THURLBY THANDAR INSTRUMENTS

TF960

6GHz Universal Counter

INSTRUCTION MANUAL

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Note: The latest revisions of this manual and device driver can be downloaded from: http:tti1.co.uk/downloads/manuals-rf.htm

Introduction

The TF960 is a portable, battery-operated, universal counter with a large 0.5" 10-digit liquid crystal display (LCD). The frequency range is from below 0.001Hz to over 6GHz and measurement functions include frequency, period, ratio, pulse width and count.

The instrument uses a high quality temperature compensated internal frequency reference which has a low aging rate and is stable to within ±1ppm over the full temperature range. Its short warm-up time allows accurate measurements to be made even under portable battery powered conditions.

Input A has configurable coupling (AC or DC), input impedance (1MΩ or 50Ω), attenuation (1:1 or 5:1), threshold (fully variable) and active edge and can be used for frequencies in the range 0.001Hz to over 125MHz. Input B is a nominal 50Ω input for frequencies in the range 80MHz to 3GHz. Input C is a nominal 50Ω input with an N-type connector for frequencies in the range 1GHz to over 6GHz. An External Reference input is provided and changeover from the internal timebase is automatic when an external reference standard is connected.

For frequency, period and frequency ratio functions the instrument uses a reciprocal counting technique to provide high resolution at all frequencies. 8 significant digits of answer are produced in a 1 second measurement time, 9 digits in 10s and 10 digits in 100s with a granularity of less than 2 counts in the least significant digit.

Indicators show measurement input configuration & function, measurement time & status, external reference connection, low battery and the units of the measurement which may be Hz, kHz, MHz, ns, us, ms or s.

The instrument has a USB interface which allows it to be remotely controlled using serial communication via a computer's USB port. The remote commands of predecessor instruments, the TF830 and the TF930, are compatible with the TF960 command set

The instrument operates from internal rechargeable NiMH batteries which give typically 24 hours operating life. The universal AC charger supplied will recharge the batteries in less than 4 hours and can be used for continuous AC operation. The instrument will also automatically be powered from a standard USB port when connected (whether remote control is in use or not) but this will not charge the batteries.

This instrument is fully compliant with EN61010-1 Safety and EN61326 EMC standards.

Input Specifications

Input A

Configurable options

Input coupling:	AC or DC
Input impedance:	1MΩ or 50Ω
Attenuation:	1:1 or 5:1
Active edge:	Rising or falling, or width high or low
Low pass filter:	Filter In (~50kHz cut-off) or Out
Trigger threshold:	Variable threshold for both DC and AC coupling
Input Impedance:	1MΩ//25pF (DC or AC coupled) or 50Ω nominal (AC coupled only).
Frequency Range:	< 0.001Hz to >125MHz (1MΩ, DC coupled). < 30Hz to >125MHz (1MΩ, AC coupled). < 500kHz to > 125MHz (50Ω, AC coupled).
Trigger Threshold:	
DC coupled:	0 to 2V (1:1 attenuation) or 0 to 10V (5:1 attenuation).
AC coupled:	Average ± 50mV (1:1 attenuation) or ± 250mV (5:1 attenuation).
Sensitivity:	Sinewave - 15mVrms 30Hz to 100MHz, 25mV to 125MHz at optimum threshold adjustment.

Input B

Input Impedance:	50Ω nominal (AC coupled).
Frequency Range:	< 80MHz to >3GHz.
Sensitivity:	12mVrms 80MHz to 2GHz, 25mVrms to 2.5GHz, 50mVrms to 3GHz.
Maximum Input Signal:	< 0dBm recommended, +13dBm (1Vrms) maximum.

Input C

Input Impedance:	50Ω nominal (AC coupled) in-band. 250kΩ at DC.
Frequency Range:	< 2GHz to >6GHz (typically 1.8GHz to 7.5GHz).
Sensitivity:	25mVrms (–19dBm) 2GHz to 6GHz.
Maximum Input Signal:	< +16dBm (1.5Vrms) recommended. Damage level +25dBm (4Vrms).

External Reference Input

Input Impedance:	>100kΩ, AC coupled.
Frequency:	10MHz.
Signal Level:	TTL, $3V_{pp}$ to $5V_{pp}$ CMOS or 1 to 2Vrms sinewave.

Maximum Input Voltage

Inputs A, B, C, and External Reference:  30VDC; 30Vrms 50/60Hz with respect to earth ground ⏚

Note that the inputs will not be damaged if subjected to an accidental short-term connection to a 50/60Hz line voltage not exceeding 250Vrms, or 250V DC.

Timebase

Measurement Clock:	50MHz.
Internal Reference oscillator:	10MHz TCXO with electronic calibration adjustment.
Oscillator Temperature Stability:	Better than ± 1ppm over rated temperature range.
Initial Oscillator Adjustment Error:	< ± 0.2ppm at 21ºC.
Oscillator Ageing Rate:	< ± 1ppm first year.
Calibration adjustment range:	> ± 8ppm.

Measurement Functions

Frequency (Inputs A, B or C)

A Input Frequency Range:	< 0.001Hz (DC coupled) to >125MHz
B input Frequency Range:	80MHz to >3000MHz.
C input Frequency Range:	<2Ghz to >6GHz.
Resolution:	up to 10 digits (see below) or 0.001Hz

Period (Inputs A, B or C)

A Input Period Range:	8ns to 1000s (DC coupled)
B input Period Range:	0.333ns to 12.5ns
C input Period Range:	0.166ns to 0.5ns
Resolution:	up to 10 digits (see below)

Pulse Width Modes (Input A only)

Functions:	Width high or low, ratio H:L (high time to low time) or duty cycle.
Pulse Width Range:	40ns to 1000s
Averaging:	Automatic within measurement time selected, up to 50 pulses.
Resolution:	20ns for one pulse; up to 1ns or 10 digits with multiple pulse averaging. 0.01% for Ratio H:L and Duty Cycle.

Total Count (Input A only)

Count range:	1 to 9 999 999 999
Minimum pulse width:	8ns

Frequency Ratio B:A

Resolution:	Equal to the resolution of the two frequency measurements. If the ratio exceeds ten digits, displays six digits plus exponent.

Measurement Time

Selectable as 100s, 10s, 1s or 0.3s. The instrument displays the average value of the input signal over the measurement time selected, updated every 2s, 1s, 0.5s or 0.3s respectively. The hardware captures the count values and continues measuring without any dead time.

