ARBITER SYSTEMS

TIMING SIGNALS, IRIG-B AND PULSES
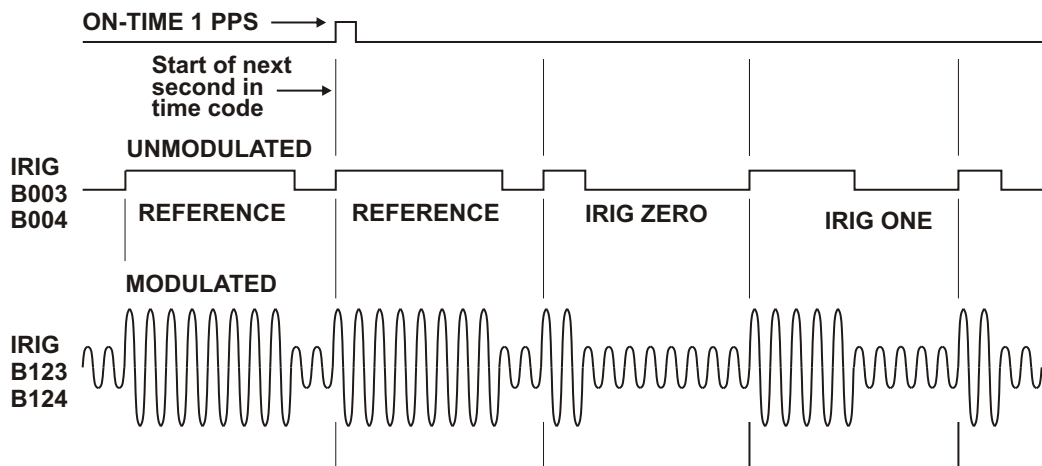
ON-TIME 1 PPS

Start of next second in time code

UNMODULATED

IRIG B003 B004

REFERENCE REFERENCE IRIG ZERO IRIG ONE

MODULATED

IRIG B123 B124

1   Introduction

This section covers some basic information about timing signals and how to connect them to your IEDs. Common questions concerning connecting timing signals include:

- What are the different types of IRIG-B, and what are the differences?
- How do you connect multiple devices to one timing output?
- How far can you transmit timing signals?
- What kind of cabling and connectors should I use?

The steps involved in getting your devices synchronized to the GPS are fairly simple and should not take long to complete. To expedite the process, make sure to:

1. determine the type of timing signal each piece of equipment requires, and
2. enable the equipment to receive the timing signal

Various methods are used to configure equipment to receive IRIG-B time codes including setting a physical jumper, or using a setup application. Some equipment can auto detect the timing signal, so that nothing else is required, other than connecting the cable.

1.1   Digital Drivers

Digital drivers specific to each clock will deliver the specified current at 4 V minimum (CMOS/TTL). Drive current is defined by the type of driver circuitry in each clock and generally falls into three ranges: (1) Low: less than 20 mA, (2) Medium: 75 mA, and (3) High: 250 mA. Outputs can be defined as unmodulated IRIG-B, 1 PPS (pulse per second), or programmable pulse. Each output may be fanned out to a number of receiving devices, depending on the overall load of the receiving devices. To determine the maximum number of devices that the digital drivers can support, you will need to determine the load current, or input impedance, for each device connected to the clock output.

1.2   Analog Drivers

Clocks may have one or more analog drivers available depending model and option, and are used exclusively for *modulated IRIG-B signals*. The analog driver supplies a 1 kHz signal that is pulse width modulated through a source resistor to connected equipment. As the load current increases, the voltage drop increases across the clock source resistor reducing drive voltage. Make sure to match the modulated output to within the required voltage range of the receiving device. Table 1 shows how the actual drive voltage varies with increasing load current. Most clocks provide 4.5 Vpp open circuit, and the Model 1088B provides 10 Vpp open circuit. For IED's with a restricted input range, match the available drive voltage to the IED through a dropping resistor of adequate power rating.

Drive Current, mA	Actual Drive Voltage, Vpp
0	4.5 (no load)
1	4.48
10	4.3
100	2.54

Table 1: Drive Current vs. Voltage

Programmable pulse modes are similar to 1 PPS only they have an adjustable period and pulse width. Modes include, pulse per second, pulse per minute, pulse per hour, pulse per day, single trigger (once per year), slow code and seconds per pulse.

1.3   IRIG-B Description

IRIG-B is a complete serial time code that occurs once per second and, depending on the configuration, contains the day of year, hours, minutes, seconds, year and other important information. All Arbiter clocks transmit Format B with four variations as seen in Table 2. Note that with the newer IRIG Standard 200-04, new code designations have appeared: BCD_YEAR is now part of the 30 bits of BCD code. Arbiter Systems is not currently using BNC_YEAR in its clocks.

