The Effects of SAW Group Delay Ripple on GPS and Glonass Signals

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Biography

Damon Adams received a B.Eng. in electrical engineering from the University of Victoria in 1997.

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Abstract

The group delay ripple of SAW filters is a large deviation from the flat group delay needed for distortionless transmission, prompting the question "does this ripple cause significant group delay distortion of GPS and Glonass signals?" The answer: SAW filter group delay ripple does not cause any group delay distortion of GPS or Glonass signals. The group delay, phase, and amplitude ripple is a product of the triple-transit response of the SAW, which is a problem similar to multipath at the antenna, and can be analyzed and mitigated with the same techniques.

One technique to eliminate the ripple from network analyzer measurements is to inverse Fourier transform the frequency domain response to the time domain, employ gating to isolate the single-transit response, and Fourier transform that response back to the frequency domain. The resulting group delay is smooth, with no obscuring ripples, and can be used to predict Glonass inter-channel biases caused by the SAW filter. Also shown is a mathematical model of the SAW filter response that shows how the triple-transit response produces the ripple, and predicts its magnitude and spacing.

Introduction

A characteristic of transversal SAW filters is the group delay ripple they exhibit in their passband; a typical IF SAW filter will have periodic ripple across its passband with an amplitude of tens to hundreds of nanoseconds. This is a large deviation from the flat group delay needed for distortionless transmission, prompting the question "does this ripple cause significant group delay distortion of GPS and Glonass signals?"

The answer: SAW filter group delay ripple does not cause any group delay distortion of GPS or Glonass signals. The group delay, phase, and amplitude ripple are products of the triple-transit response of the SAW, which is a problem similar to multipath at the antenna, and can be analyzed and mitigated with the same techniques.

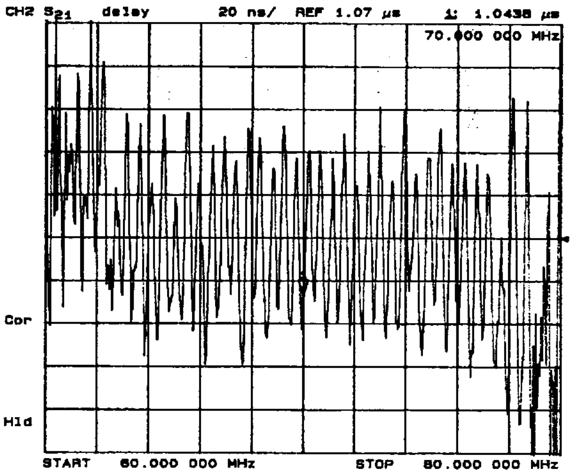

Figure 1. Group Delay of SAWTEK 854668

As evidence that the triple-transit response causes the ripple, consider the following method to eliminate it from the network analyzer measurement of a SAW filter.

The first step is to measure the frequency response of a SAW filter, in this case a SAWTEK 854688, with a vector network analyzer. Then the measured frequency response is inverse Fourier transformed to the time domain. In the time domain, a gating function is used to select the single-transit response and reject the triple-transit response. Finally, a Fourier transform is performed to take the response back to the frequency domain, and the group delay is calculated and plotted.

In the experiment for this paper, the inverse Fourier transform, the time domain gating, and the Fourier transform computations were all performed using the built-in features of the network analyzer, an HP8753A with option 010 [3]. An alternative would be to export the data points to Matlab or other math software, and do the transform operations and gating there.

Now that the triple-transit response is eliminated from the measurement, the resulting group delay is smooth, with no obscuring ripples. This is the group delay experienced by the single-transit signal, and can be used to predict Glonass inter-channel biases caused by the SAW filter. The single-transit response group delay of the SAWTEK 854668 is shown in Figure 2; compare this to the ungated measurement in Figure 1.