Resolution

The displayed resolution depends upon measurement time and input frequency. The basic resolution of period is 8 digits for every 2 seconds of measurement time. Frequency resolution is the reciprocal of period resolution. Usable resolution can be reduced by noise at low frequencies.

Accuracy

Measurement accuracy is timebase accuracy + measurement resolution + 2 counts.

Operating Facilities

Noise Filter (Input A only)

The Filter key controls a low pass filter, with a cut-off frequency of about 50kHz, to assist in obtaining stable readings at low frequencies.

Hold

Pressing the Hold key will hold the current measured value in the display, with the Hold indicator on, until the Hold key is pressed again. The measurement continues in the background when Hold is on. A long press on the Hold key clears old data and restarts the measurement.

Intelligent Power Switching

The unit automatically selects the best available power source of AC adaptor, USB or battery. Intelligent switching avoids discharging the battery overnight when operated from externally switched AC power.

A press-to-measure facility allows a quick measurement to be made by pressing a function select key which will power the instrument up in the corresponding function. The instrument will automatically switch off 15 seconds after the last key-press.

Remote Control

All capabilities can be controlled remotely and measurements read through a USB port.

The instrument can be powered (but the battery cannot be charged) by the USB host.

Interface:	Serial port emulation over USB.
Current consumption:	< 100mA (<5mA if AC adaptor power is present)
Command set:	Instrument specific. TF830 and TF930 compatible.

Power Requirements

The instrument has fixed internal rechargeable batteries and is supplied with a universal voltage external mains adaptor with interchangeable UK, Euro, Australian and US power connectors.

Battery Type:	Three 2500mAh NiMH cells.
Battery Operating Life:	Typically 24 hours
Low Battery Indicator:	‘Lo Bat' shows in display when approximately 10% of battery life remains.
Recharge Time:	< 4 hours
Adaptor Supply range:	85 to 240V, 50 or 60 Hz,
Power consumption:	5W max at DC input to unit; 15VA max at AC adaptor input (charging).

General

Display:	10 digit LCD, 12.5mm high (0.5”). Annunciators show input configuration, operating mode, measurement units and gate time.
Operating Range:	+5°C to +40°C, 20% to 80% RH
Storage Range:	-20°C to +60°C
Environmental:	Indoor use at altitudes up to 2000m, Pollution Degree 2
Size:	260mm(W) x 88mm(H) x 235mm(D)
Weight:	1050 gms (plus 170 gms AC adaptor)
Electrical Safety:	Complies with EN61010-1
EMC:	Complies with EN61326

EC Declaration of Conformity

We Thurlby Thandar Instruments Ltd
Glebe Road
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England

declare that the:

TF960 6GHz Universal Counter with USB Interface

meets the intent of the EMC Directive 2004/108/EC and the Low Voltage Directive 2006/95/EC. Compliance was demonstrated by conformance to the following specifications which have been listed in the Official Journal of the European Communities.

EMC

Emissions: a) EN61326-1 (2006) Radiated, Class B

Immunity: EN61326-1 (2006) Immunity Table 1, referring to:

a) EN61000-4-2 (2009) Electrostatic Discharge

b) EN61000-4-3 (2006) Electromagnetic Field

Performance levels achieved are detailed in the user manual.

Safety – TF960

EN61010-1 Pollution Degree 2.

Safety – AC Power Adaptor

EN60950-1

Chris Wilding

CHRIS WILDING
TECHNICAL DIRECTOR

2nd October 2012

Universal Counter

This instrument has been designed to meet the requirements of the EMC Directive 2004/108/EC.

Compliance was demonstrated by meeting the test limits of the following standards:

Emissions

EN61326 (2006) EMC product standard for Electrical Equipment for Measurement, Control and Laboratory Use. Test limits used (radiated emissions only) were Class B.

Immunity

EN61326 (2006) EMC product standard for Electrical Equipment for Measurement, Control and Laboratory Use. Test methods, limits and performance achieved are shown below (requirement shown in brackets):

a) EN61000-4-2 (2009) Electrostatic Discharge : 4kV air, 4kV contact, Performance B (B).

b) EN61000-4-3 (2006) Electromagnetic Field:
3V/m, 80% AM at 1kHz, 80MHz – 1GHz: Performance B (A) and 1.4GHz to 2GHz: Performance B (A); 1V/m, 2.0GHz to 2.7GHz: Performance B (A).

Note: The TF960 is a sensitive measuring instrument and, if subjected to a sufficiently large RF field, may count its frequency. At lower field strengths a measurement might be disturbed, particularly if the applied signal level is small. This is much more likely to occur with the B input than with the A or C inputs. In all other respects, the instrument will operate correctly (Performance A) in fields up to 3V/m.

Adaptor/Charger

This AC adaptor/charger has been designed to meet the requirements of the EMC Directive 2004/108/EC.
Compliance was demonstrated by meeting the test limits of the following standards:

Emissions

EN55022, radiated and conducted Class B.

Immunity

EN55024:1998 + A2:2003. Test methods, limits and performance achieved were:

a) EN61000-4-2 (2009) Electrostatic Discharge : 8kV air, 4kV contact, Performance B (B).

b) EN61000-4-3 (2006) Electromagnetic Field, 3V/m, 80% AM at 1kHz, Performance A (A).

c) EN61000-4-11 (2004) Voltage Interrupt: ½ cycle and 1 cycle, 0% Performance B (B); 25 cycles, 70% and 250 cycles, 0% Performance B (C).

d) EN61000-4-4 (2004) Fast Transient, 1kV peak (AC line), Performance B (B).

e) EN61000-4-5 (2006) Surge, 1kV (line to line), 2kV (line to ground), Performance B (B).

f) EN61000-4-6 (2009) Conducted RF, 3V, 80% AM at 1kHz (AC line only; DC Output connection <3m, therefore not tested), Performance A (A).

Performance Definitions

The definitions of performance criteria are:

Performance criterion A: ‘During test normal performance within the specification limits.’

Performance criterion B: ‘During test, temporary degradation, or loss of function or performance which is self-recovering’.

Universal Counter

This instrument is Safety Class III according to IEC classification and has been designed to meet the requirements of EN61010-1 (Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use).

This instrument has been tested in accordance with EN61010-1 and has been supplied in a safe condition. This instruction manual contains some information and warnings which have to be followed by the user to ensure safe operation and to retain the instrument in a safe condition.

