E086-69-880
Issue B

Instruction Manual

FTM7 Film Thickness Monitor

Description	*Item Number*
FTM7 Film Thickness Monitor	*E086-69-000*

BOC EDWARDS

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Declaration of Conformity

We, Edwards High Vacuum International,
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declare under our sole responsibility that the product(s)

FTM7 Film Thickness Monitor E086-69-000

to which this declaration relates is in conformity with the following standard(s) or other normative document(s)

EN50081-1	Electromagnetic Compatibility, Generic Emission Standard, Generic Standard Class: Residential, Commercial and Light Industry.
EN50082-1	Electromagnetic Compatibility, Generic Immunity Standard, Generic Standard Class: Residential, Commercial and Light Industry.
IEC1010-1	Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use.

following the provisions of

73/023/EEC	Low Voltage Directive.
89/336/EEC	Electromagnetic Compatibility Directive.

A. Troup

Dr. A. P. Troup, Director of Technology

24/11/97 Crawley

Date and Place

EDWARDS

P900-75-000 Issue E 2B01-010

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1 INTRODUCTION

1.1 Scope and definitions

This manual provides installation, operation and maintenance instructions for the BOC Edwards FTM7 Film Thickness Monitor (abbreviated to FTM7 in the remainder of this manual). You must use the FTM7 as specified in this manual. Read this manual before you install and operate the FTM7.

Important safety information is highlighted as WARNING and CAUTION instructions; you must obey these instructions. The use of WARNINGS and CAUTIONS is defined below.

WARNING
Warnings are given where failure to observe the instruction could result in injury or death to people.

CAUTION
Cautions are given where failure to observe the instruction could result in damage to the equipment, associated equipment and process.

In accordance with the requirements of IEC1010, the following symbols appear on the FTM7:

Caution - refer to accompanying documents

Caution - risk of electric shock

Protective conductor terminal

The units used throughout this manual conform to the SI international system of units of measurement.

1.2 Description

The FTM7 is designed to measure and display the deposition rate and thickness of films deposited in vacuum coating systems. You can also use the FTM7 to monitor material removal during etch processes.

You must use the FTM7 in conjunction with one or two water cooled crystal holders, quartz crystals, and oscillator units. Note that a crystal holder, crystal and oscillator unit are together referred to as a crystal sensor throughout this manual.

The FTM7 uses the crystal microbalance technique to measure film thickness and deposition rate. Film thickness and deposition rate are calculated from your data on the density and the acoustic impedance of the film material.

Data for up to 11 layers (materials) can be stored in non-volatile memory in the FTM7, and you can specify 'Tooling Factors' to compensate for different detector/substrate geometries so that the FTM7 may be used on a number of different deposition systems.

You can configure the FTM7 to automatically stop deposition at a specified terminal film thickness. The FTM7 will close a shutter between the deposition source and the substrate on which the film is being deposited. Two shutters can be controlled by the FTM7.

The FTM7 can show both positive and negative frequency changes. You can, therefore, observe flash-heating effects in the crystal sensor, or monitor materials being removed from a pre-loaded crystal. The FTM7 can therefore be used to monitor both the deposition and etching of thin films. Without the ability to show negative frequency shifts, you would be unaware of crystal sensor warm-up or flash heating effects which can cause large errors during film monitoring. To retain the same number of displayed significant digits when measuring negative frequency changes, the negative sign is suppressed once thickness loss is greater than 99.9 nm.

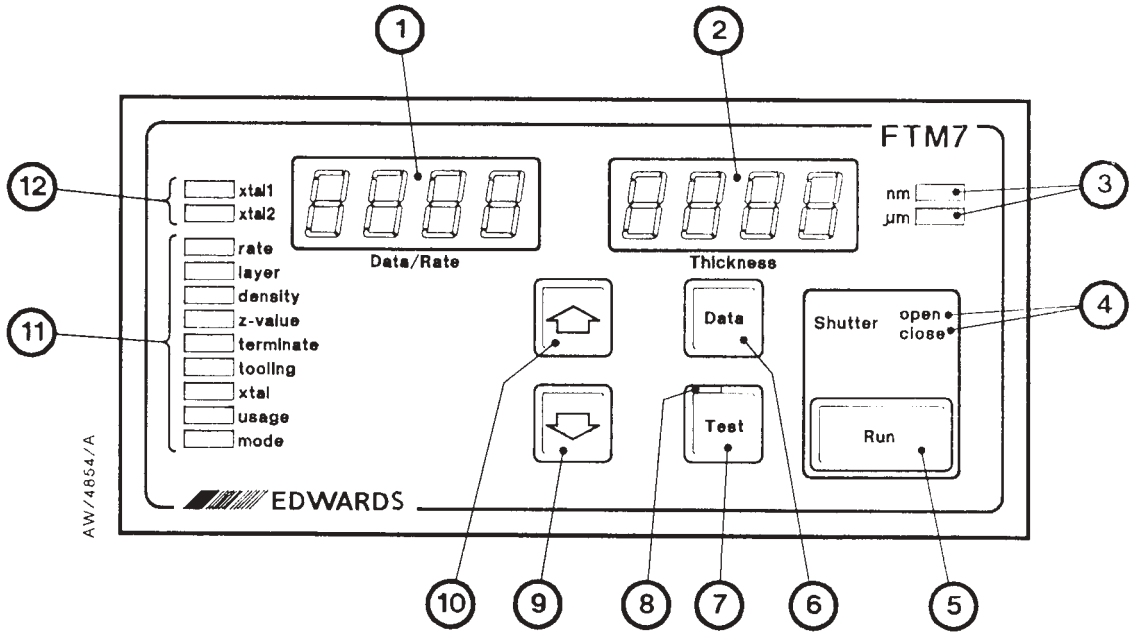
If required, you can connect your control equipment (for example, a PC) to the FTM7 through an RS232 communications link, and use your control equipment to control and monitor the operation of the FTM7.

1.3 Controls and displays

Refer to Figure 1. The controls and displays on the FTM7 are used as follows:

Data/Rate display (1)	This is a seven-segment, four-digit LED display which shows deposition rate, material or FTM7 status information.
Thickness display (2)	This is a seven-segment, four-digit LED display which shows a constantly updated reading of deposit thickness, or shows the terminal film thickness. The display is auto-ranging and the frequency of display updates is once a second.
Units LEDs (3)	One of these LEDs will be on to indicate the current thickness units.
Status LEDs (11)	One of these LEDs will be on to indicate the parameter currently shown on the Data/Rate and Thickness displays: see See Section 4.3.

Sensor LEDs (12)	One of these LEDs will be on to indicate the current crystal sensor.
Decrement and Increment buttons (9, 10)	Use these buttons to decrement or increment the value of the current parameter on the Data/Rate display, or the terminal thickness on the Thickness display: see Section 4.3.
Data button (6)	Use this to select the parameter to be displayed or modified: see Section 4.3.
Test button (7)	Use this button to select or deselect the test mode: see Section 5.2.
Test LED (8)	This LED flashes when test mode is selected: see Section 5.2.
Run button (5)	Use this button to manually open and close the shutter. It will only operate when a correctly operating crystal sensor is connected to the FTM7.
Shutter status LEDs (4)	One of these LEDs will be on to identify the status of the shutter (open or closed); the LED(s) will flash to indicate a fault: refer to Section 5.3.



1. Data/Rate display
2. Thickness display
3. Units LEDs
4. Shutter status LEDs
5. Run button
6. Data button
7. Test button
8. Test LED
9. Decrement button
10. Increment button
11. Status LEDs
12. Sensor LEDs

Figure 1 - Front panel controls and indicators

1.4 Rear panel

Refer to Figure 2 which shows the rear panel of the FTM7. Items on the rear panel are as follows:

Earth (ground) stud (1)	Use this to earth (ground) the FTM7: refer to Section 3.4.
Voltage selector/fuse holder (2)	Use this to select the correct voltage for your electrical supply: refer to Section 3.2.
On/Off switch (4)	Use this to switch the FTM7 on and off.
Shutters terminal block (5)	Use these to connect one or two shutters to the FTM7: refer to Section 3.4.
RS232 connector (6)	If required, use this to connect the FTM7 to your control equipment (for example, a PC): refer to Section 3.4.
Analogue output connector (7)	If required, use this to connect an analogue device such as a chart recorder to the FTM7. You can select what parameter is output on this connector: see Section 4.3.
Sensor 1 and 2 connectors (9, 8)	Use these to connect primary and secondary crystal sensors to the FTM7.

1.5 Principle of operation

1.5.1 Introduction

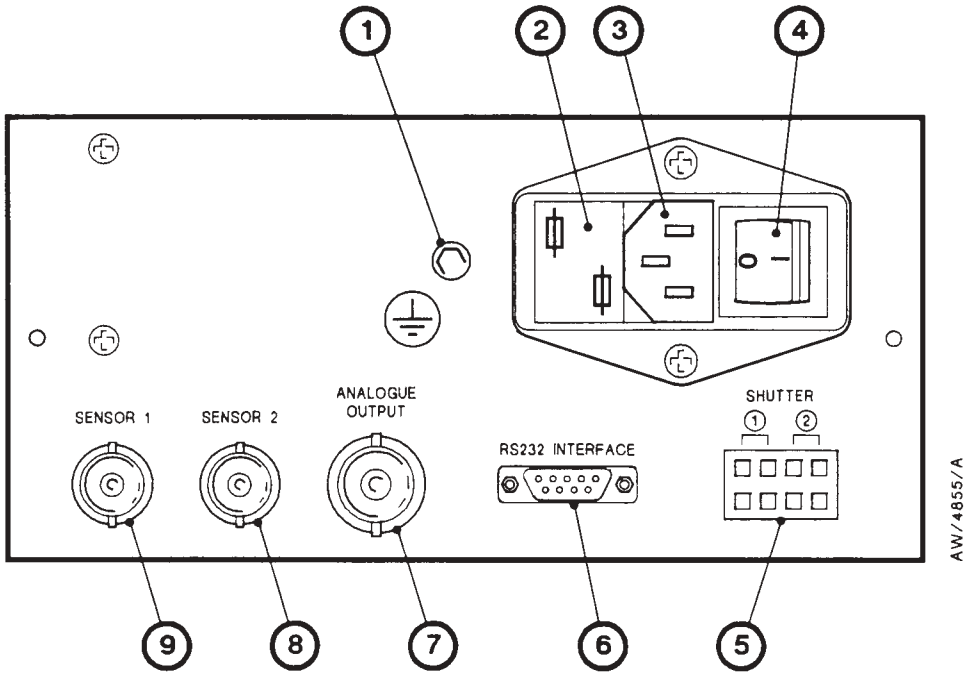
The FTM7 is a microprocessor-based frequency counter which converts frequency changes into deposition rates and thickness information for a range of deposition materials. It is used in conjunction with a quartz crystal which is placed in the deposition field, and an oscillator unit whose output frequency is controlled by the crystal.

The FTM7 samples the output of the oscillator unit and detects frequency changes caused by material being deposited on the face of the crystal. The FTM7 uses the change in frequency to calculate the rate and thickness of the material being deposited. The frequency data is modified according to any data you enter which relates to the type of material being deposited, and the geometric relationship between the deposition source, the target substrate and the crystal sensor.

