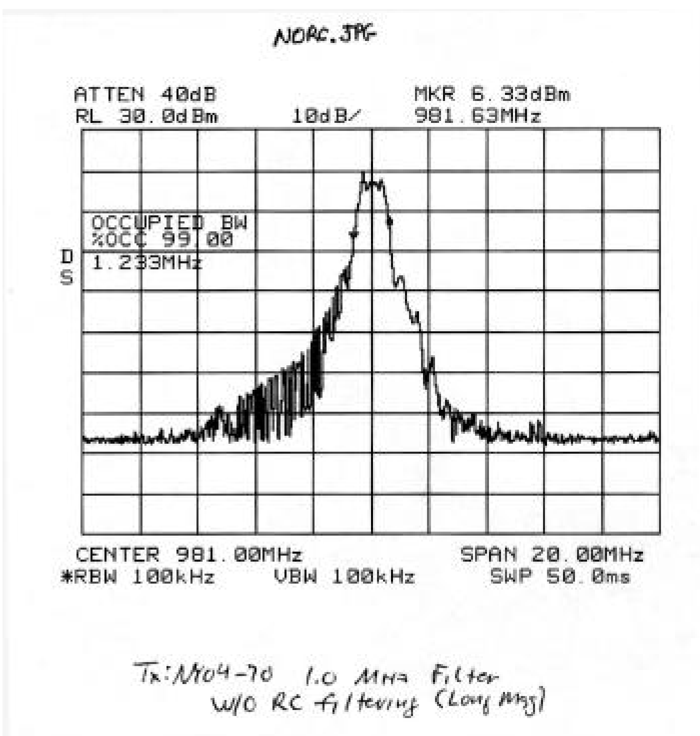
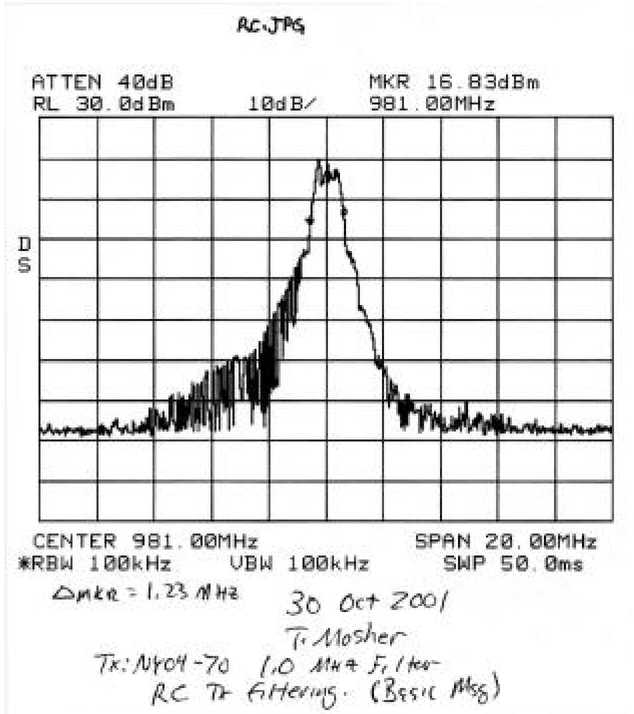