This instrument has been designed for indoor use in a Pollution Degree 2 environment in the temperature range 5°C to 40°C, 20% - 80% RH (non-condensing). It may occasionally be subjected to temperatures between +5° and -10°C without degradation of its safety. Do not operate while condensation is present.

Use of this instrument in a manner not specified by these instructions may impair the safety protection provided.

WARNING!

All accessible parts will be at the same voltage as the outer of the signal input sockets. In particular, note that the shell of the USB connector is galvanically connected to the body of the N-type and BNC inputs and will therefore be at earth ground potential when the USB port is connected to a desktop PC. However, to maintain user safety under all other circumstances it is essential that no input is connected to a voltage above 30Vdc or 30Vrms with respect to earth ground ⏚ which is the limit of Safe Extra Low Voltage (SELV) by IEC definition. Note that although the inputs will withstand short-term accidental connection to an AC line voltage up to 250Vrms, 50/60Hz, users will be at risk if the instrument 'ground' is connected to such hazardous voltages.

The instrument shall be disconnected from all voltage sources before it is opened for any adjustment, replacement, maintenance or repair. Any adjustment, maintenance and repair of the opened instrument under voltage shall be avoided as far as possible and, if inevitable, shall be carried out only by a skilled person who is aware of the hazard involved.

Do not wet the instrument when cleaning it.

The following symbols are used on the instrument and in this manual.



Direct Current



CAUTION – refer to accompanying documentation.
Damage to the instrument may occur if these precautions are ignored.



meaning that the marked terminal is connected to accessible conductive parts.

Adaptor/Charger

The adaptor/charger supplied has a universal input voltage rating of 100-240VAC, 50/60Hz. It is a Class II (double insulated) device, fully approved to EN 60950-1 (2001), UL 60950 (UL listing E245390).

Front Panel Connections

Input A

For frequencies in the range 0.001Hz (DC coupled) to >125MHz. Input impedance selectable between 1MΩ//25pF and 50Ω.



Maximum allowable input 1Vrms (1:1 attenuation) or 4Vrms (5:1 attenuation) for 1MΩ//25pF input; 1Vrms above 300kHz for 50Ω input (AC coupled).
Maximum input with respect to earth ground ⏚ is 30Vdc or 30Vrms 50/60Hz.

Input B

For frequencies in the range <80MHz to >3GHz. Input impedance 50Ω (AC coupled).



Maximum allowable input 1Vrms.
Maximum input with respect to earth ground ⏚ is 30Vdc or 30Vrms 50/60Hz.

Input C

For frequencies in the range <2GHz to >6GHz. Input impedance 50Ω (250kΩ at DC).



Maximum allowable input 4Vrms.
Maximum input with respect to earth ground ⏚ is 30Vdc or 30Vrms 50/60Hz.

EXT REF IN

For a 10MHz signal from an external reference standard only. Input impedance >100kΩ, AC coupled.



Maximum allowable input TTL, $5V_{pp}$ CMOS or 2Vrms sinewave.
Maximum input with respect to earth ground ⏚ is 30Vdc or 30Vrms 50/60Hz.

Rear Panel Connections

DC IN

DC power to operate and/or recharge the instrument is connected via the 1.3mm power socket.



Use ONLY the AC adaptor/charger provided by TTi with the instrument. Use of any other power source will void the warranty.

USB

The USB port accepts a standard USB cable. The Windows plug-and-play functions should automatically recognise that the instrument has been connected. The instrument will automatically be powered by the USB host if the AC adaptor/charger is not connected. USB power can be used without the USB connection being used for remote control.

The instrument can only be powered via its USB port if the connection is properly enumerated; it is therefore not possible to use adaptors which only provide DC power through a USB connector.

Power

The instrument has three possible sources of power**:** the internal rechargeable battery, DC input from the AC/DC adaptor/charger supplied (referred to in this manual as the AC adaptor), or USB power from a USB host port on a desk-top or portable PC. The AC adaptor, if present, will be used in preference to USB power or the battery; without the AC adaptor, USB will take preference over the battery; only if neither the AC adaptor nor USB power is present will the battery be used.

The instrument software remembers the power-up cause and conditions and acts intelligently at loss of AC adaptor or USB power to ensure that the battery is not discharged unintentionally. Power-up and power-down operation for all possible combinations of conditions are detailed in the sections that follow.

Safety Warning: The TF960 is a safety class III instrument by IEC classification. When the instrument is operated from its internal battery, AC adaptor or USB port of a portable (ungrounded) PC, all accessible parts will be at the same voltage potential as the outer of the N-type and BNC input sockets; to maintain user safety it is therefore essential that no signal input is connected to a voltage above 30V dc or 30Vrms, the limit of Safe Extra Low Voltage. Note that although the inputs will withstand accidental short-term connection to an AC line voltage up to 250Vrms, 50/60Hz, users will be at risk if the instrument 'ground' is connected to such hazardous voltages.

Battery Operation

The instrument is fitted with rechargeable NiMH cells with a capacity of 2500mAH, giving typically 24 hours use when fully charged. Charging is done using the AC adaptor supplied, see below. The **Bat** annunciator shows in the top right-hand corner of the display when the instrument is operating from its internal battery; this changes to **Lo Bat** when approximately 10% of battery life remains. During battery operation the instrument is turned on and off with alternate presses of the OPERATE key.

USB Power

The instrument can also be powered from a PC's host port, even if the instrument's battery is flat; the battery will not, however, be recharged from USB power. Connect the instrument's rear panel USB connector to a PC via a standard USB cable; the Windows' plug and play function should automatically recognise the addition of new hardware and, if this is the first time the connection has been made, prompt for the location of a suitable driver. The disk supplied with the instrument contains drivers for various versions of Windows; follow the PC's on-screen prompts to load the appropriate driver (there are two separate stages).

Note*:* If the plug and play function reports that a later version of the driver is already installed, **keep the later version**; the TF960 will operate satisfactorily with the later version.

The instrument will only be powered via its USB port if the connection is properly enumerated, so it is not possible to use adaptors which only provide DC power through a USB connector. USB power takes priority over battery power to preserve battery charge; the **Bat** or **Lo Bat** annunciator goes off to indicate this.

If the instrument is off when the USB connection is enumerated then the instrument will automatically power on and, when the USB power is removed, it will power off again. If the instrument is running on battery when the USB connection is enumerated then USB power will take precedence in powering the instrument and, when the USB connection is removed, the instrument will continue to operate from the battery. The instrument can be turned off and on with USB power connected using the OPERATE key. USB power can be used without the USB connection being used for remote control.