Use the Run button on the front of the FTM7 to open the shutter and start a deposition process.

You can then use the Run button to close the shutter, to shield the substrate from further deposition. Alternatively, you can program the FTM7 to automatically close the shutter and stop the deposition process when a user specified thickness is reached.

The parameters which you can monitor and change in the FTM7 are described in Section 1.5.2.



1. Earth (ground) stud
2. Voltage selector / fuse holder
3. Electrical supply plug
4. On/Off switch
5. Shutters terminal block
6. RS232 connector
7. Analogue output connector
8. Sensor 2 connector
9. Sensor 1 connector

Figure 2 - Rear panel

1.5.2 Deposition/etch parameters

Layer — You can store deposition film data for up to 11 different layers/materials (layers 1 to 11) into the FTM7. (Note that when you program the FTM7, layers 12 to 19 are used to select layer sequences of deposition: see Sections 4.3.3 to 4.3.5.)

Density — This is the density of materials you intend to evaporate (in g cm^{-3}).

z-value — This is the acoustic impedance of the deposition material (in 10^5 cm^2 g^{-1} s^{-1}).

Terminate — The terminal thickness of the film required. On reaching this thickness the FTM7 can automatically close the shutter to prevent further deposition.

Tooling — Tooling factor: each layer can have an associated tooling factor, which allows you to calibrate the FTM7 for differences between source-substrate and source-sensor distance and attitude (if the sensor is further from the source than the substrate, it will receive a thinner deposit than the substrate). You can calculate the tooling factor assuming a square law variation of thickness with distance, and a cosine distribution with angle. However, we recommend that you calculate the required tooling factor by experimental deposition processes. Note that:

- A tooling factor of 1.00 implies that the sensor and substrate receive the same deposit thickness.
- A tooling factor > 1.00 implies that the sensor receives a thinner deposit than the substrate.
- A tooling factor < 1.00 implies that the sensor is more heavily loaded than the substrate.

xtal — In layer-selected mode (see Section 1.5.6), this parameter (1 or 2) determines which crystal sensor is used to monitor the currently selected layer.

Usage — This represents the difference between the measured crystal sensor frequency and the 6.0 MHz frequency of a new, perfect crystal sensor. You cannot change this value.

In practice, a new crystal sensor, when installed, will usually have an oscillating frequency of approximately 5.995 MHz. The starting 'usage' value for such a crystal sensor will be approximately 5.0 kHz (as shown in the Data/Rate display). As the crystal sensor is used to measure deposition layers and it becomes coated with deposition material, its frequency decreases and the usage value increases.

The FTM7 processor assumes that the crystal sensor is defective if the frequency falls below 5.1 Mhz (which will give a usage value of 900.0 kHz).

Note: Some brittle deposition materials can cause an interface fracture between the crystal and the deposited layer, at a much lower 'usage' value. This will cause immediate crystal sensor failure. We therefore recommend that you determine acceptable limits of 'usage' by experiment for any given deposition material.

1.5.3 Principle of measurement

Complex equations for the conversion of frequency change into deposition rate and thickness data are applied by the FTM7 to the detected output of the oscillator unit. These equations take account of the density and acoustic impedance of the crystal sensor and the deposition material. Refer to Appendix 1 which describes the equations used and how they were developed.

1.5.4 Single crystal sensor/shutter operation

When you connect a single crystal sensor and shutter to the FTM7, you can use the Run button to open the shutter and start the deposition process.

You can use the Run button again to manually stop deposition, or you can configure the FTM7 to automatically stop deposition at the specified termination thickness. At this thickness, the FTM7 will automatically close the shutter to stop the deposition process.

If the crystal sensor fails, the FTM7 automatically closes the shutter, however the thickness data at the time of the failure is stored in memory. You can therefore replace the failed crystal sensor, then continue the deposition/etch process, without loss of thickness data.

1.5.5 Two crystal sensors/shutters operation

When you connect two crystal sensors and two shutters to the FTM7, you must configure the sensors and shutters so that:

- Shutter 1 is between the deposition source and both the target substrate and crystal sensor 1.
- Shutter 2 is between the deposition source and crystal sensor 2.

1.5.6 Operating modes

You can operate the FTM7 in one of two modes: backup mode and layer selected mode, as described below.

Backup mode

In this mode, shutter 1 is used to control deposition/etch (either by manual operation, or automatically at the required terminal thickness). If crystal sensor 1 fails, shutter 2 will open and the FTM7 will automatically use crystal sensor 2 to determine thickness data; deposition will continue without interruption.

Layer-selected mode

In this mode, the appropriate shutter is opened/closed depending on which crystal sensor is assigned to the layer:

- If crystal sensor 1 is assigned, shutter 1 opens/closes.
- If crystal sensor 2 is assigned, both shutters open/close.

Note that there is no back-up in this mode. If either crystal sensor fails, shutter 1 is automatically closed to protect the target substrate.

1.5.7 Sequence layer control

You can request the FTM7 to perform a predefined sequence of up to five layer depositions: to do this, select layer sequences identified by two numbers '12 1' to '19 6', as shown in Table 1; in this Table, the first two characters identify the sequence selected, and the last character specifies the first layer which will be used in the sequence.

Layer	Sequence of layers deposited
12 1	1, 2
13 1	1, 2, 3
14 1	1, 2, 3, 4
15 1	1, 2, 3, 4, 5
16 3	3, 4
17 5	5, 6
18 7	7, 8
19 6	6, 7, 8

Table 1 - Sequence layers

For example, if you select layer '19 6':

- When you initially press the Run button, the FTM7 will open the shutter and use the data entered for layer 6 to measure the deposition rate and thickness.
- When the terminal thickness for layer 6 is reached, or if you press the Run button again, the shutter is closed.
- If you then press the Run button again, the FTM7 will open the shutter and use the data entered for layer 7 to measure the deposition rate and thickness.
- When the terminal thickness for layer 7 is reached, or if you press the Run button again, the shutter is closed.
- If you then press the Run button again, the FTM7 will open the shutter and use the data entered for layer 8 to measure the deposition rate and thickness.
- When the terminal thickness for layer 8 is reached, or if you press the Run button again, the shutter is closed.
- If you then press the Run button again, the sequence is repeated for the selected layer 19 6.

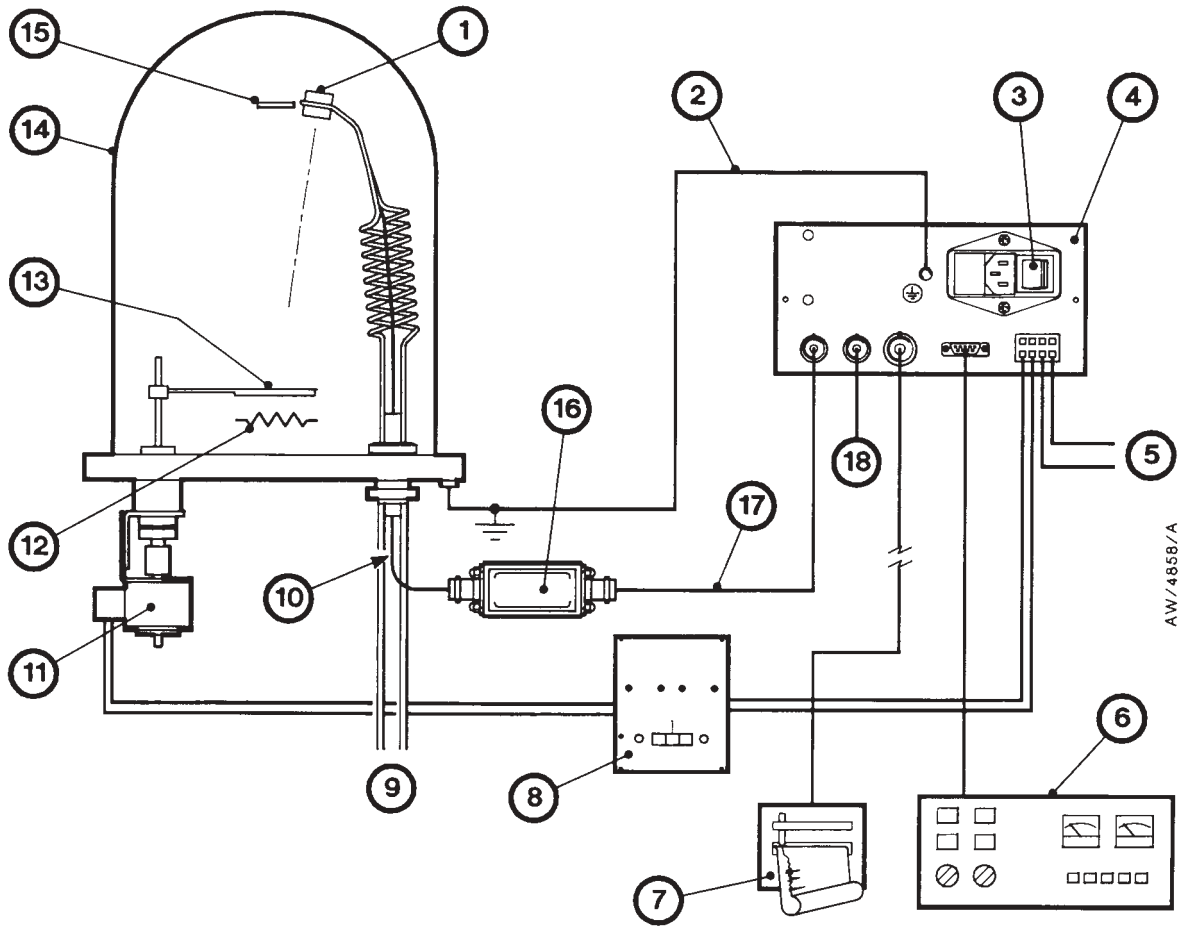
1.6 Typical installation

This manual assumes that you will use the FTM7 in conjunction with the following accessories, as shown in Figure 3:

- Water cooled crystal holder.
- Oscillator unit.
- Electromagnetic shutter actuator *.
- Electromagnetic shutter controller *.

Accessories suitable for use with the FTM7 are listed in Section 7.3.

* Optional.



