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SUBJECT: Notes on Mark IV Station-Unit Phase-Calibration Tone Extraction

What is the Phase-Calibration Signal?

The phase-calibration signal is a weak coherent signal injected through the radio-receiver system to dynamically calibrate the phase-delay/LO-phase of each observed channel. Typically this is accomplished by injecting a continuous series of very short (few picoseconds) and weak pulses just behind the receiver feed. Most VLBI systems use a 1 MHz pulse-repetition rate, which causes a phase-cal 'tone' at every integral MHz in the frequency spectrum. The strength of these pulses is normally such that the overall system temperature is raised by no more than 1-2%, so that the phase-cal system can be left on continuously during observations. The frequencies of the LO system are normally adjusted to place the phase-cal tones at a convenient frequency within each baseband channel. By convention, the LO frequencies are selected such that the phase-cal tones always appear in the baseband channels at integer multiples of 10 kHz. Note that multiple phase-cal tones will normally be present in each baseband channel of 2 MHz or greater bandwidth.

How is the Phase-Cal Signal Extracted?

The most common way to extract a phase-cal signal is to perform a multiplication with a quadrature model of the expected phase-cal tone. This is the approach taken both at the Mark III correlators and at the VLBA stations. Because the phase-cal frequencies are limited to a specific set, it is possible to construct a phase-calibration extraction scheme based on a simple lookup table, as is done by the VLBA (see attached memos). The Mark III correlators use a simple, and fairly limited, direct rotation scheme to accomplish the same end.

The purpose of the phase-cal extraction is to measure the phase of one or more phase-cal tones in each channel *with respect to the local station clock*. This means that the phase of the quadrature model must be controlled with respect to the telescope observe time (TOT). Integration-period boundaries for phase-cal extraction can be conveniently based on TOT 'second ticks' and are typically 1-10 seconds long. Note that, in general, the phase-cal-integration-period boundaries are independent of reconstituted observe time (ROT). In principle, these boundaries could be based on ROT, but the complications are substantial and unnecessary.

Extraction of multiple-tones/channel allows a direct estimate of the channel *group delay*, which is usefully related to the *multi-channel group delay*.

Requirements

The minimal requirements for Station-Unit phase-calibration tone extraction are as follows:

- #phase-cal extractors:
 - 32 (4-level rotation) [if VLBA-style implementation]
 - or** 32 (3-level rotation) [if VLSI correlator-chip implementation]
- Rotator: Independently programmable for each extractor to any multiple of 10 kHz in the video baseband channel (note that oversampling up to x16 is allowed); rotator phase must be zero at each TOT second tick;
- Integration period: 1, 2, 3, 4, 5, 6, 10, 20, 30, 60 seconds;
Phasing such that an integration-period boundary on TOT minute tick
- Dead time between accumulation periods: <10 ms
- Signal-switching:
Each of the 16 SU data channels will be connected to 2 phase-cal extractors

Implementation

VLBA-Style

Mark IV memos 176, 177, and 133 (aka VLBA memos 248,249, and 347) explain how the phase-cal extraction was implemented for the VLBA. For the SU, there is a difference that should be noted: The VLBA design assumes that samples are *always* presented to the phase-cal extractor at 32 MHz. This is possible in the VLBA formatter because data is always sampled at 32 MHz regardless of the actual sample rate going to tape. In the case of the SU, the sample rate that is available is only that which went onto tape. This means that the SU will have to make an appropriate lookup table adjustment based on the sample rate.

The amount of hardware for the VLBA-style phase-cal extraction is fairly modest. Implementation of the two 4-level x 4-level phase-cal extractors required for a single SU channel consists of two 64 Kbit RAM's (10 ns; CY7B161 or equivalent) plus nine 32-bit ripple counters (4 correlation-counters per extractor plus a common count of samples correlated) plus miscellaneous glue logic.

Figure 1 shows the VLBA implementation of eight 4-level by 4-level phase-cal extractors as a subset of logic on the Formatter Digital Switch Module. Two 3090 Xilinx chips are programmed to operate as 32 32-bit counters [only 4 counters/extractor are needed because sample count is deterministic]. The logic shown in Figure 1 is approximately one-quarter of the logic required for the Station Unit phase-cal extraction; nine 3090 Xilinx chips will be required to implement the necessary 144 counters. The details of the VLBA design are available upon request.

Note that the suggested implementation can also be reconfigured to extract two phase-cal tones per extractor (4 tones/channel) using a 2-level by 2-level multiplication table simply by reloading the RAM tables in the appropriate manner (see Mark IV memo 133).

VLSI Correlator chip

An alternate implementation is to use the new VLSI correlator chip, which has the facilities to simultaneously extract 8 different phase-cal tones of arbitrary frequency using 3-level sine/cosine rotation. The chip is currently fully-defined, but is not likely to be available in a fully-tested version until sometime in late 1994. Four of these chips would be required to implement 32 channels of phase-cal extraction. In addition, a microprocessor control is probably required for management of the correlator chips.

Software

The software support within the SU for phase-calibration requires the following capabilities:

1. Load all phase-cal-extractor RAM's from CCC-supplied tables.
2. Specify length of phase-cal accumulation period. As noted in above text, the period of the phase-cal accumulation period must always be commensurate with the TOT minute mark.
3. Read phase-cal counters (all or subset) every phase-cal integration period and hold in a crate-computer buffer for periodic reading by CCC. The CCC will be responsible combining and normalizing the counts in the appropriate manner.