AC Adaptor Operation

The AC adaptor is connected to the rear panel 1.3mm socket marked DC IN; only the AC adaptor supplied with the instrument should be used. When the AC adaptor is powered the red EXT POWER lamp will be lit, whether the instrument is on or off; if the battery is being charged the yellow CHARGING lamp will also be lit. The instrument has intelligent charging control to optimise performance and battery life plus various protection measures; it is safe to leave the AC adaptor connected for long periods of AC-powered operation though it is always good practice to disconnect the adaptor from the AC supply and the instrument if the instrument is not in use.

The instrument can be turned off and on with the AC adaptor connected using the OPERATE key. If the instrument has been turned off using the OPERATE key then it will stay off when AC power is removed and when it is re-applied. If, however, the instrument is off when the AC adaptor power is applied *and* had last been powered off by removing the AC power, then the instrument will automatically power on and, when the AC adaptor power is removed, it will power off again. This is useful when the instrument is part of a test set-up which is switched on and off with a mains power master switch.

If the instrument is running on battery (or USB power) when the AC adaptor power is applied then AC adaptor power will take precedence in powering the instrument and, when the AC adaptor power is removed, the instrument will continue to operate from the battery (or USB power). It is always good practice to disconnect the adaptor from the AC supply and the instrument if the instrument is not in use for long periods.

Switching On

The instrument can be switched on and off with alternate presses of the OPERATE key, whatever power source is being used. At power-on the default operating conditions are always as follows: Input A, Frequency, AC coupling, 1MΩ input impedance, 1:1 attenuation, rising edge polarity, no filter, 0.3s measurement time and no measurement hold; the associated annunciators will show in the display. The threshold level is set by the position of the Threshold control.

If the RESET key is held down whilst the instrument is switched on using the OPERATE key, all the annunciators will be shown in the display and for 2 seconds the main display area will show the revision number of the installed firmware. After 2 seconds all the segments of the display will show as a functional display check until the RESET key is released.

Press to Measure

With the instrument off, pressing any of the measurement function switches FREQUENCY, PERIOD or WIDTH will power up the instrument and set the selected function; all other conditions are defaulted as described above.

The instrument will then function normally and respond to all key presses. After a period of about 15 seconds with no key presses the instrument will automatically power down; this conserves the battery if operating on battery power.

Input Selection and Configuration

Inputs A, B or C are selected *with* successive presses of the INPUT SELECT key; an annunciator in the display indicates which input is active.

Input A

Input A can be used for frequencies in the range 0.001Hz to >125MHz and has a number of configuration options, described below, which allow it to count a wide range of waveform shapes and amplitudes. The maximum input voltage and onset of clipping will depend on the coupling, attenuation and input impedance settings and are given in the Specification.

The input is protected against temporary accidental connection of mains voltages up to 250Vrms at 50/60Hz.

Input A Configuration Options

The default configuration options for Input A at power-on are: AC coupling, 1MΩ input impedance, 1:1 attenuation, rising edge polarity and no filter; with the Threshold control set to mid-position a measurement should be possible with the majority of waveforms. Changes to the configurations will, however, be necessary for certain waveforms, e.g. DC coupling and low pass filter in circuit will improve measurement of low frequencies.

Input Coupling: AC coupling is the default and can be used with either input impedance setting. Select DC coupling for very low frequencies (<30Hz) or if the waveform duty cycle is very low. DC coupling should normally be used with the input impedance set to 1MΩ; selection of 50Ω is allowed but, because a 50kΩ protection resistor is fitted in parallel with the coupling capacitor, the actual impedance will be much higher than 50Ω until the input frequency is greater than approximately 300kHz. This configuration can be useful to avoid charging up the coupling capacitor on asymmetrical waveforms.
When AC coupling is selected the instrument will assume there is no signal and set the display to 0.0 after about 1 second if no transition occurs. When DC coupling is selected it will allow for very slow signals by waiting forever for an input transition; the display will continue to show the last value.

Input Impedance: 1MΩ is the default and can be used with both AC and DC coupling. It can be used directly or in conjunction with x1, x10 or x100 oscilloscope probes as appropriate to the signal amplitude. Select 50Ω for higher frequencies and where the signal source impedance is 50Ω to minimise spurious counting caused by reflections.

Input Attenuation: 1**:**1 (no attenuation) is the default. Select 5**:**1 for larger signals, particularly if noise is significant. When measuring standard logic signals, use 1:1 attenuation for 1.8V (or lower) CMOS and 5:1 for CMOS at 2.5V (or higher), or TTL. Additional attenuation can be achieved by attenuating the signal externally before being presented to the counter; a x10 oscilloscope probe can be used with the 1MΩ input impedance or a 50Ω attenuator can be used with the 50Ω input impedance to preserve matching.

Input Polarity: Rising edge (pulse High) is the default setting; with this setting Frequency and Period measurements start and finish on the rising edge and Count is the total number of rising edge occurrences. The Width measurement is from rising edge to falling edge which, together with the Period measurement, yields the calculated Ratio (High**:**Low time) and Duty (High time as a percentage of Period) measurements.
If the Polarity is changed to falling edge (pulse Low), Frequency and Period measurements will start and finish on the falling edge and Count will totalise the occurrences of falling edges. If the waveform being measured has a slow rising edge but fast falling edge, setting the Polarity to falling edge might be advantageous in reducing measurement jitter. Changing the Polarity for Width measurements, however, will change the interpretation of Ratio and Duty and should only be used with care.

Low Pass Filter: The default setting is for no filter. If Filter In is selected the **FILT** annunciator will show in the display; the nominal cut-off frequency is 50kHz. The filter is particularly useful for low frequency measurements but, with an adequate input signal, it can be helpful at frequencies up to 200kHz or more.

Trigger Level Threshold Adjustment: The trigger level control is associated with two yellow LED lamps which indicate the signal balance at the output of the A input amplifier. Their brightness varies from bright to dim depending on the relationship between the trigger threshold and the average value of the input signal. When the threshold setting matches the average value of the input signal they are of equal brightness. If a signal is applied and the instrument is not counting, move the threshold control towards the dimmer of the two lamps. Note that the smaller the input signal level, the more critical this setting becomes.

When AC coupling is selected (the default configuration) a threshold feedback mechanism is engaged, with the threshold control providing a small offset above or below the average signal level. Normally the control should be set with the marker at the midway position marked AC.