Code, Old/New	Signal Type	Code Components
B000*	Pulse width code, No carrier	BCD_{TOY}, CF, SBS
B003**	Pulse width code, No carrier	BCD_{TOY}, SBS
B120*	Sine wave, modulated, 1 kHz	BCD_{TOY}, CF, SBS
B123**	Sine wave, modulated, 1 kHz	BCD_{TOY}, SBS
*IEEE 1344 ON,	**IEEE 1344 OFF	

Table 2: IRIG-B Time Code, Types Available

The IRIG-B time code consists of 100 bits produced every second, 74 bits of which contain various time, date, time changes and time quality information of the time signal. Consisting of logic ones, zeros and reference bits, the time code provides a reliable method of transmitting time to synchronize a variety equipment.

Three functional groups of bits in the IRIG-B time code are arranged in the following order: Binary Coded Decimal (BCD), Control Function (CF) and Straight Binary Seconds (SBS). The BCD group, with IEEE 1344 OFF, contains only time information including the seconds, minutes, hours and days, recycling yearly. With IEEE 1344 ON, BCD adds year information. The CF group contains other information including time quality, leap year, pending leap seconds and parity. Reference bits separate the various components of the IRIG-B time code.
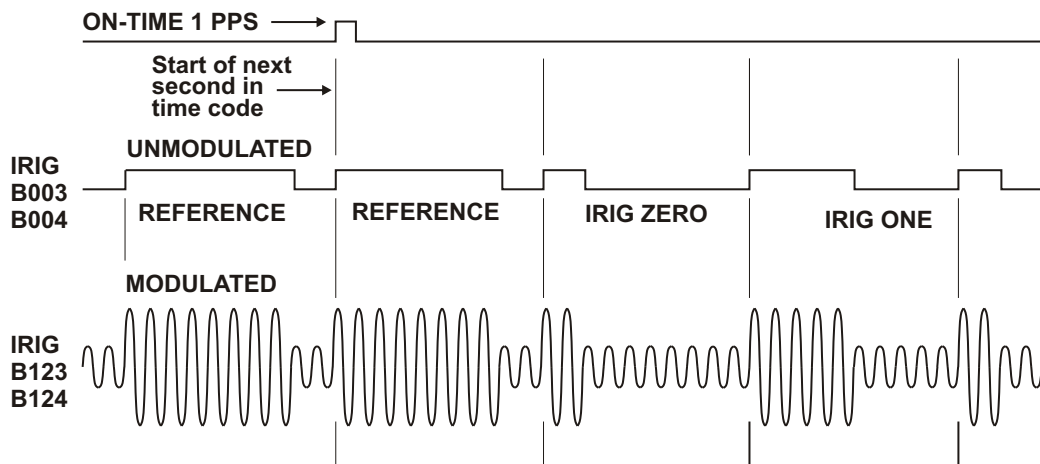

Figure 1: IRIG-B Waveforms

3

1.4 Modulated and Unmodulated IRIG-B

Figure 1 illustrates the primary differences between modulated and unmodulated IRIG-B. You will notice that the while modulated IRIG-B is distinctive because of the 1 kHz sinewave carrier, it is similar to unmodulated IRIG-B since the peak-to-peak values of the carrier follow the same form as the peaks of the digital waveform, which contain the information.

The on-time mark is the rising edge of the 1 PPS signal, which lines up with the rising edge of the second reference bit in both the unmodulated and modulated time codes.

1.5 IRIG-B IEEE 1344 Extension

As mentioned above, the turning IEEE 1344 ON in the clock enables extra bits of the Control Function (CF) portion of the IRIG-B time code. Within this portion of the time code, bits are designated for additional features, including:

- Calendar Year (old method, now called BCD_{YEAR})
- Leap seconds, and leap seconds pending
- Daylight Saving Time (DST), and DST pending
- Local time offset
- Time quality
- Parity
- Position identifiers

To be able to use these extra bits of information, protective relays, RTU's and other equipment receiving the time code must be able to decode them. Consult your equipment manual to determine if the IEEE 1344 feature should be turned ON in the clock. To view details of the IEEE Std 1344-1995, please check with the IEEE.

NOTE: A copy of of the IRIG-B 2004 specification is available for download on the Arbiter web site (at www.arbiter.com) and check under Resources, then Documentation.

