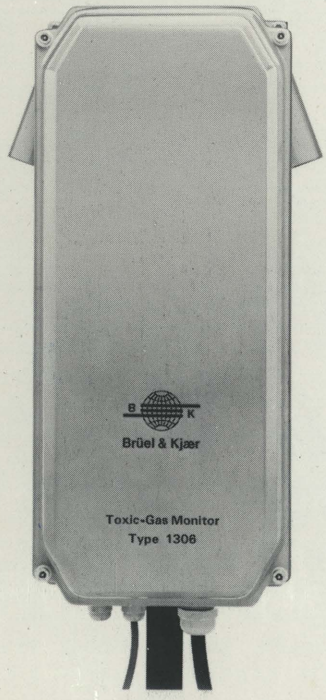
1306

Instruction Manual

Vol. 1

Operation and Interface

Toxic-gas Monitor Type 1306



The Toxic-gas Monitor Type 1306 is an extremely reliable and highly selective monitor of a gas, or group of gases. Gas-selectivity is determined by the optical filter installed. The 1306 operates automatically — drawing in a sample of air from its environment, at user-selectable intervals, and measuring the concentration of the monitored gas in it.

The 1306 is linked to a computer so that the user can request measurement/test data from it, and remotely control it by sending it commands and control data.

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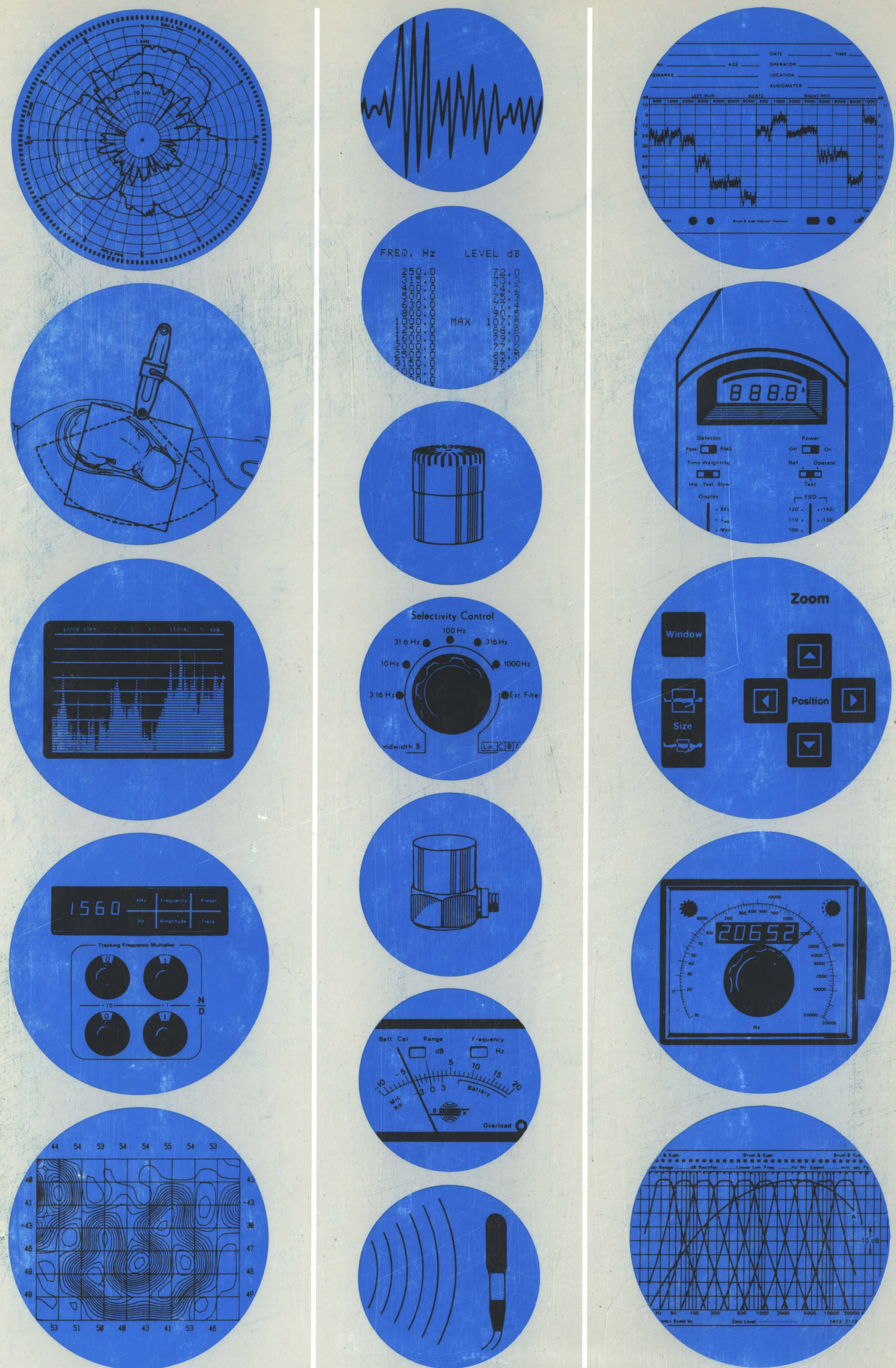
Vol. 1



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Brüel & Kjær

TOXIC–GAS MONITOR
TYPE 1306

From serial no. 1336777

June 1988

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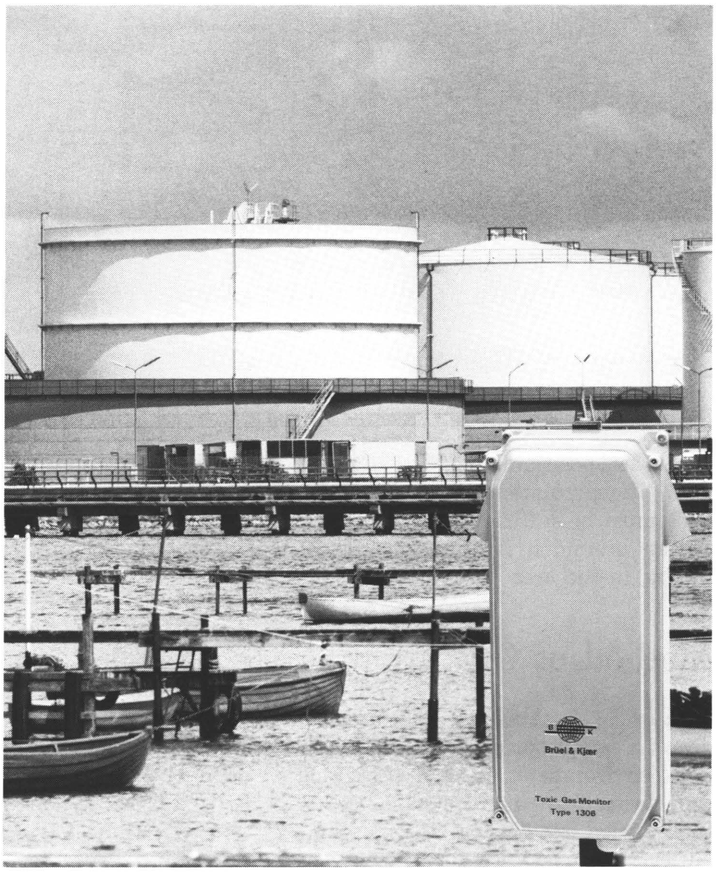
Toxic-gas Monitor

USES:

- Unattended monitoring of toxic gases and vapours
- Detection of accidental releases
- Monitoring of process emissions
- Occupational health and safety measurements

FEATURES:

- Highly selective and sensitive
- Linear over a wide dynamic range
- Unattended operation – typically 3 months
- Accurate concentration measurements
- Extremely reliable due to self-testing procedures
- Compensates for water-vapour and temperature fluctuations
- Remotely controlled by computer
- User-friendly software available
- Very stable — infrequent calibration required
- Easily maintained — running-costs are low
- Protected against voltage surges



Introduction

The Brüel & Kjær Toxic-gas Monitor Type 1306 is a highly sensitive, stable and reliable instrument designed to automatically monitor toxic gases and vapours in harsh environments. Its measurement technique is based on photo-acoustic infra-red spectroscopy. The 1306 can thus be used to monitor almost any gas which absorbs infra-red light. By choosing an appropriate optical filter from the wide range of narrow-band filters available, the 1306 can selectively measure the gas of interest. The 1306's detection threshold is gas-dependent but typically in the parts per billion (10^9) to parts per million region. Its wide dynamic range allows it to measure concentrations four orders of magnitude (i.e. a factor of 10^4) higher than its detection threshold.

The Toxic-gas Monitor's running-costs are low as it is able to function efficiently even under extreme environmental conditions for long periods of time without maintenance, and with minimal supervision.

The weather-proofed case of the 1306 encloses both the system for measuring gas concentration, and the electronics for processing signals.

For long-term monitoring the 1306 and its Power Supply ZG 0309 are mounted on a mast in a suitable location, and the 1306 is linked to a computer. This computer acts as a control station. Using the Applications Diskette BZ 5003 provided, users can communicate with a single 1306, controlling it remotely, collecting measurement and self-test data from it and calibrating it *in situ*.

Brüel & Kjær Application Software Type 7619 is available for controlling up to 31 Toxic-gas Monitors in a monitoring network. This user-friendly software automatically collects, analyses and presents measurement and self-test data from all the monitors in a network, and enables *in situ* calibration of each 1306 in the network.

The measurement and self-testing sequences of the 1306 are completely automatic. The 1306's comprehensive self-testing procedures enable it to detect and identify any relevant system fault and report it to the control station. Measurements stop if the 1306 is unable to measure reliably because of a system fault, but as soon as the fault has been corrected, the 1306 automatically resumes measurements.

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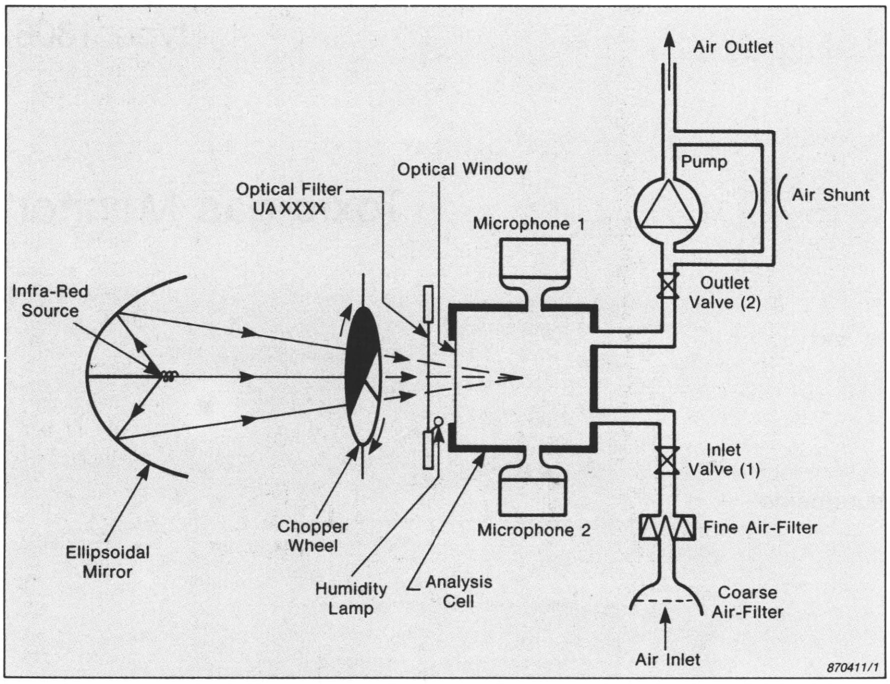

Fig. 1. The measurement system of the Toxic-gas Monitor

Correct positioning of the 1306 is vital. The circulation of air around the 1306 must be sufficient to ensure that the air around it is representative of the air in the area being monitored.

Method of Operation

At user-selectable intervals, a pump draws a sample of air from the monitor's environment, into the analysis cell, through two air-filters. The cell is then sealed by closing its inlet and outlet valves (see Fig. 1). Light from an infra-red source is reflected from a mirror and passed first through a chopper, which pulsates it; then through an optical filter, which transmits light of defined wavelength into the analysis cell through a window.
The light transmitted by the optical filter is selectively absorbed by the gas being monitored, so if any of the monitored gas is present in the cell it will absorb this light, causing the temperature of the gas to increase. As the cell is sealed, this temperature increase causes an equivalent increase in the pressure of the gas. Because the light is pulsating at the chopper frequency, the pressure will also fluctuate at this frequency, creating an acoustic wave in the cell which is directly proportional to the concentration of the gas in the cell. This is the photoacoustic effect.

Two sensitive microphones mounted within the cell wall measure the acoustic signal which is then processed by the 1306. Measurement results are sent to the control station on request.

A complete measurement takes 45-55 s — this includes the time taken to purge the cell. The time between measurements is defined by the user.

Selectivity

The selectivity of the Toxic-gas Monitor is determined by the installed optical filter. A wide range of narrow-band optical filters is available from Brüel & Kjær. By studying the absorption spectrum of the gas to be monitored as well as the absorption spectrum of any other gas which is likely to be found in the ambient air in the same area, the most appropriate optical filter can be chosen. Refer to the Product Data Sheet for the Optical Filters for details.

Water vapour, which is nearly always present in the air samples drawn into the 1306 for analysis, absorbs infra-red light slightly at nearly all frequencies and therefore contributes to the signal measured in the cell. However, by using a humidity lamp, water-vapour's contribution is measured separately during each gas measurement sequence, so that the 1306 can compensate for water-vapour's interference.

Setting-up the 1306

The user sets-up the monitor by sending it control data which specifies the following:

- the time between the finish of one measurement and the start of the next (this determines the measurement frequency);
- the *alarm level* — that is, the concentration of monitored gas which, if measured, causes the 1306 to perform measurements continually, and triggers any external alarm which may be connected to the network.

Modes of Operation

The 1306 has four different modes of operation. Three of these modes are dependent upon the concentration of monitored gas measured in the analysis cell (see Fig. 2).

(1) Normal Mode
The 1306 operates in this mode as long as the concentration of the monitored gas it measures is below a level called the *intensification level*. The *intensification level* is half the *alarm level* (see Fig. 2). Gas measurements occur with a frequency specified in the 1306's control data.

(2) Intensification Mode
The 1306 operates in this mode as soon as it measures a concentration of monitored gas which is greater than the *intensification level*. While operating in this mode the frequency of gas measurements increases as the monitored-gas concentration increases, until the *alarm level* is reached.

(3) Alarm Mode
By the time the concentration of the monitored gas reaches the *alarm level* gas measurements are being taken continually.

(4) Power-Down Mode
The 1306 operates in this mode: (a) if it is not able to measure gas concentrations reliably, or (b) if commanded to do so by the control station (e.g. during maintenance). In this mode the 1306 stops performing gas measurements and stops testing its measurement system.

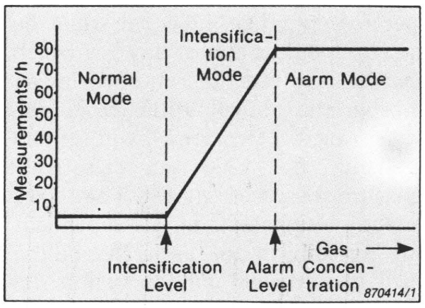

Fig. 2. Graph showing how the 1306's operating mode and measurement "frequency" is dependent on the concentration of monitored gas measured by the 1306

Remote Control

The user controls the 1306 remotely by sending commands/requests via the control station.

Commands
The user can command the 1306 to perform any one of a number of measurements or tests, or to change its mode of operation, at any time. The 1306 responds by immediately stopping what it is doing and carrying out the command. This facility is particularly useful in alarm situations and during service and maintenance.

Requests
The 1306 stores the results of its most recently completed measurement and self-test sequences. This data is continuously updated and can be requested from the 1306 at any time without disturbing its mode of operation.

Communication

A shielded, balanced, two-wire communication cable is used to connect the 1306 to its control station (computer). The cable handles communications in both directions. A single computer can control up to 31 Toxic-gas Monitors, and the total distance between the computer and the last 1306 on the cable can be up to 12 km, depending on the number of 1306s being used. Modems can be used to increase this distance.

A special procedure (DDCMP)* is used to check all data transmitted on the communication cables. This procedure makes it possible to reduce the data-transmission error-rate almost to zero. Each 1306 is given its own address and the DDCMP enables the control station to communicate individually with each monitor connected to it.

The control station and the 1306 communicate via the RS-485 interface. This interface was chosen in preference to the RS-232C interface, which most computers use, for three important reasons: (1) it allows faster serial transmission of data; (2) it allows up to 31 monitors to be connected in parallel on a single cable to a single computer which controls them, so that if any monitor in this network stops functioning or is disconnected, the control station does not lose contact with all the other monitors in the network (see Fig. 3). The monitors in this network can be 1306s or any other monitors which use the same interface and protocol, for example wind velocity/direction monitors; and (3) the RS-485 interface standard allows a much greater distance between the computer and the last 1306 on the cable.

A computer fitted with an RS 232C interface can be used as a control station by using an interface converter in the monitoring network (see Fig. 3).

* Digital Data Communications Message Protocol developed by Digital Equipment Corporation.

Self-tests	Frequency
Switch settings; temperature of gas in analysis cell; voltage supply to the 1306; Lid (to see if 1306 has been opened); A-D converter	every 260 ms
Software; processing system	every 18 s
Humidity lamp; temperature of I.R. source; frequency of chopper	same as gas measurement frequency
Microphones; preamplifiers; valves; air pump; air-shunt	every 30 min.

