TIMING ACCURACIES OF RANGE INSTRUMENTATION SYSTEMS

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Summary Comparison of telemetry inertial guidance data with radar and optical data requires that all data be accurately time tagged. Timing errors which accumulate, particularly in telemetry data processing, exceed range user requirements. The paper classifies the sources of timing errors, discusses how the errors are measured, provides typical values, and shows how the uncertainties are reduced to tolerable levels.

Introduction Range users compare telemetry inertial guidance data with radar and optical data to determine missile guidance performance. In order to model inertial guidance coefficients accurately, it is essential that the uncorrected timing errors for site-to-site comparisons accumulate to less than 100 microseconds. It is shown that radar and optics system may accumulate typical errors of 150 microseconds,, but that uncertainties can be reduced to 25 microseconds by carefully modeling the system , measuring the errors, and correcting the data prior to site-to-site comparisons. It is also shown that "state-of-the-art" telemetry systems accumulate typical errors of 20 microseconds, but that computer processing from the analog form to digital form may introduce as much as a 3 millisecond error. However, the accumulated error can be determined within 30 microseconds ±1 bit time by use of special techniques.

Classification of Timing Errors Three basic classes of instrumentation system timing errors and uncertainties are defined which affect the accuracy of timing. Timing delays caused by RF propagation between the missile and the receiving antenna are not included in the error models. The three classes of timing errors and uncertainties accounted for at the SAMTEC are:

1) Class I - Timing errors and uncertainties (systematic and random) associated with the generation and reproduction of Coordinated Universal Tim (UTC) include errors in the USNO primary UTC standard, Precision Measurement Laboratory (PML), Precise Tim Reference Station (PTRS), and individual range timing centers Central Time Signal Generators (CTSG).

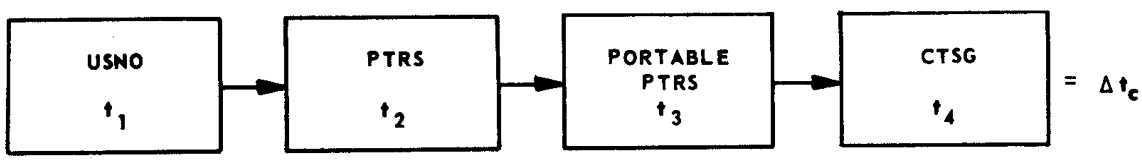
2) Class II - Timing errors and uncertainties in this class include the delays encountered in transmission of timing signals from the respective Central Time Signal Generators to each telemetry, metric radar, metric optical and range user instrumentation system site where timing is required.

3) Class III - Timing errors and uncertainties include systematic and random delays which occur during processing of real and postrealtime telemetry or metric radar data.

The distribution of UTC timing to SAMTEC and range user instrumentation sites is shown in Figure 1. Figures 2 and 3 illustrate the interrelationship between Class I, II and III timing error model terms for telemetry and metric radar instrumentation systems.

Discussion of Class I, II and III Timing Accuracy Error Models.

Class I Timing Accuracy and Error Model Δt_c Identification of Timing errors and uncertainties associated with the generation and distribution of Coordinated Universal Time (UTC) for Class I error model term is given as:



$$\Delta t_c = \pm t_1 \pm t_2 \pm t_3 \pm t_4$$

Where:

Atc = Total combined errors associated with generation and distribution of UTC.

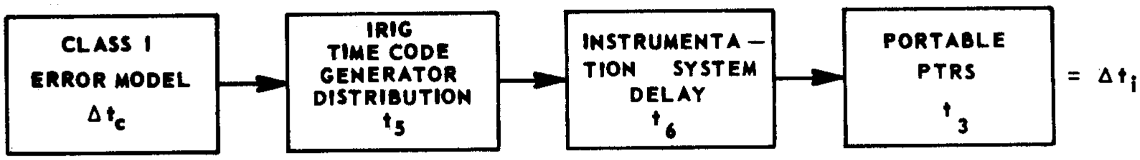
t_1 = Error and uncertainty in the primary generation of U. S. Naval Observatory UTC reference on time pulse, t_0.

t_2 = Error and uncertainty in the secondary generation and synchronization of UTC at the Precise Tim Reference Station (PTRS) located at the Precision Measurement Laboratory (PML), Vandenberg Air Force Base, California.

t_3 = Error and uncertainty in the portable PTRS used to transfer UTC to the SAMTEC CTSGs.

t_4 = Error and uncertainty accumulated between calibration intervals of the Central Time Signal Generator (CTSG).

