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Arbiter Systems, Inc. has been the leading supplier of GPS timing products to the utility industry now for more than a decade. While most customers are convinced of the value and reliability of our products, and their suitability for applications in power systems, from time to time we get requests from customers about what level of accuracy is really needed, and how to get it for the lowest installed cost.

Recently, SEL has been providing specifications for relay performance based on using a clock with specified performance of 500 nanoseconds maximum error. This is no doubt because they are planning to introduce a competitive GPS clock specified at that level of accuracy. As we share many common customers, and many of our customers would like to use their existing, proven Arbiter GPS clocks with their new SEL relays, the number of accuracy-related questions has recently been increasing.

We don't mind a little fair competition, but we don't like to see potential competitors confusing our customers with irrelevant or distracting practices. Implying that satisfactory performance can only be obtained under certain conditions, when this is clearly not true, qualifies as such a practice. Any attempt to achieve competitive advantage this way, rather than with honest product improvements, ends up costing the customer more than it costs us. We have an obligation to you, our customers, to set the record straight.

Accuracy specifications vs. real requirements

Any specification includes a number of factors, only one of which is the base performance of the product. Other considerations include cost of testing, availability of suitable standards for comparison, long-term performance, and the level of the actual customer performance requirement. Based on these considerations, a manufacturer sets specifications to give the customer the best value for his investment.

The GPS system is capable of delivering timing accuracies of within ten nanoseconds of coordinated universal time (UTC). Achieving this level of accuracy today, with the USA Department of Defense (DOD) Selective Availability (SA) turned off, is relatively straightforward. The most expensive part of providing this level of performance to the customer is actually the testing required to prove performance.

(Selective Availability is an intentional, pseudorandom error added to GPS signals to deny access to potential adversaries. The error is removed in military receivers using the encrypted 'precise' or P-code, while commercial receivers, which may use only the C/A or coarse/acquisition code, must accept any resulting degradation in performance. Arbiter clocks achieve performance of well under 100 ns rms error, even in the presence of SA; and have been doing so reliably since the 1980s, while some competitive designs have been known to fail outright when SA has been activated.)

For most applications, circuit design can be simplified and testing requirements relaxed to save the customer money, by simply specifying a lower level of performance, i.e. a larger maximum time error in the GPS clock outputs. For power system applications, there are very few real requirements for accuracy better than one microsecond. This is equivalent to 0.022 degree of phase angle at 60 Hz, and only 0.018 degree at 50 Hz. Since few (if any) metering or relaying applications use instrument transformers, meters, relays or any other product with performance this good, it is easy to see that even a 1 µs GPS clock will rarely be a limiting factor with respect to accuracy. One possible exception is the Arbiter Systems Model 1133A Power Sentinel, a meter/analyzer/phasor measurement unit (PMU) capable of synchronized phase-angle accuracy better than 0.03 degrees. This product includes a complete GPS clock internally, along with all the measurement functions.

Nevertheless, since DOD has turned off SA, performance of Arbiter GPS clocks has improved even more. This has allowed Arbiter to retroactively improve the stated performance of our products. This is not based on any change in design, but is valid for all GPS products ever made by Arbiter Systems. This will be of help to customers required to meet a 500 ns requirement.

What happens if I use a 1 µs clock with an SEL relay?

SEL would like you to think it won't work. The fact is that the worst that could happen is that the phase-angle uncertainty would increase by 0.011 degree (at 60 Hz) relative to a 500 ns specified clock (0.011 degree = 60 Hz * 360 degrees * 500 ns). In reality, since performance of the Arbiter 1093A/B/C is actually much better than 1 µs, even with SA on, you will not see any meaningful difference.

What if GPS clocks don't agree?

All GPS clocks should agree with each other, within their stated accuracy specifications. However, we've found from time to time that other manufacturers' products do not always agree with ours. We are confident that all Arbiter products meet their stated specifications, since our in-house standards are high-end Arbiter GPS clocks which have been tested and certified by the United States Naval Observatory (USNO) to be within their stated performance limits. USNO performed this test by comparing the Arbiter GPS clocks to their bank of cesium-beam standards using a precise (picoseconds) Hewlett-Packard time-interval analyzer. USNO's cesium-beam standards are the reference for UTC as maintained by USNO (called UTC-USNO), which is the master clock for the GPS system. If you hear of disagreements between Arbiter and brand Y clocks, ask if the competing product has been certified by USNO. Chances are they'll find the problem in their design with this testing.

How about backup oscillators (Holdover)?

Early in the design of the GPS system, when there were only a few operational satellites, maintaining time at the microsecond level required the clock to 'slave' a high-performance oscillator to the available GPS signals, when the satellites were in view. This oscillator would then 'hold over' the timing accuracy during periods of unavailability. The oscillators required were costly and required lots of power. They were typically either rubidium-vapor oscillators, or high-performance ovenized SC-cut overtone crystal oscillators, costing from US$500 to US$5000 and consuming several watts to tens of watts of power. Lower-performance oscillators were (and are) incapable of providing any meaningful holdover at the level of accuracy of the GPS system.

