PERFORMANCE DEGRADATION IN GPS-RECEIVERS CAUSED BY GROUP DELAY VARIATIONS OF SAW-FILTERS

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ABSTRACT

In modern RF-receivers several SAW-filters are used in RF- and IF-stages. The use of SAW-filters is critical with respect to the pseudo-range error after the decorrelation-process. We present a new simulation technique to predict the decorrelation results depending on the group delay characteristics of the filters. This technique allows an improvement of the accuracy of the GPS correlation results and a related optimization of the SAW-filter characteristics.

INTRODUCTION

The Navstar Global Positioning System (GPS) [3, 5] uses a spread spectrum coded signal to measure the distance between the receiver and the satellites. The signal of each satellite is coded with a unique pseudo-random-noise code to distinguish between the different signal-sources. The public C/A-code of Navstar-GPS uses a chiprate of about 1Mchip/s so that the signal bandwidth (at 1.575GHz) is about 2MHz. Specially for high-accuracy measurements and in differential GPS receivers not only the phase of the spreading code but also the phase of the carrier is used to measure the pseudoranges. The result of the pseudorange-measurement can not be clearly defined if the group delay variation ($\Delta\tau_{gr}$) of the receiver in the band of interest goes beyond $1/f_{HF}$. Usually the term

$$\alpha := \Delta\tau_{gr} \cdot f_0 \qquad (1)$$

(where f_0 is the centre frequency) of commercial SAW-filters is in the area of 1 to 20. In this context two effects have to be considered: One problem evolves from the slightly different frequencies (± 5kHz) of each satellite caused by the motion of the satellites. This will directly lead to a pseudorange-error if the group-delay of the receiver depends on the frequency.

The other effect arises after the decorrelation process if the different spectral components of a CDMA-signal experiences different delays.

ERRORS CAUSED BY SLIGHTLY DIFFERENT CARRIER-FREQUENCIES

The group delay of the filters in the RF-part in the band of interest can usually be aproximated by a linear variation over the frequency. The resulting pseudorange error Δl can be calculated by the formula

$$\Delta l = c \cdot \delta f \cdot \frac{\Delta\tau}{\Delta f} \qquad (2)$$

with $c = 3\cdot10^8$ m/s; $\delta f = 2\cdot5$kHz and $\Delta\tau/\Delta f$ is the derivative of the group delay variation. Because (2) will not take care of decorrelation process it is only valid for small α (<1). For the RF-filter shown in Fig 3 we obtain a pseudorange variation of 1.2 mm. The resulting position error depends on the satellite constellation and is about three times higher. In commercial GPS receivers this error can be neglected. The group delay variations of IF-Filters shows much more ripples (see Fig 4). Here the calculation of the phase has to be accomplished by integrating separately over the frequency for the inphase- and quadrature component.

$$I = \int_{f_0-B/2}^{f_0+B/2} g(f)\cdot |S_{21}| \cdot \cos\left(2\pi\ f_0\ \Delta\tau(f)\right) df \quad (3a)$$

$$Q = \int_{f_0-B/2}^{f_0+B/2} g(f)\cdot |S_{21}| \cdot \sin\left(2\pi\ f_0\ \Delta\tau(f)\right) df \quad (3b)$$

$$\varphi(f_0) = \arctan\left(\frac{Q}{I}\right) \quad (4a)$$

$$\mathrm{mag}(f_0) = \sqrt{I^2 + Q^2} \quad (4b)$$

with

$$g(f) = \mathrm{sinc}^2\left(\frac{2\pi}{B}(f - f_0)\right)$$

describing the power density of the signal.

f_0 is the center frequency of the signal with bandwidth B.

Regarding a linear approximation of the group delay over the frequency, large α will result in a significantly decreasing magnitude of the correlation peak (see fig 1). The magnitude in the passband $|S_{21}|$ is assumed to be flat and the shape of group delay is linear.

It has to be noticed that this calculation gives only an approximation. The exact solution has to be evaluated as shown later.

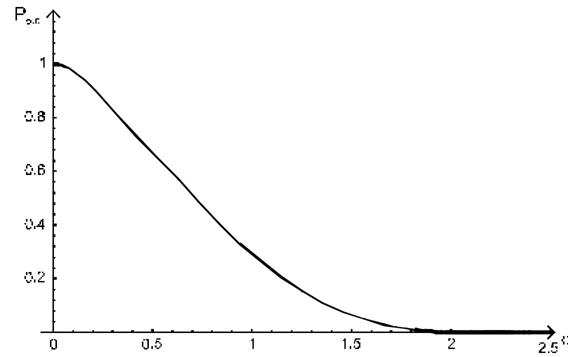

Fig. 1 decreasing output power in filters with high group delay variation

SIMULATING STRUCTURE

To obtain a reliable result of the influence in the decorrelation process a simulation of the system is necessary. The simulations were done in Matlab.