Class II Instrumentation System Timing Accuracy and Error Model Δt_i
The timing error and uncertainty of the instrumentation system (e.g., telemetry, metric radar and metric optics) are defined in the Class II error model term as:



$$\Delta t_i = \pm\Delta t_c \pm t_5 \pm t_6 \pm t_3$$

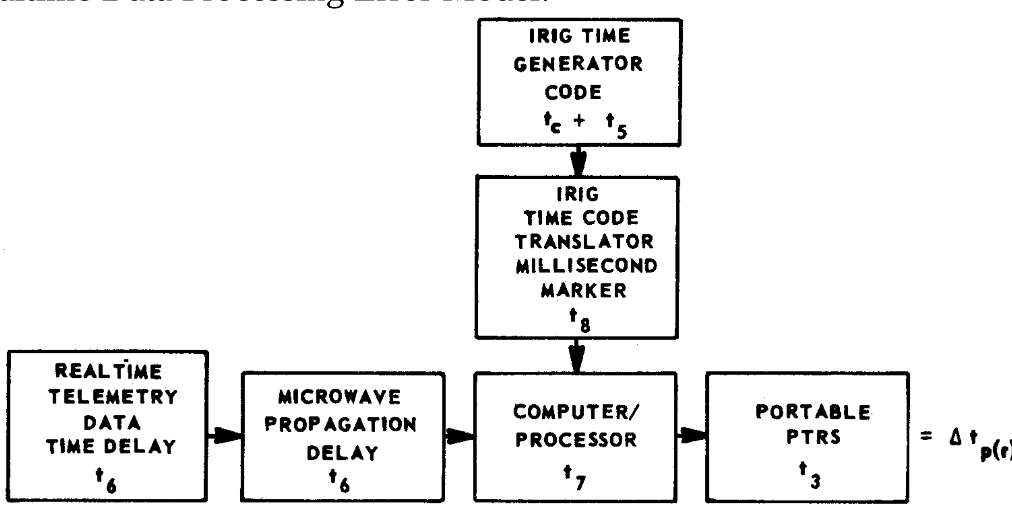
Where:

- Δt_i = Total combined error and uncertainty as determined at each instrumentation system.
- t_5 = Error and uncertainty of IRIG Time Code Generator and distribution system.
- t_6 = Error and uncertainty of each instrumentation system delay (includes coaxial cable, electronic component and microwave transmission RF propagation path losses).

Class III Instrumentation Processing System Timing Accuracy and Error Model Δt_p
Class III instrumentation data processing system accuracy error model terms are divided into two subclassifications of telemetry and metric radar instrumentation system . Each subclassification is further defined for real and postrealtime processing:

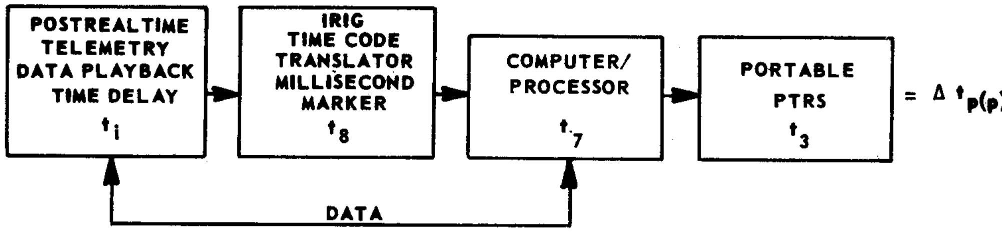
Class III Telemetry Data Processing System Timing Accuracy and Error Model Δt_p
Real, Δt_p(r), and postreal, $\Delta t_{p(r)}$, telemetry data processing timing accuracy and error model term are:

1) Realtime Data Processing Error Model:



$$\Delta t_{p(r)} = \pm t_6 \pm t_5 \pm t_8 \pm t_7 \pm t_3$$

2) Postrealtime Data Processing Error Model:



$$\Delta t_{p(p)} = \Delta t_i \pm t_8 \pm t_7 \pm t_3$$

Where:

Δt_p = Total errors and uncertainties of telemetry real or postrealtime data processing.
t_7 = Error and uncertainty of millisecond marker through computer processing.
t_8 = Error and uncertainty in time code translator millisecond marker.