1. Crystal (in holder)
2. Earth (ground) wire
3. On/Off switch
4. FTM7
5. Shutter 2 connections (if fitted)
6. Control/monitoring equipment (optional)
7. Analogue device (for example, chart recorder)
8. Shutter controller panel
9. Cooling-water connections
10. Short coaxial cable
11. Shutter actuator
12. Source
13. Shutter
14. Bell jar
15. Substrate
16. Oscillator unit
17. Long coaxial cable
18. Long coaxial cable to oscillator unit 2 (if fitted)

Figure 3 - Typical installation

2 TECHNICAL DATA

2.1 General

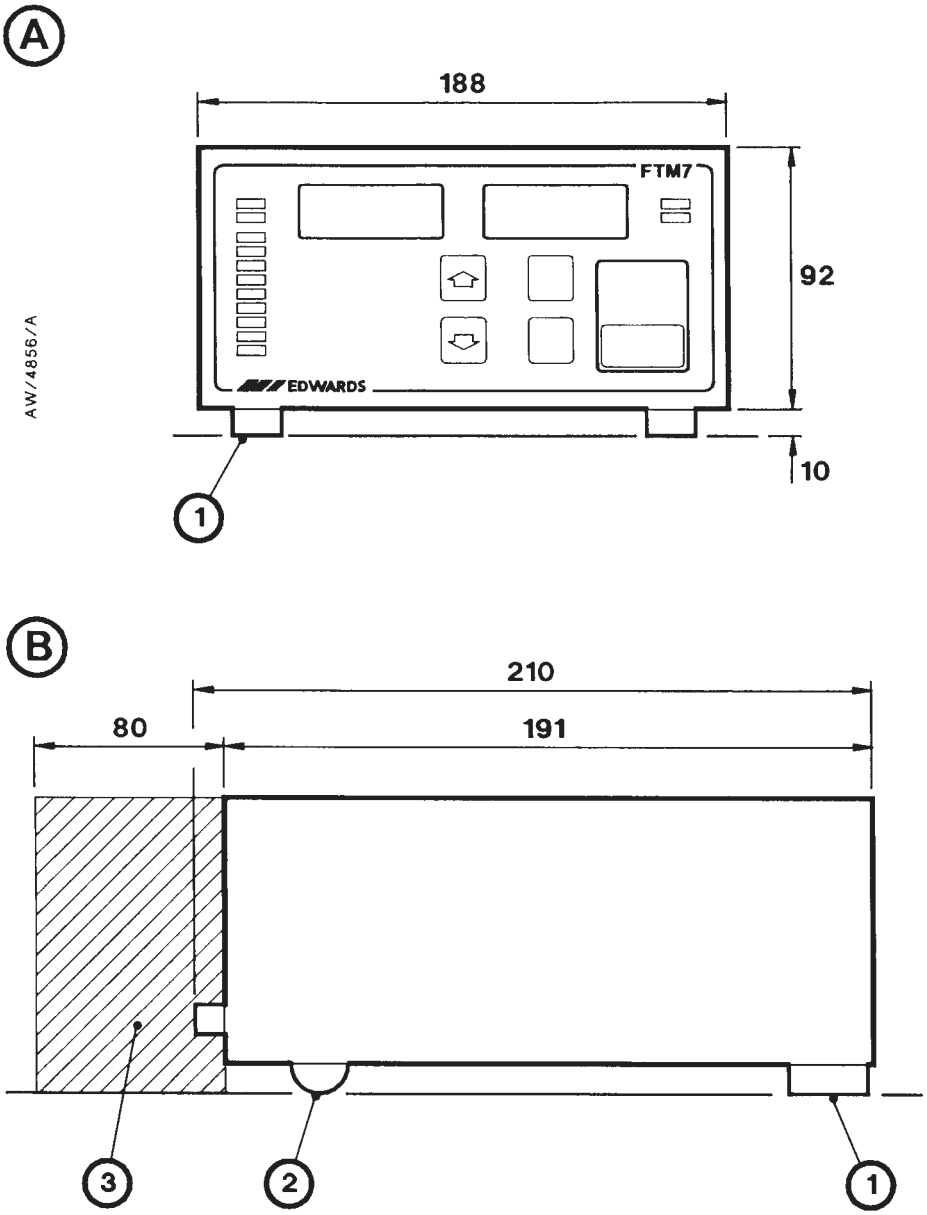
Dimensions	See Figure 4
Mass	2.8 kg
Operating temperature range	5 to 40 ^{o}C
Maximum operating humidity	80% up to 31 ^{o}C, 50% up to 40 ^{o}C
Maximum operating altitude	2000 m
IEC1010 installation category	II
IEC1010 pollution category	I
Degree of protection	IP20
Operating environment	Suitable for indoor use only

2.2 Performance

Material layer memories	11
Crystal sensor frequency	6 MHz unloaded
Thickness measurement range	0.0 nm to 999.9 µm, auto-ranging with LED indication of the scale factor (nm or µm)
Thickness resolution	0.1 nm
Rate of deposition measurement range	0.00 to 999.9 nm s^{-1}
Resolution of deposition measurement range	0.1 nm s^{-1}
Thickness sampling frequency	1 Hz
Density	0.01 to 99.99 g cm^{-3}
Acoustic impedance	1.0 to 99.9 x 10^{5} g cm^{-2} s^{-1}
Terminal thickness measurement range	0.1 nm to 99.99 µm with LED indication of scale factor (nm or µm)
Tooling factor range	0.01 to 99.9
Default values	See Table 2

Parameter	Default value
Density	1.00
Acoustic impedance (z-value)	8.834 (g cm^{-2} s^{-1})
Terminal thickness	990 (nm)
Tooling factor	1.00

Table 2 - Default values



A Front view
B Side view

1. Hinged leg
2. Rubber foot
3. Clearance required for electrical supply cable

Figure 4 - Dimensions (mm)

2.3 Electrical data

Electrical supply voltage	100/120 V or 220/240 V selectable
Electrical supply voltage tolerance	± 10%
Electrical supply frequency	50/60 Hz
Power consumption	10 W
Electrical supply fuse ratings	
220/240 V	100 mA anti-surge
100/120 V	100 mA anti-surge
Analogue output	
Voltage	0 to 1 V, 8-bit resolution
Maximum load	1 kΩ
Shutter relay switch	
Maximum rating	50 mA at 240 V a.c. or 200 V d.c.
Maximum switching power	10 W
Sensor head output voltage	10 V

2.4 Electrical connectors

Electrical supply connector	IEC plug
Analogue output connector	BNC socket
Sensor connectors	BNC socket
RS232 connector fitted to FTM7	9-way D-type socket, female
Shutter terminals	Push-in, self-lock

2.5 RS232 interface

Transfer rate	4800 baud
Protocol	1 start bit, 7 data bits, even parity, 1 stop bit

3 INSTALLATION

3.1 Unpack and inspect

Remove all packing materials and protective covers and check the FTM7. If the FTM7 is damaged, notify your supplier and the carrier in writing within three days; state the Item Number of the equipment together with your order number and your suppliers invoice number. Retain all packing materials for inspection. Do not use the FTM7 if it is damaged.

Check that your package contains the items listed in Table 3. If any item is missing, notify your supplier in writing within three days.

If the FTM7 is not to be used immediately, replace the protective covers. Store it in suitable conditions, as described in Section 6.

Qty	Description	Check (✓)
1	FTM7 Film Thickness Monitor	❑
1	Electrical supply cable	❑
1	Mounting-plate	❑
4	Screws	❑
2	Spare fuses	❑

Table 3 - Checklist of components

3.2 Configure the electrical supply voltage

1. Refer to Figure 2. Look at the voltage selector/fuse holder (2):
   - If the voltage indicated by the white mark is correct for your electrical supply, continue at Section 3.3.
   - If the voltage indicated by the white mark is not correct for your electrical supply, continue at Step 2 to reconfigure the FTM7.
2. Remove the voltage selector/fuse holder (2) from the FTM7.
3. Turn the voltage selector/fuse holder around, so that the correct voltage will be indicated by the white mark, then refit the voltage selector/fuse holder to the FTM7.

3.3 Locate the FTM7

WARNING

Do not place containers of liquids on or near the FTM7. Liquids spilled into the FTM7 can cause electrical short circuits and the risk of injury by electric shock. Solvents or corrosive liquids spilled into or onto the FTM7 can damage it.

Notes: If you want to fit the FTM7 in a rack or panel, we recommend that you make all of the electrical connections to the rear of the FTM7 (see Section 3.4) before you secure the FTM7 in the rack or panel. We also recommend that you leave the On/Off switch in the 'on' position, and use the rack isolator switch to switch the FTM7 on and off.

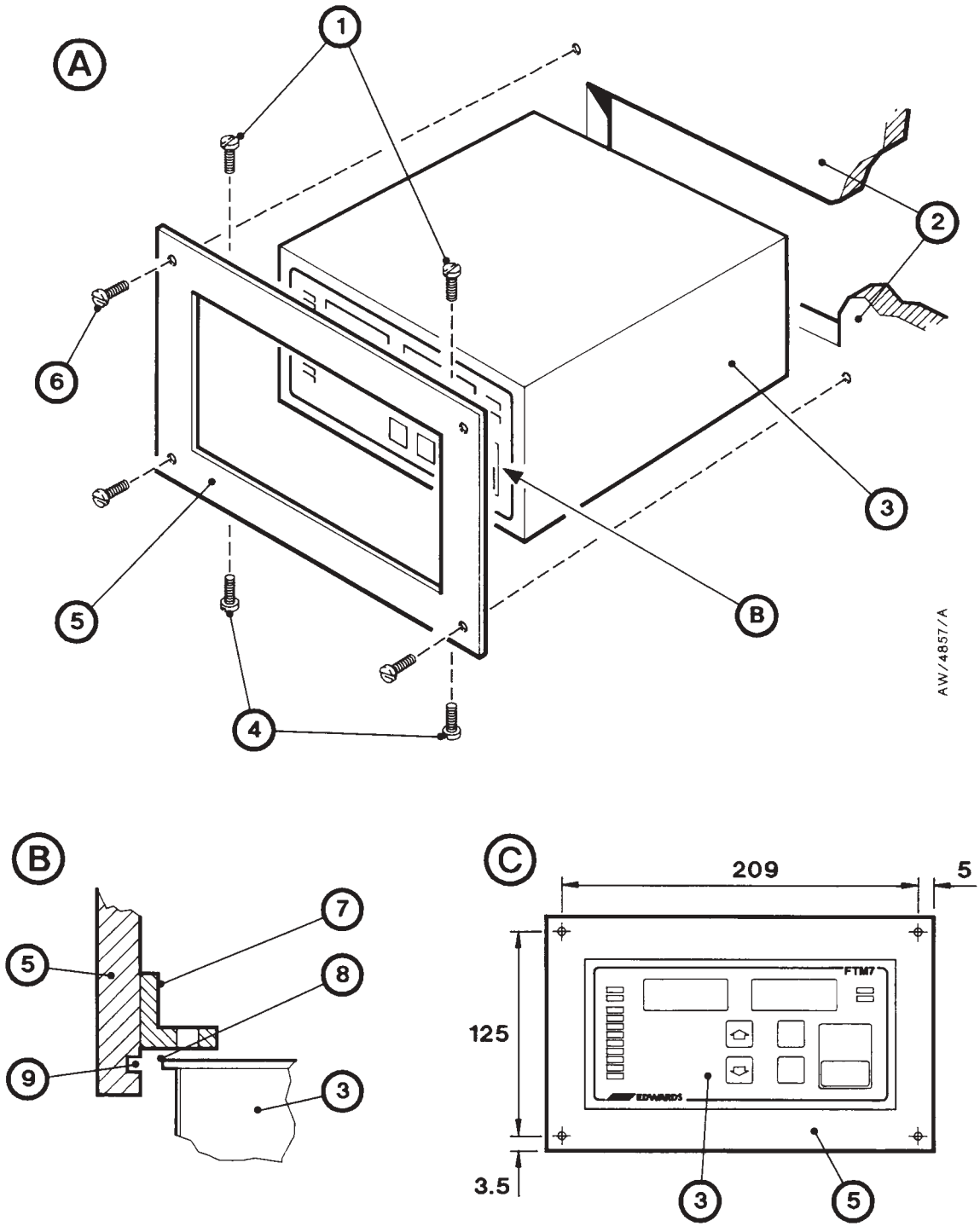
Refer to Figure 4. The FTM7 has hinged legs (1) and rubber feet (2) and can be free-standing on a table or bench, can be fitted in the AUTO 306, or can be fitted in a rack or panel.