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Table 1. Self-tests made by the Toxic-gas Monitor

Reliability

The Toxic-gas Monitor has been rigorously tested to ensure reliability of performance and results. Performance reliability is ensured by the comprehensive series of self-tests which the 1306 continuously performs. See Table 1 for details.

A **status report,** which summarises the results of the 1306's self-tests, is sent to the control station with all measurement results. The user can therefore see at a glance what, if anything, has affected the accuracy of the measurement; or which fault has caused the 1306 to stop taking gas measurements, so that appropriate action can easily be taken to correct the fault.

As soon as the condition causing the fault is corrected the 1306 automatically starts up again.

Power Supply

The Toxic-gas Monitor requires a 12 V DC power supply. This can be obtained either: from the AC mains by means of the Power Supply ZG 0309 which is provided as an accessory; or from a 12 V car battery. A car battery can also be used to provide power for short-term monitoring from a stationary vehicle.

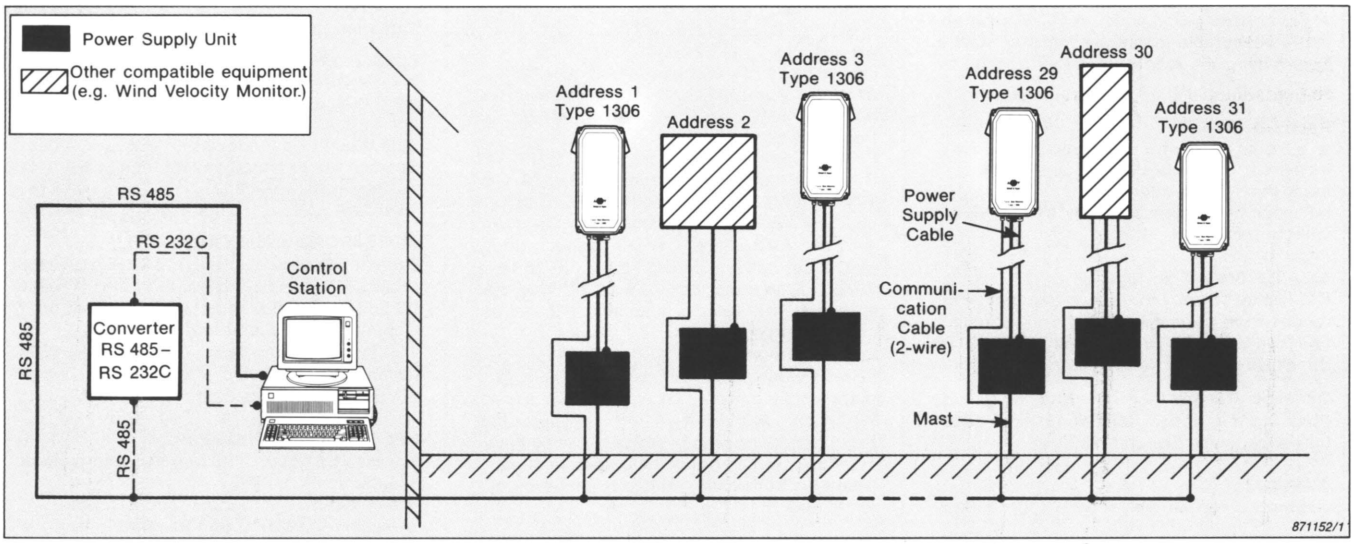

Fig. 3. A simple monitoring network comprising Toxic-gas Monitors and other compatible equipment

The 1306 is provided with an input filter which protects it from transient voltage surges on the power supply caused, for example, by lightning strikes. The 1306 resumes its automatic operation as soon as the voltage supplied to it falls within operational limits.

Maintenance

Regular maintenance of the 1306 involves calibration and change of the fine air-filter. The frequency with which these two operations need to be performed is dependent on the 1306's measurement frequency, and on the amount of suspended matter (e.g. dust) in the air it is monitoring.

The **status report** informs the user of when the 1306's fine air-filter needs to be changed. It is often practical to calibrate the 1306 when its fine air-filter is changed (typically 4 times a year). Calibration in the field (*in situ*) is performed using a known concentration of either the gas to be monitored, or a substitute gas.

If the 1306 stops taking gas measurements the user can request detailed results of all the 1306's self-tests. Using this data, service engineers can quickly diagnose any fault and perform necessary repairs without delay. This means that service costs can be minimised and that the 1306 is out of operation for the shortest possible time.

Specifications 1306

All terms relating to gas analysis are in accordance with the definitions set out in the ISO Draft International Standard 8158

Details about the optical filters which are available for use with the 1306 can be found in the "Optical Filters" Product Data Sheet.

An optical filter UA XXXX is installed in the 1306, which is then zero-point calibrated before delivery. Calibration with a specific gas is optional. A "calibration chart" gives details about the installed optical filter and the calibration of the 1306.

MEASUREMENT TECHNIQUE:
Photoacoustic infra-red detection

RESPONSE TIME:
45s - 55s (time taken to purge the cell, and measure the gas concentration in the new air sample).

ACCURACY:
Zero Drift:
Typically = Detection Threshold per 3 months●
Influence of temperature■: insignificant — compensated for internally.
Influence of pressure▲: ±1,5% of detection threshold/mbar

A gas concentration equal to 1% of the maximum measurable concentration was used in determining the following specifications

Repeatability: 1% of measured value●

Range Drift:
± 2,5% of measured value per 3 months●
Influence of temperature■: insignificant — compensated for internally.
Influence of pressure▲: – 0,01% of measured value/mbar

MEASUREMENT RANGE:●
Detection Threshold: is gas-dependent but ranges from parts/million (ppm) to parts/billion (see Table for examples of the detection threshold of some pure gases/vapours).

Dynamic Range: four orders of magnitude (that is, the upper detection limit = 10 000 times the lower detection limit)

GENERAL:
Cabinet: complies with IEC 529 & IP 53 Standards. Resistant to rain falling at a maximum angle of 60° to the vertical axis. Dust resistant

Gas/Vapour	Detection Threshold (ppm)
Phosgene	0,03
Vinyl chloride	0,2
Ammonia	0,3
Styrene	0,2
Perchloroethylene	0,05
Ethylene oxide	0,1
Benzene	0,8
Total hydrocarbons (with ref. to propane)	0,1

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Dimensions:
Height: 400 mm (15,7 in)
Width: 200 mm (7,9 in)
Depth: 102 mm (4,0 in)
Weight: 5,5 kg (12,1 lbs)
Operating Temperature: –20°C to +50°C
Relative Humidity: 95%-100% relative humidity at 50°C
Power Requirement:
Power Supply ZG 0309 complies with IEC 348 Class 1 Standards. It converts: 90, 100, 110, 120, 130, 200, 210, 220, 230, 240 V AC ± 10%, 50/60 Hz to 12 V DC. Power consumption: ~50 VA. Alternatively, a DC power supply (e.g. a car battery) providing 12 V (+15%/ –20%) to the input terminals of the 1306 can be used. The 1306 is supplied with an attached 4 m power cable.
Power Consumption:
During measurements: 34 W peak (start) and 18 W operating. On standby: 2 W (power-down mode)
Vibration Sensitivity: Strong vibrations occuring at a frequency of 20 Hz can compromise the detection-threshold specification.
Acoustic Sensitivity: Not influenced by external sound

Electromagnetic Compatibility: Complies with U.S. FCC requirements for class B computing devices.
Electromagnetic Pulse (EMP) Protection: In accordance with CCITT recommendation K17.

COMMUNICATION:
The 1306's digital interface complies with the EIA Recommended Standard RS 485. The Digital Data Communication Message Protocol (DDCMP) is used to ensure error-free and synchronized data transfer. The 1306 is supplied with an attached 4 m communication cable. The Application Diskette BZ 5003 provided allows users to control a single 1306. B & K Application Software Type 7619 is available which allows users to control up to 31 Toxic-gas Monitors in a network.

ACCESSORIES INCLUDED:
Application Diskettes .... BZ 5003
Power Supply .... ZG 0309
Spare Fine Air-filter Thumbscrew Unit, "O"-ring & Retaining Disc .... UA 0994
Fine Air-filters (10) .... DS 0714
Coarse Air-filter Unit (2) .... UC 0193
Calibration Kit consisting of:
Teflon Tubing (4m) .... AT 2177
Calibration Stub .... DB 3023
"Y"-piece .... UD 5001
"O"-ring (4) .... YJ 0770
Threaded Nut .... YM 0652

Spare Fuses:
2 × 125 mA .... VF 0030
2 × 2,0 A .... VF 0010
2 × 4,0 A .... VF 0045
Allen Key to open/close the 1306 .... QA 0161
Special Key to install optical filter .... QA 0162
"C" spanner (wrench) .... QA 0181
Tweezers .... QA 0164

ACCESSORIES AVAILABLE:
Optical Filters (22) .... UA 0968-UA 0988 .... and UA 0936
RS 232 C-RS 485 Converter .... WQ 0677
Communication Cable with 2 × 25pin connectors .... WL 0814
Communication Cable with a 25-pin and a 9-pin connector .... WL 0815

REFERENCE CONDITIONS:
● Measured at 20°C, 1013 mbar, and relative humidity (RH): 60%.
■ Measured at 1013 mbar, and RH: 60%.
▲ Measured at 20°C and RH: 60%.

For information on the installation of the Toxic-gas Monitor contact your local Brüel & Kjær representative.

2. OPERATION

2.1. INTRODUCTION

The Toxic-gas Monitor is primarily designed for long-term monitoring of toxic gases in permanent monitoring networks. Monitoring networks can vary in size and complexity depending on the user's requirements. The most simple network comprises a single Toxic-gas Monitor and its power supply, mounted on a mast in a suitable location, and linked to a computer — see Fig. 2.1.

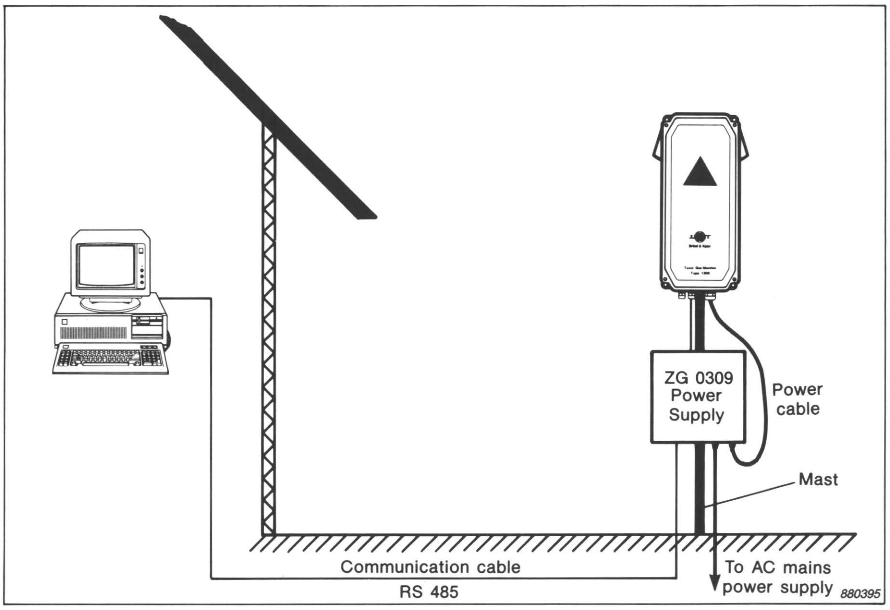

Fig. 2.1. A simple monitoring system

A computer program (software) is required to enable the user to communicate with the 1306 via the computer keyboard. Software is supplied with the Toxic-gas Monitor in the form of an Applications Diskette BZ 5003. This software allows the user to communicate with a single 1306 via an AT or PS2 IBM computer. It allows the user to request some measurement results from the 1306; send new control data to the 1306, and calibrate the 1306. The use of this software is described in detail in Volume 2 of the Instruction Manual for the 1306.

Full communication with one or more 1306s requires more sophisticated software than that provided. Optional software which is especially designed for this purpose is the Brüel & Kjær Type 7619 "Software for Toxic-gas Monitoring". This software allows the user to communicate fully, via the computer keyboard, with every 1306 in a monitoring network. The keyboard commands used to communicate with the 1306 are software-dependent and therefore will not be discussed here, but in the Instruction Manual for the software. In this chapter we will only discuss those aspects of the operation of the 1306 which are independent of the software used.

Users who wish to write their own software are provided with all relevant information to enable them to do so in Chapters 3, 4 and 5 of this manual, and some information is also provided on the diskette mentioned previously.

2.2. INSTALLATION OF THE MONITOR

A full description of all the details involved in the installation of the 1306 can be found in Volume 2 of the Instruction Manual for the 1306.

2.3. THE MEASUREMENT PRINCIPLE

An overview of the Toxic-gas Monitor's measurement principle is given in Chapter 1 of this manual. However, in order to fully understand the various measurements performed by the 1306 during a gas-measurement sequence, a more detailed description of the effect of infra-red light on the air sample in the analysis cell is necessary.

When broad-band infra-red light, that is light with a wide range of frequencies, is passed through a particular gas, the gas will selectively absorb light at particular frequencies — absorbing some frequencies of light more strongly than others. Every gas has its own unique absorption spectrum. Fig. 2 in Chapter 1 illustrates a typical absorption spectrum of a gas. By carefully choosing an optical filter which only transmits light in a region of the spectrum where the gas to be monitored absorbs strongly, the 1306 can selectively measure the concentration of this gas.

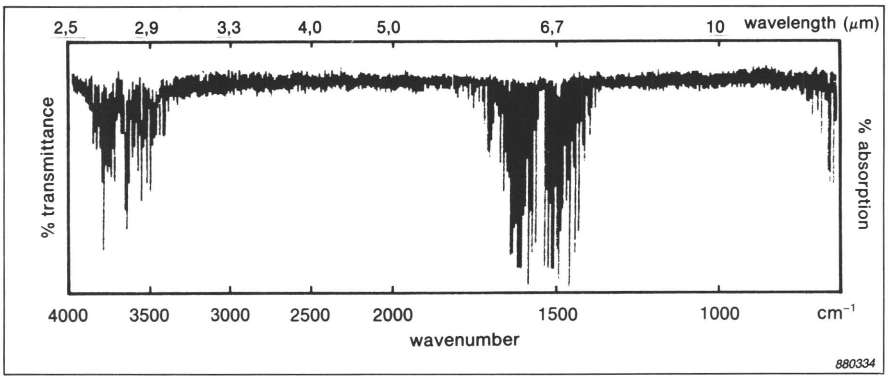

Fig. 2.2. High resolution transmittance spectrum of water vapour

Gases normally found in atmospheric air do not absorb — to any measurable extent — the light which is transmitted by the optical filter, and therefore they are not considered to "interfere" with the signal which is measured in the analysis cell. However, water vapour, which is almost always present in the air sample in the cell, absorbs infra-red light at nearly all frequencies over a large region of the spectrum (see Fig. 2.2). Thus, no matter which optical filter is installed in the 1306, some of the infra-red light reaching the cell will be absorbed by the water vapour present and produce a signal which contributes to the total signal measured in the cell when the infra-red light is on. Because the signal produced by water vapour "interferes" with the signal produced by the gas being monitored, it has to be measured separately so that the 1306 can compensate for water-vapour's contribution.

2.3.1. Determination of Water-vapour's Signal Contribution

A very small lamp (humidity lamp) is mounted between the optical filter and the analysis cell window (see Fig. 1 in Chapter 1 of this manual). When this light is switched on it emits pulses of infra-red light with wavelengths between approximately 0,5μm–3μm. This light is filtered by the glass covering the lamp's filament, as well as the analysis-cell window, so that the wavelength of the light entering the cell is between 2–3μm. Water vapour absorbs strongly in this region of the spectrum (see Fig. 2.2) and therefore produces a signal which can be measured. The greater the concentration of water vapour in the cell (that is, the higher the humidity of the air in the cell) the greater the signal produced by it. This is why the measurement of this signal is often referred to as the "humidity" measurement.

There are not many toxic gases which strongly absorb infra-red light in the 2–3μm region of the spectrum and therefore, if any such gas is present in the cell during a humidity measurement, it will not interfere significantly with the signal produced by water-vapour.

By measuring the total signal in the cell when the *humidity lamp* is on, water-vapour's signal contribution to the total signal measured in the cell when the *infra-red light* is on can be determined. Details of this procedure are provided in Chapter 5 of this manual.

2.4. THE GAS–MEASUREMENT SEQUENCE

During the gas-measurement sequence a series of operations and measurements are performed which enable the 1306 to calculate the concentration of the monitored gas in its analysis cell. The sequence of these operations and measurements is illustrated in Fig. 2.3 and can be described as follows:

1. The inlet and outlet valves are opened; the infra-red light source is switched on; and the chopper and pump are started.
2. When the analysis cell has been thoroughly flushed, the pump is stopped and the valves are then closed so that the air sample is sealed in the analysis cell. The air in the analysis cell is still turbulent at this stage, so the 1306 waits 3—4 s to allow the air in the cell to stabilise before starting the measurement discussed in the next step.