Measurement Errors Timing accuracies and error uncertainties are measured for ech of the Class I, II and III model term and are published in the SAMTEC Systems Performance and Accuracy Report (Reference 1).

Class I - Timing errors are measured by the SAMTEC Precision Measurement Laboratory using an HP-E21-5061A Cesium Beam Frequency Standard, HP-5248M Electronic Counter, Time Interval Unit HP-5267A, and an HP-180A Oscilloscope equipped with an HP-1801A Dual Channel Vertical and HP-1823A Time Base Plug In. The measurement accuracy is ±2.0 microseconds. The measurements are made at each Central Tim Signal Generator (CTSG) on a quarterly basis. The one pulse per second time output of the portable reference frequency standard is used to determine the time delay interval difference of the CTSG. The counter and the oscilloscope are used to measure the accuracy of the me pps repetition rate as referenced to the UTC on time zero crossing.

Class II - Timing delays and uncertainties of instrumentation system time code pulses are determined with the same type of precision measurement equipment described under the Class I error. The only exception is that an HP-E21-5065A Portable Rubidium Frequency Standard is used in lieu of the Cesium standard and an HP-5050B Printer is used to print out the sampled time delay over the measurement period. Like the Class I errors these measurements are also performed on a quarterly basis with an accuracy of ±1 microsecond.

Class III - Timing delays accrued during the processing of analog data into digital data are determined with a special recorded timing tape. This tape is processed and the delta time differences between. the precise one pps special timing tape and the normal time code formats are determined. This determination is performed in accordance with range user program support requirements and is performed concurrent to the missile launch operation. The accuracy of this determination is ±50 microseconds.

Typical SAMTEC Timing Accuracy and Error Uncertainties Table I shows typical timing accuracy values for the SAMTEC systems. As shown, Class I errors are only several microseconds, Class II intersite radar errors typically accrue to 125 microseconds, and optics errors to 100 microseconds. However, these uncertainties can be reduced to t25 microseconds (typical) by applying results of the quarterly measurement program prior to data processing. Telemetry receive/record timing errors are typically 20 microseconds, but Class III computer processing worst case errors of 3 milliseconds for realtime and 1 millisecond in postrealtime formatted playbacks have been observed. The realtime telemetry timing errors and uncertainties are primarily caused by microwave transmission propagation delay losses. This propagation error occurs during the transmission of telemetry data from the remote receiving site to the telemetry data processing area where local timing is applied to the incoming delayed data. The timing errors which occur during the postrealtime processing of formatted telemetry tapes are caused by the uncertainty of the millisecond computer marker. Thus, it can be seen that the Class III telemetry timing errors are excessively large and must be corrected by special means if the range user's requirements are to be met. In the continuing effort to minimize timing errors and uncertainties SAMTEC is investigating better means for compensating for accumulative propagation delays.

Special Telemetry Data Time Tagging Techniques Federal Electric Corporation, it its role of providing technical support to SAMTEC, has responded to the data time tagging problem by developing a new method (Reference 2) which enables the large Class III timing errors, as observed during computer processing of analog telemetry data, to be reduced to tolerable levels. This method is accomplished by recording two serial telemetry data tapes during the missile launch operation at one reference station. One tape is required for normal range user recorded telemetry data. The second is a special timing tape which inserts a special data word into the received telemetry signal bit stream at precise one second intervals. The accuracy of this one second timing pulse has a me sigma standard deviation of plus or minus five microseconds from the on time UTC reference. The special tape is then processed to establish timing biases. This information is then used to determine the total errors caused in the recording and processing of time tagged data on the normal tape. This method has enabled tine tagged telemetry data to be correlated to within a one sigma accuracy of 25 microseconds of the on time (to) pulse referenced to UTC over the entire normal recorded magnetic tape. (The 25 microsecond error represents the sample-to-sample comparison variations which occur throughout a mission. The actual uncertainty is 30 microseconds due to the 5 microsecond uncertainty of the on time pulse.)

Conclusions From the information presented, it is shown that SAMTEC radar and metric instrumentation systems timing accuracies and error uncertainties can be corrected to plus or minus 25 microseconds relative to UTC.