If the FTM7 will be free-standing on a table or bench, if required swing down the hinged legs (1) and place the FTM7 in its required operating position.

To fit the FTM7 in the AUTO 306, refer to the AUTO 306 instruction manual.

To fit the FTM7 in a rack or panel; use the following procedure:

1. Refer to Figure 5. Place the FTM7 (3) against the rear of the mounting-plate (5), so that the lip on the front of the FTM7 fits into the slot on the rear of the mounting-plate, as shown in detail B.
2. Secure the mounting-plate to the FTM7:
   - Fit two of the screws supplied (1) through the bracket (7) at the top rear of the mounting-plate and into the FTM7.
   - Fit the other two screws supplied (4) through the bracket at the bottom rear of the mounting-plate and into the FTM7.
3. Use suitable screws (6) through the fixing holes on the mounting-plate (5) to secure the FTM7 and the mounting-plate in the rack or panel (2).



1. Screws (2 off)
2. Panel
3. FTM7
4. Screws (2 off)
5. Mounting-plate
6. Screws (4 off)
7. Bracket
8. Lip
9. Slot

Figure 5 - Fit the FTM7 in a panel or rack

3.4 Make the electrical connections

WARNING

Route all cables and wires away from hot or cold surfaces. If you do not, the cables or wires may be damaged, and there may be a risk of injury by electric shock, or of damage to the FTM7.

CAUTION

If you install the FTM7 inside an Auto 306 cabinet or other control cabinet, a 0 to 250 V signal may be applied to the shutter connector (5).

If you use the FTM7 mounted outside a cabinet, that is on a bench, for your own safety you must not apply more than 24 V to the shutter connector.

Note: When you install the crystal sensor(s) and shutter(s), ensure that they are correctly configured: if you only install a single crystal sensor, connect it to sensor 1 connector; if you only install a single shutter, connect it to the shutter 1 terminals on the shutter terminal-block.

Use the following procedure to make the electrical connections. Refer to Figure 3 which shows a schematic diagram of the installation. The connectors on the rear of the FTM7 are shown in Figure 2.

1. Connect a suitable earth (ground) wire (2) between the FTM7 earth (ground) stud and the baseplate earth (ground) point. Note that if you have fitted the FTM7 in the AUTO 306, you will have disconnected an earth (ground) wire from the blank panel removed from the AUTO 306 control cabinet: connect this wire to the FTM7 earth (ground) stud.
2. Fit the two wires from the shutter controller panel (8) to the shutter 1 terminals on the FTM7 shutter terminal block; to fit each wire:
   - Gently push a small screwdriver into the upper square slot of the terminal block, then push the end of the wire into the lower circular hole in the terminal block.
   - Ensure that no bare wire is visible outside the terminal block, then remove the screwdriver to secure the wire in place.
3. If necessary, fit the two wires (5) from the second shutter controller to the shutter 2 terminals on the FTM7 shutter terminal block: use the method in Step 2.
4. Connect the short coaxial cable (10) from the connector on the end of the oscillator unit (16) marked 'XTAL' to the crystal (1).
5. Connect the long coaxial cable (17) from the connector on the end of the oscillator unit (16) marked 'FTM' to the sensor 1 connector on the FTM7.
6. If required, connect the second crystal sensor: use the method in Steps 4 and 5, but connect the long coaxial cable (18) to the sensor 2 connector on the FTM7.

7. If required, connect a suitable analogue device (7) to the analogue output connector on the FTM7.

8. If required, connect the RS232 cable (supplied as an optional extra) to the mating socket (female) on the FTM7. Connect the other end of the cable to your control monitoring equipment (6). Refer to Appendix A3 for details of operation using the RS232 interface.

9. Fit the IEC socket on the end of the electrical supply cable to the electrical supply plug on the rear of the FTM7 (Figure 2, item 3).

10. Connect the other end of the cable to the electrical supply; use one of the following methods:

    - Fit a suitable three-pin fused plug to the end of the cable, and fit the plug to an electrical supply socket.
    - Connect the wires in the cable to a suitable electrical supply, as follows:
        - Connect the brown wire to the live electrical supply.
        - Connect the blue wire to the neutral electrical supply.
        - Connect the green/yellow wire to earth (ground).
    - To connect the FTM7 electrical supply cable to an AUTO 306 system, refer to the AUTO 306 instruction manual for the location of terminal block TB1 and:
        - Connect the brown wire in the cable to terminal 7 on terminal block TB1.
        - Connect the blue wire in the cable to terminal 14 on terminal block TB1.
        - Connect the green/yellow wire in the cable to an earth (ground) terminal on terminal block TB1.

3.5 Test the installation

Note: We recommend that you take note of the version of software installed in the FTM7; you may need to supply this information if a fault develops in the FTM7: see Section 5.3.2.

1. Refer to Figure 2. Move the On/Off switch (4) to the 'on' position (position '1'). Alternatively, if you have fitted the FTM7 in a rack, switch on the rack isolator to turn on the FTM7.

2. The Data/Rate display should then show F7, and the Thickness display should then show the version of the software installed in the FTM7. If the displays are incorrect, refer to Section 5.3 for fault finding.

3. Refer to Figure 1. Check that the Data/Rate and Thickness displays (1, 2) then change to show values close to zero, typically in the form:

0.0	-0.1

   If the displays are incorrect, refer to Section 5.3 for fault finding.

4. Check that the xtal1 LED (1) is on. If the LED is not on, refer to Section 5.3 for fault finding.

5. Select test mode: refer to Section 5.2.

6. If test mode was successful (that is, no faults were found), if you do not want to use the FTM7 immediately, switch off the On/Off switch on the rear of the FTM7 (Figure 2, item 4), or switch off the rack isolator if you have fitted the FTM7 in a rack. Alternatively, continue at Section 4 to operate the FTM7.

4 OPERATION

WARNING

Do not place containers of liquids on or near the FTM7. Liquids spilled into the FTM7 can cause electrical short circuits and the risk of injury by electric shock. Solvents or corrosive liquids spilled into or onto the FTM7 can damage it.

Note: The following sections describe manual operation and monitoring of the FTM7. Refer to Appendix A3 if you will use your own control equipment (connected through the RS232 connector) to control and monitor the operation of the FTM7.

4.1 Introduction

If you require accurate and repeatable deposition results, you must enter calibrated parameter data into the FTM7; the parameters you can enter into the FTM7 are listed in Section 1.5.2.

Section 4.2 describes how to switch on the FTM7. Section 4.3 describes how to display and change data. Section 4.4 describes how to calculate parameter data, and Section 4.5 describes how to control deposition processes.

For less accurate deposition processes, you can go directly to Section 4.5 and ignore the instructions to calculate and enter parameter data. If you do, the FTM7 will use any previously entered parameter data, or use the default data (see Table 2).

4.2 Switch on the FTM7

Move the On/Off switch on the rear of the FTM7 (Figure 2, item 4) to the 'on' position (position '1').

Alternatively, switch on the rack isolator if you have fitted the FTM7 in a rack.

4.3 Data display and entry

Note: Data entered into the FTM7 is stored in a non-volatile memory. When the FTM7 is switched off, the data will be retained in the memory for several years. When you switch on the FTM7, if the memory is faulty, error E3 will be displayed and default values will be used: see Table 2.

4.3.1 Select data for display

Refer to Figure 1. The status LEDs (11) identify the parameter currently shown on the displays.

To select a different parameter for display, press and release the Data button (6); in general:

- Each time you press the Data button, the next lower status LED will go on, and the current value of the corresponding parameter will be shown on the displays.
- If you press the Data button twice when the 'mode' LED is on, the 'mode' LED goes off, the 'rate' LED goes on, and the current rate data is shown on the displays.
- If you press and hold in the Data button, the FTM7 will automatically cycle through the display parameters (that is, show one parameter after another). Release the Data button when the required parameter is displayed.

4.3.2 General data entry procedure

Notes: *If you do not press a button for 10 seconds: if the FTM7 is in sequence layer control (see Section 1.5.7), the display will revert to show the layer display; otherwise the display will revert to show deposition rate and thickness data.*

You cannot enter data if a shutter is open, if a shutter has been closed due to crystal sensor failure, or if the FTM7 is in power fail recovery (the shutter status LEDs flash) after an electrical supply failure while the shutter was open: if you press the Increment or Decrement buttons, they will be ignored in these conditions.

If you press and hold in the Increment or Decrement button, the displayed data will automatically increment/decrement rapidly. In addition, data values for layer/sequence or crystal 'scroll'; that is, if the display shows '19 6' during layer/sequence entry (as in Section 4.3.3) and you press the Increment button, the display will scroll to show '1'. Similarly, if the display shows' 1' and you press the Decrement button, the display will scroll to show '19 6'. Other data values increment to their maximum value or decrement to their minimum value. These facilities allow you to easily make large changes to displayed data.

Specific data entry procedures are described in Sections 4.3.3 to 4.3.5.

Refer to Figure 1 and use the following procedure to enter data into the FTM7:

1. Display the parameter to be changed: refer to Section 4.2.1.
2. Change the displayed data:
   - Press and release the Decrement button (9) to reduce the displayed data by one in the least significant (right-hand) digit.
   - Press and release the Increment button (10) to increase the displayed data by one in the least significant (right-hand) digit.

3. When the display shows the new data to be entered, press the Data button (6) to enter the data into the FTM7 and to display a different parameter (see Section 4.2.1). If you do not touch any of the buttons for 10 seconds: the new data will be lost and the display will revert to show rate and thickness data: see the Note above.

4.3.3 Enter layer data

Note: To configure the FTM7 for manual operation, enter a terminal thickness of 0. You must then use the Run button to close the shutter; the shutter will not close automatically.

1. Refer to Figure 1. Press the Data button (6) until the 'layer' status LED (11) is on.
2. Use the Increment and Decrement buttons (10, 9) to select the required layer number (1 to 11) or sequence layer number (12 1 to 19 6) on the Data/Rate display (1).
3. Press and release the Data button (6); the 'density' LED (11) will then go on, and the last entered or default value of density is shown on the display.
4. Use the Increment and Decrement buttons (10, 9) to change the displayed data to the required value.
5. Press and release the Data button (6); the 'z-value' LED (11) will then go on, and the last entered or default z-value will be displayed.
6. Use the Increment and Decrement buttons (10, 9) to change the displayed data to the required value.
7. Press and release the Data button (6); the 'terminate' LED (11) will then go on, and the last entered or default termination thickness value will be displayed.
8. Use the Increment and Decrement buttons (10, 9) to change the displayed data to the required value.
9. Press and release the Data button (6); the 'tooling' LED (11) will then go on, and the last entered or default tooling factor value will be displayed.
10. Use the Increment and Decrement buttons (10, 9) to change the displayed data to the required value.
11. Press and release the Data button (6); the 'xtal' LED (11) will then go on, and the last entered or default crystal sensor value will be displayed.
12. Use the Increment and Decrement buttons (10, 9) to change the displayed data to the required value (1 or 2, for crystal sensor 1 or 2).
13. Press and release the Data button (6); the 'usage' LED (11) will then go on, and the currently selected crystal usage factor will be displayed.
14. Press and release the Data button (6) four times; the 'layer' LED (11) will then go on, and the layer (1 to 11) or layer sequence (12 1 to 19 6) will be shown on the Data/Rate display (1).