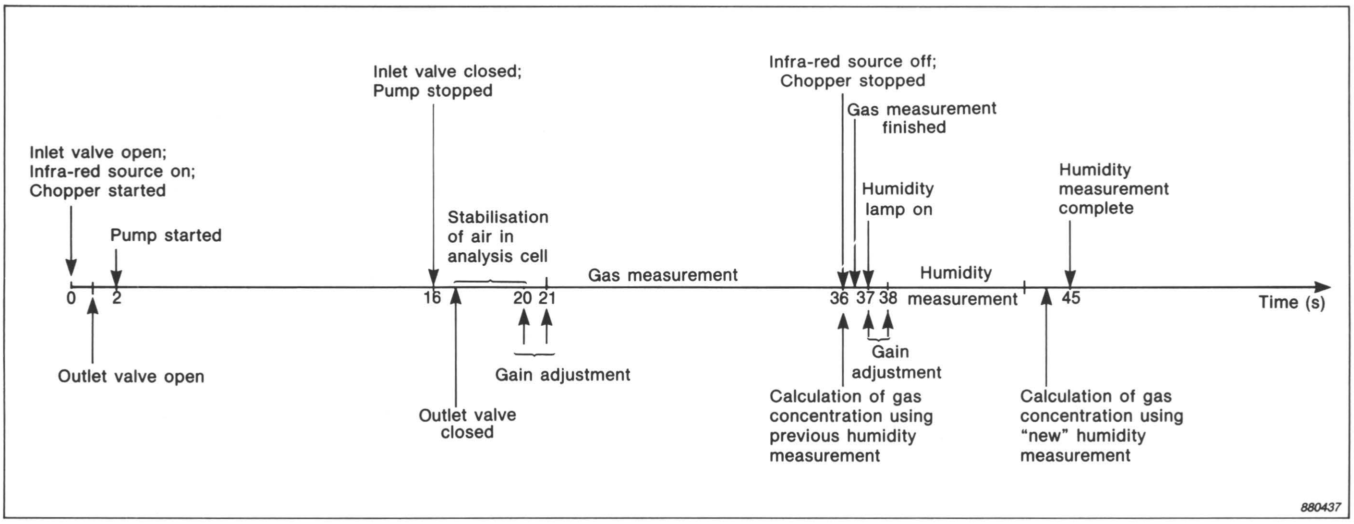

Fig. 2.3. The gas-measurement sequence of the 1306

3. A quick preliminary measurement is made of the total signal in the analysis cell. This measurement allows the gain of the amplifier to be set to its optimum value.
4. The total signal in the cell is measured. The infra-red light source is switched off, and the chopper is stopped. The total signal is compensated for water-vapour's signal contribution using the humidity value measured during the previous gas-measurement sequence, and the gas concentration calculated in mg/m^3.
5. The humidity lamp is switched on. A quick preliminary measurement is made of the total signal in the analysis cell. This measurement allows the gain of the amplifier to be set to its optimum value.
6. The total signal in the cell is measured. The humidity lamp is switched off.
7. The total signal measured in (4) above is now compensated for water vapour's signal contribution just determined (in step 6), and the gas concentration is calculated in mg/m^3.

The whole gas-measurement sequence takes between 45 s - 55 s to complete. However, users can get the results of a gas measurement 37 - 40 s after the start of a measurement, but this gas concentration is that which is calculated using the previous humidity measurement (see step 4 above). Under normal circumstances the humidity in the cell will not fluctuate widely between one gas measurement and the next, and therefore the results obtained in step 4 and step 7 will not differ greatly.

2.4.1. Time Taken to Complete a Gas Measurement

The whole gas-measurement sequence can be performed in 45 s. However, up to 10 s extra time is sometimes needed to perform one or more of the following operations:

- perform an extra preliminary measurement so that the gain of the amplifier can be adjusted (see Steps 3 and 5 in Section 2.4);
- allow the infra-red light source to warm up;
- allow the pump to run for a longer period of time when the air-filter is nearly blocked. This ensures that there is a complete change of the air in the cell between gas measurements.

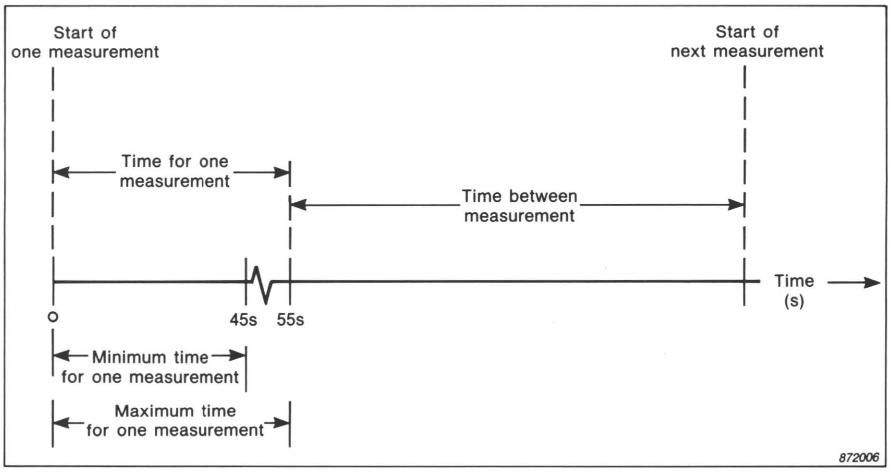

Fig. 2.4. The relationship between time for one gas measurement, time between gas measurements and the "frequency" of gas measurements

This means that the time between the start of one measurement and the start of the next is not a constant parameter and therefore it is not possible to refer to the "frequency" of gas measurements (i.e. the number of measurements which are performed per hour). Fig. 2.4 illustrates this point. The time between measurements is, however, a constant quantity, and it is therefore this parameter which is used to control the rate at which gas measurements are performed when the 1306 is operating in its normal mode.

2.5. OPERATING MODES

The 1306 can operate in four different modes: normal, intensification, alarm and power-down modes. These operating modes are described in Chapter 1 of this manual.

2.6. START–UP SEQUENCE OF THE 1306

When the 1306 is supplied with power it performs a start-up sequence. The 1306 also performs a start-up sequence when it has been "reset". The conditions which cause the 1306 to "reset" are given in Section 2.8. During a start-up sequence the following tasks are performed:

1. The processor system is checked and the results of the last gas- and self-test measurements made by the 1306 are deleted from its memory. If any faults are detected in the processor system, the 1306 will indicate the fault by setting the *software* flag to "1" in its status report (see Section 2.10).

2. A hardware test is performed if this test has been enabled (i.e. if switch no. 2 of the upper bank of switches in the 1306 has been set to "1" — see Volume 2 of the Instruction Manual for the 1306 for details). This test checks that the chopper, infra-red light source, air pump and valves are functioning correctly.

3. If the hardware test described above shows the 1306 to be functioning correctly, the 1306 will start to perform its self-tests in the following order:

   i) *almost continuous self-tests;*
   ii) *regular self-tests;*
   iii) *gas-measurement sequence self-tests.*

These self-tests are discussed in detail in Section 2.7.

If, during the start-up sequence described above the 1306 is found to be functioning correctly, it will perform a gas measurement and air-humidity measurement and then continue to operate in normal, intensification or alarm mode until such time as either (1) an operating error causes it to operate in its power-down mode, or (2) the user *commands* it to change its mode of operation (see Section 2.9.3).

However, if during the start-up sequence, a fault is detected which makes it impossible for the 1306 to measure gas concentrations accurately, the 1306 will automatically go into its power-down mode, and report the operating fault in its status report (see Section 2.10).

2.7. SELF–TESTS

The primary task of the 1306 is to measure the concentration of gas in its analysis cell. However, this is not the only task which the 1306 performs. It also performs a comprehensive series of self-tests and environmental measurements. The results of these self-tests and measurements are summarised in a report called a **status report** (see Section 2.10). Each time measurement results are requested from the 1306 they are sent together with this report. This allows the user to evaluate the 1306's performance and judge the quality of the gas measurements it performs.

There are three main series of self-tests:

1. **Almost continuous tests** — these tests are performed whenever the 1306 is not performing any other test or measurement. They check the software and processing system of the 1306, check that the temperature and power supply to the 1306 are within operational limits, and measure vibration noise in the analysis cell (see Section 2.7.1).
2. **Regular tests** every 30 min — these check most of the electrical and mechanical parts of the 1306 (see Section 2.7.2).
3. **Gas-measurement sequence tests** performed during each gas-measurement sequence — these check the components most vital to the measurement procedure (see Section 2.7.3).

The frequency with which each series of self-tests is performed is dependent upon the operating mode of the 1306. Table 2.1 illustrates how frequently each series of self-tests is performed during each operating mode. In Fig. 2.5 this dependency is represented in graphical form — where, for the purpose of illustration a "time between measurements" of 10 minutes has been chosen.

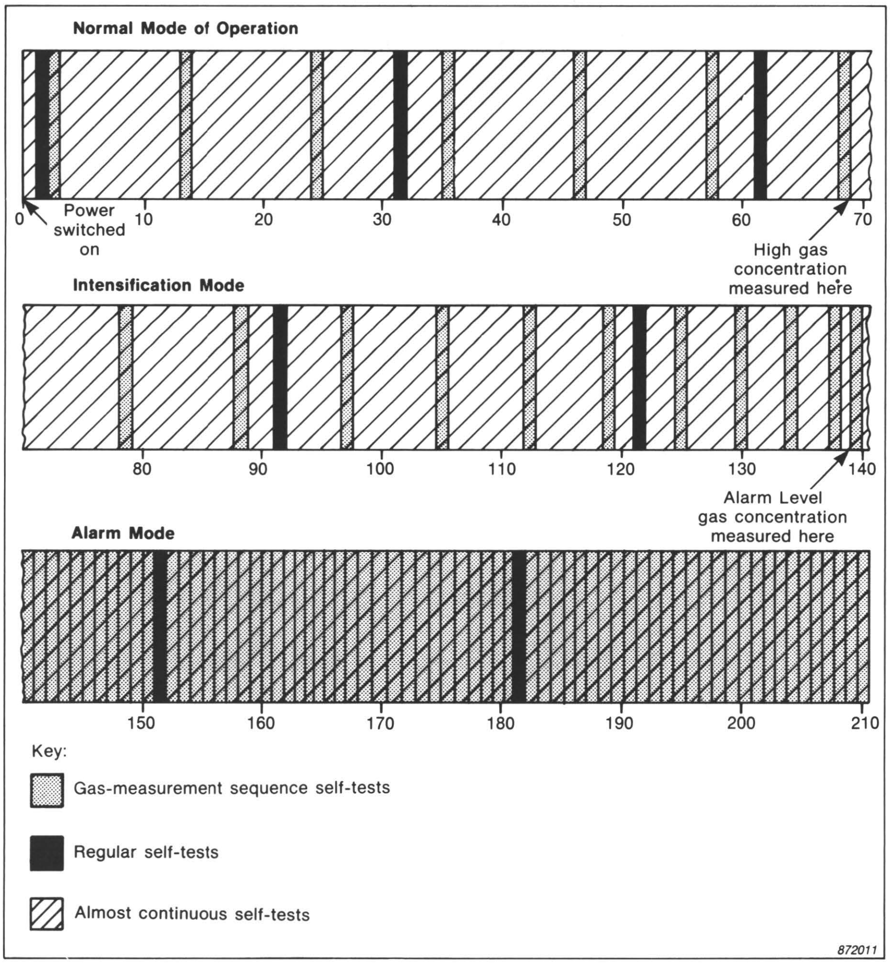

Fig. 2.5. Frequency of the self-tests during the various operating modes of the 1306

Self-tests	Normal Mode	Intensification Mode	Alarm Mode	Power-down Mode
Almost continuous self-tests	performed between all other tests	performed between all other tests	performed less often than in other operating modes	performed continuously
Regular self-tests	every 30 min.	every 30 min.	every 30 min.	not performed
Gas-measurement sequence self-tests	with the same frequency as gas measurements	with the same frequency as gas measurements	with the same frequency as gas measure ments	not performed

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Table 2.1. "Frequency" of the self-tests during different operational modes

2.7.1. Almost Continuous Self-tests

This series of tests is performed almost continuously whenever the 1306 is not performing any other measurement- or self-testing sequence. This series of tests is the only one which is performed when the 1306 is operating in power-down mode (see Section 2.5) because the performance of these tests does not consume too much power.

The following tests are included in this series:

Power supply

The voltage supply to the 1306 is measured after the input filter of the 1306. The input filter circuitry protects the 1306 from electromagnetic pulses and transient pulses on the power supply — e.g. caused by lightning strikes. If the voltage supply to the 1306 does not lie between 8,3V and 15V, gas measurements are not performed and the status report will indicate the fault.

Two kinds of power failure are detected by the 1306. The first is where theinput voltage drops below 8,3V but not below 7,5V; and the second is where the input voltage drops below 7,5V. The way in which the 1306 responds to each of these situations is described below.

1. If the input voltage to the 1306 falls below 8,3V but not below 7,5V, the **Power supply** failure will be indicated in the status report and the 1306 will stop performing gas measurements.

   As soon as the input voltage supply to the 1306 is restored to a value above 9,3V the 1306 will automatically resume its measurement and self-testing sequences — starting up where it left off — and the power failure will no longer be indicated in the status report.

2. If the input voltage to the 1306 falls below approximately 7,5V there will no longer be enough power to either perform gas measurements or to allow the micro-processor in the 1306 to function. The computer will therefore no longer be able to communicate with the 1306.

When the input voltage supply to the 1306 is restored to a value above 9,3 V the 1306 will perform its start-up sequence (that is, it automatically "resets" itself) before starting to take gas measurements. Users will have to initiate communication with the 1306 after this type of power failure before gas-measurement results can be requested from the 1306. The status report received with gas-measurement results will only indicate that the 1306 has "reset" itself (the power-failure will not be indicated).

Users can find out whether the "reset" of the 1306 was caused by this type of power failure by referring to Section 2.8.

Temperature

A temperature sensor located within the analysis cell measures the temperature of the cell. If this temperature lies below –20°C or above +70°C, the 1306 stops performing gas measurements and indicates the fault in the status report.

Normally the infra-red light is switched off between gas measurements, but if the temperature sensor measures a temperature below –5°C the 1306 does not switch off its infra-red light source between measurements. The heat produced by the infra-red light source will keep the temperature of the 1306 as high as possible above ambient temperatures, so that it can continue operating for as long as possible in extremely cold environments.

Monitor's Lid

A lever located between the monitor and its lid, activates a micro-switch if the lid is removed. If the micro-switch is activated it is indicated in the status report.

Switch Settings

The 1306 "reads" the settings of both its upper and lower banks of switches. Details of these switches and their functions are provided in Section 2.1 in Volume 2 of the Instruction Manual for the 1306. The user can request to read the settings of these switches be requesting the **Measurement Test Data** block from the 1306 (see Sections 2.9.2 & 4.4.3 of this Manual).

- By reading the setting of Switch 1 on its upper bank of switches the 1306 can find out whether it has been "reset" (see Section 2.8).
- By reading the setting of switch 2 on its upper bank of switches the 1306 can find out whether it has to perform the "hardware test" during its start-up sequence (see Section 2.6). If this switch is set to "1" (open) the hardware test is included in the start-up sequence. If this switch is set to "0" (closed) the hardware test is not included in the start-up sequence.

Vibration Noise

This is the noise measured in the analysis cell when the infra-red light source and the mechanical chopper are both switched off. Under these conditions any noise measured in the cell will be mainly due to the air "splashing" against the cell walls if the 1306 is vibrating on its mast, for example, during a storm.

It is only vibration noise with a frequency around 20 Hz (the chopper frequency) which has any real influence on the signals measured in the cell during a gas-measurement sequence. If the 1306 is mounted on a stable mast which does not resonate at a frequency around 20 Hz, the vibration-noise signal will normally not contribute significantly to the signals measured in the cell during a gas-measurement sequence Usually the vibration noise in the cell does not contribute more than a few microvolts to the measured signals.

The total signal measured during a gas-measurement sequence is therefore not compensated for vibration noise. However, if this vibration noise is found to be greater than half the total signal measured during a gas-measurement sequence, it will be indicated in the status report (see **background noise** flag in Section 2.10.1). The user is thereby made aware that the measured gas concentration is artificially high due to a significant contribution from either vibration noise or chopper noise. If you are interested in finding out to what extent the vibration noise has interfered with the measurement of gas concentration, you can request **Measurement Test Data** from the 1306 (see Section 2.9.2 & 4.4.3). In this data the *Vibration real value* (in volts) is the signal produced by vibration noise in the cell, and the *Raw gas value* (in volts) is the total signal measured in the cell with the infra-red light on.

Processing System and Software

The 1306 checks its own processing system and software. If it finds any errors it will stop performing gas measurements and automatically "reset" itself before going into a power-down mode of operation. This means that when measurement data is requested the status report which accompanies it will indicate the software error and the reset.

2.7.2. Regular Self-tests

These tests are performed every 30 minutes during the normal, intensification and alarm modes of operation of the 1306. During these self-tests most of the electrical and mechanical parts of the 1306 are checked. If any mechanical component is found to be functioning incorrectly the 1306 will repeat the test on the faulty component almost immediately. If the fault is still present, the 1306 will indicate the type of fault in its status report and stop taking gas measurements. After 30 minutes the 1306 will perform its regular tests again. If the 1306 still detects the fault, the test on the faulty component will be repeated almost immediately. If the fault is no longer detected, the 1306 will remove the fault indication in its status report, and start performing gas measurements and self-tests automatically again; but if the fault is still present, the indicated fault will remain in its status report and the 1306 stop taking gas measurements.

Regular tests can be divided up into the following groups:

1. **Pnuematics tests** — to check the air-shunt and air-filter are not blocked and that the pump and the valves are functioning properly.

2. **Microphone(s) and preamplifier(s) tests** — these tests check that the microphones and their associated preamplifiers are functioning correctly.

3. **Analogue to digital converter test** — checks that the analogue to digital converter is functioning correctly.

4. **Chopper test** — checks that the mechanical chopper is balanced.

These tests are described in detail below.