This setting should count most signals, but on very small signals some slight adjustment may be needed for maximum sensitivity. The usable adjustment range from this position is approximately ±50mV (1:1 attenuation) or ±200mV (5:1 attenuation).

If DC coupling is in use then the feedback mechanism is disconnected and the threshold is directly adjusted by the control over the range of nominally 0 to 2V (1:1 attenuation) or 0 to10V (5:1 attenuation).

There is some over-range at each end of the control. The Threshold control should be adjusted in the direction which brings both yellow LED lamps on and then finely adjusted to get the most stable measurement.

For waveforms with slow edges adjusting the threshold will, of course, affect the Width and associated Ratio and Duty cycle measurements but not Frequency, Period and Count.

The Threshold control should always be adjusted slowly, as there is a noise rejection filter with a long time constant in the circuit.

Input B

Input B is used for frequency measurements in the range 80MHz to >3GHz. The input impedance is nominally 50Ω. The maximum input voltage from 20MHz to 3GHz is 1Vrms and the input is diode clipped with inputs over 250mVrms.
The input is protected against temporary accidental connection of mains voltages up to 250Vrms at 50/60Hz.

The signal being measured should have a 50Ω source impedance to avoid standing waves which could give spurious results. The input cable should be kept as short as possible and 50Ω coaxial cable should be used.

Note that, because of the wide bandwidth of this input, signals mixed with other components which fall within the frequency and sensitivity range of the input can cause incorrect counting; externally attenuating or filtering the signal before presenting it to the counter may help to obtain a correct reading. In particular, when attempting to count the highest frequency component of a signal with broadband noise or other interference, an external high pass filter may be needed, especially with small signals above 2GHz. The C input provides better performance above this frequency.

Input C

Input C is used for frequency measurements in the range 2GHz to >6GHz. Although the sensitivity is not specified outside this range, it will typically count frequencies from 1.8GHz up to 7.5GHz. The input impedance is nominally 50Ω. An input coupling capacitor is followed by a resistive attenuator and a PIN diode limiter. The maximum input voltage for correct counting is 1.5Vrms (+16dBm) and the maximum input without damage is 4Vrms (+25dBm). There is a 250kΩ DC coupled bleed resistor to minimise the risk of static build up destroying the input coupling capacitor. This input is also protected against temporary accidental connection of mains voltages up to 250Vrms at 50/60Hz.

The signal being measured should have a 50Ω source impedance to avoid standing waves which could give spurious results. The input cable should be kept as short as possible and 50Ω coaxial cable should be used.

This input has a sharp low frequency cut off below 1.5GHz and has much better noise immunity than the B input. It also has much better large signal handling capabilities. Unless the Ratio B:A capability is needed the C input should be preferred for all signals above 2GHz.

Function and Measurement Time Selection

Function and measurement time are selected using the keys immediately below the display. The annunciators in the display show the current settings.

Function Selection – A input

Pressing the FREQUENCY, PERIOD or WIDTH key will immediately set the instrument to that function; pressing and holding the key down for more than 1 second will change the function to

COUNT, RATIO or DUTY respectively, the 2nd function printed above the key in blue; the selected function is shown by the appropriate annunciator in the display.

FREQUENCY and PERIOD measurements are directly displayed in the appropriate units.

COUNT is a simple totalise function. The displayed value can be frozen with the HOLD key; the count continues in the background. The count can be restarted (set to zero) using RESET, the 2nd function of HOLD. When the count reaches the maximum of 9999999999, the next active edge restarts the count from zero.

The WIDTH measurement can be set to measure either the High time (above the threshold) or Low time (below the threshold) by choosing the appropriate polarity setting, see earlier Input A Configuration Options section.

Selecting RATIO with the A input active shows the ratio of High time to Low time (RATIO H**:**L) or vice-versa, according to the polarity setting. Low (inactive) time is calculated by subtracting the measured High (active) time from the period.

Selecting DUTY shows the High time or Low time (depending on polarity setting) expressed as a percentage of the total period.

Function Selection – B input

With Input B (80MHz – 3GHz) selected only the FREQUENCY and PERIOD functions can be used; attempts to select WIDTH, COUNT or DUTY will be ignored by the firmware; the **B** annunciator will flash briefly to indicate that this is not a valid selection and the existing setting will remain unchanged.

Selecting RATIO with Input B selected (by a long press on the PERIOD key) is valid, but sets the instrument to a RATIO B**:**A mode (Frequency B **:** Frequency A), not RATIO H**:**L as described for the A input. The ratio B:A is obtained by making simultaneous frequency measurements on the two inputs and dividing the B result by the A result. The result of the calculation is as accurate as the measurements. Each signal can be any frequency within the permitted range of the respective input. If the ratio is so large that the decimal point cannot be shown on the display, then the result is shown with six digits and an exponent.

Function Selection – C input

With Input C (2GHz – 6GHz) selected only the FREQUENCY and PERIOD functions can be used; attempts to select WIDTH, COUNT, RATIO or DUTY will be ignored by the firmware; the **C** annunciator will flash briefly to indicate that this is not a valid selection and the existing setting will remain unchanged. There is no RATIO capability with either of the other inputs.

Measurement Time

Measurement time is changed using the left ◄ and right ► MEASUREMENT TIME keys, the selected time being shown by the appropriate annunciator in the display. With a suitable signal connected to the selected input the **Measure** annunciator will flash in the display to indicate that the signal has been detected; the **Measure** annunciator continues to flash until a true result for that selected measurement time is displayed, at which point it stays on continuously. Further display updates then show the running average of the signal behaviour over the last 0.3s (1 update every measurement), 1s (2 updates per second), 10s (1 update per second) or 100s (1 update every 2 seconds) depending on the selected measurement time. Note that if a 1s, 10s or 100s measurement time is selected, starting or restarting a measurement gives a true result with, generally, 7 digits resolution after 0.3s, 8 digits after 1s, 9 digits after 10s and, finally, 10 digits after 100s. The units and the decimal point position are automatically adjusted to give the result in the most convenient units.

Pressing the HOLD key will freeze the displayed measurement and the **Hold** annunciator will be shown; Hold is cancelled by a second press of the HOLD key. The measurement continues in the background while Hold is selected.