The FTM7 is now ready for deposition for the currently displayed layer.

4.3.4 Select backup or layer select mode

1. Press and release the Data button until the 'mode' LED is on; the last entered or default crystal sensor mode (1 or 2) will be shown on the display
2. If necessary, use the Increment and Decrement buttons to change the mode:
   - Select '1' for backup mode.
   - Select '2' for layer select mode.
3. Press and release the Data button three times; layer information will then be shown on the display again.

4.3.5 Configure the analogue output

1. Press and release the Data button until the 'mode' LED is on; the current crystal sensor mode (1 or 2) will then be shown on the display.
2. Press and release the Data button; the Data/Rate display will then show the last entered or default analogue mode (0 to 39).
3. Use the Increment and Decrement buttons to select the required analogue output mode: refer to Appendix 1.
4. Press and release the Data button to display rate/thickness data again.

4.4 Calculate parameter data

4.4.1 Density calibration

Use multiple beam interferometry or a stylus measuring device to calculate the results of test depositions. To calibrate the density:

1. Fit a new crystal.
2. Set the density to the bulk value or estimated value: refer to Section 4.3.3. Note that the bulk densities of common deposition materials are given in Table 4.
3. Set the z-value to 8.834×10^5 g cm^{-2} s^{-1} (or to your predetermined or estimated value).
4. Set the tooling factor to 1.0 (or to your predetermined or estimated value).
5. Place several test substrates, properly masked for thin film thickness measurement, as close to the crystal as possible and make a trial deposition onto a new crystal. The thickness of the deposit should be approximately 80 nm.
6. Take note of the indicated thickness values and then use multiple beam interferometry or a stylus measuring device to measure the actual thickness on the substrates; calculate the average value.

7. Use the following equation to calculate the material density:

$$D_a = D_e \cdot \frac{T_{ind}}{T_m}$$

Where :

Da	=	actual density
D_e	=	estimated density (bulk value)
$T\ ind$	=	indicated thickness
Tm	=	measured thickness

8. Record the actual density and enter it into the FTM7 as described in Section 4.3.3.

4.4.2 Calculate the tooling factor

Use a tooling factor of 1.0 and the known or previously calibrated density, the known z-value (or a z-value of 8.834×10^5 g cm^{-2} s^{-1}) :

1. Fit a new crystal.
2. Place several test substrates, properly masked for thin film thickness measurement, as close to the crystal as possible and make a trial deposition onto the new crystal. The thickness of the deposit should be approximately 80 nm.
3. Take note of the indicated thickness, measure the thickness of the deposit on each sample, then calculate the average film thickness.
4. Use the following equation to calculate the new tooling factor:

$$Tooling\ \ factor = \frac{T_m}{T_{ind}}$$

5. Record the actual tooling factor and enter it into the FTM7 as described in Section 4.3.3.

Material	Symbol	Density ($g\ cm^{-3}$)	Acoustic impedance ($x\ 10^5\ g\ cm^{-2}\ s^{-1}$)
Aluminium	Al	2.70	8.17
Aluminium oxide	Al_2O_2	3.97	*
Antimony	Sb	6.62	11.49
Arsenic	As	5.73	8.83
Barium	Ba	3.50	*
Beryllium	Be	1.85	16.25
Bismuth	Bi	9.80	*
Bismuth oxide	Bi_2O_2	8.90	*
Boron	B	2.54	22.69
Cadmium	Cd	8.64	12.94
Cadmium selenide	CdSe	5.81	*
Cadmium sulphide	CdS	4.83	8.66
Cadmium telluride	CdTe	5.85	9.00
Calcium	Ca	1.55	*
Calcium fluoride	CaF_2	3.18	11.39
Carbon (graphite)	C	2.25	2.71
Cerium (III) fluoride	CeF_3	6.16	*
Cerium (IV) oxide	CeO_2	7.13	*
Chromium	Cr	7.20	28.94
Chromium (III) oxide	Cr_2O_3	5.21	*
Cobalt	Co	8.71	25.73
Copper	Cu	8.93	20.20
Copper (I) sulphide (Alpha)	Cu_2S (Alpha)	5.60	*
Copper (I) sulphide (Beta)	Cu_2S (Beta)	5.80	*
Copper (II) sulphide	CuS	4.60	*
Cryolite	Na_3AlF_6	*	*
Erbium	Er	9.05	*
Gadolinium	Gd	7.89	*
Gallium	Ga	5.93	14.88
Gallium arsenide	GaAs	5.31	5.55
Germanium	Ge	5.35	17.10
Gold	Au	19.3	23.17
Hafnium	Hf	13.09	*
Hafnium oxide	HfO_2	9.63	*
Indium	In	7.30	10.49
Indium antimonide	InSb	5.76	10.98
Indium oxide	In_2O_2	7.18	*
Iridium	Ir	22.4	68.40
Iron	Fe	7.86	25.29
Lanthanum	La	6.17	*
Lanthanum fluoride	LaF_3	5.94	*
Lanthanum oxide	LaO_3	6.51	*
Lead	Pb	11.3	7.81
Lead sulphide	PbS	7.50	15.59
Lithium	Li	0.53	*
Lithium fluoride	LiF	2.64	11.40
Magnesium	Mg	1.72	12.18
Magnesium fluoride	MgF_2	3.00	*
Magnesium oxide	MgO	3.58	21.47
Manganese	Mn	7.20	23.41

Table 4 - Bulk densities and acoustic impedances for common deposition materials

Material	Symbol	Density ($g\ cm^{-3}$)	Acoustic impedance ($x\ 10^5\ g\ cm^{-2}\ s^{-1}$)
Manganese (II) sulphide	MnS	3.99	*
Mercury	Hg	13.46	*
Molybdenum	Mo	10.2	34.34
Neodymium fluoride	NdF_3	6.51	*
Neodymium oxide	Nd_2O_3	7.24	*
Nickel	Ni	8.91	26.66
Niobium	Nb	8.57	17.90
Niobium pentoxide	Nb_2O_3	4.47	*
Palladium	Pd	12.0	24.72
Platinum	Pt	21.4	36.06
Potassium chloride	KCl	1.98	4.30
Rhenium	Re	21.04	*
Rhodium	Rh	12.41	*
Rubidium	Rb	1.53	*
Samarium	Sm	7.54	*
Scandium	Sc	3.00	*
Selenium	Se	4.82	10.21
Silicon	Si	2.32	12.39
Silicon dioxide (fused quartz)	SiO_2	2.20	8.25
Silicon monoxide	SiO	2.13	*
Silver	Ag	10.5	16.68
Silver bromide	AgBr	6.47	7.48
Silver chloride	AgCl	5.56	6.68
Sodium	Na	0.97	*
Sodium chloride	NaCl	2.17	5.62
Sulphur	S	2.07	*
Tantalum	Ta	16.6	33.68
Tantalum (V) oxide	Ta_2O_3	8.20	*
Tellurium	Te	6.25	9.80
Terbium	Tb	8.27	*
Thallium	Tl	11.85	*
Thorium (IV) fluoride	ThF_4	6.32	*
Tin	Sn	7.30	12.19
Titanium	Ti	4.50	14.05
Titanium (IV) oxide	TiO_2	4.26	*
Titanium oxide	TiO	4.90	*
Tungsten	W	19.3	54.14
Tungsten carbide	WC	15.6	58.44
Uranium	U	18.7	37.08
Vanadium	V	5.96	16.65
Ytterbium	Yb	6.95	*
Yttrium	Y	4.34	10.57
Yttrium oxide	Y_2O_3	5.01	*
Zinc	Zn	7.04	17.17
Zinc oxide	ZnO	5.61	15.87
Zinc selenide	ZnSe	5.26	12.22
Zinc sulphide	ZnS	4.09	*
Zirconium	Zr	6.51	*
Zirconium oxide	ZrO_2	5.60	*

Table 4 - Bulk densities and acoustic impedances for common deposition materials (continued)

4.4.3 Determine the acoustic impedance

Determine the acoustic impedance after the density and tooling factor have been calibrated. The acoustic impedance only becomes important for heavily loaded crystals, and frequently the value for quartz (8.834×10^5 g cm^{-2} s^{-1}) is adequate (see Appendix A1). Table 4 shows the acoustic impedance of some of the common deposition materials; where "*" is shown in the table, no data for the material is available: calculate the necessary value, or use the default value.

Calculate the acoustic impedance for the material as described below:

1. Fit a new crystal.
2. Deposit a layer of the material until the crystal sensor ceases to oscillate and note the material thickness at which failure occurred.
3. Fit another new crystal and load it to 80% of the value noted in Step 1.
4. Place a masked sample in the substrate holder and make a second, short deposition (with a thickness of approximately 80 nm).
5. Take note of the indicated value.
6. Use multiple beam interferometry or a stylus measuring device to measure the correct deposition thickness.
7. Modify the acoustic impedance (z-value), as described in Section 4.3.3, until the correct thickness is displayed.

4.5 Deposition/etch processes

4.5.1 Prepare and enter data

1. Prepare a table of the parameter data to be entered. Table 5 shows parameter data for a typical two-layer deposition.
2. Enter the data for each layer into the FTM7: refer to Section 4.3.3.
3. Select and enter the crystal sensor mode: refer to Section 4.3.4.
4. Select and enter the analogue output mode: refer to Section 4.3.5.

Layer	Material	Density	z-value	Terminal Thickness	Tooling factor	xtal
1	Cr	7.2	28.94	20 µm	1	1
2	Cu	8.93	20.20	500 µm	1	1 or 2

Table 5 - Parameter data for a typical two-layer deposition

4.5.2 Start/stop deposition/etch

Note: During sequence layer operation, when the shutter is closed, the Data/Rate display identifies the sequence layer and the material layer. For example, if the Data/Rate display shows '16 4', this indicates that sequence 16 has been selected, and that the deposition/etch parameters for layer 4 will be used in the next deposition/etch cycle.

Use the procedure below to start a deposition/etch process. During deposition/etch, the deposition/etch rate will be shown on the Data/Rate display, and the film thickness will be shown on the Thickness display. The xtal1 and xtal2 LEDs will identify the crystal sensor in use.

Note that if you select sequence layer operation (see Section 1.5.7) and you have entered terminal thicknesses for each of the layers in the sequence, you must press the Run button at the end of layer deposition/etch process to start the deposition/etch process for the next layer in the sequence.

1. Select the required layer: refer to Section 4.3.3.
2. Refer to Figure 1. Press and release the Run button (5); the Data/Rate and Thickness displays will then show zero and the appropriate shutter will open to start the deposition/etch.
3. If you have configured the FTM7 for manual operation, press the Run button when required to close the shutter and stop deposition.

   If you have configured the FTM7 for automatic operation, the FTM7 will automatically close the shutter at the specified termination thickness.
4. If you have selected sequence layer operation, continue at Step 2 to start the deposition/etch process for the next layer in the sequence.
5. Repeat Steps 1 to 4 as necessary, for further depositions.