1. Pnuematics Tests:

Air-filter

With both the inlet and outlet valves open (see Fig. 2.6), the pump is started and the pressure difference across the pump is measured. Using this value the 1306 can calculate how long the pump must run to ensure that the analysis cell is completely flushed

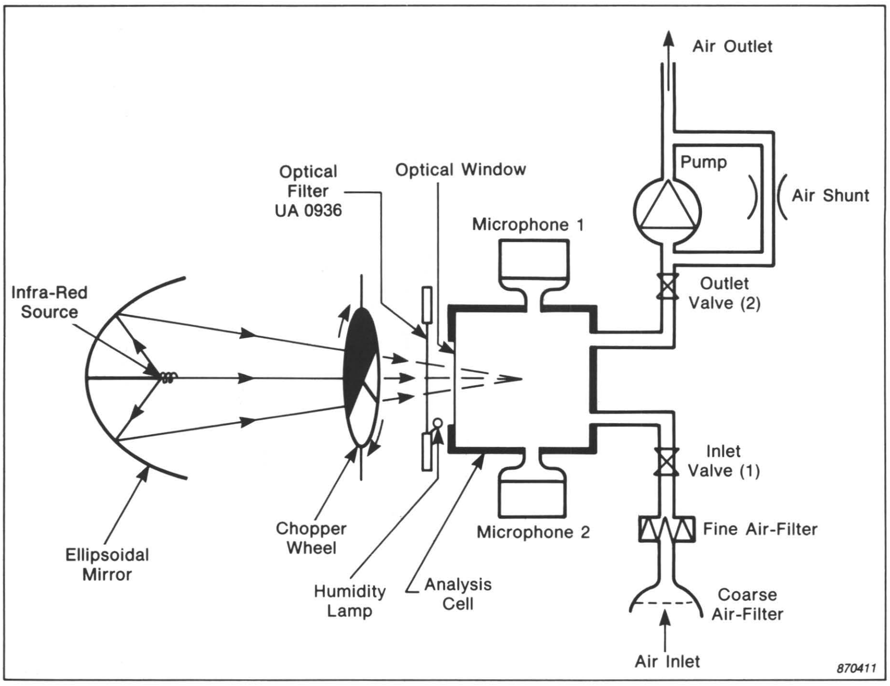

Fig. 2.6. The measurement system of the 1306

before starting a new gas measurement. If this pressure difference is outside operational limits it indicates that either the air-filter is blocked or that the fine air-filter has not been mounted correctly and the user is given a warning in the status report (see Sections 2.10. & 4.4.3. for further details).

Pump/Inlet Valve

While the pump is running, the inlet valve is closed and the pressure difference across the pump is measured. If this pressure is too low it indicates that either the pump or the inlet valve is faulty. In this condition the 1306 is unable to perform reliable gas measurements so it stops performing gas measurements, and reports the detected fault in the status report.

Pump/Outlet Valve

The pump is stopped, then the inlet valve is opened and the outlet valve is closed and the pump is started up again. The pressure difference across the pump is measured. If it is too low it indicates that either the pump or the outlet valve is faulty. In this condition the 1306 is unable to perform reliable gas measurements so it stops performing gas measurements, and reports the detected fault in the status report.

Air-shunt

The pump is stopped abruptly, and during the first second after the pump-stop the decrease in pressure across the air-shunt is measured. If this decrease is less than half the pressure measured in the *Pump/Outlet Valve* test described above, it indicates that the air-shunt is blocked. The user is given a warning in the status report.

Pressure Transducer Offset

With both the inlet and outlet valves open the pressure transducer's offset value is read. This value is used to correct all measurements made by the pressure transducer.

2. Microphone(s) and Preamplifier(s) tests:

During all signal measurements in the analysis cell, both microphones are used. The microphones amplify the signal they measure by means of the preamplifiers connected to them. The amplified signals from both microphones are then passed into a summing amplifier (amplifier 3 in Fig. 2.7).

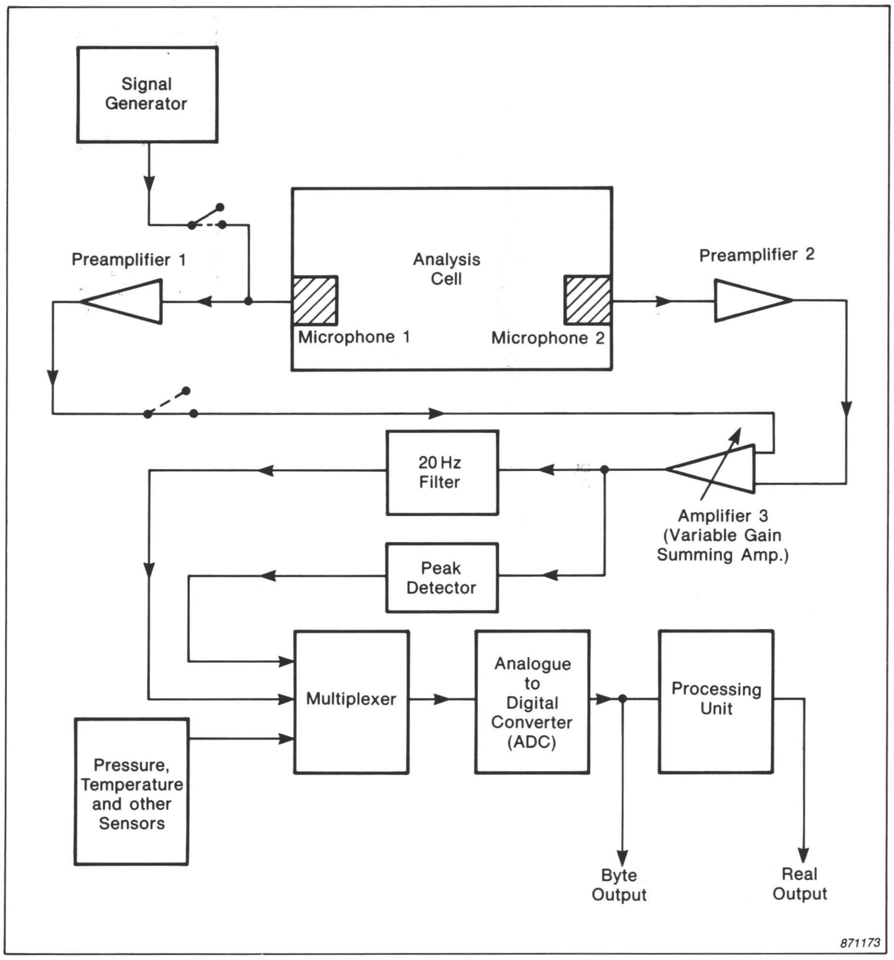

Fig. 2.7. The electronic part of the 1306

Preamplifier 1

A signal from an in-built signal-generator is sent to microphone 1 and preamplifier 1. The electronic circuitry in the 1306 is such that the signal which is received by microphone 1 and sent as an acoustic signal to microphone 2 and then amplified by preamplifier 2 is negligible. This means that the signal reaching the summing amplifier is effectively only the signal sent via preamplifier 1 (see Fig. 2.7). If this measured signal is not correct it indicates a fault in preamplifier 1.

If preamplifier 1 is faulty, reliable gas measurements cannot be performed so the 1306 stops performing gas measurements and reports the detected fault in the status report.

Microphone 1/Microphone 2/Preamplifier 2

Preamplifier 1 is switched off and then a signal is sent from the signal-generator to microphone 1 which acts as a loudspeaker and sends an acoustic signal into the analysis cell. This signal, which is received by microphone 2 and is amplified by preamplifier

2, is measured. If this signal is not correct it indicates that microphone 1 and/or microphone 2 and/or preamplifier 2 is faulty.

If microphone 1 and/or microphone 2 and/or preamplifier 2 is faulty, reliable gas measurements cannot be performed so the 1306 stops taking gas measurements and reports the detected fault in the status report.

3. Analogue to digital converter test:

The 1306 first sends its A-D converter an overload signal and then checks that all the A-D converter's bits have been set to "1". It then sends an undetectable signal to its A-D converter and checks that all the A-D converter's bits have been set to "0". If the A-D converter does not set all its bits to "1", and then set all its bits to "0" in this test, or if the ADC does not respond to these signals, it indicates a fault in the A-D converter.

If the A-D converter is faulty, gas measurements will no longer be performed and the fault will be indicated in the status report.

Note: There is one other way in which the 1306 is able to detect an A-D converter fault. During the almost continuous self-tests, the A-D converter is used to convert the analogue signals from the temperature sensor and the potential difference transducer (see Section 2.7.1). If the A-D converter is not able to convert these signals the 1306 will stop performing gas measurements and report the A-D converter fault in the status report.

4. Chopper test: (measures chopper noise in the analysis cell)

In this test the chopper is checked to see that it is in balance — that is it is rotating without causing other parts of the 1306 to vibrate.

The test is performed by measuring the noise in the analysis cell when the infra-red light source is off and the mechanical chopper is running. This noise is produced by mechanical noise — primarily produced by the chopper — and is therefore called chopper noise.

If the chopper noise is found to be greater than half the total signal measured during a gas measurement, this indicates chopper imbalance and will be indicated in the status report (see **background noise** flag in Section 2.10.1).

If you are interested in finding out to what extent chopper noise has interfered with the measurement of gas concentration, you can request **Measurement Test Data** from the 1306. In this data the *chopper real value* (in volts) is a measure of the chopper noise in the cell, and the *Raw gas value* (in volts) is the total signal measured in the cell with the infra-red light on (see Section 4.4.3). A comparison of these two values will give an indication of how chopper noise has influenced the measured gas concentration.

2.7.3. The Gas-measurement Sequence Self-tests

During a gas-measurement sequence the three components which are most vital to the measurement procedure are checked. These are: the infra-red light source, the mechanical chopper, and the humidity lamp. If any of these components is found to be malfunctioning the 1306 will repeat the test on the faulty component almost immediately. If the fault is still detected the 1306 will indicate the fault in its status report and no gas measurement will be performed. After a period of time equal to the "time between gas measurements" the gas-measurement sequence self-tests will be performed again. If the previously detected fault is no longer detected, the 1306 will complete a gas-measurement sequence and its status report will no longer indicate the fault.

The components are checked in the following way:

1. ***Infra-red light source*** — the intensity of the light from the infra-red light source is measured;
2. ***Mechanical chopper*** — the frequency of the mechanical chopper is measured.
3. ***Humidity lamp*** — is checked by measuring to see that a current is flowing through it.

2.8. CONDITIONS CAUSING THE 1306 TO RESET

There are four different situations which will cause the 1306 to "reset" itself, that is, cause it to execute its start-up sequence. In effect this means that the results of the previous gas-measurement and self-test sequences are cleared from the 1306's memory, and certain tests are performed to check that the 1306 is functioning correctly before it starts operating automatically again (see Section 2.6). Control data parameters are not affected by a "reset" of the 1306 (see Section 2.9.1). The four situations causing the 1306 to reset are listed below:

1. If the 1306 detects an error in its software/processing system (see Section 2.7.1).
2. If switch no. 1 on the monitor's upper bank of switches has been closed (that is, set to "0") and then opened again.
3. If the user sends a "reset" command to the 1306.
4. If the power supply to the monitor falls below 7,5 V (see Section 2.7.1).

The user can find out what caused the 1306 to "reset" by reading the status report:

- If a software/processor system error is reported with the "reset" then the cause of the "reset" is a detected fault in the 1306's software/processor system.
- If the 1306's lid is reported "open" as well as the "reset" of the 1306, then the cause of the "reset" is possibly due to switch no. 1 of the 1306's upper bank of switches being closed and opened.
- If the "reset" is the only error reported then the user can request to read the last command sent to the 1306 (see Section 2.9.2) to see whether a "reset" command was the reason for the "reset".
- If neither of the previous three reasons caused the 1306 to "reset", then a power supply failure to the 1306 caused it to "reset".

In the **Total data** block which can be read from the 1306 (see Section 2.9.2) the user can find the *total operating time of the 1306 since it was last reset.* If the cause of the "reset" was:

1. a power supply failure to the 1306, then this time parameter indicates when the power supply to the 1306 was restored;
2. a software/processor system error, then this time parameter indicates the time at which the last software/processor system error was detected.

2.9. COMMUNICATING WITH THE 1306

Users need to communicate with the 1306 for several important reasons: (1) to allow the user to control the 1306's operation by sending it *control data*; (2) to allow the user to request measurement/test data from the 1306; and (3) to allow the user send commands to the 1306 — commands which are able to interrupt the automatic measurement and self-testing sequences of the 1306.

Users communicate with the 1306 via the controlling computer's keyboard. As mentioned previously, the software which is used to control the 1306s in a monitoring system determines which keyboard commands have to be used in order to communicate with a 1306, and therefore these commands are not discussed in this manual.

The 1306 can only transmit data in discrete packages called *data blocks* which differ from one another in the type of and/or the amount of data they contain; and only receive and respond to certain discrete *commands*. These *data blocks* and *commands* are discussed in the following sections.

2.9.1. Sending Data to the 1306

Users are only able to send certain *data blocks* to the 1306 (see Fig. 2.8). The data contained in these *blocks* over-writes (that is, replaces) the data which is already stored in the 1306 memory. The following data can be sent to the 1306:

- *Control data block*
- *EEPROM data blocks* — this is the data stored in the EEPROM (Electrically Erasable Programmable Read Only Memory) of the 1306. There are several EEPROM data blocks.

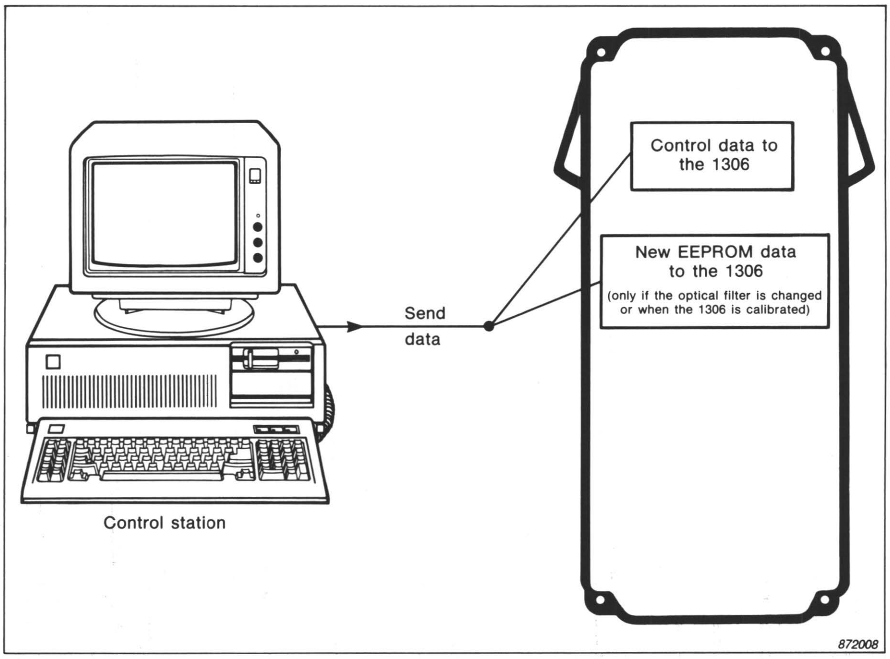

Fig. 2.8. Data blocks which can be sent to the 1306

Control Data Block

When a monitoring system is installed the various monitors in the system will need to be individually set-up with control data. This control data provides each monitor with the parameters which allow it to operate as a unique monitor within a monitoring system. For example, if five 1306's are used to monitor two different gases in 5 different locations, the user could set the alarm level in the 1306s monitoring the most-toxic gas to a lower level than the alarm level in the 1306s monitoring the less-toxic gas; and the time between measurements can also be set to suit the individual user's requirements.

Control data is stored in a special memory called EEPROM (Electrically Erasable Programmable Read Only Memory). This memory is not cleared when the 1306 is "reset". The only way in which control data parameters in the 1306 can be changed is by sending new control data parameters to the 1306 to replace the parameters already stored there.

The following operating parameters are contained in the *control data block*:

- The **alarm level** — that is, the concentration of gas (in mg/m^3) which causes the 1306 to perform gas measurements continually.
- The **time between measurements** (in seconds) — that is, the time the 1306 must wait between finishing one measurement and starting the next measurement.
- **User data** — that is, data which is stored for general information. It could, for example, describe the geographical location of the 1306.

On delivery, the 1306 has the following control data stored in its memory:

- The alarm level = 1,0 mg/m^3 (factory setting)
- The time between gas measurements = 600 s (factory setting)

The factory settings given above remain in the 1306 until the user chooses to replace them with new values by sending new control data to the 1306 (see Section 4.3).

Note: A "reset" of the 1306 does not affect the value of the parameters stored in the *control data block* in the 1306.

EEPROM Data Blocks

There are several different data blocks in the EEPROM of the 1306 (see Fig. 4.1) but users will only need to send new EEPROM data to some of these blocks. Sending a new EEPROM data block to the 1306 replaces the data already stored there.

New EEPROM data needs to be sent to the 1306 in the following circumstances:

1. during the calibration procedure — it is the data in the *calibration factor block* of the EEPROM which needs to be changed (see Section 4.6.3); and
2. if the optical filter of the 1306 is changed — it is the *filter identity block and the filter factor block* of the EEPROM which need to be changed (see Section 4.6.1 and 4.6.2).

Note: A "reset" of the 1306 does not affect the data stored in the EEPROM of the 1306.

2.9.2. Requests for Data from the 1306

The 1306's only stores the results of its most recent measurements and self-tests in its memory. As soon it completes a new measurement sequence these results replace those already stored in its memory. Therefore data has to be requested from the 1306 after each gas measurement otherwise it is lost.