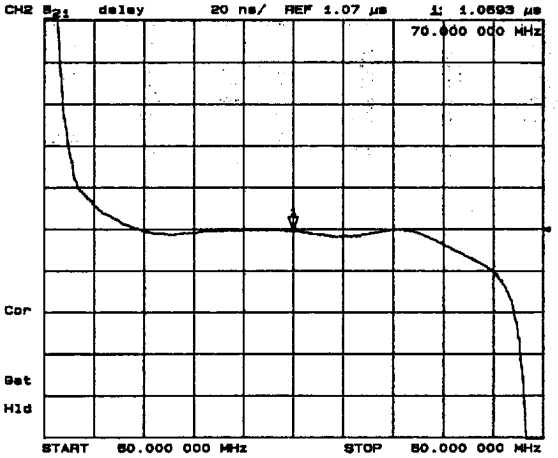

Figure 2. Group Delay of SAWTEK 854668 with time-domain gating of single-transit response.

Although the ripple does not cause group delay distortion, it does indicate the presence of the triple-transit response. The effect of the triple-transit response is similar to reception of multipath at the antenna, and is analyzed using the same techniques. The relevant parameters to determine auto-correlation function distortion are the ratio of the triple-transit response to the single-transit response, and the delay between single-transit and triple-transit, which can be read off the time domain response of the SAW obtained by the inverse Fourier transform (see Figure 3). The effects of the triple-transit response depend on the duration of the delay between the single-transit response and the triple-transit response, and the spacing of the early and late correlators.

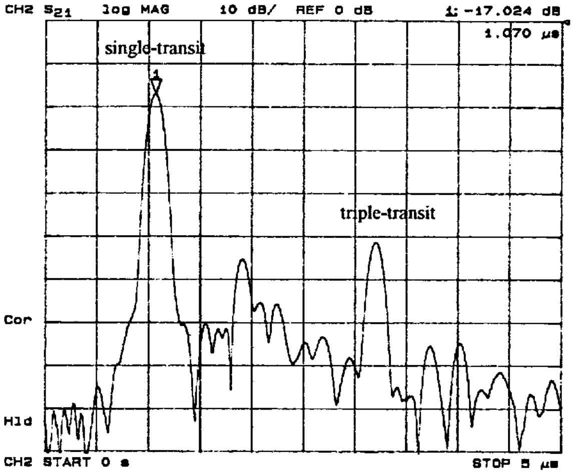

Figure 3. SAWTEK 854668 time-domain response

Multipath mitigation techniques that are effective against auto-correlation curve distortion, such as Narrow Correlator®, also work on SAW delayed responses. Like antenna multipath, the effects of SAW triple-transit multipath becomes especially significant if the delay between single and triple-transit responses is less that (1 + x/2) chips, where x is the spacing between early and late correlators. As the delay decreases below this threshold, the late correlator increasingly produces more auto-correlation power from the triple transit response. Below (1 - x/2) chips, the early correlator also produces increasing auto-correlation power as well. For this reason, Narrow Correlator® is preferable to wide correlator for SAW filters with delays of less than 1.5 chips between single and triple-transit responses. Narrow Correlator® spacing also minimizes the inequality between early and late auto-correlation delay for the triple-transit response.

The early and late correlators are near the peak of the single transit auto-correlation function, while the delay to the triple transit response put it on a weaker part of the auto-correlation function. That means the correlation process further reduces the already weak triple-transit response; for a delay of greater than one chip that process attenuation is 15 to 30 dB, depending on the auto-correlation function of that code. The particular model of SAW filter tested in this paper has a delay of about 2 GPS chips, or 1 Glonass chip, between single and triple-transit responses (note that the delay between single and triple-transit responses is the time it takes for two transits). Narrow Correlator® processing further attenuates the triple-transit response, which is already 35 dB weaker than the single-transit response, by an additional 15 to 30 dB for both GPS and Glonass. Note the similarity between the gating technique and correlator operation with a multipath signal; both the gating function and the correlator tend to further attenuate signals if they have sufficient delay from the main time domain response.

Most IF SAWs have delay times similar to, or longer, than the one tested, so in general IF triple-transit response does not significantly effect Narrow Correlator® operation on GPS or Glonass signals, and wide correlator operation on GPS signals. The single to triple-transit response delay of many IF SAWs is below 1.5 Glonass chips, which can degrade wide correlator operation on Glonass signals. Keep in mind that RF SAWs tend to have shorter delay than IF SAWs; however, the analysis methods above work for them as well.