1.6 1 Pulse-per-Second (1 PPS)

A one pulse-per-second timing signal is very simple in concept. It is a digital bit transmitted every second with a pulse width of 10 milliseconds. A critical part of this signal is that it is "on time" at the rising edge when compared with the signal from the Global Positioning System (GPS). When configured from any of the TTL/CMOS (5-volt) drivers, it has the same drive power as the IRIG-B and the programmable pulse. See Figure 1 for a comparison between unmodulated IRIG-B and 1 PPS.

1.7 Programmable Pulse (PROG PULSE)

All clocks have an independent programmable pulse feature that may require some jumper and firmware configuration. There are many available programmable pulse modes from which to choose that include setting the pulse width and time zone. To configure, please see relevant section in the specific clock operation manual.

Programmable Pulse Mode	Configured Feature
Seconds per pulse	X number of seconds between pulses, 0 – 60,000
Pulse per hour	Number of seconds after each hour, 0 – 3599
Pulse per day	Hour, minute, second, fractional seconds
Single trigger	Day, hour, minute, second, fractional seconds
Slow code	2 seconds on the minute, 4 seconds on the hour, 6 seconds on the day
Pulse polarity	Positive or negative–going pulse

Table 3: Programmable Pulse Modes and Features

2   Connecting Outputs

To connect cabling, refer to the operation manual for the specific clock model. To adapt to a BNC style connector, you may use a BNC Breakout[1], or other similar adapter.

2.1   Wiring to Screw Terminals

To mount wiring to screw terminals, prepare the cable by stripping back at least 1/4" of the insulation and any shielding, and DO NOT tin the bare wire with solder. To attach wires to terminals, first loosen the screw counter-clockwise, insert the wire, then turn clockwise to tighten. Ground the shield (if present) to the GND (ground) connector on the rear panel of the clock rather than the receiving end.

2.2   How Far Can I Run IRIG-B Cabling?

Before laying cable to transmit IRIG-B over long distances, take time to consider the following factors: (1) resistive losses in cabling, (2) electromagnetic interference, (3) propagation delays and (4) installation and maintenance costs.

Note that when cable is laid from point A to point B that two cables are involved: one outgoing and one return. For coaxial cable, the resistance is different for the center conductor than for the outer conductor, or shield. For twisted pair wires, both outgoing and return wires will be the same. As a simple example, to connect an IRIG-B signal to a device 100 feet away from the clock, you must account for resistive losses in 200 feet of wire.

For details on distributing IRIG-B signals over long distances, see application note, *AN101, Distributing Timing Signals in a High-EMI Environment*. Download file *appnote101.pdf* at the following link:

http://www.arbiter.com.

For important considerations about IRIG-B connections, distribution of signals and accuracy, download the file at the same link, *irig_accuracy_and_connection_requirements.pdf*

---

[1]Pomona Electrics, www.pomonaelectronics.com, (800) 444-6785, (425) 446-6010, part no. 4969 and 4970

2.3 Synchronizing Multiple IED's

In many installations, master clock signals are "fanned out" to a number of devices. This method makes more efficient use of the clock synchronizing capability since the clock drivers are designed to handle multiple loads. The exact number of possible loads must be determined from the input impedance of each connected IED.

2.4 Connecting Unmodulated IRIG-B

To drive multiple loads from one unmodulated IRIG-B output, make sure that the loads are wired in parallel. A common term for this is "daisy-chaining", however the idea is to drive all of these loads in parallel from a single output. It is much simpler to connect loads using unmodulated IRIG-B than for modulated, because all of the loads are driven at the same voltage.

To determine load current for one Unmodulated IRIG-B output:

1. Determine the impedance or resistance (R_{dev}) of each IED load (check device manuals).
2. Calculate the load current for each device ($I_{dev} = 5V \div R_{dev}$).
3. To get the total current, sum up all the load currents for all devices connected to the output in question. $I_{devT} = I_{dev1} + I_{dev2} + \ldots + I_{devN}$,   where T = Total for N devices.

2.4.1 Unmodulated Example

For example, if the input impedance of the IED is 5 kilohms, determine the device current (I) as seen in Calculation 1:

$$I = V \div R_{dev} = 5 \ Volts \div 5000 \ Ohms = 0.001 \ Amps \ (1 \ mA) \tag{1}$$

If you were to connect ten of the same IED's to the same output, then the total current drawn would be 10 x 0.001 A = 0.01 A (10 mA).

Another method is to determine the lumped impedance of all of the connected IED's in parallel. Then, determine the overall current by dividing the drive voltage (5 V) by the computed lumped impedance value. This current should not exceed 75 mA.

2.5 Connecting Modulated IRIG-B

While the modulated driver supplies approximately 4.5 volts peak-to-peak (Vpp) open circuit, it can supply 3 Vpp into 50 ohms. This amounts to about 0.060 A (60 mA) drive current.