4.6 Failures during deposition/etch

4.6.1 Crystal sensor failures

Single crystal installations

If you have a single crystal sensor and shutter connected to the FTM7, if the crystal sensor fails, the shutter will automatically close and both the open and close shutter LEDs will flash alternately, however the FTM7 will assume that the process is still in progress.

To continue the process without loss of thickness information:

- Replace the failed crystal sensor.
- Press the Run button to open the shutter again and continue deposition/etch.

Two crystal installations

In backup mode, if crystal sensor 1 fails during a deposition/etch process, the FTM7 will automatically switch to use crystal sensor 2.

In layer selected mode, if either crystal sensor fails, the shutter will automatically close, however the FTM7 will assume that the process is still in progress.

To continue the process without loss of thickness information:

- Replace the failed crystal sensor.
- Press the Run button to open the shutter again and continue deposition/etch.

4.6.2 Electrical supply failures

If the electrical supply fails during a deposition/etch process, the shutter will automatically close, however the FTM7 will assume that the process is still in progress.

When the electrical supply is restored, press the Run button to open the shutter again and continue the deposition/etch without loss of thickness information.

4.7 Switch off the FTM7

Move the On/Off switch on the rear of the FTM7 (Figure 2, item 4) to the 'off' position (position '0').

Alternatively, switch off the rack isolator if you have fitted the FTM7 in a rack.

5 MAINTENANCE

5.1 Check the electrical connections

Regularly do the following checks:

1. Inspect all of the electrical connections to the FTM7 and check that they are secure. Tighten any loose connections.
2. Inspect all of the electrical cables and wires and check that they are not damaged and have not overheated. Replace any cable or wire which is damaged or which has overheated.

5.2 Run the test mode

Refer to Figure 1. At any time when no shutter is open, you can press the Test button (7) to initiate test mode. When you initiate test mode, the following should occur:

- The Test LED (8) will go on.
- For approximately two seconds, all of the LEDs on the front panel will go on and the Data/Rate and Thickness displays (1, 2) will both show 8.8.8.8. You can therefore check that there are no failed LEDs or display segments.
- All of the LEDs will then go off for approximately 2 seconds.
- Both shutter relay contacts will then open for one second, and then close again; the shutter status LEDs (4) will go on and off to reflect the shutter relay status. This sequence will repeat three times. This allows you to check for correct operation of the shutter(s) connected to the FTM7.
- The current crystal sensor frequency will be shown on the Data/Rate and Thickness displays (1, 2), updated once a second. If a crystal sensor and oscillator have been correctly connected, the displays will typically show a frequency of approximately 5999 900. If the displays show a different frequency, refer to Section 5.3 for fault finding. The Test LED flashes on and off while xtal sensor data is shown and you may press the shutter button to open the shutter, start a deposition and observe the frequency change. When the xtal frequency is shown, the analogue output is driven: the output voltage ramps from 0 to 1 V in 5 seconds then returns to 0 V before repeating the cycle to enable you to calibrate your analogue output device.

Press the Test button (7) again to deselect test mode. When you deselect test mode, the Test LED (8) will go off.

If any of the above checks fail, refer to Section 5.3 for fault finding.

5.3 Fault finding

WARNING

Disconnect the FTM7 from the mains supply before you remove the cover. If you do not, there may be a risk of injury by electric shock, or of damage to the FTM7.

WARNING

Disconnect the shutter controller cables from the FTM7 before you remove the cover. If you do not, there may be a risk of injury by electric shock.

5.3.1 General fault finding

Refer to Table 6 for general fault finding.

Symptom	Check	Action
No LEDs are on and the displays are blank.	Is the FTM7 disconnected from the electrical supply ?	Ensure that the electrical supply cable is correctly fitted to the FTM7 and to the external electrical supply.
	Is the FTM7 switched off ?	Ensure that the On/Off switch on the rear of the FTM7 is switched on, and that the external electrical supply is on.
	Is the FTM7 configured incorrectly ?	Check that the FTM7 is correctly configured for your electrical supply.
	Has the electrical supply fuse failed ?	Inspect the fuse and replace if necessary.
The LEDs are on, but the displays are blank.	Is a crystal connected ?	Check that there is a crystal in the crystal holder. Switch the unit off then on again.
	Is a crystal connected to the sensor input ?	Connect the crystal. Switch the unit off then on again.
	Is there a fault in the FTM7 ?	Run the test mode to check for correct FTM7 operation. If the displays remain blank, contact your supplier or BOC Edwards.
In test mode, a crystal sensor frequency of 0 to 400 is displayed.	Are the electrical connections incorrect ?	Check for open circuits between the FTM7, the oscillator unit, the crystal holder and the crystal. Rectify any problem found.

Table 6 - Fault finding

Symptom	Check	Action
The displays all show 000, 000.	Is the oscillator unit connected the wrong way round ?	Check that the oscillator unit is correctly connected to the crystal.
In test mode, a crystal sensor frequency of 400 to 510 000 is displayed.	Is the oscillator unit connected the wrong way round ?	Check that the oscillator unit is correctly connected to the crystal.
	Is there a poor connection in the crystal holder, or is it faulty ?	Inspect the crystal holder and crystal. Replace the crystal holder and crystal as necessary.
	Is the crystal overloaded ?	Inspect the crystal and replace it if necessary.
In test mode, a crystal sensor frequency of 510 000 to 599 900 is displayed.	Is the crystal nearly overloaded ?	The crystal is probably heavily coated, but is still operating at this time. We recommend that you inspect the crystal and replace it as soon as possible.
In the test mode, the shutter status LEDs do not operate correctly.	Is the FTM7 faulty ?	If the LEDs do not operate correctly, but go on at the start of the test mode, the FTM7 is faulty: contact your supplier or BOC Edwards.
The xtal1 LED flashes.	Is the crystal sensor disconnected or mis-connected ?	Check the electrical connections between the crystal holder, the oscillator unit and the FTM7; correct any problem found.
The xtal1 LED flashes (continued).	Is the crystal sensor faulty ?	If the electrical connections are correct, the crystal sensor is probably faulty: replace the crystal sensor.
	Is a cable damaged ?	If you replace the crystal sensor and the problem still exists, check the continuity of the coaxial cables and replace any damaged cable.
A shutter does not operate.	Has the crystal sensor failed ?	Run the test mode and refer to the previous symptoms in this table, to determine if the crystal sensor has failed, or whether the FTM7 is faulty, and to identify the actions to take.
	Is there an electrical connection fault ?	If the FTM7 shutter status LEDs operate correctly, inspect the connections between the FTM7 and the shutter; rectify any problem found.
	Is the shutter faulty ?	Inspect the shutter and replace if necessary.

Table 6 - Fault finding (continued)

Symptom	Check	Action
None of the buttons have any effect.	Was there a transient electrical problem, or is there an earth (ground) fault ?	Switch off the FTM7, then switch it on again and run the test mode. If there is no apparent problem, check the earth (ground) connections and rectify any problem found.
	Are the FTM7 controls disabled ?	If you have connected the FTM7 to your control equipment through the RS232 connector, ensure that you have not inadvertently disabled the FTM7 controls; if so, send a reset command: refer to Appendix A3.
The Increment and Decrement buttons have no effect.	Is the shutter open ?	If so, this is not a fault: you cannot change deposition data when the shutter is open during a deposition process.
	Has the shutter closed due to a crystal sensor failure ?	If so, this is not a fault: you must replace the crystal and restart and finish the deposition process before you can change deposition data.
-	-	If you have made all of the checks above and still cannot identify the cause of a fault, or if you cannot rectify a fault, contact your supplier or BOC Edwards.

Table 6 - Fault finding (continued)

5.3.2 Display fault messages

Fault messages are displayed on the Data/Rate display. The messages and their meanings are shown in Table 7.

Note that these meanings are supplied for information only. If any of these messages are displayed, you must contact your supplier or BOC Edwards for advice; you **cannot** service or repair the FTM7 yourself.

When you read Table 7, take note of the following:

- The 232 message will only appear during initial switch-on (refer to Section 3.5); if shown, the message will also appear on the Thickness display.
- Messages E3 to E7 will only appear during initial switch-on (refer to Section 3.5).
- Messages E101 to E106 and Pxxx will only appear during normal operation.
- Message Pxxx means a message which starts with P and is followed by up to three digits. If you contact your supplier or BOC Edwards after this message has been displayed, you will be requested to supply the following information:
  - The actual fault message (Pxxx) displayed.
  - The software version number (see Section 3.5).

Fault message	Meaning
232	The RS232 hardware has failed.
E3	The non-volatile memory test has failed.
E4	The main counter chip is faulty.
E6	A front panel button is permanently 'on'.
E7	The digital to analogue output chip is faulty.
E101	The main counter chip has failed to program three times.
E102	As E101.
E103	As E101.
E105	The digital to analogue chip has failed to program three times.
E106	As E105.
Pxxx	There is a software fault.

Table 7 - Display fault messages

6 STORAGE AND DISPOSAL

6.1 Storage

When you want to store the FTM7, return it to its protective packaging and store it in clean, dry conditions.

When required for use, install the FTM7 as described in Section 3.

6.2 Disposal

Dispose of the FTM7 and any components safely in accordance with all local and national safety and environmental requirements.

7 SERVICE AND ACCESSORIES

7.1 Introduction

BOC Edwards products, spares and accessories are available from BOC Edwards companies in Belgium, Brazil, China, France, Germany, Israel, Italy, Japan, Korea, Singapore, United Kingdom, U.S.A, and a world-wide network of distributors. The majority of these centres employ Service Engineers who have undergone comprehensive BOC Edwards training courses.

Order spare parts and accessories from your nearest BOC Edwards company or distributor. When you order, please state for each part required:

- Model and Item Number of your equipment
- Serial number (if any)
- Item Number and description of part

7.2 Service

BOC Edwards products are supported by a world-wide network of BOC Edwards Service Centres. Each Service Centre offers a wide range of options including: equipment decontamination; service exchange; repair; rebuild and testing to factory sepcifications. Equipment which has been serviced, repaired or rebuilt is returned with a full warranty.

Your local Service Centre can also provide BOC Edwards engineers to support on-site maintenance, service or repair of your equipment.

For more information about service options, contact your nearest Service Centre or other BOC Edwards company.

7.3 Accessories

Accessory	**Item Number**
Oscillator unit	E086-66-000
Crystals (pack of 5)	E086-68-000
Water cooled crystal holder	E086-67-000

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APPENDIX A1- MEASUREMENT THEORY

A1.1 Crystal sensor operation

The sensor element for the FTM7 is a quartz crystal oscillator. The crystal itself is a plano-convex plate approximately 14 mm in diameter and 3 mm thick, which is excited into thickness shear-mode vibrations by an oscillator unit at a frequency of approximately 6 MHz.

The frequency of oscillation is determined by the mass of material which is deposited on the crystal surface, when the crystal is exposed to the deposition source. As the deposit builds up, the oscillations slow down. BOC Edwards use a plano-convex crystal since this shape induces most of the oscillations to occur in the central exposed region of the crystal. This increases the sensitivity of the crystal to deposited material, and means that the crystal may be firmly clamped around the rim; this increases the effectiveness of the cooling mechanism.