One interesting difference between antenna multipath and the SAW filter triple-transit response; the latter is deterministic and can be characterized for a particular SAW filter. If the triple-transit response is strong enough to affect correlator accuracy, the auto-correlation function distortion can be determined a-priori and compensated for.

To understand how the triple-transit response causes the ripple, consider this simple model of the frequency domain transfer function of the SAW filter.

The input, single-transit output, and the triple-transit output, are represented by voltage phasors. All the phasors are normalized to the input voltage, and the time t = 0 (the choice of time is arbitrary; the relative angles between the phasors are the same at any instant.) The input voltage phasor has amplitude of 1 and a phase of zero.

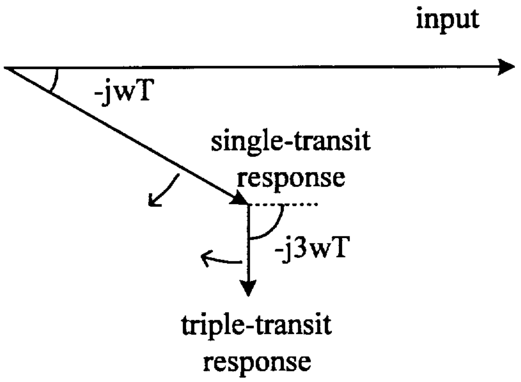

Figure 4. Phasor representation of SAW input and outputs.

The single-transit output magnitude is always smaller than the input due to the path loss as the wave propagates across the substrate. The phase of the single-transit output is shifted relative to the input phasor due to the distance the surface wave travels across the substrate. The triple transit response is even lower in magnitude; it is energy not absorbed by the output transducer on the first transit, and suffers the path loss of two additional transits before returning to the output transducer again. Its propagation delay is three times that of the single transit, and its phase shift is proportionately larger.

The net output is the vector sum of the single transit and the triple transit outputs, where the first term is the single-transit component, and the second term is the triple-transit component.

$\vec{y}(\omega)$: output vector, normalized to input [V/V]

A_1 : single-transit amplitude, normalized to input [V/V]

A_2 : triple-transit amplitude, normalized to input [V/V]

T : single transit propagation delay [s]

f : frequency [Hz]

$$\omega = 2\pi f$$

$$\vec{y}(\omega) = A_1 e^{-j\omega T} + A_2 e^{-j3\omega T}$$

This model can be extended to include other delayed responses and feedthrough by adding more phasors, but in most instances the single-transit and triple-transit will dominate the output. Calculating the magnitude and phase of the ratio of the net output vector to the input vector gives the modelled amplitude and phase response of the SAW; Matlab, or another math program, is useful for performing the computations. As the phasors rotate at different rates the magnitude and phase of the net output vector change periodically as a function of frequency. This is the amplitude, phase, and group delay ripple.

The interaction between the phasors is easier to analyze and understand if only the single-transit and triple-transit responses are included in the model. The rotation of the single-transit vector tends cancels some of the rotation of the triple transit vector, so the ripple repeats with the following spacing.

$\Delta\omega$: ripple spacing [rad/s]

Δf : ripple spacing [Hz]

$$\Delta\omega = \frac{\pi}{T}$$

$$\Delta f = \frac{1}{2T}$$

The group delay is the derivative of the phase as a function of frequency, so it's ripple is even more pronounced.

the ripple can be approximated as a sinusoid component, which is computationally easier to deal with than the exact phasor solution. The approximation is good if the triple-transit amplitude is much smaller than single-transit amplitude. The expression for the modelled amplitude is

$A(\omega)$: output amplitude, normalized to input [V/V]

$\theta(\omega)$: output phase, relative to input [rad]

$$A(\omega) = A_1 + A_2 \sin(-2\omega T)$$

$$\theta(\omega) = -\omega T + \arctan(\frac{A_2}{A_1}) \sin(-2\omega T)$$

The group delay is the derivative of the phase with respect to angular velocity.

