IRIG-B Time Code Accuracy and Connection Requirements with comments on IED and system design considerations

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Basic Accuracy Capability of the IRIG-B Time Code

The original use of the IRIG time codes was as a 'time track' to be recorded along with test data on multichannel instrumentation tape recorders (ITRs) at missile test ranges. The IRIG-B code, with a 100 bit per second signalling rate and a 1 kHz sine wave carrier, was ideal for recording on voice-grade channels. Due to bandwidth limitations of these voice-grade channels (delay and phase shifts), the IRIG-B code was guaranteed only to provide one millisecond resolution and accuracy, equal to one period of the (1 kHz) carrier signal.

When the modulated IRIG-B code is transmitted over a direct connection (i.e. no ITR), channel bandwidth limitations are far less significant. It is relatively easy to build IRIG-B generation hardware with accuracy of one microsecond, and to demodulate the signal at an accuracy level of tens of microseconds. The challenge is to accurately generate and detect the carrier phase angle. Most decoders use simple zero-crossing detectors, which are generally adequate although the signal slew rate has an inflection point (caused by the change in signal level) at the on-time mark. For most applications using the modulated IRIG signal, however, this level of performance (tens of microseconds) has proved adequate.

Since the modulated IRIG signal is basically an audio signal, like a telephone signal, similar techniques may be used for distribution. The input impedance of a typical decoder is several kilohms, so a low source impedance driver (tens of ohms) can drive hundreds or even thousands of loads – in theory at least. Line termination is not generally required.

Unlike the audio-band modulated signal, the unmodulated or level-shift IRIG-B time code must be transmitted over a channel with dc continuity, which generally means a direct connection. So, this code was not widely used by the missile range community, who therefore were not particularly concerned with its potential performance.

Observe that the unmodulated IRIG-B signal is a digital signal. Its accuracy is usually the same as the clock's one pulse-per-second output, since both signals are typically generated using similar drivers. This means that the IRIG-B unmodulated signal can easily be generated with the fundamental accuracy of digital logic: a few tens of nanoseconds.

Most substation 'intelligent electronic devices' (IEDs) that accept the unmodulated IRIG time code use an optically-isolated input. This breaks ground loops, making possible direct connection throughout a control room without excessive concern for grounding and potential differences. Such optocouplers only require a few milliamperes of input current, making it possible to connect many loads to a single IRIG-B driver. The optocoupler output is normally connected via a pulse-conditioning circuit to a logic input (a timer-counter, for example) which measures the time of arrival and width of each IRIG pulse. The accuracy of this process is also quite good: easily better than one microsecond, and potentially a few tens of nanoseconds.

Unmodulated (Level-Shift) IRIG-B Time Code Wiring

Unmodulated or level-shift IRIG time code is generally developed by a system clock at a level of approximately 5 volts peak, i.e. the 'high' level is approximately +5V and the 'low' level approximately zero volts. This signal is normally distributed using copper wiring, which may be either coaxial (typically the common RG-58 types) or shielded twisted pair. Most drivers are unbalanced and the clock outputs are often coaxial (typically BNC).

For applications requiring the ultimate in accuracy (i.e. sub-microsecond), issues such as cable delay (1 to 1.5 nanosecond/foot or 3 to 5 ns/meter) and ringing caused by the fast rise and fall times of the signal coupled with imperfect line termination (which causes reflections) must be considered. For such applications, it is customary to use direct coaxial connections with one load per driver, and lines are generally terminated at either the source or load to reduce ringing if the line length exceeds a few feet. Since the characteristic impedance of coaxial cable is typically 50 (sometimes 75 or 93) ohms, compared with the input impedance of the optocoupler circuit of around 1000 ohms, overloading of the driver often precludes more than one load being used per output when the load includes a 50-ohm termination.

However, in most applications such measures are fortunately not required. It is usually possible to connect an unmodulated IRIG driver to numerous IEDs, using pretty much any reasonably-clean setup of either coax or twisted-pair lines. For accuracies at the level of one microsecond and up this is generally sufficient, providing that the IEDs themselves are properly designed (see later section) and the cable lengths not excessive. In particular, at the one-millisecond level of performance, it can be said with relative certainty that any setup providing a signal that can be decoded at all will give adequate performance.