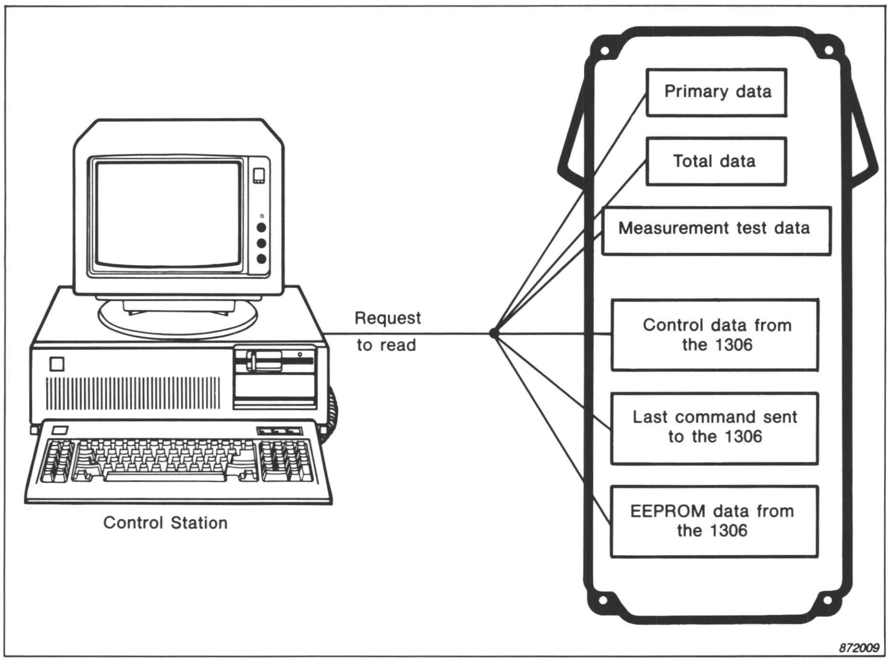

Fig. 2.9. Data blocks which can be requested from the 1306

Users can request to read the results of the most recent measurements and self-tests performed by the 1306. All this data is organised into discrete packages called *data blocks.* These *data blocks* vary in the type of data and in the amount of detailed data they contain. The *data blocks* which are available from the 1306 on request are illustrated in Fig. 2.9. The various *data blocks* are described as follows:

1. **Primary data** — this *data block* contains the following information:
   - the actual gas concentration last measured;
   - the actual time between gas measurements;
   - the time which will elapse before the next measurement is due to start;
   - the Status Report.

When the 1306 is operating in its normal mode this data block provides the user with the most essential data. However, if the 1306 is operating in either its intensification or alarm mode the user is likely to want more detailed data from the 1306. The **Total data** block provides more detailed information.

2. **Total data** — this *data block* contains the same information as the Primary *data block*, and in addition gives the following information:
   - the background-noise level in the cell;
   - the temperature of the gas in the cell;

- the power supply to the 1306;
- the total operating time (since the 1306 was last reset).

3. **Measurement test data** — this *data block* is primarily intended for use by service personnel to help in predictive maintenance of the 1306. Details of the data in this block are given in Section 4.4.3.

4. **Control data** — this *data block* gives the operating parameters which are stored in the 1306's memory (see Section 2.9.1 for details).

5. **Last command sent to the 1306** — this *block* allows the user to read the last command which was sent to the 1306 (see Section 2.9.3 for details).

6. **EEPROM data** — these *data blocks* contain many factors, constants and parameters which are necessary to the operation of the 1306.

More detailed information about each of the data blocks listed above can be found in Chapter 4.

2.9.3. Sending Commands to the 1306

The user is able to send a number of commands to the 1306. These commands interrupt the 1306's automatic operation. When the 1306 receives one of these commands it will stop whatever it is doing and execute the command immediately. Once the command has been sent it is not possible to stop its execution except by sending it another command which has a higher order of priority. The *commands* which the user can send to the 1306 are illustrated in Fig. 2.10. These commands are listed below in their approximate order of priority (see Section 4.5.3 for further details):

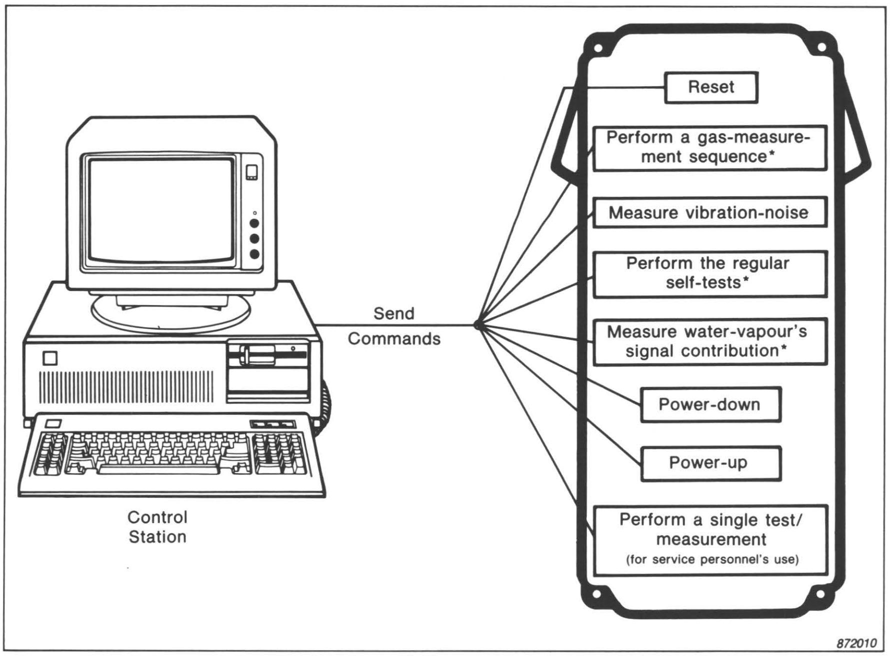

Fig. 2.10. Commands which can be sent to the 1306

- Reset
- Perform a gas-measurement sequence*
- Measure vibration-noise in the cell*
- Perform the regular self-tests*
- Measure water-vapour's signal contribution*
- Operate in power-down mode
- Operate in power-up mode
- Perform a single test/measurement — these commands are primarily designed to be used by service personnel.

Reset command: The "reset" command has the highest priority, followed by the forced-measurement commands.

* **Forced measurement commands:** All those commands marked with an asterisk can be used to force a measurement — even in a situation where the 1306 has gone into a power-down mode of operation due to a detected fault in the 1306. If a forced measurement is commanded in such a situation, the 1306 will not go into a power-down mode of operation when it detects an operating error. The user must therefore take full responsibility for assessing the reliability of such a forced measurement, and full responsibility for any adverse effect such a measurement could have on the 1306 in these circumstances.

Power-down command: If the 1306 is operating in either its normal, intensification, or alarm mode, the user can use this command to force the 1306 to operate in its power-down mode.

Power-up command: If the 1306 has been operating in power-down mode, the user can use this command to force the 1306 to operate in its power-up mode. If the user commands the 1306 to operate in this mode, it will respond in one of two ways depending upon how long it had been operating in its power-down mode before receiving the power-up command:

1. If more than 30 minutes have elapsed since the 1306 performed its regular self-tests, it will start by performing these self-tests. If these tests show the 1306 to be operating properly, the 1306 will then perform a gas-measurement sequence, and continue to operate automatically in a mode appropriate to the gas concentration it measures.

2. If less than 30 minutes have elapsed since the 1306 performed its regular self-tests, it will start a gas-measurement sequence immediately, and continue to operate automatically in a mode appropriate to the gas concentration it measures.

2.10. THE STATUS REPORT

The Status Report is the report which accompanies all measurement data from the 1306. This report summarises the results of all relevant self-tests and therefore allows the user to easily evaluate the 1306's performance and judge the quality of the gas measurements it performs. The status report consists of 16 flags which are divided into two equal groups:

- **8 Warning Flags**
- **8 Operating-error Flags**

If, during the self-testing sequences, any component is found to be operating outside of its operational limits, or is found to be functioning imperfectly the relevant flag will be set (to "1").

2.10.1. Warning Flags

If any of these flags are set to "1" the user is warned that measurement results must be judged in relation to the flags which have been set. These flags are listed in Table 2.2 together with the self-tests associated with them, and a comment about how the user should judge the reliability of measurement results which are received with the relevant warning flag set to "1".

W A R N I N G F L A G S		
Flag Description	**Reason why the Warning Flag is Set (to "1")**	**Reliability of Measurement Results (if the flag is set)**
Old measurement (checked each time measurement data is read from the 1306)	The 1306 warns the user that these measurement results have already been read-out — indicating that no new measurements have been completed since the last measurement data was requested.	The measurement is "old". Its reliability is dependent on any other flags which may be set (to "1") in the Status Report sent with these results.
Extra measurement; or Zero calibration required (checked during every measurement)	(1) If during the gain-setting operation of a gas-measurement sequence the 1306 measures a concentration of gas which is greater than half the alarm level, this less-reliable gas concentration will be immediately sent to the user together with a Status Report in which this flag is set (to "1"). The user is thus given about 20 s extra warning of increased gas concentrations. When final gas concentration results are available this flag is reset (to "0"). (2) If during a gas-measurement sequence the total signal measured in the cell is found to be less than the total signal measured in the cell when it was filled with dry zero-gas during its last calibration, this flag will be set and will not be reset when the gas-measurement sequence is complete. Thus the user can distinguish whether (1) or (2) has caused this flag to be set.	Results not reliable. In case (1) the user is given forewarning of increased toxic-gas levels; and in case (2) the user is warned that the 1306 requires zero calibration.
Humidity lamp (tested during gas-measurement sequence)	The humidity lamp is checked by measuring the current through it. If this current is zero, this flag is set.	When the humidity lamp is not functioning, the 1306 compensates for the presence of water vapour by using the water vapour signal measured during the previous measurement. Results are therefore only reliable if the humidity of the air has not changed since the last gas measurement was performed.
Air-shunt (tested every 30 min.)	The inlet valve is opened, the outlet valve is closed, and the pump is started. After a few seconds, the pump is stopped abruptly and the decrease in pressure across the air-shunt is measured during the first second. If this pressure is found to decrease by less than 50%, this flag is set.	Reliable but the microphones could be damaged by overloading if the 1306 is allowed to continue operating in this condition. Service is advisable.

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Table 2.2. Warning Flags (part 1 of table)

W A R N I N G F L A G S (continued)		
Flag Description	**Reason why the Warning Flag is Set (to "1")**	**Reliability of Measurement Results (if the flag is set)**
Air-filter (tested every 30 min.)	With both the inlet and outlet valves open, and the pump working, the pressure difference across the pump is measured. If it is found to be greater than 110 mbars or less than 12 mbars, this flag will be set. The user can read the value of the pressure difference across the pump from the measurement test data. (1) If this pressure is above 110 mbars it indicates that either the fine air-filter, or the coarse air-filter is blocked; and (2) if the pressure is below 12 mbars it indicates that the fine air-filter has been incorrectly mounted.	Not reliable. In case (1) there is a risk that the cell is not properly flushed between measurements; and in case (2) any particulate matter (e.g. dust) which enters the cell with the air sample could reduce the accuracy of the measurement.
Background noise (vibration noise tested almost continuously) & chopper noise every 30 min.)	Two background noise measurements are made: the first is performed with the IR source off and the chopper off (this measures **vibration noise**, that is, any "noise" caused by the "splashing" of air in the cell e.g. during stormy weather); and the second is performed with the IR source off and the chopper on (this measures the **chopper noise**). If either one of these signals is found to be greater than half the total signal measured during a gas measurement, this flag is set.	Not reliable because the total signal measured during a gas measurement is not compensated for any signal contributions due to vibration and chopper noise — the gas concentration measured is thus likely to be too high. These two quantities can be read from the measurement test data (see Section 4.4.3.). If the **chopper noise** is significantly greater than the **vibration noise** it could indicate chopper imbalance —in which case service is advisable.
Lid opened (checked almost continuously)	A mechanical "feeler", located between the monitor and its lid, activates a micro-switch if the 1306's lid is removed. If this micro-switch is activated, this flag is set. This flag is not reset when the lid is replaced. The flag can be reset by sending control data to the 1306. Strong sunlight on the open 1306 can upset measurement accuracy. Users are therefore advised not to take gas measurements when the lid of the 1306 has been removed.	Not necessarily reliable because the 1306 could have been damaged during the time it was open. It is advisable to check the monitor.
Reset (checked almost continuously)	This flag is set if: (1) the 1306 detects an error in its software (in which case the **software** flag is also set to "1"); or (2) switch no. 1. on the 1306's upper bank of switches is set to "0" and then to "1" (in which case the **lid opened** flag is also set to "1"); or (3) the user sends a "reset" command to the 1306; or (4) the power supply to the 1306 drops below 7,5 V and is then restored to a value above 9,3 V. In this situation, the user has to initialise the communication link with the 1306 before being able to request data from it.	Measurements may be reliable. The user can check by sending control data to the 1306. If this causes the flag to be reset (to "0"), then the 1306 is functioning correctly and will resume measurements. If not, service is necessary.

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Table 2.2. Warning Flags (part 2 of table)

2.10.2. Operating-error Flags

If any of the operating-error flags are set to "1" it will indicate to the user that the 1306 is not capable of measuring gas concentrations accurately, and has therefore started operating in its power-down mode. As long as any of these flags is set to "1" the 1306 will not be able to resume gas measurements unless commanded to do so (by sending it a forced command — see Section 2.9.3). These flags are listed in Table 2.3 together with the self-tests associated with them, and the recommended course of action a user should take if any of these flags have been set to "1".

Further information about these status flags can be found in Section 4.7.

OPERATING-ERROR FLAGS		
Flag Description	**Test Performed & Reason why the Operating-error Flag is Set (to "1")**	**The User is Recommended to:**
Software error (tested almost continuously)	The 1306 checks its processing system and software. If any error is found this flag is set. Any error will also cause the 1306 to reset and therefore the "reset" warning flag will also be set.	Send control data to the 1306. If this causes the flag to be reset (to "0"), then the 1306 is functioning correctly and will automatically resume its measurement and self-testing sequences. If not, service is necessary.
Pump/ valve(s) (tested every 30 min.)	The pressure difference across the pump is measured when: (1) the inlet valve is closed, and the outlet valve is open, and the pump is running; (2) the outlet valve is closed, the inlet valve is open, and the pump is running; and (3) both valves are open and the pump is running. If the pressure measured during (1)/(2) is less than 120mbar and/or the pressure measured during (3) is less than 12 mbars, this indicates a fault in the pneumatic system of the 1306 and this flag will be set.	If this flag is set after installation of the optical filter, check that Step 11 of Section 5.1.2. (in Volume 2 of the Instruction Manual for the 1306) has been performed. If the flag is still set have the monitor serviced.
Microphone (s)/pre-amplifier(s) (tested every 30 min.)	Two tests are performed: (1) the internal signal generator sends an electrical signal to preamplifier 1 and it measures this signal; and (2) with preamplifier 1 switched off, the internal signal generator sends an electrical signal to microphone 1. Microphone 1 acts as a loudspeaker sending an acoustic signal into the cell which is received and measured by microphone 2 and amplified by preamplifier 2. If either of these measured signals is not correct, it indicates a fault in a preamplifier(s)/microphone(s), and this flag is set.	Have the monitor serviced.
Infra-red light source (tested during gas-measurement sequence)	The intensity of the light emitted by the IR source is measured. If the intensity measured is outside the pre-set limits it indicates that the IR light source is not functioning correctly, and this flag is set.	Have the monitor serviced.
Chopper (tested during gas-measurement sequence)	An infra-red (IR) detector measures the frequency of the IR pulses directed into the analysis cell. If this frequency is not correct, it indicates that the chopper is not functioning properly, and this flag is set.	Have the monitor serviced.

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Table 2.3. Operating-error Flags (part 1 of table)

O P E R A T I N G – E R R O R F L A G S (continued)		
Flag Description	**Test Performed & Reason why the Operating-error Flag is Set (to "1")**	**The User is Recommended to:**
Power supply **(tested almost continuously)**	A potential-difference transducer measures the supply voltage after the input filter of the 1306. If this voltage exceeds 15 V or falls below 8,3 V, the 1306 stops performing gas measurements, and this flag is set. (Note: If the voltage falls below 7,5 V the user will be unable to communicate with the 1306 and this will cause the 1306 to "reset" itself when power is restored to it (see Section 2.7.1. for further details)).	As soon as the supply voltage falls below 15 V or becomes greater than 9.3 V this flag will be reset (i.e. set to "0") and the 1306 will automatically resume its measurement and self-testing sequences.
Temperature **(tested almost continuously)**	A temperature sensor measures the temperature inside the cell. If this temperature exceeds +70°C or falls below –20°C, or cannot be read because Step 12 of Section 5.1.2. (of Volume 2 of the Instruction Manual for the 1306) has not been performed, the 1306 stops performing gas measurements and this flag is set.	Check that Step 12 of Section 5.1.2. (of Volume 2) has been performed. As soon as the temperature inside the cell falls below +60°C or rises above –20°C this flag will be reset (i.e. to "0") and the 1306 will automatically resume its measurement and self-testing sequences.
Analogue-Digital Converter **(tested almost continuously)**	The 1306 tests its A-D converter by sending an overload signal to it and checking that all ADC bits have been set to "1". The 1306 then sends an undetectable signal to its ADC and checks that all ADC bits have been set to "0". If it is not possible to set all ADC bits to "1", and then to "0", or there is no response from the ADC, the ADC is not functioning correctly and this flag will be set.	Have the monitor serviced.

