Symmetricom®

Measuring and Monitoring Synchronization In a Network

White Paper 09-03

Introduction

Proper synchronization in a telecommunications network is critical to its operation. Inadequate synchronization compromises quality of service, leading to such impairments as data retransmission, digital video freeze and distortion, and severe degradation of encrypted services. In particular, SONET and SDH require that careful attention be paid to synchronization; otherwise frequent pointer movements lead to high levels of jitter and wander and compromised service quality.

Characterizing network operation and equipment by measuring synchronization in a live network and in the laboratory is an important means of ensuring networks and equipment meet national and international synchronization requirements. Standards bodies and organizations such as ANSI and Telcordia in North American, ETSI in Europe, and ITU-T internationally have published documents outlining synchronization limits both for equipment and for networks. Thus, for example, separate jitter and wander limits are specified for primary reference sources (such as cesium clocks and GPS timing receivers), BITS clocks (equipment distributing synchronization), and SONET network elements operating in a network.

Measurement Theory

When addressing synchronization, standards from ANSI, ETSI, Telcordia and ITU-T refer to phase, frequency, MTIE, and TDEV in discussions of jitter and wander. The understanding of phase, in particular, is critical because the other measurements – frequency, MTIE and TDEV – are all derived from phase. Before commencing with a discussion of phase, it is important to list a number of terms equivalent to phase used by the standards bodies and in the industry. One such term is TIE or “time interval error”, perhaps the most common term used for phase in the standards. Another such term is “phase deviation” which acknowledges the fact that phase must always be measured with the measured signal compared to some other actual or ideal reference clock.

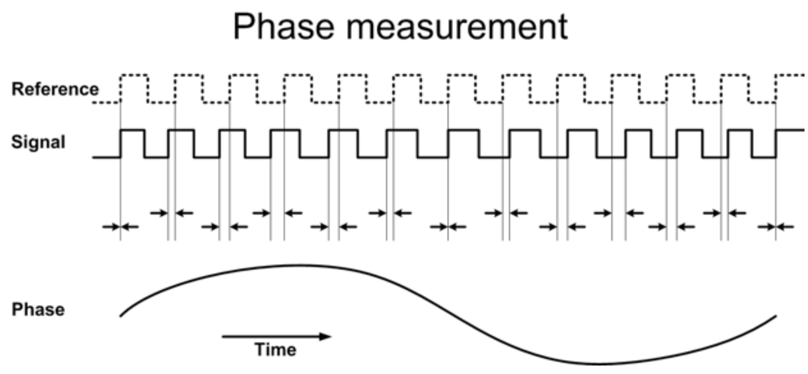

Fig. 1. Phase is measured by periodically timing the difference between a reference and the signal and plotting this difference over time.

To measure phase, some kind of phase detector is required. A phase detector typically senses when a signal passes through a set voltage threshold, timing the threshold crossing relative to a reference. This procedure is illustrated in figure 1, where positive-going edges of the signal are timed with respect to a reference with these differences plotted as phase. An ideal signal, one without jitter or wander, would be represented as a series of zeroes and hence would lie on the x-axis. The dividing line between noise components classified as jitter with those classified as wander is often designated as 10 Hz in the standards. Thus noise components above 10 Hz are jitter and noise components below 10 Hz are wander.

With slower-moving wander components removed with a high-pass filter, jitter is then generally characterized by subtracting the minimum value from the maximum value resulting in a measure of peak-to-peak jitter. The phase unit used in this case is UI or "unit interval" where one UI is equal to a 360 degree phase movement. In the case of wander characterization, additional steps are required. First, jitter components are removed by a low-pass filter and then two separate calculations are performed for two alternative views of wander.

MTIE or "maximum time interval error" is computed by repeated searches through the filtered phase data for maximum phase excursions over a series of time windows. The larger the time window or "tau", the larger is the MTIE. MTIE is a monotonically increasing function of tau; it can only increase or stay the same as tau increases. MTIE is thus a kind of peak detector. TDEV or "time deviation" by contrast is an "rms" measure of wander over various integration times or "taus". TDEV is a root variance based on Allan Variance, a measure commonly used to characterize atomic clock stability. TDEV was specifically designed for the characterization of wander noise processes operating within the network. Both MTIE and TDEV characterize wander over a range of values ranging from short-term wander to long-term wander.

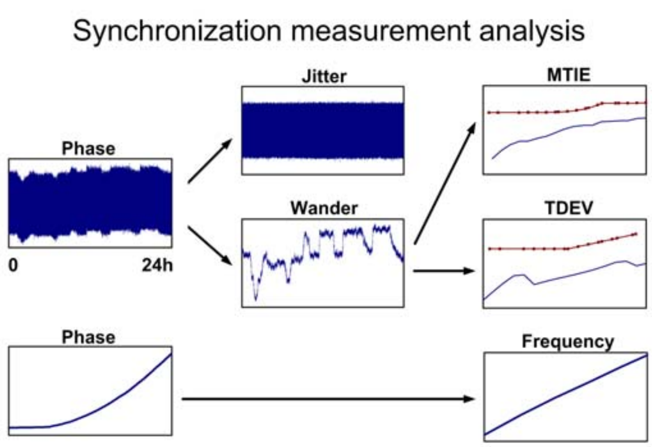

Fig. 2. Measurements used by Telcordia, ANSI, ETSI and ITU-T to characterize synchronization (phase, frequency, MTIE and TDEV) are all derived from phase. A high-pass filter applied to phase reveals jitter while a low-pass filter applied to phase reveals wander.

In Figure 2, a 24-hour phase measurement is separated with filters into jitter and wander, with wander forming the basis for MTIE and TDEV calculations. In the MTIE and TDEV graphs the measurements (the lower curves) are compared to standards (the upper curves with markers). The MTIE and TDEV measurements are everywhere below the limits specified by these particular standards (in this case ANSI) so this measurement meets the wander requirements.

Also shown in Figure 2 is a second phase measurement showing a quadratic shape characteristic of a drifting oscillator. Frequency is the rate of change of phase over time. In mathematical terms, frequency is derived from phase by differentiating phase. In graphical terms, frequency is the slope of phase. Thus as the slope of the phase plot on the left increases, so does the frequency in the plot on the right. In this case frequency increases linearly, a common occurrence in drifting oscillators. Standards organizations have universally set a very strict frequency accuracy limit for telecommunications networks, a part in 10^{11}, which accounts for the necessity of primary reference sources such as cesium clocks or GPS timing receivers.

Synchronization Measurement and Monitoring Equipment

A variety of equipment can be employed to measure or monitor network synchronization. In addition to specialized jitter and wander test sets, such general purpose measurement instrumentation such as counters and time interval analyzers can be used along with commercially available special-purpose software. All this test equipment requires a reference clock, either a primary reference source such as a GPS timing receiver, a suitable atomic oscillator, or a signal traceable to a primary reference source.

Maintenance of quality synchronization is of such importance that equipment designed to provide network synchronization has, in modern designs, included the built-in capability of measuring phase, frequency, MTIE and TDEV. This includes both BITS synchronization distribution equipment and GPS primary reference sources. Miniaturization of the circuitry used for synchronization measurements has led recently to compact synchronization modules for multiple channel synchronization measurements.