Switching between FREQUENCY and PERIOD measurement on the same input, or switching between WIDTH, RATIO H:L and DUTY (Input A), will immediately convert the present measurement; otherwise, a change of function (including a change of input) or measurement time will initiate a new measurement. A new measurement may also be started without a change of function or measurement time by using RESET, the 2nd function of the HOLD key.

Measurement Principles

Frequency and Period

The instrument uses a measurement method generally known as reciprocal counting. After each measurement interval (gate time) ends, it waits for the completion of the present cycle of the input signal before capturing the count data. It has therefore measured the time taken by a whole number of input cycles with a resolution of one cycle of its internal measurement clock. It then calculates the average period of the input signal by dividing the total time by the number of input cycles; the frequency is the reciprocal of this period value. This method yields much more accurate results at low frequencies than the traditional method of counting input cycles for an exact gate time.

The hardware captures count values without either stopping or resetting the counters. This is known as “capture and continue” counting, and means there is no dead time at the end of each gate interval. This allows successive measurements to be concatenated without incurring a one clock cycle uncertainty at the intermediate points of the measurement. The instrument uses this capability to give a rolling update in the display more often than the selected gate time. Each of these updates show the average value of the input frequency over the time interval equal to the selected gate time immediately preceding it being displayed.

If the signal has frequency modulation the instrument will display the average value across the gate time; the modulation is almost certainly not synchronous with the gate, so there will be small random variations in the displayed value.

If the signal has amplitude modulation, its amplitude at the trough of the modulation must exceed the sensitivity threshold of the input. Counting deeply modulated signals requires both considerable amplitude and a sensitive adjustment of the trigger threshold.

Width, Duty Cycle and Ratio H:L Measurements

When Width mode is selected, the instrument continues to use the capture and continue method to measure the signal period. It cannot measure the width of the active part of the signal this way because, by definition, there are gaps between the measurements while the signal is in the inactive state. Instead, it measures the width of a sample of individual cycles of the input signal at a rate up to about 1000 samples per second. It accumulates up to 50 such samples spread across the selected gate time, computes the average and displays the result. Each sample has a resolution of 20ns, and the average is displayed with a resolution up to 1ns. The values for duty cycle and ratio H:L (better thought of as the ratio active:inactive) are computed from the average width and the accurately known period. The display resolution presented in these modes is a reasonable representation of the probable measurement accuracy.

Ratio B:A

This mode is entered by a long press of the WIDTH / RATIO key when the B input is selected. It takes as nearly simultaneous capture and continue measurements of both input signals as possible. Because each measurement terminates on a transition of its respective signal the two measurements are not exactly simultaneous unless the signals are synchronously related. This is not likely to be an issue unless the signals are significantly frequency modulated.

Note that this method is completely different to the previous model (the TF830) which implemented ratio B:A mode by counting the B input using the A signal as the reference timebase.

Timebase and Other Accuracy Considerations

The following is intended as a guide to determine the limits of measurement error.

Internal Oscillator

The instrument has an internal temperature compensated crystal oscillator (TCXO) which has been factory set from a Rubidium reference standard such that it is within ± 0.2ppm (parts per million) after warm-up in an ambient of 21ºC. At ambient temperatures other than 21ºC the additional error is less than ± 1ppm over the whole operating range 5ºC to 40ºC.

The ageing rate is less than ± 1ppm in the first year and decreases exponentially with time. The recommended calibration period is 1 year, see Maintenance section.

External Reference

If measurements are to be made which require still greater accuracy than can be obtained using the TCXO, an external 10MHz frequency standard may be applied to the External Reference input. The signal should be TTL, 3Vpp to 5Vpp CMOS or 1 to 2Vrms sinewave. The external reference is used to phase lock the internal oscillator and must only be a high accuracy 10MHz signal. It is not possible to make ratiometric measurements by applying a non-standard signal. The presence of an external reference signal of adequate amplitude is automatically detected and phase lock is attempted; the **`Ext Ref`** display annunciator is shown when the external reference is detected. Note that if an improper signal is applied then the internal oscillator will be pulled off frequency and measurement accuracy significantly impaired.

Noise

When measuring low amplitude, low frequency sinewaves noise will cause variations in the displayed result at each display update. Users should make every effort to maximise the amplitude of the signal presented to the input. The internal noise of the instrument is random, with a significant low frequency (1/f) element. Selecting a longer gate time will reduce the effect of this noise, and allow the user to see the extremes of the variation and establish an approximate average. This method may be less effective on signals with externally induced intermittent or non-random noise (such as supply frequency interference).

Signal level

In general it is obvious from the variations of the display value that a signal is too small for reliable counting, but on the B input at frequencies over about 2GHz and on the C input at frequencies over about 5GHz the effect of insufficient signal can be very subtle. A signal 2 or 3dB below the true threshold might only show an error in the eighth digit in a consistent way that is not obviously detectable; for true accuracy users are recommended to ensure that the signal level meets the published specification even though the instrument is typically notably more sensitive.

The USB interface allows the instrument to be controlled using serial communications via a computer's USB port.

The instrument is supplied with a disk containing drivers for various versions of Windows. Any driver updates are available via the TTi website, www.tti-test.com. The disk also contains a text file with information and details of the software installation procedure.

The remote command format and the remote commands themselves are detailed later in this section. The remote commands of the earlier TTi TF830 Universal Counter can also be used on the TF960, allowing existing programs to be used. However, the TF960 has no address capability and those commands associated with ARC (Addressable RS232 Control) will be accepted but ignored.

Remote/Local Operation

At power−on the instrument will be in the local state; in this state all keyboard operations are possible. When the instrument receives a command the remote state will be entered and the **Rem** annunciator will show in the display. In this state the keyboard is locked out, except for the Local (RESET) and OPERATE keys, and remote commands only will be processed.

The instrument may be returned to the local state by a long press of the Local (RESET) key; the **Rem** annunciator will go off. However, the effect of this action will remain only until the instrument receives another character from the interface, when the remote state will once again be entered. Sending the LOCAL command also exits the remote state.

USB Interface

The USB interface of this instrument is implemented using a USB to UART device which then communicates with a UART inside the main processor. Once the device drivers are installed on a PC the device will appear to be a standard COM port as if it were inside the PC. This port can then be accessed by Windows applications in exactly the same way as a standard port.

If it is anticipated that more than one TF960 might be connected to the same PC it is recommended that the drivers be copied first to a suitable location on the hard disc and then installed from there when the first unit is attached. The operating system can then subsequently find the drivers without requiring the CD.

