Analysis of Phase Cal Extraction Algorithms and a Proposal for a Parallel Multitone Phase Cal Extraction Software Development

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0. Introduction

Phase cal signals are currently used in VLBI observations for a monitoring of a phase properties of receivers and data acquisition racks. It was also proposed [1] to use these signals for a system temperature calibration.

The phase cal signals are injected into VLBI data stream by the means of a picosecond pulse generator driven by 1 MHz reference clock. When downconverted to a videoband, the signals look like harmonics of 1 MHz frequency shifted by some friquency offset. It means that when a broad band (up to 16 MHz) is used, it contains up to 16 harmonics simultaneously.

An attitude to get complete information about phases and amplitudes of all harmonics in the analysed band may give us an additional increase of the calibration accuracy.

Hardware approach to the parallel multitone phase cal extraction was proposed in [2]. Here algebraic analysis of the parallel multitone extraction algorithm is presented.

1. Algorithms analysis

To determine phases and amplitudes of the calibration tones we need to measure, basically, accumulated voltages of the comlex harmonics of interest:

(1) $$V_{tone} = \Sigma_k\ S(dt*k) * \exp\{-2\pi i*(F_{tone}+F_{offset})*dt*k\},$$

where $S(dt*k)$ - input signal sampled at a time $t=dt*k$,

dt - sampling interval, nominally $dt=1\mu sec/N_s$, $N_s=1,2,...,32$ - whole number,

k - sample number with respect to the pre-determined reference time,

F_{tone} - tone frequency, nominally $F_{tone}=1MHz*N_{tone}$, $N_{tone}=1,2,...,16$ - whole number,

F_{offset} - offset frequency, frequently used as 10 KHz.

Expression (1) is the basic one to be used and it is directly implemented (with some approach of complex exponent presentation) in the current hardware and software phase cal extractors.

To clearify the idea of the parallel multitone extraction some algebraic transforms of (1) need to be done.

Lets choose a whole number K as

(2) $K = M / (1MHz*dt) = N_s*M$, M=1,2,... - whole number.

Actually K is a several microsecond period, expressed in terms of a sampling intervals dt.

Than it is possible to re-write (1) as follows:

(3) $V_{tone}=\Sigma_k S(dt*k)*\exp\{-2\pi i*F_{offset}*dt*k\}*\exp\{-2\pi i*F_{tone}*dt*mod_K(k)\}$,

Substitution of k by $mod_K(k)$ in the second exponent is possible because of

(4) $F_{tone}*dt*k = 1MHz*N_{tone}*(1\mu sec/N_s)*(mod_K(k)+n*K) =$

$= F_{tone}*dt*mod_K(k)$ + whole number of circles.

Than (3) may be decomposed into K partial summs, each of which is accumulated at a phase $j=mod_K(k)$ inside the period of K points.

(5) $V_0 = \Sigma_n S(dt*(n*K+0)) * \exp\{-2\pi i*F_{offset}*dt*(n*K+0)\}$,

$V_1 = \Sigma_n S(dt*(n*K+1)) * \exp\{-2\pi i*F_{offset}*dt*(n*K+1)\}$,

....

$V_j = \Sigma_n S(dt*(n*K+j)) * \exp\{-2\pi i*F_{offset}*dt*(n*K+j)\}$,

....

$V_{K-1} = \Sigma_n S(dt*(n*K+K-1))* \exp\{-2\pi i*F_{offset}*dt*(n*K+K-1)\}$,

where n = whole part of k/K, k = n*K+j.

It is significant, that partial summs $V_0,...,V_{K-1}$ contain different samples and their summ

(6) $V_{total}= \Sigma_j V_j$

contains all samples processed. It is also remarkable that partial summs V_j do not contain phase factors of the tone frequencies F_{tone}.

It is obvious that summ Vtotal is nothing else but accumulated voltage of the first harmonic of frequency $F=F_{offset}=10KHz$, exactly the same what we can have using (1) at $N_{tone}=0$, $F_{tone}=0$.

To calculate a response for any other harmonic we need just to do spectral transform of the small set of already accumulated data $V_0, V_1, \ldots, V_j, \ldots V_{K-1}$ as follows:

$$(7) \quad V_{tone} = \Sigma_j V_j * \exp\{-2\pi i * F_{tone} * dt * j\} =$$

$$= \Sigma_j \Sigma_n S(dt*(n*K+j)) * \exp\{-2\pi i * F_{offset} * dt * (n*K+j)\} * \exp\{-2\pi i * F_{tone} * dt * j\}$$

$$= \Sigma_k S(dt*k) * \exp\{-2\pi i * (F_{tone}+F_{offset}) * dt * k\}.$$

The result of (7) for any phase cal harmonic F_{tone} is axactly the same, as obtained by the traditional approach (1).

An advantage of the proposed algorithm is:

to calculate the partial summs Vj we need to do exactly the same number of operations as with the traditional algoritm (1) for one selected harmonic, but using accumulated partial summs Vj we can then calculate responses for all harmonics in the base-band processed.
The secondary calculation tafes very small number of operations with respect to the primary one.

The sensitivity and all normalizations for each harmonic obtained with the parallel algorithm are exactly the same as in the case of traditional single tone extraction algorithm.

References:

1. D.S.Bagri. Using Pulsecal Amplitudes to Determine System Temperatures. VLBI Acq. Memo 137, 1993 Mar 05.

2. S.V.Pogrebenko. Proposal for a Multiband & Multitone Phase Calibration Signal Extraction for the EVN Upgrade Project. EVN Doc #2, 1993 Jan 18.