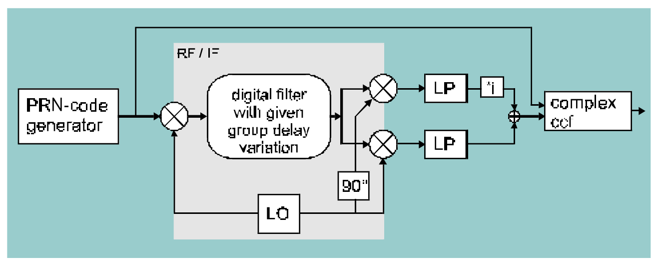

Fig. 2 structure of the simulating software

The GPS-code is mixed up to an IF-frequency (fig. 2) and filtered by a digital FIR-filter, whose group delay characteristics correspond to those of the SAW-filter. The IF-frequency and the relative bandwidth of the filter have to be chosen as a compromise between the order of the FIR-filter and the resolution of the result. In practice an IF of 1/16 of the sample rate and a bandwidth of 1/32 of the sample rate is adequate.

After the filtering the complex signal is mixed down to the baseband and complex correlated with the PRN-code of the input. By shifting the local oscillator the effect of a slight change of

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the input frequency in a GPS-receiver can be evaluated.

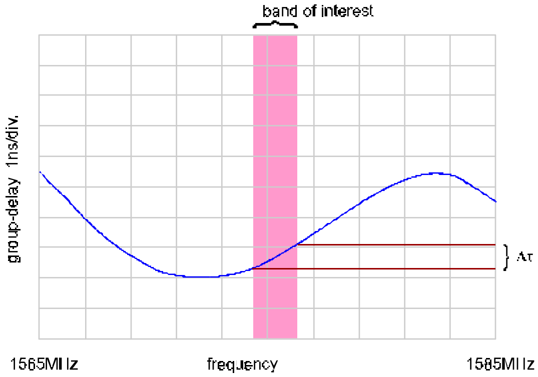

Fig. 3 typical measured group delay of a RF-filter

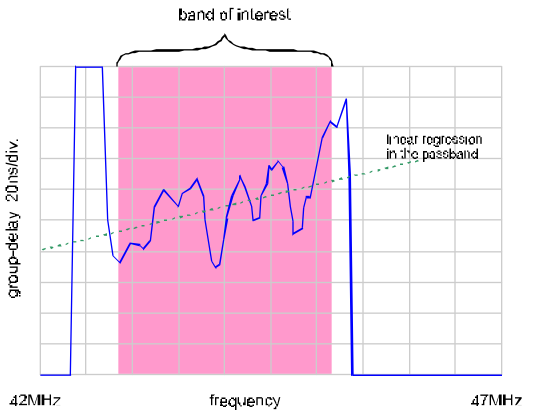

Fig. 4 typical measured group delay of an IF-Filter

FILTER MODELLING

For the filterdesign [2] two models have been evaluated. Because of stability-problems it is recommended to use only finite impulse response (FIR) filters.

The first approximation is the composition of several high-order linear bandpass-filters with two different group delays. An additional group delay in FIR filters can be implemented by inserting zeros before the coefficients. If the passbands of the filters do not overlap, the complete filter can be generated by the superposition of the partial filters. This model is easy to calculate but it is only a rough approximation of the SAW-filter.

Another method is to optimize the coefficients of a FIR-filter directly with a Simplex algorithm [4] to achieve the wanted group delay and a flat amplitude in the band of interest. To reduce calculation time the bandpass-characteristic is implemented later by folding the coefficients with those of a high order phase linear standard-bandpass.

RESULTS

The results of a filter with two discrete group delays (model one) can be taken from Fig. 5. Fig 5a shows the ideal case with no group delay variations. With small variations ($\alpha < 0.2$, Fig. 5b) an average delay will be measured. If the difference between the two group delays approaches the region of α=0.5 (180°) (Fig. 5c) two correlation peaks appear and the power of each decreases. An effect like this will not only reduce the accuracy of the GPS-receiver dramaticaly, it will also introduce problems for the carrier-tracking loop in the decorrelation process.

The simulations with a two-level group delay filter can be considered as a worst case. Nearly statistically distributed group delay variations like the IF-filter in Fig. 4 lead only to a degradation of the magnitude of the correlation peak. The influence of slight frequency drifts of the input frequency can be roughly estimated by its linear regression in the passband.