Modulated IRIG-B Time Code Wiring

As mentioned in the introduction, the modulated IRIG signal is similar in many ways to a voice-grade audio or telephone signal, and it can be distributed with similar methods. The rise and fall times of the signal are low, and the decoders generally use an automatic gain-control amplifier to compensate for varying input signal levels, so there are no significant considerations with respect to reflections or signal loss. Similarly, delays are small compared with the achievable accuracy of perhaps 50-100 microseconds at best, so cable delays are not an issue. IED inputs are normally transformer-isolated, so ground loops will also not be a problem.

Best practice for modulated IRIG, adequate for all installations within a substation, is to use shielded twisted pair cable to connect the IEDs to the clock. Choice of cable type, gauge, stranding etc. is pretty much up to the station designer based on other considerations, such as ease of routing and termination, and minimizing costs.

IED Considerations

To ensure adequate performance in the substation environment, certain practices should be followed in the design of the IED. These include the following:

Modulated IRIG Inputs

Inputs for modulated IRIG signals should:
1. Provide galvanic isolation (typically a telephone line transformer with 2500 Vrms minimum isolation) and immunity to C37.90 transients.
2. Compensate for signal level variations from a few hundred mV p-p up to perhaps 10 Vpp, to allow for different clock output levels and potential attenuation by system cabling.
3. Determine zero-crossings to better than 50 microseconds.

Unmodulated IRIG Inputs

Inputs for unmodulated IRIG signals should:
1. Provide galvanic isolation (typically an optocoupler with 3750 Vrms isolation) and immunity to C37.90 transients.
2. Tolerate reflections and other non-ideal behaviors caused by imperfect signal routing.
3. Tolerate signal level variations, perhaps from 3 V to 6 V peak for proper operation.
4. Accept peaks and transients of >10 V repetitive (ringing and overshoots) and several hundred volts minimum (in normal mode) due to C37.90-type transients without damage or mis-operation.

Remember that a time code signal, unlike a data signal, is highly repetitive and redundant, and has well-known characteristics (pulse shape, repetition rate etc.). These characteristics may be used to advantage to design inputs resistant to common system integration problems, while still delivering excellent performance. For example, ringing and overshoot on an IRIG signal can easily be handled by recognizing that the pulse width (high or low) is always at least 2 ms, so any ‘earlier’ transitions are either noise, or ringing and overshoot. Your eye can easily identify these on a scope display, and it is possible to design a pulse conditioning circuit and firmware that will do likewise. An IED that fails to do this reliably will present system integration problems to the customer.

General Considerations for IED Clock Synchronization

Each IED should have its own internal clock that is synchronized by the incoming time code signal through firmware algorithms. Older IEDs sometimes used the incoming IRIG clock directly, specifically the 1 kHz ‘sliced’ carrier signal of a modulated IRIG signal, as a time base. This gives up many potential improvements that can be had with a slaved local clock.

This local clock does not need to be anything spectacular. It can be the existing processor clock, driving a counter-timer chip. What it must do is provide a local time reference that will run continuously in the absence of any synchronizing input. This local clock may, of course, be many years off if it has never been set; but if so, it should know this as well.

The local clock, and the firmware controlling it, should do the following:

1. It should operate independently of the external timecode reference.
2. Its time should be compared to the time code, when available, and the local clock time updated ONLY if there is a persistent, fixed offset between 'local' time and 'time code' time. This is called an 'error bypass,' and it is made possible by the redundancy of the time scale. The error bypass is normally 3 to 5 seconds, which prevents undesired time jumps caused by time code errors and transients.
3. It should control local time updates in a predictable manner. This may depend on the application: it may be desirable to reset time immediately, despite any 'jump' it might cause in recorded data (thereby reducing the number of subsequent, incorrect time tags) or it may be desirable to 'slew' local time to match system time at a controlled rate. Either choice may be appropriate, as may a 'hybrid' choice (slew for small errors, jump for large errors). The important thing is that this is a design choice, which should be appropriate to each IED and not left to chance.
4. In normal operation, it should track the reference time code (or other control input) using a control loop, driving the static error to zero and thereby compensating for local clock offsets, ageing, and drifts.
5. It should monitor its own operation, including status (locked to external time code; unlocked but time has been set and is now drifting; never locked etc.).
6. It should provide an estimate for how far off its time might be, based on known characteristics of the IED clock oscillator and the length of time the IED has been without a synchronizing input.
7. It should manage multiple sources of synchronization, if they are available. Examples might be: set from the front panel; set remotely by SCADA or system operator; set from a local battery-backed real-time clock; set by IRIG time code; set by NTP; etc. Each of these potential sources of synchronization has strengths and weaknesses, and these must be managed by the control firmware since multiple sources of synchronization might be available simultaneously. Example: "What do I do if I get an NTP tag or SCADA update which is greatly different from the time I'm getting from the IRIG input?"
8. It should be aware of so-called 'non-sequence events', such as changeovers from winter to summer time and leap seconds.
9. It should be able to provide time outputs (tags) in whatever form the user application requires.
10. Unless some particular system consideration requires otherwise, modern IEDs should use unmodulated, optically-isolated IRIG-B time code inputs. They are lower in cost and higher in performance than modulated inputs.