Installation of the interface drivers is achieved by connecting the instrument to a PC via a standard USB cable. The Windows' plug and play functions should automatically recognise the addition of new hardware attached to the USB interface and, if this is the first time the connection has been made, prompt for the location of a suitable driver. Two layers of driver are required and the standard Windows prompts will appear twice. Provided that these prompts are followed correctly Windows will install the appropriate drivers and establish a COM port within the PC. The number of the new COM port will depend upon the number of previously allocated COM ports within that PC.

***Note**:* If the plug and play function reports that a later version of the driver is already installed, **keep the later version**; the TF960 will operate satisfactorily with the later version.

A unique code embedded in each instrument ensures that it will receive the same COM port number each time it is attached to the PC, irrespective of which physical USB port it is connected to. A different unit will prompt again for installation of the drivers the first time it is attached, and will receive a different COM port number.

The operating parameters of the COM port must be set to match the internal requirements of the instrument: baud rate 115200, 8 bits, no parity. The default values are set in the Properties page in Device Manager, but many communications programs override the default settings and each will need to be correctly configured.

Remote Command Format

Serial input to the instrument is buffered in an input queue which is filled, under interrupt, in a manner transparent to all other instrument operations. The instrument will send XOFF when the queue is nearly full; XON will be subsequently be sent when sufficient space becomes available for more data to be received. This queue contains raw (un–parsed) data which is taken, by the parser, as required. Commands (and queries) are executed in order and the parser will not start a new command until any previous command or query is complete. Responses to commands or queries are sent immediately; there is no output queue.

Commands must be sent as specified in the commands list and must be terminated with the command terminator code 0AH (Line Feed, LF). Commands may be sent in groups with individual commands separated from each other by the code 3BH (;). The group must be terminated with command terminator 0AH (Line Feed, LF).

Responses from the instrument to the controller are sent as specified in the commands list. Each response is terminated by the <RESPONSE MESSAGE TERMINATOR> 0DH (Carriage Return, CR) followed by 0AH (Line Feed, LF).

<WHITE SPACE> is defined as character codes 00H to 20H inclusive with the exception of the LF character (0AH). <WHITE SPACE> is ignored except in command identifiers. e.g. '*I DN?' is not equivalent to '*IDN?'. The high bit of all characters is ignored. The commands are case insensitive.

Each query produces a specific <RESPONSE MESSAGE> which is listed with the command in the remote commands list.

Command List

This section lists all commands and queries implemented in this instrument. The commands of the TF830, all of which have been implemented on this instrument, are identified by “TF830” on the right-hand side of the Remote Command Summary list (next section).

Each command is completely executed before the next command is started.

The following nomenclature is used:

<rmt>	<RESPONSE MESSAGE TERMINATOR>
<c>	A single character, either a digit or a letter.
<nr1>	An integer number.

Function Selection

F<c> Sets the measurement function to <c>, where c corresponds to the following:

0	B Input Period
1	A Input Period
2	A Input Frequency
3	B Input Frequency
4	Frequency Ratio B**:**A
5	A Input Width High
6	A Input Width Low
7	A Input Count
8	A Input Ratio H**:**L
9	A Input Duty Cycle
C	C Input Frequency
D	C Input Period

The new function is selected immediately and a new measurement is started.

AC Set A Input to AC coupling.

DC Set A Input to DC coupling.

Z1 Set A Input to 1MΩ input impedance.

Z5 Set A Input to 50Ω input impedance.

A1 Set A Input to 1:1 attenuation.

A5 Set A Input to 5:1 attenuation.

ER Set rising edge of waveform as start of measurement.

EF Set falling edge of waveform as start of measurement.

FI Low Pass Filter In (on).

FO Low Pass Filter Out (off).

When remote state is first entered the filter stays set as it was in the local state. When remote state is cleared the filter setting remains as it was in the remote state.

L Low frequency mode. Applicable to TF830 only. Command accepted but ignored by TF960, which is automatically in low frequency mode while DC coupling is selected.

Threshold Commands

TO <nr1> Use with AC coupling. Threshold automatically adjusts to the average level of the waveform being measured, offset by <nr1> mV, where <nr1> is a number in the range -60 to +60; if no sign is present, <nr1> is assumed to be positive.

TO? Returns the current **TO** Threshold value in the form SnnnnmV<rmt>, where S is the sign, nnnn is the Threshold voltage in mV and mV is the units specifier. S is only present if the sign is negative.

TT <nr1> Use with DC coupling. Threshold set to a level of <nr1> mV, where <nr1> is a number in the range -300 to +2100; if no sign is present, <nr1> is assumed to be positive.

TT? Returns the current **TT** Threshold value in the form SnnnnmV<rmt>, where S is the sign, nnnn is the Threshold voltage in mV and mV is the units specifier. S is only present if the sign is negative.

Values for **TT** and **TO** assume an input attenuation setting of 1:1; for 5:1 attenuation the effective levels will be the set value x 5.

TA Use with DC coupling. Threshold Level set to achieve auto triggering; the threshold automatically adjusts to the average level of the waveform being measured (no offset).

In all cases the threshold level is set irrespective of the position of the front panel control. When remote state is first entered the trigger level is exactly as it had been set from the front panel (the **TO?** or **TT?** command can be used to read this value, corresponding to whether AC or DC coupling is currently set). When the remote state is cleared the trigger level reverts to the setting determined by the current front panel control position. Note that although mV resolution is provided, offsets within the instrument result in the actual value being only approximately correct. It is accurate enough to allow the setting of standard logic thresholds, but if maximum sensitivity to small signals is required when DC coupled then some experiment may be required.

Using **TO <nr1>** with DC coupling or **TT <nr1>** with AC coupling may give unpredictable results; it is up to the user to use settings consistent with each other and with the measurement application.

TA requires the user to first set DC coupling; **TA** can be useful for automatically finding a useable measurement threshold for low frequency waveforms that require DC coupling, or for higher frequency waveforms with very small duty cycles. There is no equivalent front panel setting.

TC Threshold Level to centre position.

TN Threshold Level to negative pulse position.

TP Threshold Level to positive pulse position.

These three commands are only included to maintain compatibility with the TF830 and are used to set the threshold level to one of three ‘preset’ positions available under remote control on that counter. ‘Centre’ is equivalent to the threshold level control at the midway 'AC' position. ‘Negative pulse’ and ‘positive pulse’ are equivalent to –60mV and +60mV respectively, with AC coupling selected (the only coupling available on the TF830).