Using present telemetry system performance characteristics, the formatted data recorded on magnetic tape can only be correlated to approximately one millisecond. Application and use of the special telemetry timing tape results in one sigma timing accuracies of 30 microseconds ±1 bit time over the entire recorded magnetic tape. Realtime worst case 3 millisecond timing errors are under investigation, one possible solution being considered is to offset the propagation effects by furnishing timing from the remote site to the processing area concurrent with the telemetry signal.

This timing accuracy program allows range users to correlate and analyze site-to-site recorded data for missile performance evaluation.

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References

1. SAMTEC Technical Report TR-72-1, Systems Performance and Accuracy Report, Space and Missile Test Center, Air Force Systems Command, Vandenberg Air Force Base, California, March, 1972.

2. Pickett, R. B., Improving Telemetry Timing Accuracy, <u>ITC Proceeding, Volume VI</u>, 1971, page 286.

Table I TYPICAL TIMING ACCURACIES AND ERROR UNCERTAINTIES AT SAMTEC INSTRUMENT SYSTEM LOCATIONS

Instrumentation System	Class I Δt_c CTSG Error Budget (μsec.)	Class II Δt_i Instrumentation System Error Budget (μsec.)	Class III Δt_p Processing System Error Budget (msec.)		$\Sigma \Delta t_e$ $\Delta t_c \pm \Delta t_i \pm \Delta t_{p(r\ or\ p)}$ Total Accumulated Time Delays
			$\Delta t_{p(r)}$	$\Delta t_{p(p)}$	
Vandenberg Air Force Base					
- CTSG	-0.5 ± 2.0***				0.5 ± 2.0 μsec.
- AN/FPS-16 Metric Radar	-0.5 ± 2.0	-127.4 ± 6.3			-127.9 ± 8.3 μsec.
- AN/TPQ-18 Metric Radar	-0.5 ± 2.0	-32.7 ± 3.6			-33.2 ± 5.6 μsec.
- LA-24 Optical System	-0.5 ± 2.0	-107.1 ± 1.4			-107.6 ± 3.4 μsec.
- Telemetry Data Center TDC-10*	-0.5 ± 2.0		-3.0		-3.0 msec.
**				-1.0	-1.0 msec.
- Telemetry Data Center TDC-20*	-0.5 ± 2.0		-3.0		-3.0 msec.
**				-1.0	-1.0 msec.
- Telemetry Data Center TDC-30*	-0.5 ± 2.0		-3.0		-3.0 msec.
**				-1.0	-1.0 msec.
- Telemetry Data Center TDC-40*	-0.5 ± 2.0		-3.0		-3.0 msec.
**				-1.0	-1.0 msec.
- Telemetry Receiving Site TPRS-6(s)	-0.5 ± 2.0	-3.2 ± 0.3			-3.7 ± 2.3 μsec.
- Telemetry Receiving Site TPRS-6(2)	-0.5 ± 2.0	-3.2 ± 0.3			-3.7 ± 2.3 μsec.
- Telemetry Receiving Site TPRS-10	-0.5 ± 2.0	-3.1 ± 0.2			-3.6 ± 2.2 μsec.
- Telemetry Receiving Site TPRS-11	-0.5 ± 2.0	-3.1 ± 0.2			-3.6 ± 2.2 μsec.
Anderson Peak IGOR Optical System	-0.5 ± 2.0	-1.0 ± 1.0			-1.5 ± 3.0 μsec.
Santa Ynez Peak IGOR Optical System	-0.5 ± 2.0	-10.0 ± 35.0			-10.5 ± 35.0 μsec.
Pillar Point Air Force Station					
- CTSG	-0.1 ± 2.0				-0.1 ± 2.0 μsec.
- AN/FPQ-6 Metric Radar Multiple Radar Interrogator (MRI)	-0.1 ± 2.0	-26.8 ± 3.2			-26.9 ± 5.2 μsec.
Hyperion Time Code Generator		-55.1 ± 2.1			-55.2 ± 4.1 μsec.
- AN/FPS-16 Metric Radar (MRI)	-0.1 ± 2.0	-11.2 ± 2.3			-11.3 ± 4.3 μsec.
- Telemetry Receiving Site TPRS-1 and 2	-0.1 ± 2.0	-22.5 ± 9.7			-22.6 ± 11.7 μsec.
Canton Island					
- CTSG	+1.7 ± 2.0				+1.7 ± 2.0 μsec.
- AN/TPQ-18 Metric Radar	+1.7 ± 2.0	-152.0 ± 4.0			-150.3 ± 6.0 μsec.
USNS Huntsville T-AGM-7					
- CTSG	±0.0 ± 2.0				±0.0 ± 2.0 μsec.
- CAPRI Radar	±0.0 ± 2.0	-39.1 ± 0.0			-39.1 ± 2.0 μsec.
- Telemetry Receiving Station	±0.0 ± 2.0	-7.1 ± 0.0			-7.1 ± 2.0 μsec.