Make sure to check the acceptable voltage range for the equipment. Some modulated IRIG-B decoders are fairly sensitive to peak-to-peak voltage levels (3.3 Vpp $\pm$ 0.5 Vpp), others are more tolerant (0.1 – 10 Vpp). With added loads, the clock's modulated driver produces more current, which reduces the output voltage at the clock output terminals. Calculation 2 shows how to calculate the available output voltage with a 10 mA drive current.

$$Vpp = 4.5 \ Vpp - I \times 19.6 \ Ohms \tag{2}$$

Therefore, if you had 10 mA of load current (I load) the available voltage (Vpp) would be 4.304 Vpp. If the load current equals 100 mA, then the available voltage would be 2.54 Vpp. So, you can see how the increasing load current (i.e number of loads) affects the available drive voltage at the clock output. See also Table 1.

2.6 Wire Losses

Another factor affecting the available voltage is the resistive losses through the cabling. Wire has a certain resistivity associated with it that is determined by its metallic composition, and resistance determined by the diameter and length. For example, single-strand, 22 AWG (bare, enamel-coated) copper wire has a resistance of approximately 19.6 ohms per 1000 feet. To compute the loss we must include both wires in the connection, signal and return. For coaxial cabling, the resistance of the center conductor is rated differently than the shield. For a twisted pair, both of them should essentially have the same resistance per cut length. Using 500 feet of 22 AWG shielded twisted pair wire, and including the source resistor, the available voltage at 100 mA would be as calculated in equation 3.

$$Vpp\ available = 4.5 - I \times 19.6\ (R_{source}) - I \times 19.6\ (R_{wire}) = 0.58\ Vpp \tag{3}$$

So, you can see that most of the drive voltage is lost with 100 mA of current and 500 feet of 22 AWG twisted pair transmission line; this includes the voltage losses at the source resistor. 0.58 Vpp may not be detected by the decoder in some IED's. *To assure reliable detection, make your cable runs as short as possible, use a larger gauge wire and carefully distribute the loads.*

2.7 Voltage Matching for Modulated IRIG-B

With modulated IRIG-B, it was mentioned that certain decoders are very intolerant of drive voltage variation. If the IED specification says that the acceptable voltage range is 3.3 Vpp $\pm$ 0.5 volt, and the available voltage is high, then you must reduce the voltage using a dropping resistor (R_{drop}). The value of the dropping resistor is determined by dividing the difference voltage (V_{diff}) by the device current (I_{dev}). For example, suppose that the available voltage is 4.3 Vpp, the (nominal) acceptable voltage is 3.3 Vpp, and the device current is 10 mA. Determine the dropping resistor value.

$$R_{drop} = V_{diff} \div I_{dev} = (4.3 - 3.3) \div 0.01 = 100.4\ Ohms \tag{4}$$

The Power dissipation (P) is:

$$P = I^2 R = 0.01^2 \times 100.4 = 0.01\ Watts \tag{5}$$

In this example, an eighth-watt resistor should work fine.

For a voltage that is too low, then the modulated IRIG-B signal level must be increased by some other means, such as (1) distributing the load differently to reduce the current (raising the available voltage), (2) by reducing the loss through the wiring, or (3) by using an amplifier.

2.8 Cable Delays

Electromagnetic waves travel at the speed of light (C) in free space or vacuum and a fraction of that speed through cabling. The speed of an electromagnetic wave in free space is given by Constant 6.

$$C \approx 9.82 \times 10^8\ feet/second \tag{6}$$

Since electromagnetic waves travel slower through any cable, cable manufacturers normally specify cable with a velocity factor (VF), which is a percentage of the speed of light in free space, and characteristic of the specific cable. The Velocity Factor for the RG-6 cabling used by Arbiter Systems for GPS antenna connections, is about 83% of C. Most transmission lines have velocity

factors in the range of 65% to 97%. Using these values you can determine the actual time delay in your cable distribution system and compare it to your required accuracy. As an example, 840 feet of RG-6 cable (with a velocity factor of 83%) would delay the timing signal by one microsecond. For IRIG-B timing applications, these delays may not be important, compared to other criteria. Otherwise, you would be forced to compensate for the time delay using another method, such as advancing the timing output or placing another master clock at the remote site.

2.9 Solutions

There are many solutions to providing an accurate timing signal to equipment in distant locations. However, the most satisfying solution may not be to string cabling for hundreds of meters. The costs associated with installing and maintaining cabling over a wide area may be unsatisfactory. Since the GPS is so pervasive, it may prove to be less costly to install another clock at a distant location, which would also improve accuracy and provide redundancy. Before installing cabling over a wide area, be sure to first examine all the possibilities.