Metrology is the science of measurement. Calibration is a comparison between measurements, with one measurement being of known correctness called the reference (or standard). Traceability refers to an unbroken chain of calibrations relating an instrumentös measurements to a known reference. It is important to note that traceability is the property of a measurement result, not of an instrument. The official definition of traceability is contained in the International Vocabulary of Metrology - Basic and General Concepts and Associated Terms (VIM; 2008):

Metrological Traceability: property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

In other words, traceability is the property of a measurement result, such as an NTP or PTP timestamp, whereby the result can be related to a reference, such as UTC(NIST), through an unbroken chain of comparisons, all having stated uncertainties.

This paper will document the unbroken chain of comparisons from the point of the NTP/PTP timestamp measurement back to UTC. Each link in the chain has an associated uncertainty which is composed of time offset and jitter. The uncertainty of the entire traceability chain is typically computed as the square root of the sum of the squares of the individual uncertainties. This means that the largest uncertainty tends to dominate the result. Improving links in the traceability chain with small uncertainties has a minimal effect on the overall result.

NOTE: An uncertainty is another way of stating accuracy. For example, a timestamp that is traceable to UTC with an uncertainty of 100 nanoseconds means that the timestamp is accurate to UTC to within 100 nanoseconds.

METROLOGICAL AND LEGAL TRACEABILITY

Metrological traceability in the VIM (above) is the only type of traceability defined in an international standards document. Metrological traceability requires measurements and uncertainty calculations. The numbers in this paper satisfy this requirement up to the point of the NTP/PTP timestamps generated by the Time Server. You will need to continue the traceability chain up to the point of the timestamps generated by your workstations.

Legal traceability means that you must be prepared to convince a jury in an adversarial proceeding that your time was correct at some instant in the past. The exact amount of evidence required to prove traceability in a court of law varies from case to case. If you have established metrological traceability for a given time period, then you have also established legal traceability for that time period. To prove this in court some recordkeeping, such as log files, is essential. The question of how extensive your policies and procedures need to be in order to prove traceability must be decided based on your specific requirements and is beyond the scope of this paper.

GPS-SYNCHRONIZED NETWORK TIME SERVERS

The UTC traceability chain for NTP / PTP timestamps using the Global Positioning System (GPS) is shown in Figure 1 and Table 1.

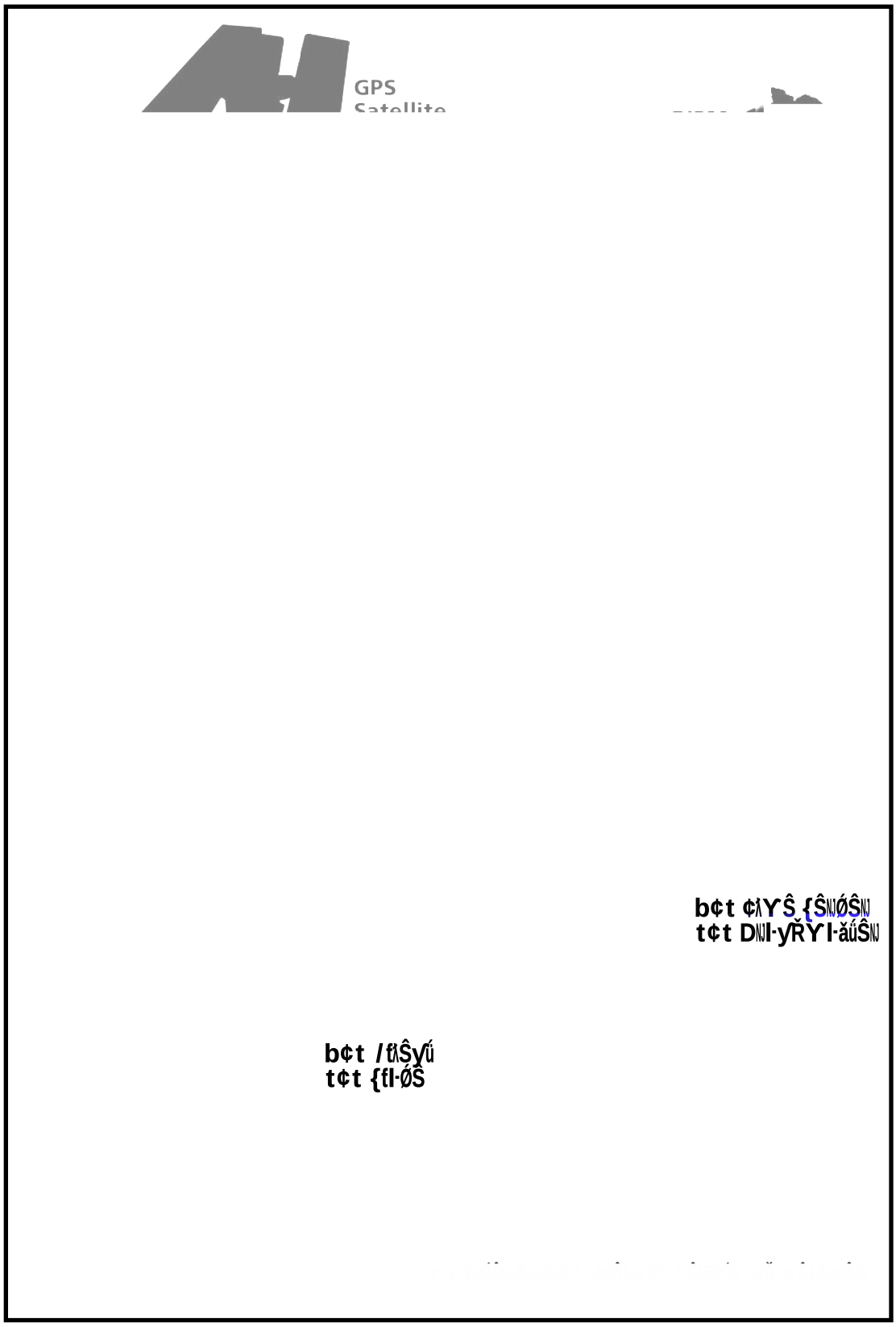

Figure 1. GPS-Synchronized Network Time Server UTC Traceability Chain

CDMA-SYNCHRONIZED NETWORK TIME SERVERS

The CDMA cell phone system basically acts as a repeater of GPS timing information. To establish UTC traceability for CDMA Network Time Servers, two links are inserted into the GPS traceability chain as shown in Figure 2 and Table 2.