*Real time Propagation Error

**Postrealtime Formatting Errors

***Accuracy of PML Measurement

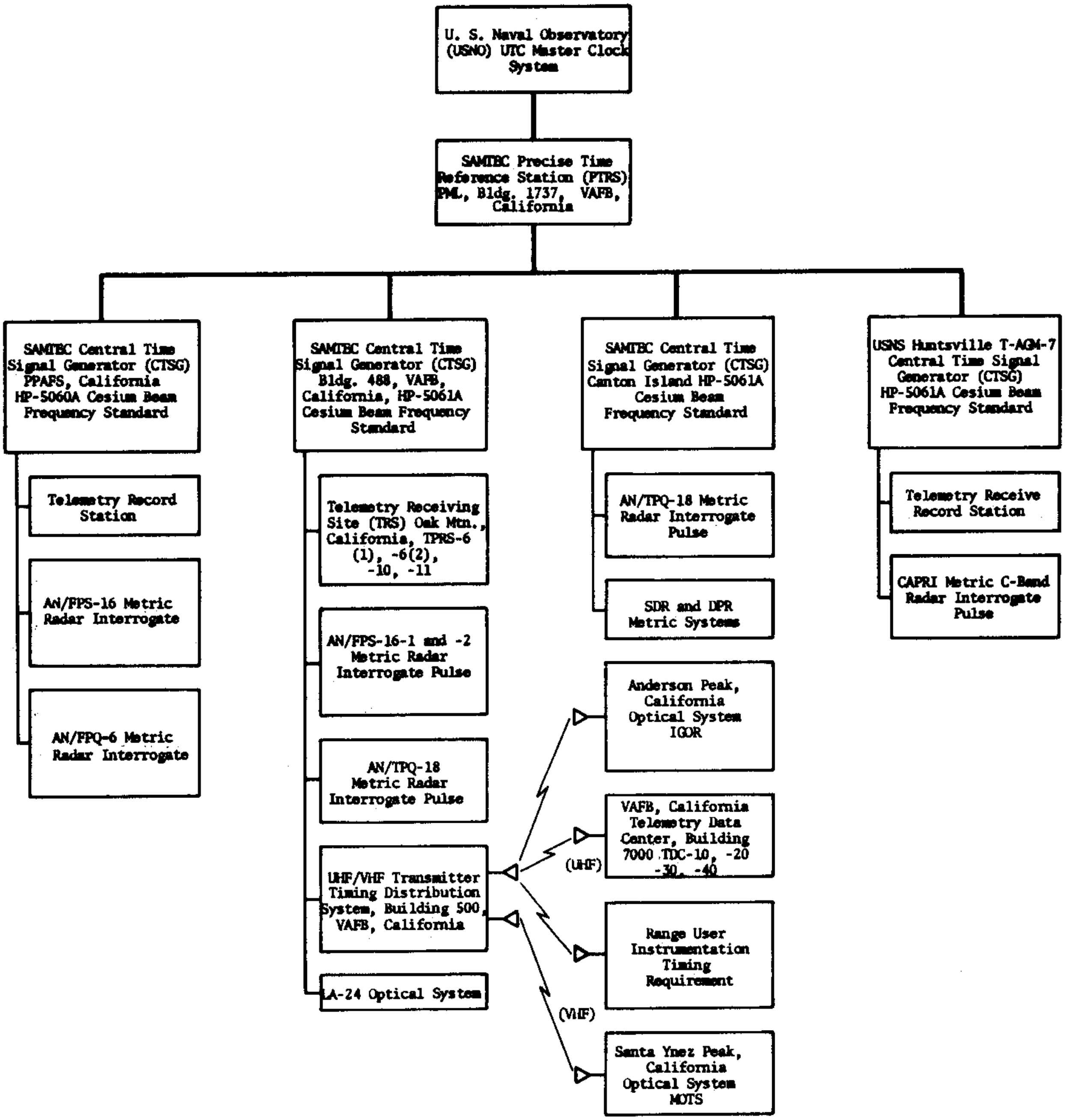

Figure 1 SAMTEC INSTRUMENTATION SYSTEMS UTC/IRIG TIMING AND FREQUENCY ACCURACY TRANCEABILITY TO USNO PRIMARY UTC STANDARD