Figure 2 - BFSK w/ RC & SAW filters



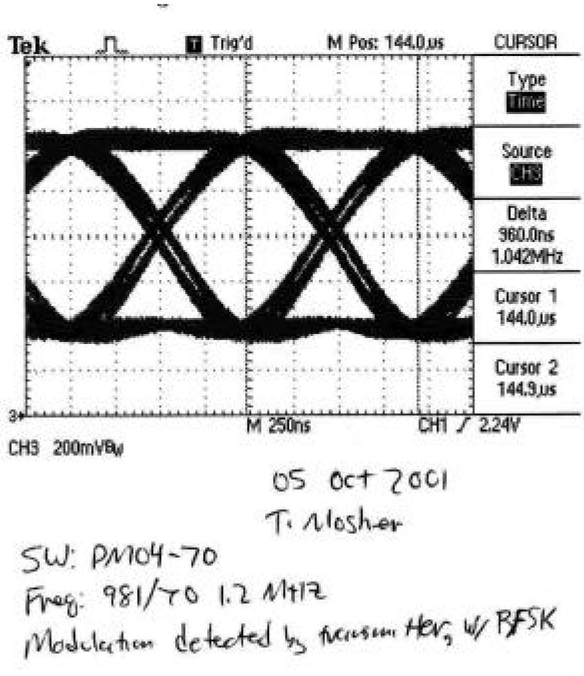
<u>Observations:</u>

1. The 99% occupied bandwidth is approximately 1.2 MHz for both cases. RC filtering has no effect on the occupied bandwidth.
2. There are what appears to be periodic spurs in the transmitted spectrum that are suppressed by the RC filter. These are most apparent at 1, 1.5, and 2 MHz above the peak signal.
3. From about 30 dB below the peak signal, the RC filtered spectrum is slightly narrower than the unfiltered signal.

Time Domain

The following three plots show the transmitted signal as monitored by the ownship receiver, and show the effect of one pass through a SAW filter.

Figure 3 - BFSK w/ SAW filter only



Note that this modulation has an ample eye pattern opening, but has none of the overshoot characteristic of RC filtering. This is the modulation on which all of the Pre-MOPS testing was performed, though this sample was measured using the 1.2 MHz filter rather than the 1.5 MHz filter in used in the transmitter units.

Figure 4 - BFSK w/ RC and 1.2 MHz SAW filter

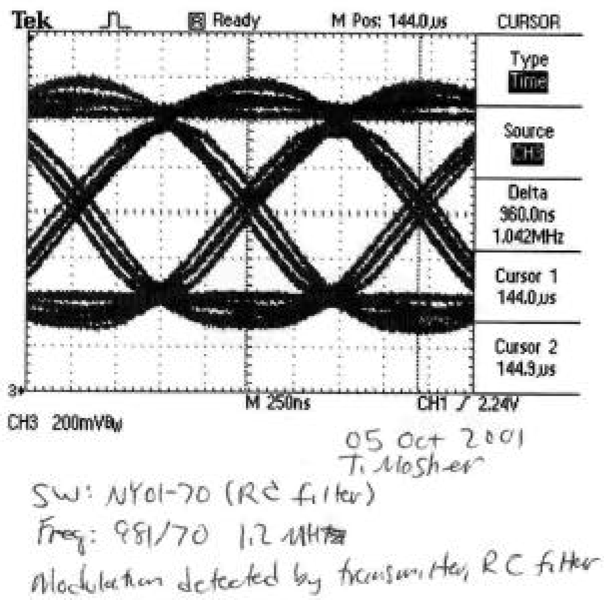


Figure 4 shows the effect of adding RC filtering to the modulation in Figure 3. There is some overshoot present, which serves to limit the frequence response by smoothing the transitions between adjacent bits. Note here that the 1.2 MHz SAW filter is causing some ISI, as evidenced by the optimum sampling points being not well focused.

Figure 5 - BFSK w/ RC and 1.5 MHz SAW filter

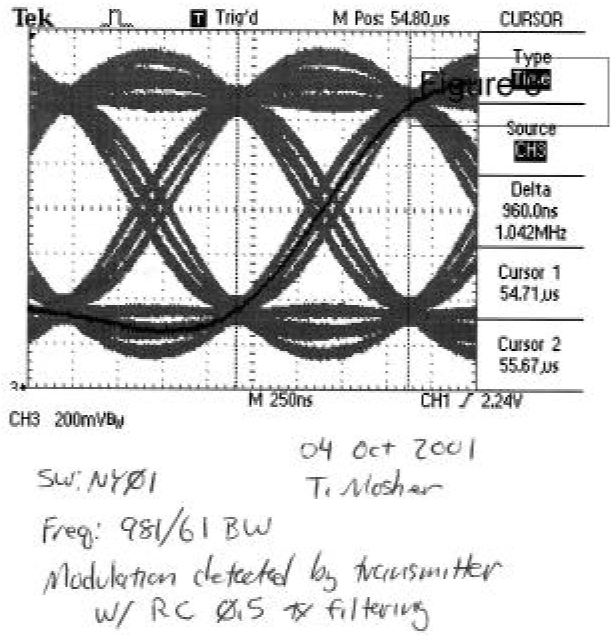


Figure 5 shows the effect of using the 1.5 MHz SAW filter rather than the narrower 1.2 MHz filter. It is debatable whether this eye pattern has substantially less ISI than Figure 4.