Measurement Commands

M<c> Sets the measurement time to <c>, where c corresponds to the following:

1	0.3s
2	1s
3	10s
4	100s

The new measurement time is selected immediately and a new measurement is started.

E? Every Result Query. Measurement results are sent continuously at the interval set for the measurement time (0.3s, 1s, 10s or 100s). Since these are ‘measurement time’ intervals, all results will be valid measurements. Stopped by <STOP> or any other command.

C? Continuous Result Query. Measurement results are sent continuously at the rate at which the LCD is updated for the selected measurement time – every 2s, 1s, 0.5s or 0.3s for measurement times of 100s, 10s, 1s or 0.3s respectively. Measurements are sent whether the <**Measure**> annunciator was flashing or not, i.e. the measurement may not be valid. Stopped by <STOP> or any other command.

N? Next Result Query. The measurement at the next LCD update provided the <**Measure**> annunciator is not flashing, i.e. the next valid measurement.

? Current Result Query. The measurement at the most recent LCD update whether the <**Measure**> annunciator was flashing or not, i.e. the measurement may not be valid.

The format of the response is the same for all forms of the query and is as follows:

NNNNNNN.NNNeSEuu<rmt>

where:

NN.NN	is the displayed answer with the decimal point in the corresponding position (11 characters).
e	is the letter e for exponent.
S	is a plus or minus sign indicating the sign of the exponent.
E	is the exponent value to give the answer in Hz or seconds
uu	is the units specifier: Hz, s_ , %_ or _ _ ; _ is a space (2 characters)

If there is nothing to measure and the display is zero the response will be:

0000000000.e+0_ _<rmt>

STOP Stops further measurements being sent in response to E? or C?; any other command will also stop further measurements being sent, as well as initiating the action of that command.

Miscellaneous Commands

***IDN?** Returns the instrument identification in the form <name>, <model>, 0, <version><rmt> where <name> is the manufacturer's name, <model> is the type of instrument and <version> is the revision of the firmware installed.

I? Identify Query. Returns the instrument model number only.

***RST** Resets the instrument to its power-on default values *and* sets the Threshold Level to the midway 'AC' position. Also empties remote I/O queues and clears error status.

R Reset measurement. Performs the same operation as pressing the front panel RESET key under the same conditions.

S? Status Query. Reads and returns the instrument status. The response is sent immediately. The response is xy<rmt>, where x and y are numeric digits expressed in ASCII format. The first digit is the status byte and is a bit significant value in the range 0 to 7. The meaning of each bit is as follows:

bit 0 External standard connected.

bit 1 An error has occurred.

bit 2 A continuously updated bit indicating that an input signal is being counted. It does not necessarily guarantee that there is sufficient signal for an accurate result.

The second byte contains the error number of the last error that occurred. The value is cleared to zero after each status query. Error numbers are as follows:

0 No error has occurred since the last status query.

1 A command syntax error – one or more commands ignored.

LOCAL Returns the instrument to local operation and unlocks the keyboard.

UD <data> Store user data; maximum string length 250 characters. The string may contain any character between 20H and FFH inclusive except 3BH (;). Can be used to give the instrument an identifying or information data string which can be queried using the **UD?** command. Examples of use are Serial No., calibration due date, owner's name, etc.

UD? Returns user data from store.

Remote Command Summary

The commands of the TF830, all of which have been implemented on this instrument, are identified by "TF830" on the right-hand side.

F0	B Input period.	
F1	A Input period.	TF830
F2	A Input frequency.	TF830
F3	B Input frequency.	TF830
F4	Frequency ratio B**:**A.	TF830
F5	A Input width High.	TF830
F6	A Input width Low.	TF830
F7	A Input count.	TF830
F8	A Input ratio H**:**L.	
F9	A Input duty cycle.	
FC	C Input frequency	
FD	C Input period	

AC	A input AC coupled.	
DC	A input DC coupled.	
Z1	A input 1MΩ input impedance.	
Z5	A input 50Ω input impedance.	
A1	A input 1:1 attenuator.	
A5	A input 5:1 attenuator.	
ER	Rising edge (A Input only).	
EF	Falling edge (A Input only).	
FI	Filter In (A Input only).	TF830
FO	Filter Out (A Input only).	TF830
L	Low frequency mode.	TF830
TT <nr1>	Trigger threshold set to nnnn mV (-300 to +2100mV). DC coupling.	
TO <nr1>	Trigger auto (average), offset by nn mV (-60 to +60mV). AC coupling.	
Values assume	1:1 attenuator; for 5:1 attenuation thresholds will be set value x5.	
TO?	Returns current TO Threshold setting in mV	
TT?	Returns current TT Threshold setting in mV	
TA	Trigger auto (average, without offset). Set DC coupling first.	
TC	Trigger centre.	TF830
TP	Trigger positive.	TF830
TN	Trigger negative.	TF830
M1	Measurement time 0.3s.	TF830
M2	Measurement time 1s.	TF830
M3	Measurement time 10s.	TF830
M4	Measurement time 100s.	
E?	Every result query.	TF830
C?	Continuous result query.	
N?	Next result query.	TF830
?	Current result query.	TF830
STOP	Stops further measurement results being sent.	
I?	Identifier query. Returns model number only.	TF830
***IDN?**	Instrument identification. Returns full instrument identification.	
R	Reset measurement.	TF830
***RST**	Reset instrument to default settings.	
S?	Status query.	TF830
LOCAL	Returns instrument to local operation.	
UD <data>	Store user data.	
UD?	Returns <data>.	

The Manufacturers or their agents overseas will provide a repair service for any unit developing a fault. Where owners wish to undertake their own maintenance work, this should only be done by skilled personnel in conjunction with the Service Information available from the Manufacturers or their agents overseas.

Calibration

Calibration at the time of delivery is guaranteed as in the Specification. However, annual routine recalibration is recommended to maintain the high accuracy that this instrument offers. Recalibration may be carried out, without dismantling the instrument, using a suitable precision frequency standard; details are provided in the Service Information.

Cleaning

If the instrument requires cleaning use a cloth that is only lightly dampened with water or a mild detergent.

WARNING! TO AVOID ELECTRIC SHOCK, OR DAMAGE TO THE INSTRUMENT, NEVER ALLOW WATER TO GET INSIDE THE CASE. TO AVOID DAMAGE TO THE CASE OR DISPLAY WINDOW NEVER CLEAN WITH SOLVENTS.



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