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Table 2.3. Operating-error Flags (part 2 of table)

3. INTERFACE AND COMMUNICATIONS PROTOCOL

3.1. RS 485 INTERFACE

3.1.1. Introduction

The digital interface of the 1306 Toxic-gas Monitor conforms to EIA Recommended Standard RS 485. This serial interface standard allows up to 32 devices to be connected by a single 2-wire interface cable. Each device can be either a controller (master) or a passive receiver (slave). The interface standard allows all 32 devices to be controllers, but the DDCMP protocol used by the 1306 restricts the system to one controller and 31 receivers. In this case the controller is a computer and the receivers are the 1306 Toxic-gas Monitors. Fig. 3.1 shows a simple system.

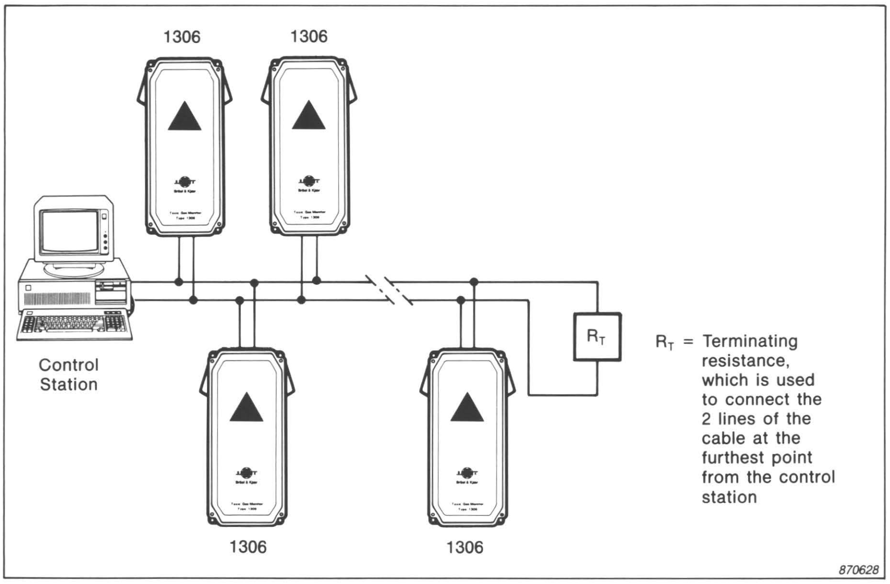

Fig. 3.1. A simple monitoring system. The optimum value of the terminating resistance is 54 Ω

3.1.2. Differential Transmission

The main advantage of the RS 485 interface over other systems is that it uses differential transmission. This method increases reliability and allows communication over greater distances. Two wires are used for data transmission, the signal being the difference in voltage between the two. Most interference (electrical noise) will affect both wires in the same way, and so while the actual voltages on each wire may change, the voltage difference between them is unaffected. This method of transmission is therefore much less affected by interference than other (single-ended) transmission systems, as shown in Fig. 3.2. The Brüel & Kjær Toxic-gas Monitor uses transmission voltages of 0 to 5 V on each wire, giving a difference signal of ± 5 V.

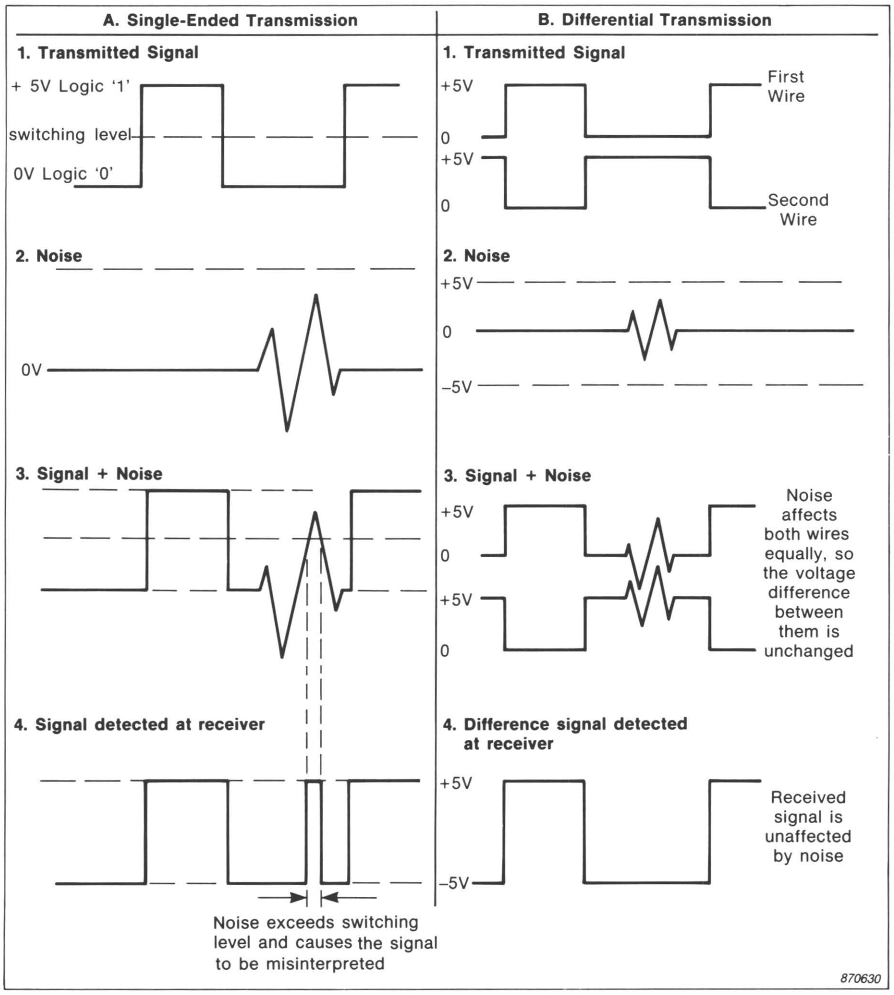

Fig. 3.2. The effect of noise on single-ended and differential signals

3.1.3. Use of Equipment with an RS 232 C Interface

Many computers and similar equipment are fitted with an RS 232 C interface. These can be used to control Toxic-gas Monitors if an interface converter is inserted into the system between the computer and the monitors, as shown in Fig. 3.3. The converter changes single-ended signals (RS 232 C) into differential signals (RS 485) and vice-versa. It also adjusts the voltages, currents and input and output resistances to those required for each interface system. For details of the values required, refer to the appropriate standards.

A special type of RS 232 C – RS 485 converter is available from Brüel & Kjær (Accessory No. WQ 0677). Details of this type of converter (type 1), and the cable connections which are necessary to connect it between an XT/AT/PS 2 IBM computer and the 1306s in a monitoring system, are given in Volume 2 — Installation and Maintenance, Section 3.3.4.

Alternative Types of Converter:

If users do not wish to use the converter WQ 0677, which is available as an accessory to the 1306, another type 1 converter may be used as long as it meets the following requirements:

- the RS 485 cable is half-duplex;

- the direction of transmission is controlled by the computer's *Request to Send* RS 232 C wire

These two requirements must also be met if users wish to use a completely different type of converter, a type 2 converter — where there is **no** internal galvanic separation between input and output ports of the converter.

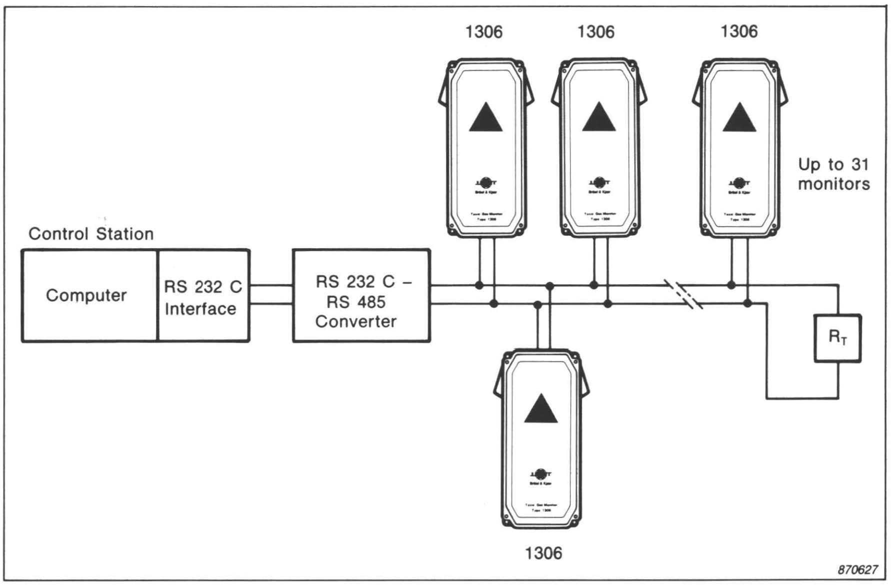

Fig. 3.3. Control of the 1306 using a computer with an RS 232 C interface

Using a Type 2 Converter:

In this type of converter there is a **no** internal galvanic separation between the input and output ports of the converter. The way in which such a converter is connected between the computer and the first 1306 in a monitoring system is illustrated in Fig. 3.4. The

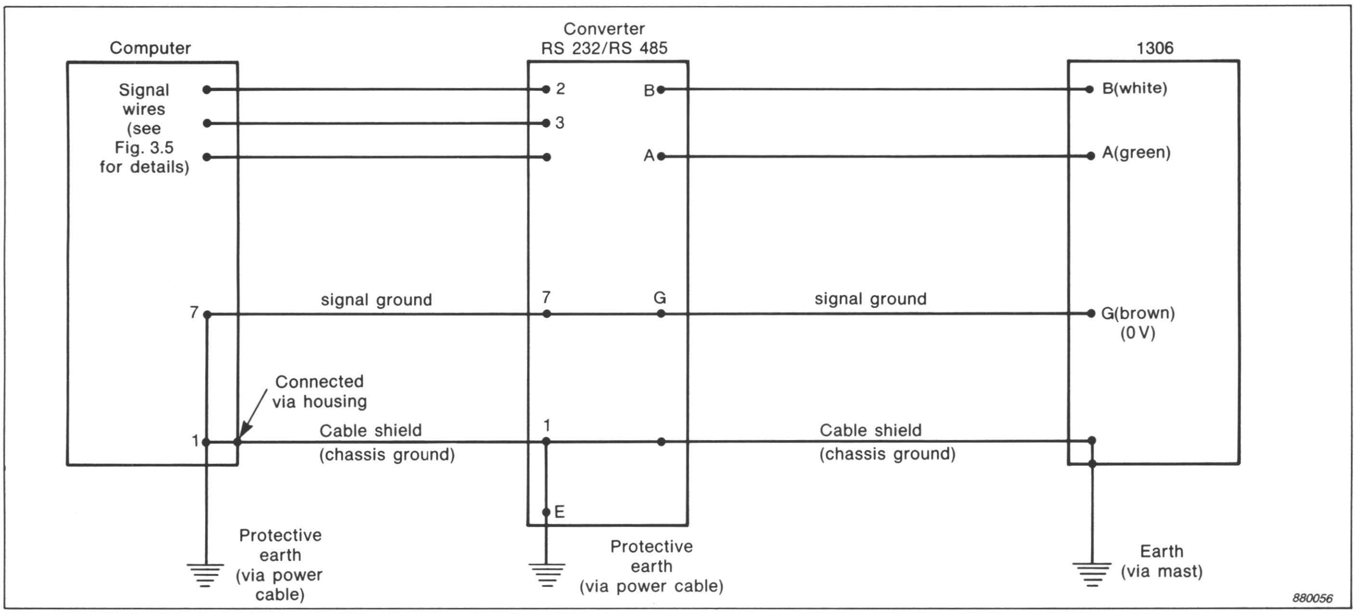

Fig. 3.4. Communication cable connections to the type 2 converter

signal ground wire of the RS 232C cable connecting the converter and the computer, and the signal ground wire of the RS 485 cable connecting the converter and the 1306 are inter-connected by the converter. Similarly, the chassis ground wires of the RS 232C and RS 485 cables are also inter-connected by the converter.

When using this type of converter, the signal-ground wire and the chassis-ground wire must be connected together at only one point. This is done by connecting the pins no. 1 and no. 7 together in the plug which attaches RS 232C cable to the computer.

Pin connections on the plugs used on the RS 232C cable:

Because no standard type 2 converter is available it is not possible to specify exactly which of the signal lines on the RS 232C cable need to be used. Therefore all those signal lines which could possibly be used have been shown in Fig. 3.5. You will notice that:

- there is a direct connection between pins of the same number on each side of the cable (that is, there is **no** nul-modem);
- pin no. 1 and pin no. 7 are connected together in the plug to the computer;
- the chassis-ground wire (cable shield) is connected to the metal housing in the plugs; and
- the plug which is used to house the pin connections should be the type of plug which can be screwed firmly into the computer's port.

Full details of the pin connections on an RS 232C cable linking an IBM PS2/50 computer with an RS 232C/RS 485 converter are illustrated in Fig. 3.5.

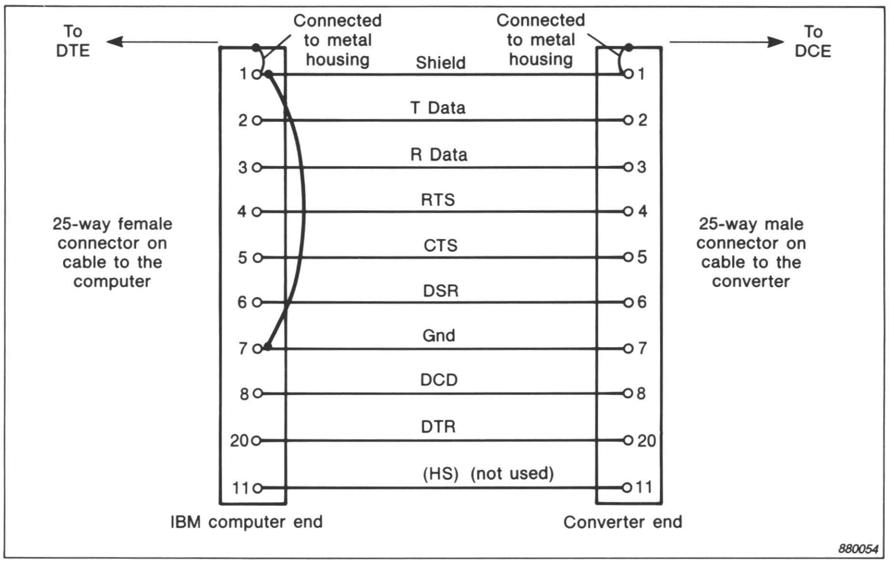

Fig. 3.5. Details of the pin connections on the RS 232C cable linking an IBM PS2/50 computer to an RS 232C/RS 485 converter

3.1.4. Large Systems

The RS 485 interface standard allows a maximum distance of 1,2 km between the control station and the most distant monitor. However, because the DDCMP protocol used by the 1306 greatly reduces the error rate, a much greater distance can be tolerated before

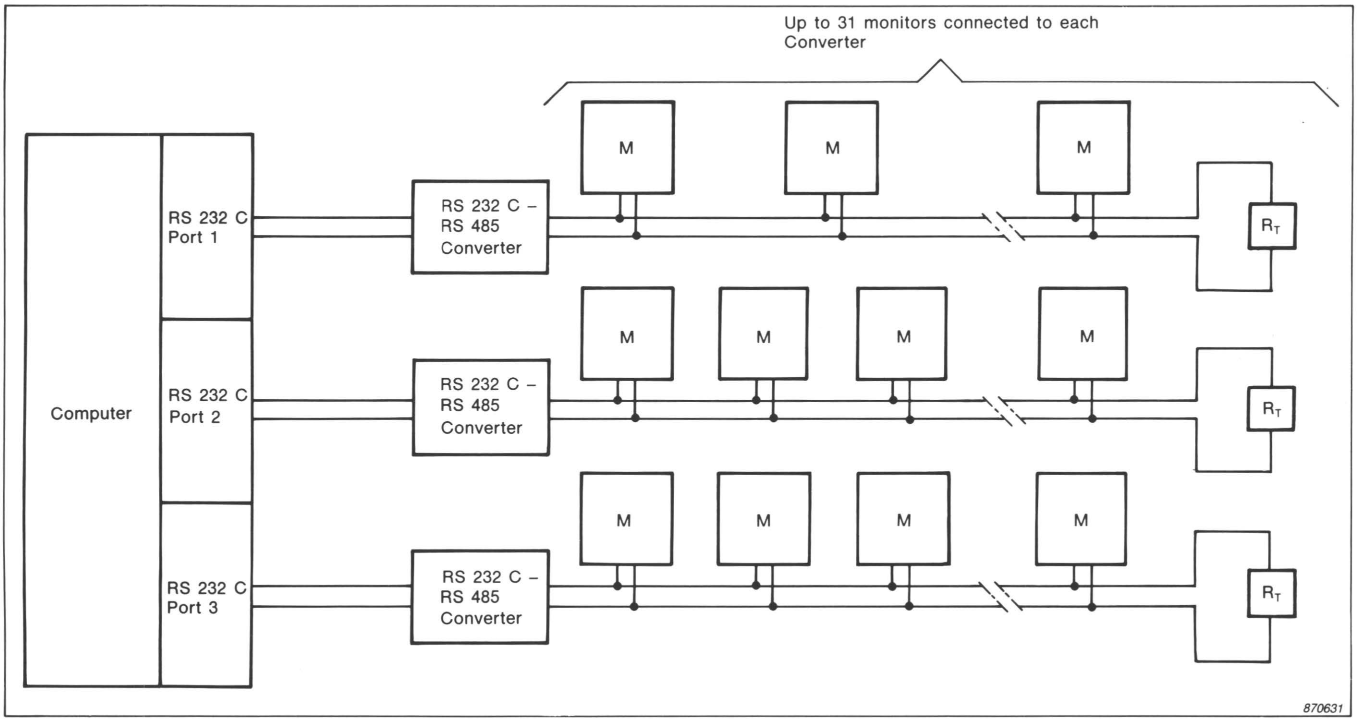

Fig. 3.6. Control of a large system using a computer with multiple RS 232 C I/O ports

the error rate becomes unacceptable. The actual distance depends on the number of monitors in the system, but is typically around 12 km.