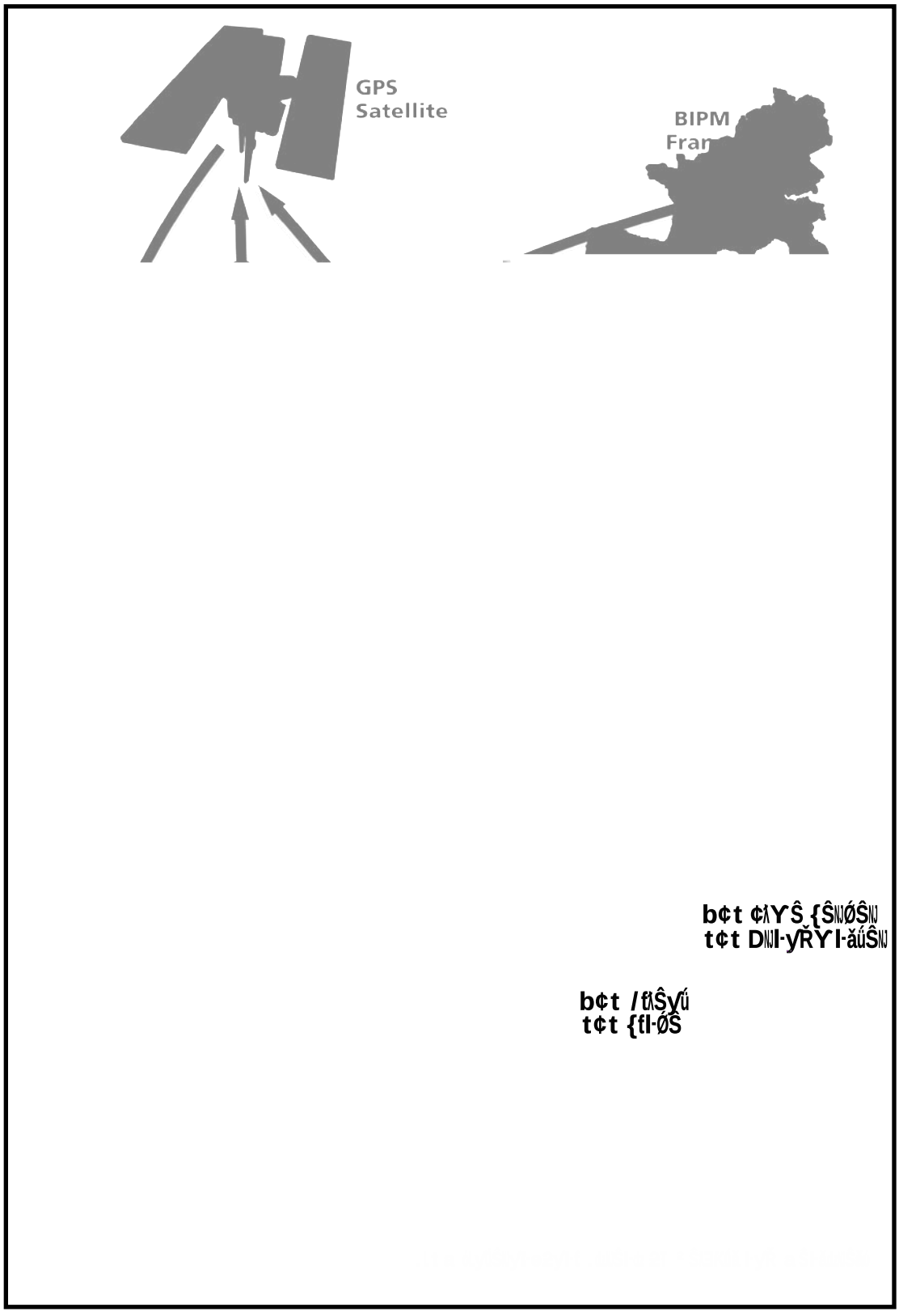

Figure 2. CDMA-Synchronized Network Time Server UTC Traceability Chain

Table 2. CDMA-Synchronized Network Time Server Traceability Chain

Link	Reference	Compared To	Uncertainty (Stated)
A	UTC per BIPM Circular-T	UTC(NIST or USNO)	< 10 nanoseconds
B	UTC(NIST or USNO)	GPS Time from Satellite Transmissions	< 10 nanoseconds
C	GPS Time from Satellite Transmissions	GPS Receiver at CDMA Base Station	< 100 nanoseconds
D	GPS Receiver at CDMA Base Station	CDMA Base Station Transmissions	< 1 microsecond < 10 us worst-case
E	CDMA Base Station Transmissions	CDMA Receiver Inside Network Time Server	< 10 microseconds < 101 us worst-case
F	CDMA Receiver Inside Network Time Server	NTP Server Timestamps	< 10 microseconds*
		PTP Grandmaster Timestamps	< 8 nanoseconds*
G	Network Time Server NTP / PTP Timestamps	NTP Client	< 2 milliseconds (LAN)
		PTP Slave	< 100 nanoseconds (LAN)