A1.2 Measurement in first generation instruments

When quartz crystal resonators were first used to monitor film deposition, it was assumed that the deposited film would have the same effect as an equivalent distributed mass of quartz, thus:

[1] $$T_f = \frac{N_q \cdot D_q \cdot f^2 \cdot (f_q - f)}{D_f}$$

where:

T_f = film thickness (cm)

D_q = density of quartz (g cm^{-3})

D_f = density of film (g cm^{-3})

N_q = frequency constant for the quartz crystal oscillating in thickness mode (Hz cm^{-1})

f = frequency of load crystal (Hz)

f_q = frequency of unloaded crystal (Hz)

Early crystal detectors were unable to withstand heavy loading and so it was reasonable to assume f approximately = f_q, in which case equation [1] shows that the deposit thickness is proportional to frequency change.

Note, however, from equation [1] that the 'proportionality constant' is not in fact a constant since the term

$$\frac{N_q \cdot D_q \cdot f^2}{D_f}$$

explicitly contains the current crystal frequency, which of course is changing.

A1.3 Measurement in second generation instruments

Second generation film thickness monitors resulted from improvements in crystals, oscillator circuits and compact, low cost integrated circuits. Crystals could withstand much heavier loading. These second generation instruments used the following equation:

[2] $$T_f = N_q \cdot \frac{D_q}{D_f} \cdot (T - T_q)$$

where:

T = period loaded crystal

T_q = period of unloaded crystal

This equation is still an approximation, but is much more accurate than equation [1]. Note that, provided 'period' is the basic measurement, the equation is linear. This measurement technique proved to be a considerable improvement and was widely accepted.

A1.4 Measurement in the FTM7

The original assumption - that the effect of loading a quartz crystal with a film material is equivalent to loading it with an equivalent mass of quartz - is of course questionable. Further advances in instrumentation showed that for very thick films, equation [2] was not valid.

A more rigorous acoustic analysis of the film material, and of the loaded crystal as a one dimensional composite resonator of quartz, leads to the following equation:

[3] $$T_f = \frac{D_q}{D_f} \cdot N_q \cdot T \cdot \frac{Z_f}{3.14\, Z_q} \cdot \tan^{-1} \left\{ \frac{Z_q}{Z_f} \cdot \tan \left[3.14 \left(1 - \frac{T_q}{T} \right) \right] \right\}$$

where:

Z_f = acoustic impedance of the film material

Z_q = acoustic impedance of quartz.

This equation now takes account of the acoustic impedance of the material relative to quartz (acoustic impedance ratio).

Equation [3] reduces to equation [2] if $Z_f = Z$. The ability of equation [3] to describe more accurately the behaviour of a heavily loaded crystal has been demonstrated. The use of microprocessing technology in the FTM7 allows equation [3] to be solved economically. It should be noted, however, that the deviation of behaviour from that predicated by equation [2] only becomes appreciable for heavily loaded crystals, and for the majority of applications equation [2] is adequate.

APPENDIX A2 - ANALOGUE OUTPUT CONFIGURATION

The analogue output can be configured to output deposition/etch rate or film thickness in one of a number of different ways, as described in Section 4.3.5. Refer to Table A2-1 for the different outputs which you can select.

When you read Table A2-1, take note of the following:

- In deposition mode, the analogue output zero value is at 0 V and full scale is 1 V. In etch mode, the analogue output for zero thickness is at 1 V, and negative values of thickness (deposit removal) cause the analogue output voltage to fall towards 0 V.
- If you select an analogue output mode where a value for full-scale deflection is specified (for example, modes 0 to 3), if the rate or thickness exceeds the full scale value, the analogue output will saturate at 1 V.
- If you select an analogue output mode where 'terminal thickness range' is specified (for example, modes 4 and 5), full scale deflection of the analogue output is set to the next power of 10 higher than the terminal thickness for the current layer. For example, if the terminal thickness for the current layer is 55 nm, the full scale deflection of the analogue output will be 100 nm.
- If you select an analogue output mode where 'modulo' output is specified (for example, modes 6 and 7):
    - The output corresponds to measured film thickness until the modulo value is reached, when the output falls to zero.
    - The output then corresponds to (thickness - modulo-value) until thickness reaches twice the modulo value.

  This output method allows very accurate recording of the deposition history. The thickness at any point in the record of outputs (T) is given by:

$$T = (T_{fs} \,.\, Z) + T_r$$

  where:

  T_{fs} = full scale thickness

  Z = the number of times the output has fallen to zero

  T_r = the residual thickness measured.

  Use the smallest modulo scale for maximum resolution.

Mode	Process	Parameter	Full scale deflection
0	Deposition	Deposition/etch rate	10 nm s^{-1}
1	Etch	Deposition/etch rate	10 nm s^{-1}
2	Deposition	Film thickness	10 nm
3	Etch	Film thickness	10 nm
4	Deposition	Film thickness	Terminal thickness range
5	Etch	Film thickness	Terminal thickness range
6	Deposition	Film thickness	modulo 10 nm
7	Etch	Film thickness	modulo 10 nm
8	Deposition	Deposition/etch rate	100 nm s^{-1}
9	Etch	Deposition/etch rate	100 nm s^{-1}
10	Deposition	Film thickness	100 nm
11	Etch	Film thickness	100 nm
12	Deposition	Film thickness	Terminal thickness range
13	Etch	Film thickness	Terminal thickness range
14	Deposition	Film thickness	modulo 100 nm
15	Etch	Film thickness	modulo 100 nm
16	Deposition	Deposition/etch rate	1 µm s^{-1}
17	Etch	Deposition/etch rate	1 µm s^{-1}
18	Deposition	Film thickness	1 µm
19	Etch	Film thickness	1 µm
20	Deposition	Film thickness	Terminal thickness range
21	Etch	Film thickness	Terminal thickness range
22	Deposition	Film thickness	modulo 1 µm
23	Etch	Film thickness	modulo 1 µm
24	Deposition	Deposition/etch rate	10 µm s^{-1}
25	Etch	Deposition/etch rate	10 µm s^{-1}
26	Deposition	Film thickness	10 µm
27	Etch	Film thickness	10 µm
28	Deposition	Film thickness	Terminal thickness range
29	Etch	Film thickness	Terminal thickness range
30	Deposition	Film thickness	modulo 10 µm
31	Etch	Film thickness	modulo 10 µm
32	Deposition	Deposition/etch rate	100 µm s^{-1}
33	Etch	Deposition/etch rate	100 µm s^{-1}
34	Deposition	Film thickness	100 µm
35	Etch	Film thickness	100 µm
36	Deposition	Film thickness	Terminal thickness range
37	Etch	Film thickness	Terminal thickness range
38	Deposition	Film thickness	modulo 100 µm
39	Etch	Film thickness	modulo 100 µm

Table A2-1 - Analogue output modes

APPENDIX A3 - RS232 INTERFACE

A3.1 Connector pin functions

The functions of the pins in the RS232 connector are shown in Table A3-1.

Pin	Signal	Function
2	TxD	Transmit data
3	RxD	Receive data
4	RTS	Request To Send
5	CTS	Clear To Send
7	Ground (earth)	-

Table A3-1 - Pins in the RS232 connector mating-half

Use the signals as shown below:

TxD — The FTM7 uses this pin to transmit serial data. The data is transmitted at 4800 baud, with 1 start bit, 7 data bits, even parity, and 2 stop bits.

RxD — The FTM7 uses this pin to receive serial data. This data must be in the same form as the data transmitted from the FTM7 (see above).

RTS — This output from the FTM7 is 'on' (high) when the FTM7 can receive data. The output is 'off' (low) when the FTM7 is busy. Data transmitted to the FTM7 when this output is off may not be received correctly.

CTS — The FTM7 can only transmit data when this input is on.

A3.2 Communications protocol

The RTS and CTS signals can be used to regulate the flow of characters through the serial link.

The master device can use the CTS signal to control the transmission of data by the FTM7:

- When CTS is off (low), the FTM7 transmissions are inhibited.
- When CTS is on (high), transmissions by the FTM7 are enabled.

If your master device cannot provide a suitable CTS signal, you should link the CTS and RTS pins in the RS232 connector mating-half.

The FTM7 is designed such that you will not normally need to use the RTS signal to regulate data transmission by the master device. However, if the FTM7 reports overrun errors on the interface, you must use the RTS signal.

A3.3 Message protocol

For reliable operation, use the following message protocol between the master device in your control system and the FTM7:

- The master device transmits a command message (with any parameters) to the FTM7.
- The FTM7 interprets the message, then transmits a reponse message to the master device.
- The master device receives the FTM7 reponse message.

The master device must wait until it has received the FTM7 response message before it attempts to transmit another command message.

Refer to Section A3.4 for descriptions of the command messages, and refer to Section A3.5 for descriptions of the return messages.

A3.4 Command messages

A3.4.1 Introduction

Each command message to the FTM7 consists of a string of characters which define the command, terminated by the **<cr>** (carriage return) character (ASCII decimal 13). Some command messages are then followed by command parameters, each of which is also terminated by **<cr>**.

Only the following characters will be recognised: alphanumerics (upper or lower case),".", "+", "-" and **<cr>**; all other characters will be ignored.

The commands available are summarised in Table A3-2; note that in a command message, you can either send the full command name, or the specified two-character abbreviated command. We recommend that you use abbreviated commands, as these require less processing by the FTM7.

Note that commands are not always valid; when invalid, a command will be ignored by the FTM7. The 'validity' column of Table A3-2 identifies command validity as follows:

- Validity 'A' commands are always valid.
- Validity 'PS' commands are only valid when there is no deposition/etch process in progress.
- Validity 'PR' commands are only valid if a deposition/etch process is in progress.

The uses of the command messages are fully defined in Sections A3.4.1 to A3.4.16.

Command name	Abbreviated command	Use	Validity
CHKAOMODE	CA	Check the analogue output mode.	A
CHKMATERIAL	CM	Check the layer (material) parameters.	A
CHKRATE	CR	Check the deposition/etch rate.	A
CHKSHUTTER	CS	Check the shutter status.	A
CHKTHICKNESS	CT	Check the thickness.	A
CHKVERSION	CV	Check the software version.	A
CHKXTAL	CX	Check the crystal used.	A
KEYBOARD	KB	Disable the FTM7 controls.	A
PROGAOMODE	PA	Program the analogue output mode.	PS
PROGMATERIAL	PM	Program material parameters.	PS
RESET	RS	Reset the FTM7.	A
SELMATERIAL	SM	Select layer (material).	PS
SHUTTERCL	SC	Close the shutter.	A
THICKCHG	TC	Change the terminal thickness.	PR
THICKLOOK	TL	Open the shutter.	PS

Table A3-2 - Commands

A3.4.2 Check the analogue output mode

Command message: **CHKAOMODE<cr>**

Return message: **{return code}<cr>{analogue mode}<cr>**

Use this message to check the analogue output mode. In the return message:

{analogue mode} is in the range 0 to 39: refer to Appendix A2.

A3.4.3 Check the current layer data

Command message: **CHKMATERIAL<cr>**

Return message: **{return code}<cr>{layer}<cr>{density}<cr>{z-value}<cr>{terminal thickness}<cr>{tooling factor}<cr>{xtal}<cr>**

Use this message to check the parameters for the current layer. In the return message:

{layer} is in the range 1 to 35 and defines the current layer or sequence layer: see Table A3-3.

{density} is in the range 0.01 to 99.99 and defines the density of the deposition material for the layer.