The problem lies in the uncertainty of analytically calculated results. Without a complete simulation the influence of filters with an α greater than one can not be predicted. Fig. 6 shows filter characteristics which lead to a notch in the decorrelation peak and a phase uncertainty of about 140 degrees.

[1] Ruppel et al., :„SAW Devices for Consumer Communication Applications“, IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol. 40, No. 5, Sept. 1993

[2] Unbehauen, Rolf: „Netzwerk- und Filtersynthese: Grundlagen und Anwendungen“, Oldenbourg 1993, pp. 696-704

[3] Parkinson, Spilker: „Global Positioning System: Theory and Applications“, American Institute of Aeronatics and Astronautics, Washington, 1996

[4] MathWorks: „Signal Processing Toolbox User´s Guide“, MathWorks Inc., 1996

[5] “GPS Interface Control Document ICD-GPS 200, NAVSTAR GPS Space Segment and Navigation User Interfaces”, ARINC Research corp., 1991

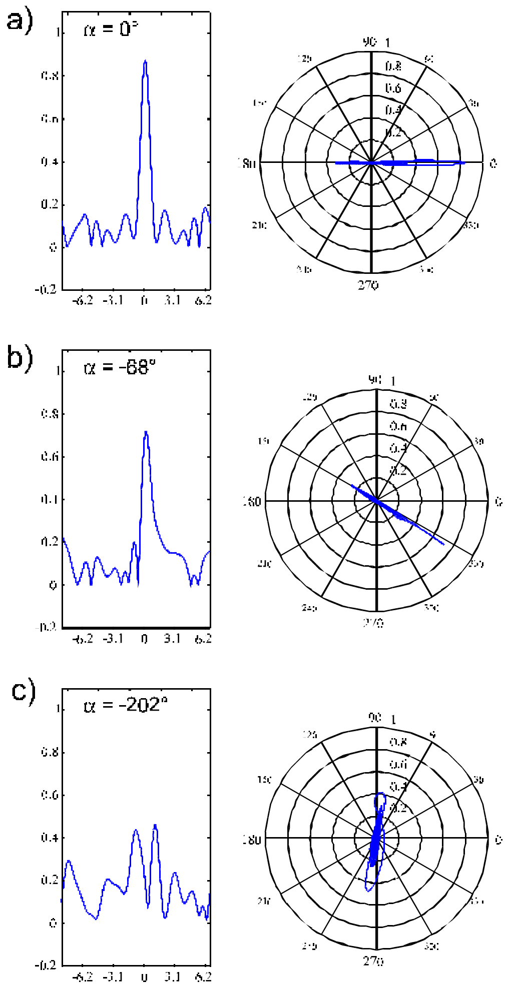

Fig. 5 Decorrelation-results in magnitude and phase of a two-delay SAW-filter

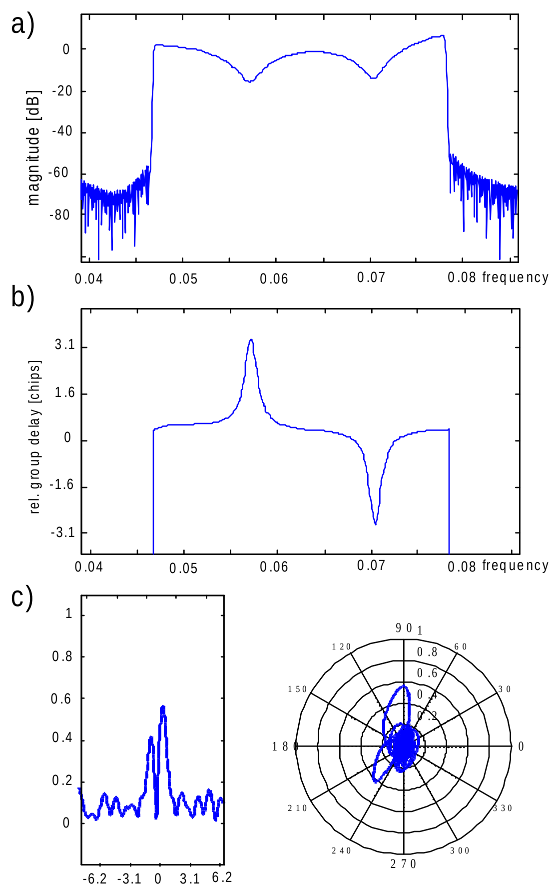

Fig. 6 Magnitude (a), group delay (b) and decorelation results (c) of a critical filter