Considerations for Sampling or Time Tagging

There are two basic methods for sampling the inputs to an IED. The first is to sample with a free-running clock, and then time-tag each point. The second is to use the local clock to generate sampling signals at known points in time.

Many (perhaps most) older IED designs used the first of these methods. Depending on the accuracy of the tagging process, this can introduce significant errors. These errors can easily be the largest errors in the data acquisition system. Where the IRIG 1 kHz clock is used directly for time tagging, resolution and accuracy are limited to 1 ms at this step alone. With this method, the errors of both processes (sampling and time tagging) contribute to overall performance and both must be considered.

The second method is to use the local clock to generate sampling signals. These signals can be generated at known points in time (since the clock is synchronized), with little or no additional error. Then, the reported event times can be accurately known, limited only by the performance of the IED's signal processing firmware. This performance can then be optimized for best performance. New designs for IEDs should use this approach.

Time Code Grounding Considerations for IED and System Design

From time to time, there is a discussion about how and where (and if) grounding of the time-code signal lines is required. IED designers can be tempted to use a non-isolated input in their device to save a little money. Best engineering practice generally requires any signal line to be grounded (earthed) at some point. For most analog signals, including time-code signals, this is normally the signal source.

Since ground loops are to be avoided, it is important to ground each signal at one point only. This must be the source if there is the possibility to have multiple loads attached to a given source. Therefore, time-code inputs in such a system must provide galvanic isolation.

There is also the system cost issue. Floating time-code outputs can be built, but require (costly) floating power supplies, whereas an isolated input requires no power supply. Compare a simple system having four IEDs driven by a clock: system A has one output, driving four optically-isolated IED inputs in parallel; and system B has a clock with four isolated outputs, each driving a single, grounded IED input. Clearly system A will have a lower equipment cost, since system B requires (in addition to optical isolators) floating power supplies for each independent output.

For these reasons, it has become best industry practice to ground time-code outputs from clocks, and use galvanic isolation of time code inputs to IEDs.

Fiber-Optic Distribution

No discussion of time-code distribution would be complete without mention of fiber optics. Fiber-optic cables have the advantage of immunity to electromagnetic interference. They can be used to distribute time codes in severe-EMI environments. However, while substations may reasonably be considered high-EMI environments, the expense of fiber-optic cable and drivers is generally not justified for most connections, particularly between clock and IEDs in the same rack or control room.

This is because the galvanic isolation provided at the IED input also provides great immunity to damage from substation surge voltages. The occasional transient signal propagated to the optical isolator or transformer output is easily dealt with by the pulse-conditioning or demodulation circuits, and even if a transient is detected by the counter-timers, it is easily identified and ignored. As a final protection, error bypass in the local clock guarantees continuous and accurate operation.

There are applications for fiber distribution of time codes, particularly between substations or control houses, where the length of the link makes copper connections undesirable. For these applications, where lengths can be many kilometers and losses require an ac-coupled signal, IRIG time code may be transmitted using modified Manchester encoding. This was first defined by PES-PSRC in IEEE Standard 1344-1995 (annex F) and later adopted by IRIG itself in IRIG Standard 200.

However, the cost of such systems must be weighed against the alternative of placing an additional GPS clock at the remote location. In almost all cases, the cost is lower, and reliability and flexibility greater, when a second GPS clock is used instead of a long fiber-optic link.