If it is required to control more than 31 monitors from a single control station, then a computer with several input/output ports (I/O ports) should be used. A maximum of 31 monitors can then be connected to each port and information from the different I/O ports can be sorted by the computer. If the computer has RS 232 C I/O ports, then each port will need its own interface converter, as described in Section 3.1.3. An example of this type of system is shown in Fig. 3.6. Note that because of the time taken to collect information from each monitor, the total number of monitors in the system is limited, if the computer is to be able to collect information from all monitors without interruption.

An alternative method is to increase the number of monitors in the system and / or the distance to the furthest monitor by adding repeaters at intervals to 'square-up' the signal. A digital signal which has been affected by noise and cable attenuation can be restored to the original signal by a repeater, provided the switching level is not exceeded. This process is shown in Fig. 3.7.

A 1306 Toxic-gas Monitor can be modified to act as a repeater. However the use of repeaters in a gas monitoring system has two disadvantages:

1. Each repeater will be a weak point in the system, as a fault in the repeater will cause loss of communication with all subsequent monitors further down the line.

2. The 1306 is fitted with internal electronic circuits to protect it against interference from the electro-magnetic pulses (EMP's) such as those generated by a nuclear explosion. There is no room in the 1306 for extra circuits to protect a repeater, and so the repeater will have no EMP protection.

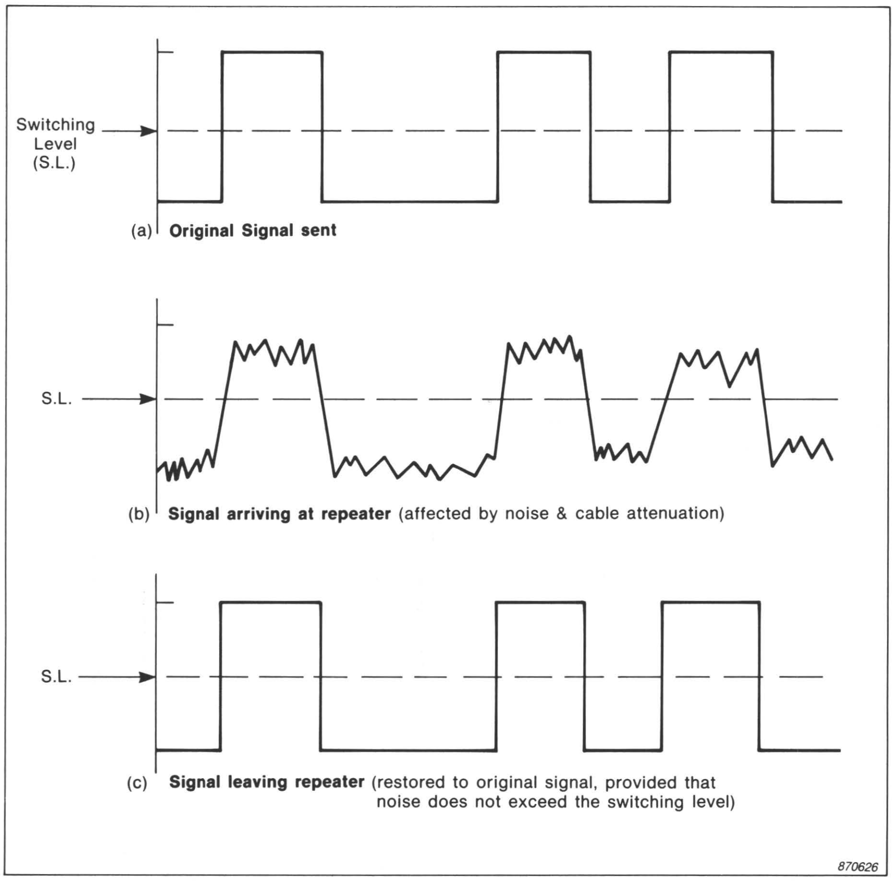

Fig. 3.7. 'Squaring-up' of a digital signal by a repeater

3.2. DDCMP PROTOCOL

3.2.1. Introduction

The DDCMP Protocol was chosen to provide the most reliable system possible for transmitting data between the monitors and the computer, while at the same time providing a system which is relatively simple to implement.

The protocol allows a single controlling device (master) to communicate with up to 254 controlled devices (slaves). In this case the master is the computer and the slaves are the 1306 Toxic-gas Monitors.

The following sections are intended to be a brief introduction to the DDCMP protocol, and a description of how it is implemented in the 1306. If writing software to control the 1306, the information here should be used in conjunction with Chapter 4, and with the DDCMP specification published by the Digital Equipment Corporation *. The Applications Diskette BZ 5003, which is provided as an accessory with the 1306, also provides the user with (1) a file called `DDCMP.INC` which shows how to handle the data transfer protocol between the computer and the 1306; and (2) a file called `CAL1306.PAS` which is a source file (it can be read and changed by a text editor and it can be printed out).

* Available from the Software Distribution Center, Digital Equipment Corporation, Maynard, Massachusetts 01754, USA, or from your local Brüel & Kjær representative.

3.2.2. Cyclic Redundancy Checking (CRC)

The main feature of the DDCMP protocol is that it uses a CRC (Cyclic Redundancy Check) system to check for errors in the received data. The most common method of error checking in digital data transmission systems is a simple parity check. This method can detect all single errors, but multiple errors in a single piece of data can go undetected. The CRC system provides a much more reliable check, as most multiple errors can also be detected.

The CRC system uses a binary number, known as the generator polynomial, which is known to both the sender and the receiver. At the sender a series of mathematical operations are performed on the data to be transmitted, using this generator polynomial, and the result is a binary number known as the CRC check number. This check number is transmitted together with the data. At the receiving end, similar operations are performed on both the received data and the check number, and the result indicates whether or not an error has occurred.

The CRC system cannot correct errors – correction must be performed by re-transmitting the data until it is received correctly.

3.2.3. Data Format

DDCMP transmits data in the form of messages. These messages contain the data itself, and also control information and error checking codes. The messages, and the data blocks contained in them, must be multiples of 8 bits (1 byte) in length. The data blocks can be any length up to 16383 bytes, but the CRC error checking is most effective with data blocks up to 4093 bytes long.

Three types of messages are used by DDCMP – Data, Control and Maintenance. Only Data and Control messages are normally used by the 1306. The use of maintenance messages is possible, but is not recommended, as reliability is reduced.

Control messages consist of five types:

1. **Acknowledge (ACK).** Used to acknowledge that a message has been received correctly.

2. **Negative Acknowledge (NAK).** Used to indicate that an error has occurred. Described in detail in Section 3.2.7.

3. **Reply to Message Number (REP).** Indicates that the computer has sent a data message but has not received an acknowledge with the same message number. **REP** messages are described in detail in Section 3.2.6.

4. **Start (STRT)** Used to reset the data counters and synchronize transmission when initializing the system. This process is described in Section 3.2.8.

5. **Start Acknowledge (STACK)** Used to acknowledge a STRT message when initializing the system (see Section 3.2.8).

3.2.4. Message Headers

Each DDCMP message begins with an 8-byte header. For a control message the header alone will form the complete message, as shown in Fig. 3.8. For a data message the

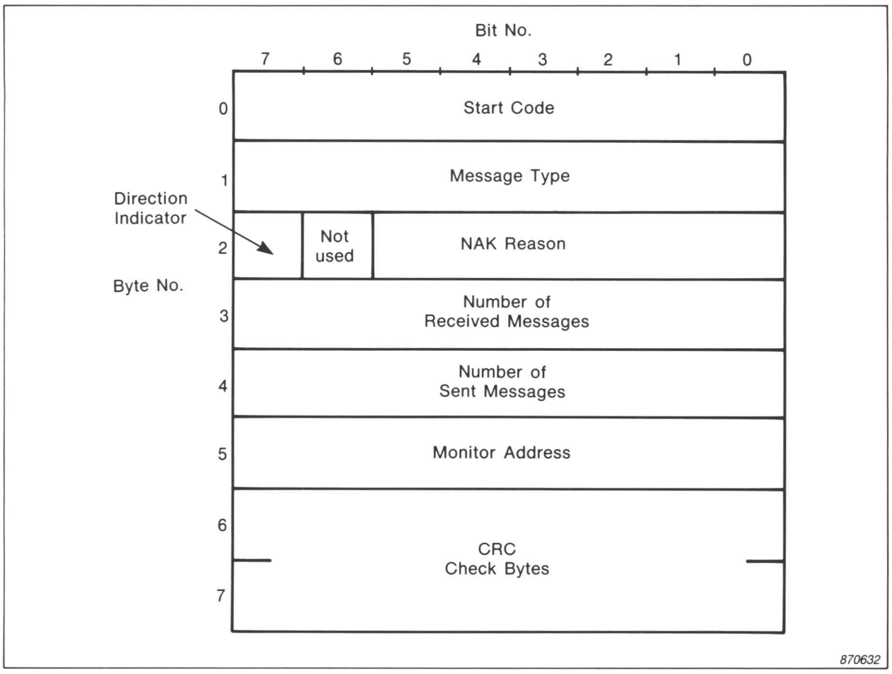

Fig. 3.8. DDCMP control message

header will be followed by N data bytes, where N is the number contained in the Data Counter field (see below). These data bytes are followed by their own two CRC error check bytes, as shown in Fig. 3.9.

The purpose of each section of the header is as follows:

Start Code
Indicates the type of message. 81H (81 Hexadecimal = 129 decimal) indicates a **data** message. 5H indicates a **control** message.

Data Counter (data messages only)
Indicates the number of data bytes contained in the message. **Data counter 1** is the least significant byte (low byte), **data counter 2** is the most significant byte (high byte).

Message Type (control messages only)
Used to distinguish between the different types of control message as follows:

01 ACK
02 NAK
03 REP
06 STRT
07 STACK

NAK Reason (NAK messages only)
Used to indicate the type of error which has caused the NAK message to be sent. Types of error and corresponding NAK reason numbers are listed in Section 3.2.7. In control messages other than NAK's, these bits are set to 0.

Direction Indicator
This is used to indicate a change of direction of message transmission. It is set to '1' by the transmitting device to indicate that it has finished transmission, and is waiting for a response from the other device.

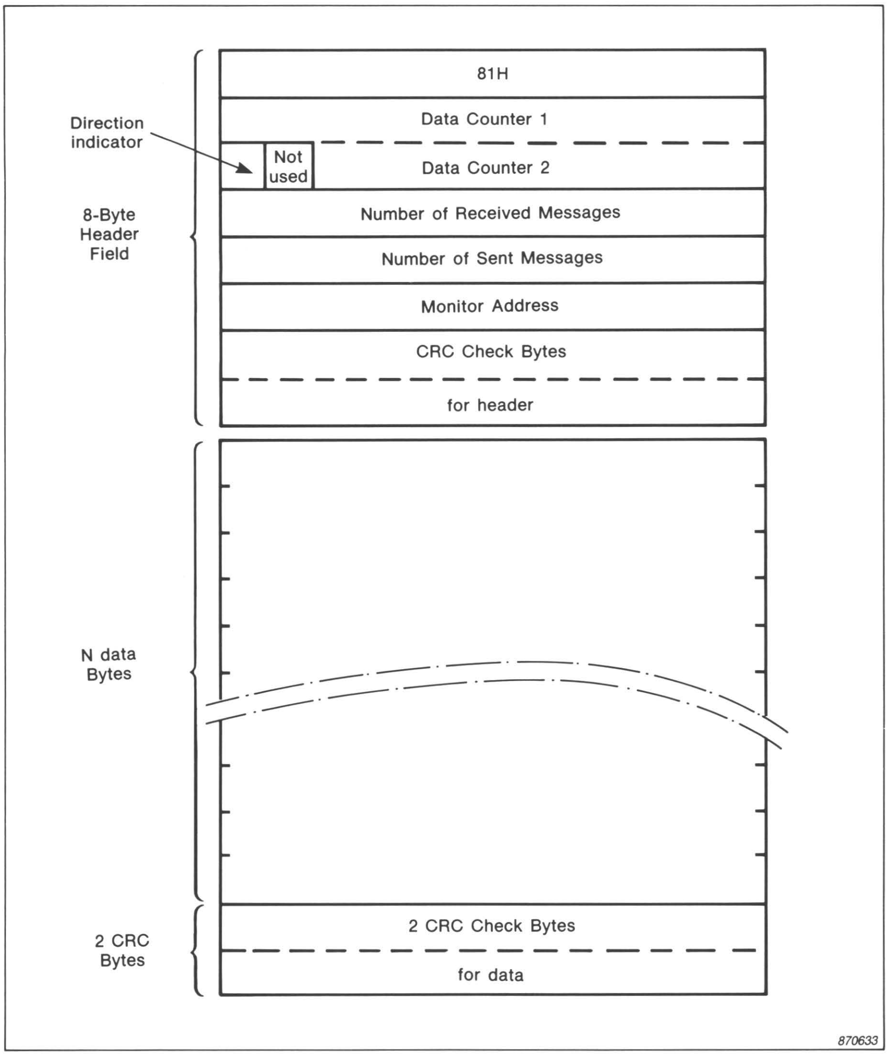

Fig. 3.9. DDCMP data message. The total value of the 2-byte data counter = N

Number of Messages (Received and Sent)
Each message is given a number, which is set-up by the transmitter in the "Number of Sent Messages" field. This number is used for error checking, and for detecting lost messages. The "Number of Received Messages" field is used when combining an acknowledge signal for a previous message with the current message. The computer and the monitors count the messages independently. In a message sent from the computer, the "Number of Sent Messages" field contains the number of messages sent by the computer, which will not necessarily be related to the number sent by the monitor. When the monitor sends a message, it sets the "Number of Sent Messages" field to the number of messages it has sent, which is not necessarily related to the number sent by the computer. The use of these two bytes is explained in more detail in Section 3.2.5. – Exchange of Messages, and also in Sections 3.2.6 and 3.2.7, which deal with the response of the system to errors.

Address Field
Indicates the address of the monitor communicating with the control station. The controller sets this to the address of the monitor it wants to talk to, the monitor sets it to its own address.

CRC Check Bytes
Used for CRC error checking on the previous six bytes of the header field.

3.2.5. Exchange of Messages

All exchanges of messages begin with a data message from the computer to the 1306, followed by a combined data and acknowledge message from the 1306. The data contained in these messages is described in Chapter 4. It includes instruction bytes, measurement results and error status information, but as far as the DDCMP protocol is concerned it is just data, and is referred to in this chapter simply as data.

The procedure for an exchange of messages is as follows (see Fig. 3.10):

1. The computer sets up the DDCMP header field, including the message number and the CRC check bytes. In Fig. 3.10 it is assumed that the number of the first message is 1, but this could actually be any number, depending on how many messages have been sent before. The computer then sends the complete **data** message, including the header field, and starts a timer. This timer determines how long it should wait for a correct response from the 1306, before reporting an error. The length of this time depends on the software used by the computer. The computer also stores the complete data message in memory, in case it has to be sent again due to an error.

2. When the 1306 receives the message it checks the CRC byte and message number. If there are no CRC errors, and the message number corresponds to the one expected, then it replies with a combined data and acknowledge message (**data / ACK**). The number of received messages field is used to acknowledge the received message, the number of sent messages field is set to the next message number.