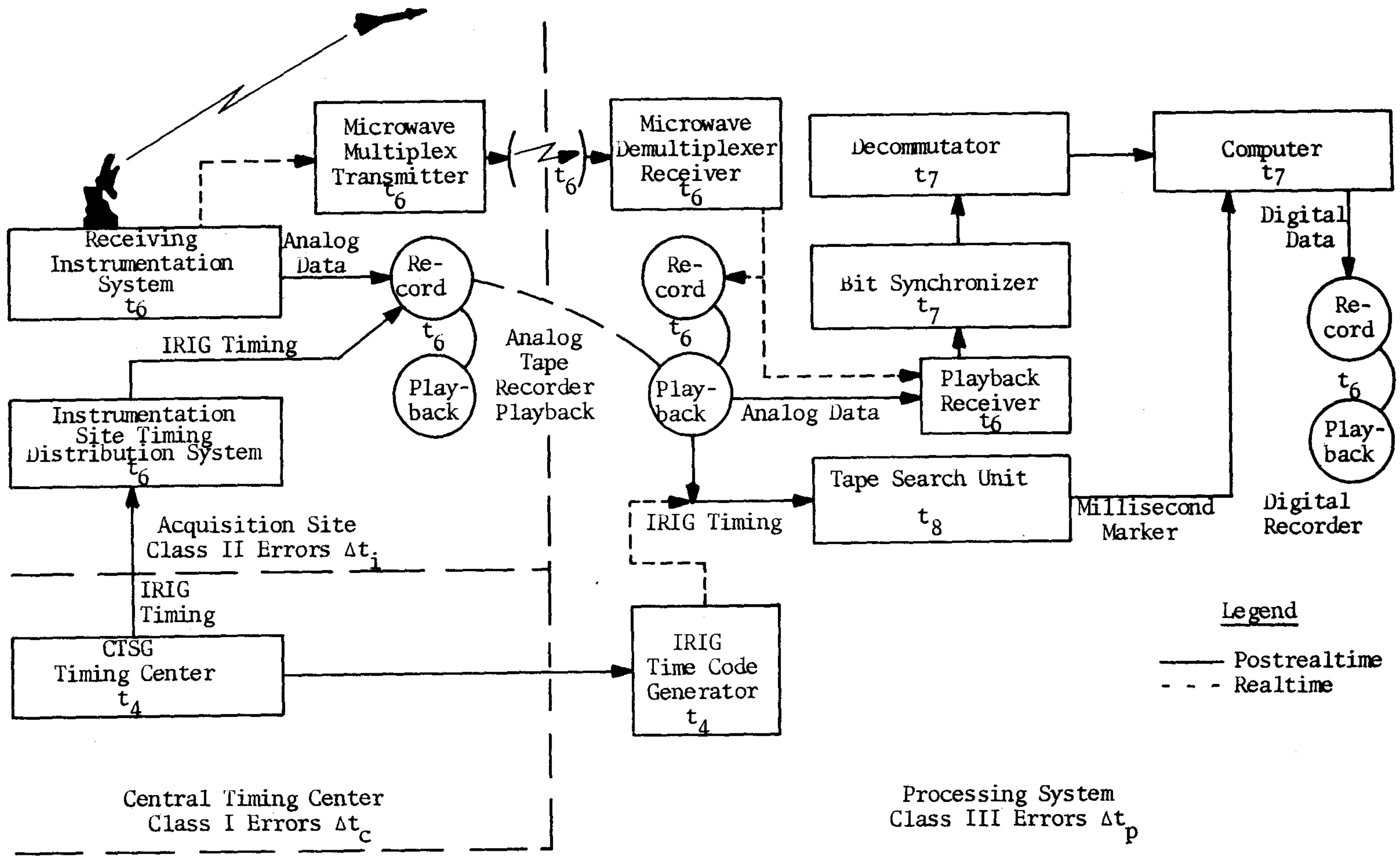

Figure 2 CLASSIFICATION OF REAL AND POSTREALTIME TELEMETRY INSTRUMENTATION AND PROCESSING SYSTEM TIMING ERRORS