Figure 6 - BFSK w/ RC filter only

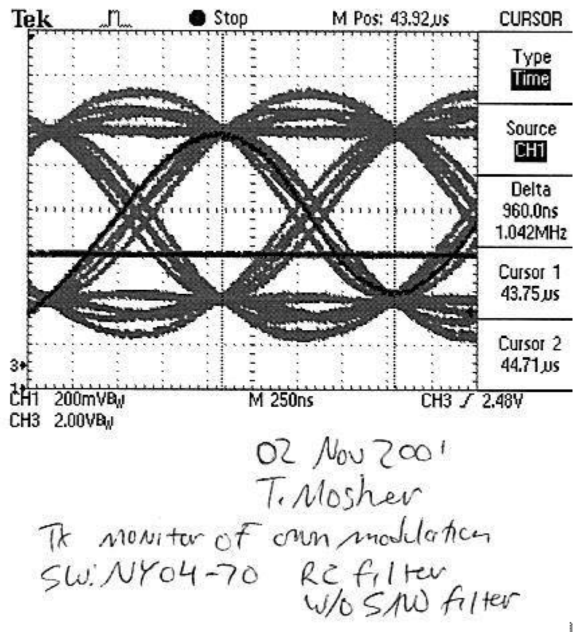


Figure 6 shows the effect of Raised Cosine filtering without using a SAW filter. In comparing Figure 5 to Figure 6, one can see that the eye pattern in Figure 6 is more open at the optimum sampling point. This is due to the time delay distortion that is present to different degrees in all of the example SAW filters. The RC filtering is implemented with a linear phase filter, which creates no time delay distortion.

<u>Observations:</u>

Comparison of the eye patterns of Figures 3, 4, and 5 shows that the addition of RC filtering in addition to SAW bandpass filtering does slightly narrow the eye opening due to the increase of the transition zone, but overall does not substantially shrink the eye pattern opening. RC filtering without SAW filtering (as shown in Figure 6), provides the least possible phase distortion.

MSR comparison measurements

Comparison measurements were made for reception of random messages by both of the proposed receiver bandwidths, with both BFSK and RC filtered signals. The following table contains relative comparison data of reception of UAT messages with no interference source. The reference signal level was determined to be the threshold of 100% MSR, and FEC is disabled for these measurements. Since this data was collected for a "quick look" comparison, only 3 data points were measured, separated by 3 dB each, rather than doing a detailed curve trace at 1 dB increments over the full performance range.

Table 1 - MSR vs. Tx Filtering and Rx BW

Tx Signal	Rx w/ 1.2 MHz	Rx w/ 0.8 MHz
BFSK ref lvl	100%	100%
BFSK ref - 3 dB	88%	91%
BFSK ref - 6 dB	12%	15%
RC ref lvl	100%	100%
RC ref - 3 dB	78%	73%
RC ref - 6 dB	7%	6%

Comparison of the left and right columns shows that receiver performance is not strongly affected by the receiver bandwidth in the no-interference case.

Comparison of the BFSK vs. RC cases shows that receiver performance is slightly degraded by use of the RC filtered signal. By referring to earlier detailed work deriving the MSR vs signal strength (see UAT-WP-6-09), we can estimate that the degradation amounts to less than 0.4 dB, which is very near to the plant noise in making these measurements.

Conclusion

Taken together, the frequency and time domain measurements presented show that there is at most a marginal degradation of receiver performance due to use of Raised Cosine filtering of the transmitted signal. The benefits of RC filtering include slightly narrower transmitted spectrum, and better suppression of close-in emissions.