{z-value} is in the range 1.0 to 99.9 and defines the acoustic impedance for the layer.

{terminal thickness} is in the range 0.0 to 99990.0 and defines the terminal thickness (in nm).

{tooling factor} is in the range 0.01 to 99.90 and defines the tooling factor.

{xtal} is in the range 1 to 3 and specifies the crystal sensor: if {xtal} = 3, this specifies that the FTM7 is operating in backup mode.

A3.4.4 Check the deposition/etch rate

Command message: **CHKRATE<cr>**

Return message: **{return code}<cr>{rate}<cr>**

Use this message to check the current deposition/etch rate. In the return message:

{rate} is in the range 0.0 to 999.90 and defines the current rate (in nm s^{-1}).

A3.4.5 Check the shutter status

Command message: **CHKSHUTTER<cr>**

Return message: **{return code}<cr>{status}<cr>**

Use this command to check the shutter status. In the return message:

{status} is 0 (shutter closed) or 1 (shutter open).

RS232 {layer}	Equivalent Data/Rate display		Applicable material layer
1 to 11	1 to 11		1 to 11
12	12	1	1
13	13	1	1
14	14	1	1
15	15	1	1
16	16	3	3
17	17	5	5
18	18	7	7
19	19	9	9
20	- (not used)		- (not used)
21	12	2	2
22	13	2	2
23	13	3	3
24	14	2	2
25	14	3	3
26	14	4	4
27	15	2	2
28	15	3	3
29	15	4	4
30	15	5	5
31	16	4	4
32	17	6	6
33	18	8	8
34	19	7	7
35	19	8	8

Table A3-3 - RS232 layer data

A3.4.6 Check the current thickness

Command message: **CHKTHICKNESS<cr>**

Return message: **{return code}<cr>{thickness}<cr>**

Use this message to check the current thickness. In the return message:

{thickness} is in the range 0.0 to 99990.0 and defines the thickness (in nm).

A3.4.7 Check the FTM7 software version

Command message: **CHKVERSION<cr>**

Return message: **{return code}<cr>{s/w version}<cr>**

Use this message to check the version of the software in the FTM7. In the return message:

{s/w version} is an ASCII string which defines the software identification and its version.

A3.4.8 Check the current crystal sensor

Command message: **CHKXTAL<cr>**

Return message: **{return code}<cr>{xtal}<cr>{frequency}<cr>**

Use this message to check the current crystal sensor. In the return message:

{xtal} is in the range 1 or 2 and defines the crystal sensor number.

{frequency} defines the crystal frequency (in Hz).

A3.4.9 Disable the FTM7 controls

Command message: **KEYBOARD<cr>**

Return message: **{return code}<cr>**

Use this message to disable the FTM7 controls. After you have sent this command, the controls on the FTM7 are ignored. You must send a RESET command to re-enable the FTM7 controls (see Section A3.4.12).

A3.4.10 Select the analogue output mode

Command message: **PROGAOMODE<cr>{analogue mode}<cr>**

Return message: **{return code}<cr>**

Use this message to select the analogue output mode. In the command message:

{analogue mode} is in range 0 to 39 to specify the required mode: see Appendix A2.

Note that the 'layer' and 'mode' LEDs on the front of the FTM7 will flash when this command message is accepted.

A3.4.11 Program layer parameters

Command message: **PROGMATERIAL<cr>{layer}<cr>{density}<cr>{z-value}<cr>{terminal thickess}<cr>{tooling factor}<cr>{xtal}<cr>**

Return message: **{return code}<cr>**

Use this message to enter the deposition/etch parameters for a layer into the FTM7. In the command message:

{layer} is in the range 1 to 11 and specifies the layer.

{density} is in the range 0.01 to 99.99 and defines the density.

{z-value} is in the range 1.0 to 99.9 and defines the acoustic impedance.

{terminal thickness} is in the range 0.1 to 99990.0 and specifies the required terminal thickness (in nm).

{tooling factor} is in the range 0.01 to 99.90 and specifies the tooling factor.

{xtal} is in the range 1 to 3 and specifes the crystal sensor: set **{xtal}** to 3 to select backup mode.

Note that the parameter LEDs on the front of the FTM7 will flash as the parameter data is entered into the FTM7.

A3.4.12 Reset the FTM7

Command message: **RESET<cr>**

Return message: **{return code}<cr>**

Use this message to reset the FTM7. When you send this command message, this is equivalent to switching off the FTM7, then switching it on again. Note that the FTM7 controls are enabled after this command message.

After you have sent a RESET command, wait for three seconds or more before you send another command message. Note that if the command is accepted, the **{return code}** cannot be guaranteed to be sent to your control equipment, and during re-initialisation, correct operation of the RS232 control signals are not guaranteed. We therefore recommend that you empty and ignore any input queue in your master device.

A3.4.13 Select layer (material)

Command message: **SELMATERIAL<cr>{layer}<cr>**

Return message: **{return code}<cr>**

Use this message to select the layer. In the command message:

{layer} is in the range 1 to 35 and specifies the layer: see Table A3-3.

Note that the 'layer' LED on the front of the FTM7 will flash when this command message is accepted.

A3.4.14 Close the shutter

Command message: **SHUTTERCL<cr>**

Return message: **{return code}<cr>**

Use this message to close the shutter.

A3.4.15 Change terminal thickness

Command message: **THICKCHG<cr>{terminal thickness}<cr>**

Return message: **{return code}<cr>**

Use this message to change the terminal thickness. In the command message:

{terminal thickness} is in the range 0.1 to 99990.0 and specifies the required terminal thickness (in nm).

A3.4.16 Open the shutter

Command message: **THICKLOOK<cr>**

Return message: **{return code}<cr>**

Use this message to open the shutter. When you send this message, it is equivalent to pressing the Run button on the FTM7.

A3.5 Return messages

A return message consists of a **{return code}** terminated by a **<cr>** character (as for command messages), together with return parameters where appropriate: refer to the command messages described in Section A3.4.

{return code} is an ASCII coded integer and its value specifies whether the command was successfully acted upon: refer to Table A3-4.

{return code}	Meaning
0	Command received successfully - no fault.
1	Unknown command received.
2	Invalid command: deposition/etch process in progress
3	Invalid command: deposition/etch process not in progress.
4	Conversion error: a command parameter was not converted to a real value.
5	Parameter error: a command parameter was outside the valid range.
6	Command too long: the number of characters in the command was > 15.
7	Parameter too long: the number of characters in a command parameter was > 15.
8	Program error: there was an internal FTM7 program error.
9	Buffer full: the command was ignored because the input buffer was full.
> 15	Communications error: {return code} will be 15 + **{comms error}**, where **{comms error}** is one of (or a summation of) the following communications error codes: **Code** — **Meaning** 1 — Overrun error 2 — Parity error 4 — Framing error 8 — Received Break For example, if **{return code}** = 17 (15+2), a parity error has been detected. If **{return code}** = 18 (15+2+1), an overrun error and a parity error have been detected.

Table A3-4 - Return codes

A3.6 Programming example

A3.6.1 RS232 connections

Use the pins in the FTM7 RS232 connector mating-half to connect to an IBM PC/XT or PC/AT as shown in Table A3-5. You must use screened, multicore cable to make the connections. The connector that is fitted to the FTM7 is a 9-way, female, D-type connector.

FTM7 connector mating-half		IBM PC XT DB25 connector pin numbers	IBM PC XT/AT signal	IBM PC AT DB9 connector pin numbers
Pin number	Signal			
2	TxD	3	RxD	2
3	RxD	2	TxD	3
4	RTS	5	CTS	8
5	CTS	4	RTS	7
7	Ground (earth)	7	Ground (earth)	5
		20, 6*	DTR, DSR	4, 6*

* Link these pins in the connector.

Table A3-5 - RS232 connections to an IBM PC/XT or PC/AT

A3.6.2 Sample program

The example software shown in Figure A3-1 is written in QuickBASIC Version 4.0 or later and shows how to check the FTM7 software version, how to read the material parameters for the currently selected layer, and how to select the analogue output mode.

```
' FTM7 QuickBASIC RS232 Programming Example
' Clear the computer screen and display a heading
CLS
PRINT "FTM7 RS232 Test": PRINT
' Open up a serial port for communicating with the FTM7
' com2 = serial port 2, 4800 = baud rate, E = even parity
' 7 = number of data bits, 2 = number of stop bits
' Change com2 to com1 for serial port 1
comfil$ = "com2:4800, E, 7, 2"
OPEN comfil$ FOR RANDOM AS #1
' Set up the command ChkVersion, use the short form "cv"
comand$ = cv
' The print command sends the data to the FTM7 and adds
' the Carriage Return code
PRINT #1, comand$
' Line Input reads the data back from the FTM7
LINE INPUT #1, retcode$
' Display the command and return code
PRINT "Command sent - " + comand$,
PRINT "Return Code - " + retcode$
' Check that the FTM7 did not return an error
IF retcode$ <> "0" GOTO FTM7error
' As there was no error, read in the Version number
LINE INPUT #1, Verno$
' and display it
PRINT "Unit ID - " + Verno$: PRINT
' So far we have sent cv<cr> and received back
' 0<cr> FTM7 VX.XX<cr> which is 13 characters at 2 msec
' each. The FTM7 updates at once a second so there
' is no point in continually communicating with it.
' The next instructions are a simple delay
FOR I% = 1 TO 1000
NEXT I%
' Set up the command ChkMaterial and use the short form "cm"
comand$ = "cm"
PRINT #1, comand$
LINE INPUT #1, retcode$
PRINT "Command sent - " + comand$,
PRINT "Return Code - " + retcode$
IF retcode$ <> "0" GOTO FTM7error
' No error so read in the material parameters
LINE INPUT #1, Mat$
LINE INPUT #1, Den$
LINE INPUT #1, Zval$
LINE INPUT #1, Term$
LINE INPUT #1, Tool$
LINE INPUT #1, Xtal$
```

Figure A3-1 - QuickBASIC programming example

```
' Display the parameters along a line
PRINT "Material - " + Mat$;
PRINT "Density - " + Den$;
PRINT  "Z-value - " + Zval$;
PRINT  "Terminate - " + Term$;
PRINT  "Tooling - " + Tool$
PRINT "Xtal - " + Xtal$: PRINT
' The next instructions are a simple delay
FOR I% = 1 TO 1000
NEXT I%
' An example to program a value in the FTM7
' ProgAOMode in short form "pa"
comand$ = "pa"
AOMode$ = "8"
PRINT #1, comand$
PRINT #1, AOMode$
LINE INPUT #1, retcode$
PRINT "Command Sent - " + comand$, " Value Sent - " + AOMode$,
PRINT "Return Code - " + retcode$
' We must check for no error and that the command is
' allowed in the current FTM7 state. Test this by
' manually opening the shutter and seeing the report
IF retcode$ <> "0" THEN
IF retcode$ = "2" THEN
PRINT "The Command is not valid during Deposition or Etch."
ELSE GOTO FTM7error
END IF
END IF
GOTO finished
FTM7error:
        LOCATE 23, 1: PRINT "Return code error"
' These lines wait for any key press to exit
finished:
IF INKEY$ = "" THEN GOTO finished
END
```

Figure A3-1 - QuickBASIC programming example (continued)