As the GPS signals became more available, in the period leading up to the operational status of the GPS system, the value of these expensive oscillators became less and less. Eventually, with the GPS signals available 24 hours a day with near-100% reliability, these oscillators became a liability rather than an asset.

This is because the complexity and power consumption of these oscillators reduced system reliability. As parts counts increase, and power dissipation goes up (both true of these oscillators), reliability drops. We still offer a product (Model 1083B GPS Satellite-Controlled Frequency Standard) which uses a high-performance ovenized oscillator, but it is designed for specialty applications in standards labs or microwave communications, where a high-spectral-purity frequency standard output (5 or 10 MHz) is needed.

Reliability is more important than accuracy, and reliability is maximized by low parts count. The design used in the Models 1093A/B/C and new Model 1094B GPS Clocks has the lowest possible oscillator parts count: zero! It does this by using the existing processor crystal and correcting out its offset by slaving to GPS digitally.

Arbiter offers a separate product note on overall reliability of GPS timing applications, which covers this issue in more detail. However, with Arbiter GPS clocks, the most significant source of system failure is antenna system damage. Such problems persist until the antenna system can be repaired. Even a clock with a 1 part in 10^9 per day aging oscillator (this is a very high-performance, ovenized oscillator) will be off by about two milliseconds after one week. A one part per million (1 ppm) TCXO will be off by 0.6 second after a week, and a 10 ppm uncorrected (except for initial errors) oscillator will be off by 6 seconds.

The better solution, now used by most of our customers, is to take a little extra care in antenna system design to protect it from damage. This approach delivers the most reliable and accurate performance available from the GPS system, and at the lowest cost.

Correction for system offsets

GPS clocks are subject to timing errors due to system design and installation. These are mostly fixed offsets dependent on system parameters, and Arbiter GPS clocks can correct for them to yield the correct time. These include antenna cable delays and distribution delays (delay of clock output signals going to IEDs).

Cable delays are equal to the length of the cable divided by the propagation velocity of the signal along it. Propagation velocity is typically some sizeable fraction (65 to 85%) of the speed of light. (The fraction depends on the dielectric constant of the cable insulation.) Uncorrected, these delays cause errors in the output of the GPS clock. The magnitude of the errors can be estimated by calculating the electrical length of the cable, as described above.

Delay in free air (100% of the speed of light) is about 3.3 ns per meter or 1 ns per foot. For typical cables, these numbers are closer to 5 ns per meter or 1.5 ns per foot. So, for a 75 m (250-foot) cable run, the timing outputs of a GPS clock will be off by up to 375 nanoseconds of additional error, if nothing is done to compensate for it. In most power-system applications this error is not very important; but in systems needing the highest level of performance, it must be corrected. All Arbiter clocks provide means for this correction.

Delays are also caused by routing the output signals over significant distances, for example between racks in different buildings. Arbiter clocks also provide means to correct for system delays, but be aware that this correction is applied equally to all outputs and if there is a significant difference in distance between the IEDs to be synchronized, there will be a difference in timing. Again, in most power systems, this error will not be consequential, and with the Arbiter system-delay compensation, you can compensate for the most ‘critical’ IED in the station.

How about GPS system problems?

The GPS system is not perfect, and from time to time, one of the satellites has a problem that causes it to transmit a signal that is in error. However, the GPS system is highly redundant, especially for timing applications in a fixed location. In this mode (called position-hold mode or overdetermined timing mode), each receiver channel is given fixed X, Y, and Z coordinates and asked to solve for T, or time. The results are averaged together, reducing noise, both natural and man-made, e.g. SA. This is one reason why Arbiter clocks, using this method, were able to deliver timing accuracy better than 100 ns even when SA was on.

The availability of numerous satellites in view, typically 6 to 10, allows an additional feature in timing applications. This is called ‘receiver autonomous integrity monitoring’ or RAIM. Remember that a GPS timing solution, with a fixed position, yields several solutions for T which can be averaged together to get an improved estimate of time. Before averaging, however, the various time solutions can be compared and any ‘outliers’ ignored. This makes the clock resistant to errors caused by satellite failure.

Of course, failed satellites are also a problem for other users of GPS, and the ‘control segment’ (ground-based part of the GPS system) continually monitors the satellites looking for these problems too. When one is detected, all satellites transmit a signal (part of the ‘almanac’ message) which reports that a particular satellite is transmitting bad data. Once this happens, the receiver will automatically ignore the bad satellite. RAIM is just one more method, above and beyond, that Arbiter provides to ensure reliable, accurate time, anywhere in the world, 24 hours a day, 365.24 days a year.

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