$T_d(\omega)$: group delay [s]

$$T_d(\omega) = -\tfrac{d}{d\omega}\theta(\omega)$$

$$T_d(\omega) = T + 2T \arctan(\frac{A_2}{A_1}) \cos(-2\omega T)$$

The following values were measured with a network analyzer for a SAWTEK 854688 (see Figure 3):

$T = 1.07\ \mu s$

$A_1 = 10^{\frac{-17}{20}}$

$A_2 = 10^{\frac{-52}{20}}$

$$T_d(f) = T + 2T \arctan(\frac{A_2}{A_1}) \cos(-4\pi f T)$$

$$T_d(f) = 1.07\mu s + (38.1ns)\cos(-(13.4\mu s)f)$$

The modelled group delay has a ripple component with a peak amplitude of 38.1 ns, and a ripple spacing of 469 kHz.

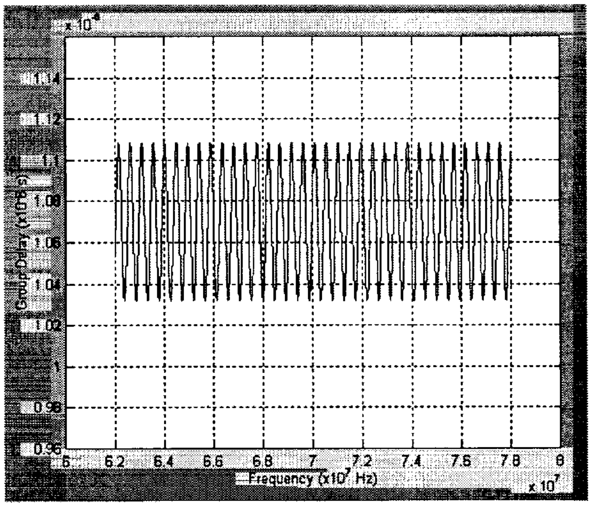

Figure 5. Modelled Passband Group Delay of SAWTEK 854688

The modelled amplitude agrees well with the average amplitude of the measured group delay ripple in Figure 1 (the variation in measured amplitude suggests another delayed response that is not included in the model). The modelled spacing of the ripples agrees very well with the measured spacing.

The converse applies as well; given the ripple spacing and magnitude, the single-transit time and ratio of the single transit and triple transit magnitudes can be solved.

T_{d-pk} : peak amplitude of ripple [s]

$$T = \frac{1}{2\Delta f}$$

$$\frac{A_2}{A_1} = \tan(\frac{T_{d-pk}}{2T})$$

The relative amplitudes of the single-transit and the triple-transit, and the single-transit delay are the most useful parameters for predicting the multipath effects on the correlator. If you dont have values for them, but you do have a group delay plot showing the ripple, you can calculated them from the above expressions.

Conclusions

SAW filter group delay ripple is a product of the triple-transit response and does not cause any group delay distortion of GPS or Glonass signals.

The triple-transit response is like a multipath signal generated internally within the SAW. It can be analyzed and mitigated with the same techniques as multipath at the antenna. If the delay between the single-transit and triple-transit response is larger than 1 chip for Narrow

Correlator®, or 1.5 chips for wide correlator, the triple-transit delay is like distant multipath and is attenuated a further 15 to 30 dB by the correlation process. In general, IF SAWs have a delay between the single-transit and triple transit response of 2 GPS chips or more, which has minimal effect on both wide correlator and Narrow Correlator® operation on GPS signals. That same delay is one Glonass chip or more, which has minimal effect of Narrow Correlator® operation, but is below the 1.5 chip threshold for wide correlator. RF SAWs tend to have shorter delays, but can be analyzed with the same methods.

The single-transit response group delay, which has the obscuring ripple removed, can be used to predict the Glonass inter-channel biases caused by the SAW. The single-transit group delay is obtained by measuring the frequency domain response of the SAW filter with a network analyzer, inverse Fourier transforming the to the time domain, gating to select the single-transit response, Fourier transforming back the frequency domain, and calculating the group delay.

Acknowledgements

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References

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