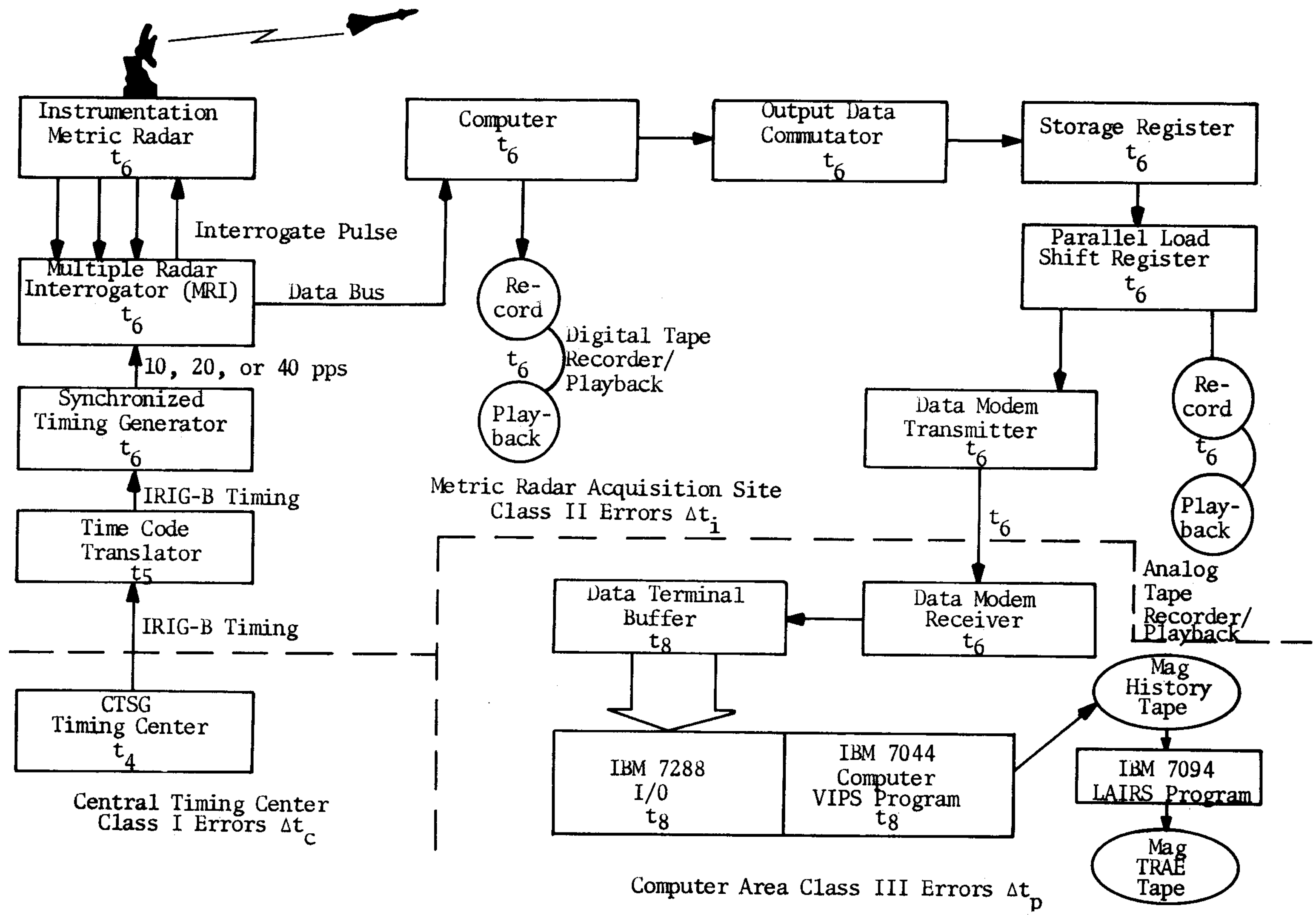

Figure 3 CLASSIFICATION OF METRIC RADAR INSTRUMENTATION AND PROCESSING SYSTEM TIMING ERRORS