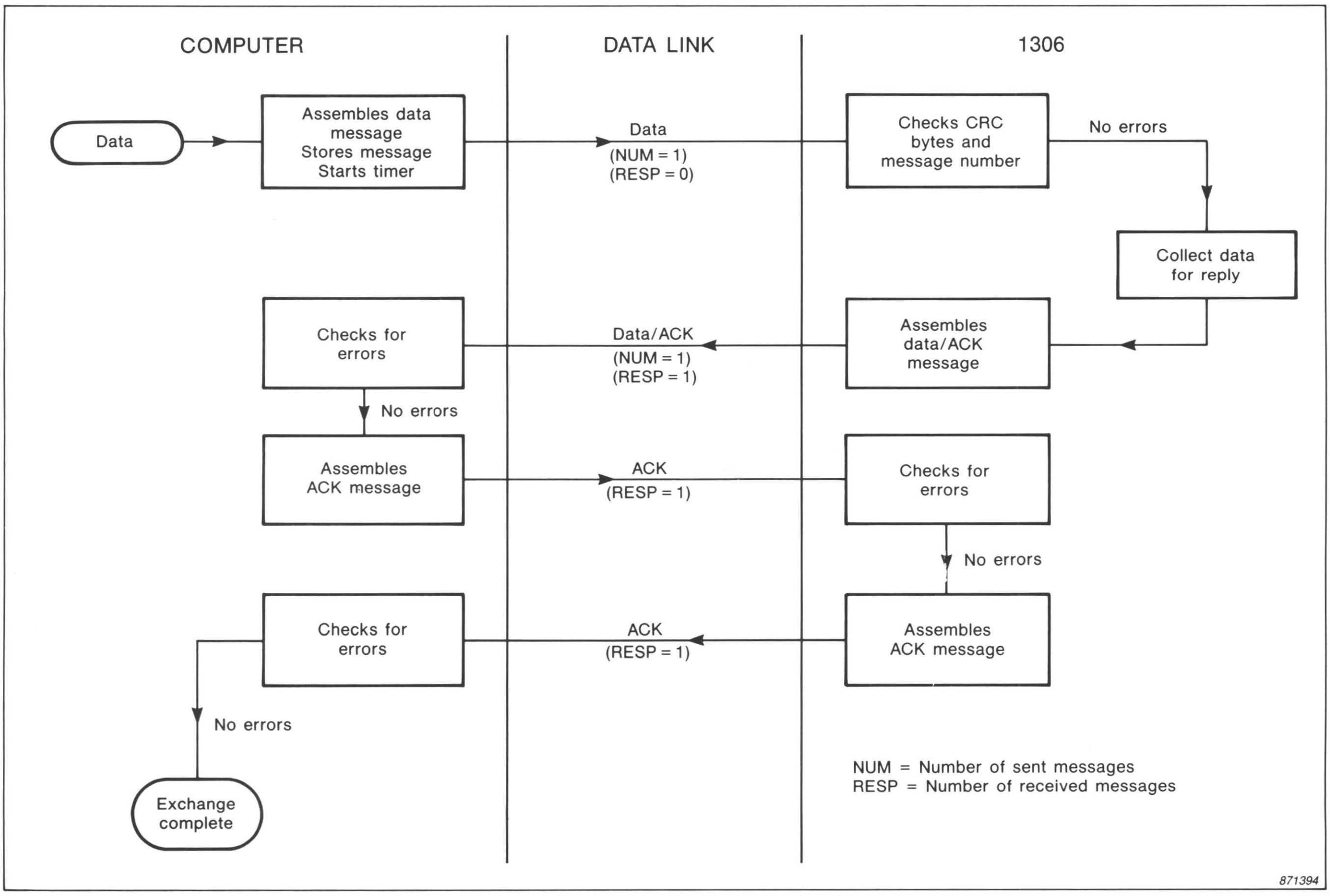

Fig. 3.10. Exchange of messages with no errors. The message number of the first message is assumed to be 1

If the 1306 does not receive the message, or receives it with errors, then it either takes no action, or sends a **NAK** message. This depends on the type of error, and is explained in Section 3.2.7.

3. The computer receives the **data / ACK** message and checks for errors. If there are no errors, it returns an acknowledge message having the same message number as the **data / ACK** message from the 1306, and re-starts the timer.

   If the computer does not receive the message before the timer expires, or receives it with errors, then the computer sends a **REP** message. These messages are explained in Section 3.2.6.

4. If the 1306 receives the acknowledge correctly, it returns another acknowledge with the same message number.

   If it does not receive the acknowledge, or receives it with errors, then it takes no action. The computer then transmits a **REP** message when the timer expires.

5. When the computer receives the acknowledge from the 1306 correctly, then the exchange of messages is complete.

In the above description it is assumed that messages are sent one at a time, with each device waiting for a response from the other before continuing. The computer can also send messages one after the other, without waiting for a reply from the 1306. This method is described in Section 3.2.9.

For more details of the message exchange procedure, refer to the DDCMP specification.

3.2.6. Response of the Computer to Errors

The response of the computer to errors depends on the individual software used, but always involves the computer sending either a **NAK** message or a reply to message number (**REP**) message.

The computer can send a **NAK** message to the 1306 when it has received a data message, but has detected a CRC error in the data. The NAK error reason number field in the DDCMP header is set to **02**. On receiving this NAK message, the 1306 re-transmits the data message.

The computer sends a **REP** message when it has sent a data message to the 1306, but has not received an acknowledge message with the correct message number before the timer has expired. This can happen for two reasons:

1. The data message from the computer to the 1306 was lost, or received in error, as shown in Fig. 3.11. Because the 1306 has not received the message correctly, the message number of the **REP** message will not correspond to that of the last correctly received data message. In this case the 1306 replies to the **REP** with a **NAK** message. On receiving the **NAK**, the computer re-transmits the data message. This procedure can be repeated if necessary until the 1306 has received the data message correctly. However, if the same error occurs persistantly, then the computer should report it to the user.

2. The **data / ACK** message from the 1306 to the computer was lost or received with an error (other than a CRC data error), as shown in Fig. 3.12. Because the original data message was correctly received, the message number of the **REP** will correspond to

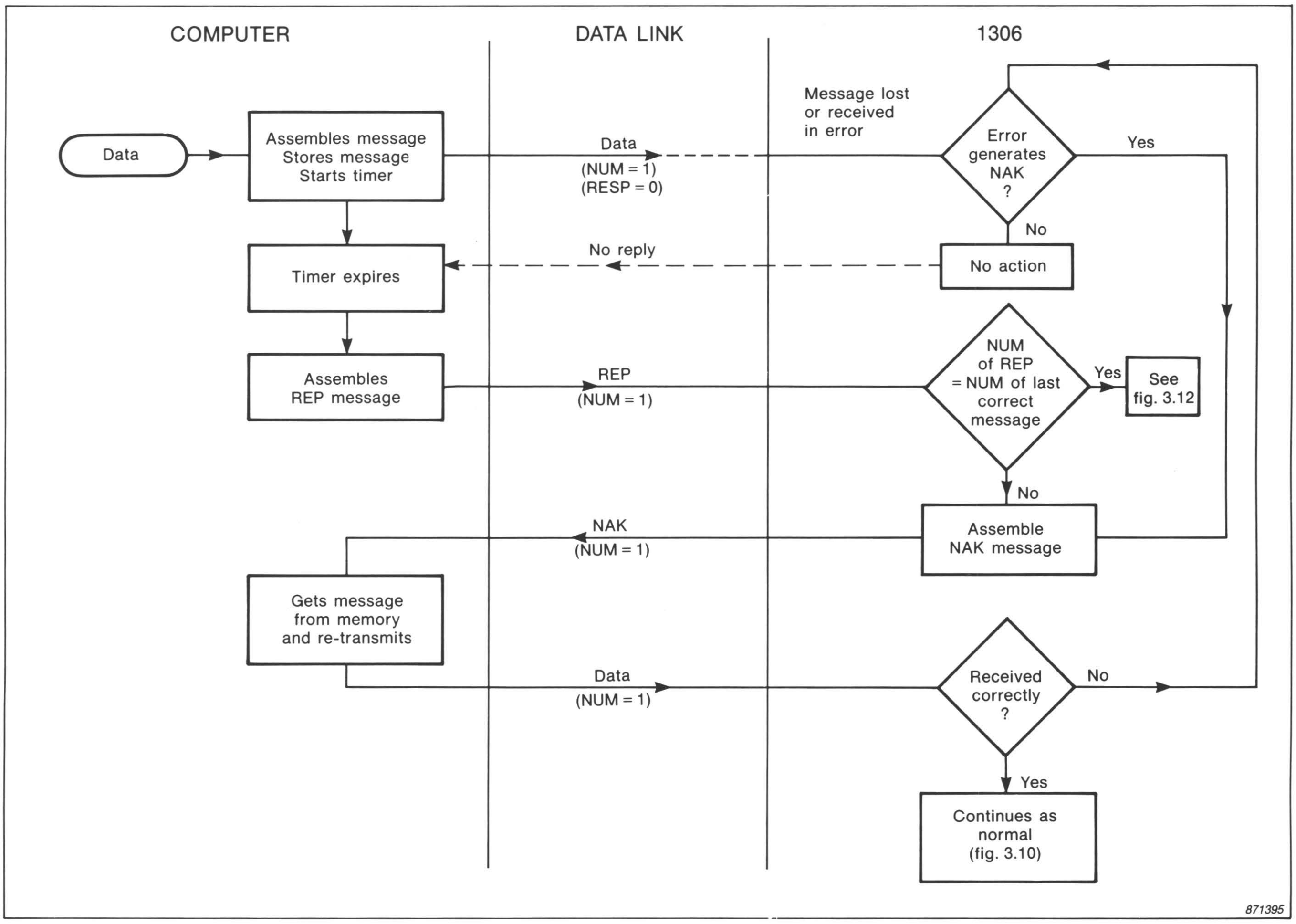

Fig. 3.11. Exchange of messages with data message in error. The message number of the first message is assumed to be 1

that of the last data message correctly received by the 1306. In this case the 1306 replies to the **REP** by re-transmitting the **data/ACK** message. If this is correctly received, then transmission can continue as normal. If not the timer expires and the **REP** message is sent again. If the error occurs persistantly, then the computer should report it to the user.

For more details of error handling procedures, refer to the DDCMP specification

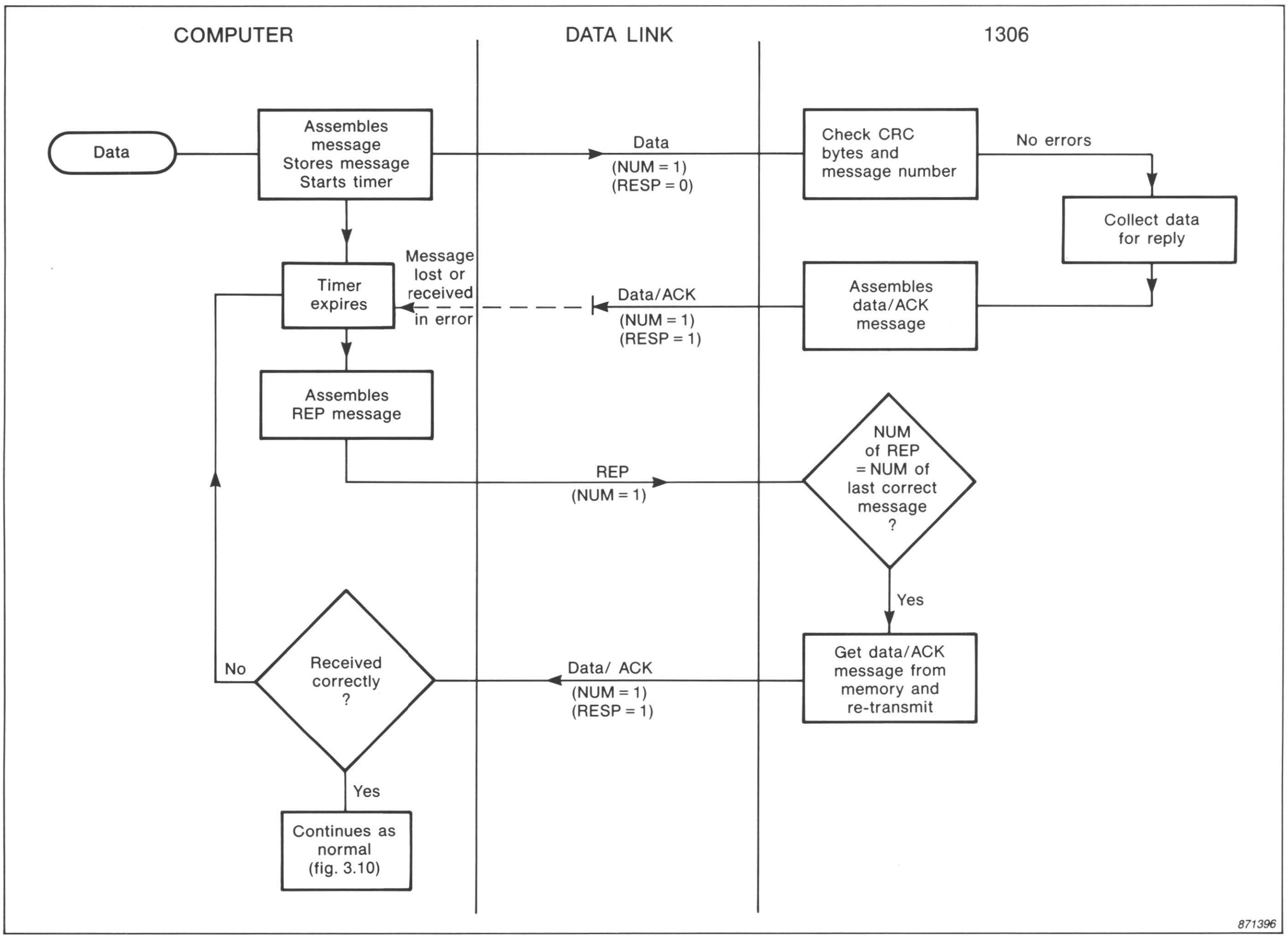

Fig. 3.12. Exchange of messages with acknowledge message in error. The message number of the first message is assumed to be 1

3.2.7. Response of the 1306 to Errors

While the response of the computer to errors depends on the particular software used, the response of the 1306 is fixed.

The DDCMP protocol allows the option of the slave device reporting errors to the master, by means of negative acknowledge messages (**NAK**'s). Systems which use **NAK** messages are more efficient than those which do not, because an error does not leave the communication link idle while waiting for the timer to expire and the error to be reported. However, more complex software is required to implement the **NAK** messages.

The DDCMP protocol specifies seven possible types of **NAK** message, each in response to a different error condition, and having a different **NAK** reason number in the message header field. Any individual system can use some or all of the **NAK** messages. The 1306 uses four of them.

Table 3.1 lists the types of error condition which can occur, and the response of the 1306 to each.

Error Condition	Response of 1306	NAK reason number
CRC error in the header field of received message	Ignores message	—
CRC error in the data field of received message	NAK message	02
Received data message has the wrong number	Ignores message	—
Received acknowledge message has the wrong number	Ignores message (but stores up to 4 messages for later use if required — see section 3.2.9)	—
More than 4 messages need to be stored	NAK message	08
Received REP message has wrong number	NAK message	03
Received message is longer than the maximum allowed length	NAK message	10 H
Invalid header field	Ignores message	—

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Table 3.1. Response of the 1306 to errors

3.2.8. Initializing the System

When the computer begins operation, the system must be initialized before the first data messages can be sent. That is, all the devices must be synchronized and all the message number counters reset to zero. The computer does this by initializing each monitor in turn, as follows:

First the computer takes the monitor out of running mode. That is, it inhibits communication by effectively 'switching off' the circuits in the 1306 which control communication. The computer does this by sending a start message (**STRT**), as shown in Fig. 3.13 (a). This message is not acknowledged.

The computer then puts the monitor back into running mode, as shown in Fig. 3.13 (b), by sending another **start** message. The 1306 responds to this by returning a **start** message. The computer then sends a **STACK** message to the 1306, which responds by sending an **acknowledge** message. Once the computer has received this message, communication with the monitor can begin, as described in Section 3.2.5. The computer then repeats the procedure for each monitor in turn.

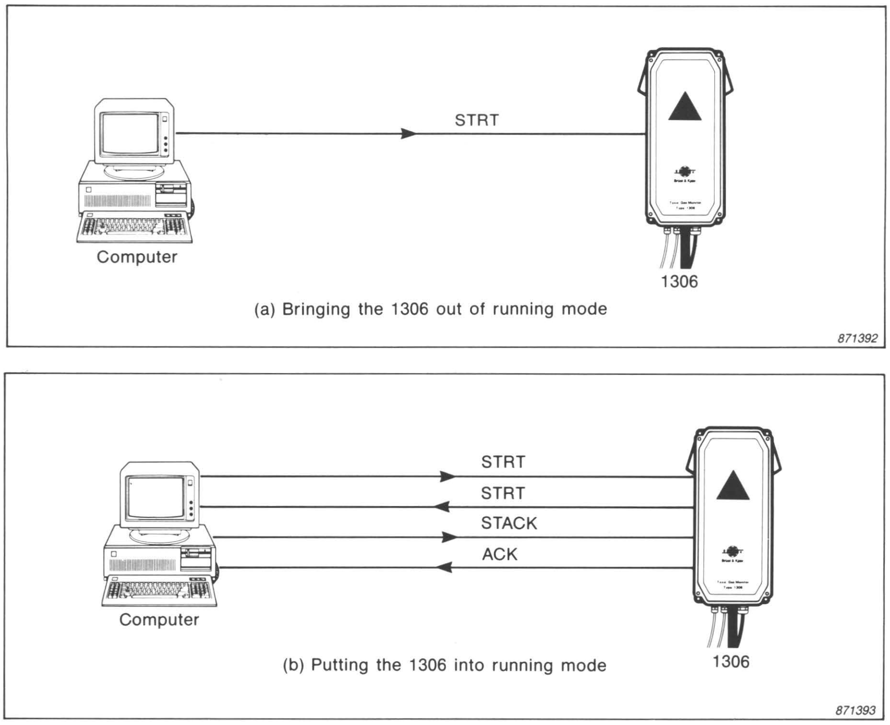

Fig. 3.13. Initializing the system

3.2.9. Block Data Transfers

In the procedure described in Section 3.2.5, messages are sent one at a time. That is, each device waits for a response from the other before sending any further messages. In this case the direction indicator bit of the DDCMP header field is set to ‘1’ throughout the message exchange.

Depending on the software used, the computer can send several data messages in succession, without waiting for each message to be acknowledged by the 1306. In this case the computer sets the direction indicator bit to ‘0’ in all but the last message.

If this system is used, the response of the 1306 to errors is exactly as described in Section 3.2.7. However, messages which arrive at the 1306 out of sequence are stored in a buffer (area of memory) by the 1306 until all earlier messages have been correctly received and acknowledged. Messages which have been sent by the 1306, but not acknowledged by the computer are also stored in the buffer.

The buffer can hold a total of 4 messages (received and / or transmitted). If more than 4 messages need to be stored, the 1306 sends a **NAK** message, as described in Section 3.2.7. The computer should then stop transmitting until the error has been corrected and all previous stored messages cleared from the buffer.

The actual response of the computer to errors depends on the software used — see Section 3.2.6.

4. DATA TRANSFER BETWEEN THE 1306 AND THE COMPUTER

This chapter is intended for those writing their own software to control the 1306. If you intend to use Brüel & Kjær software (Type 7619), then you do need to use the information given here.

4.1. INITIATING A DATA TRANSFER

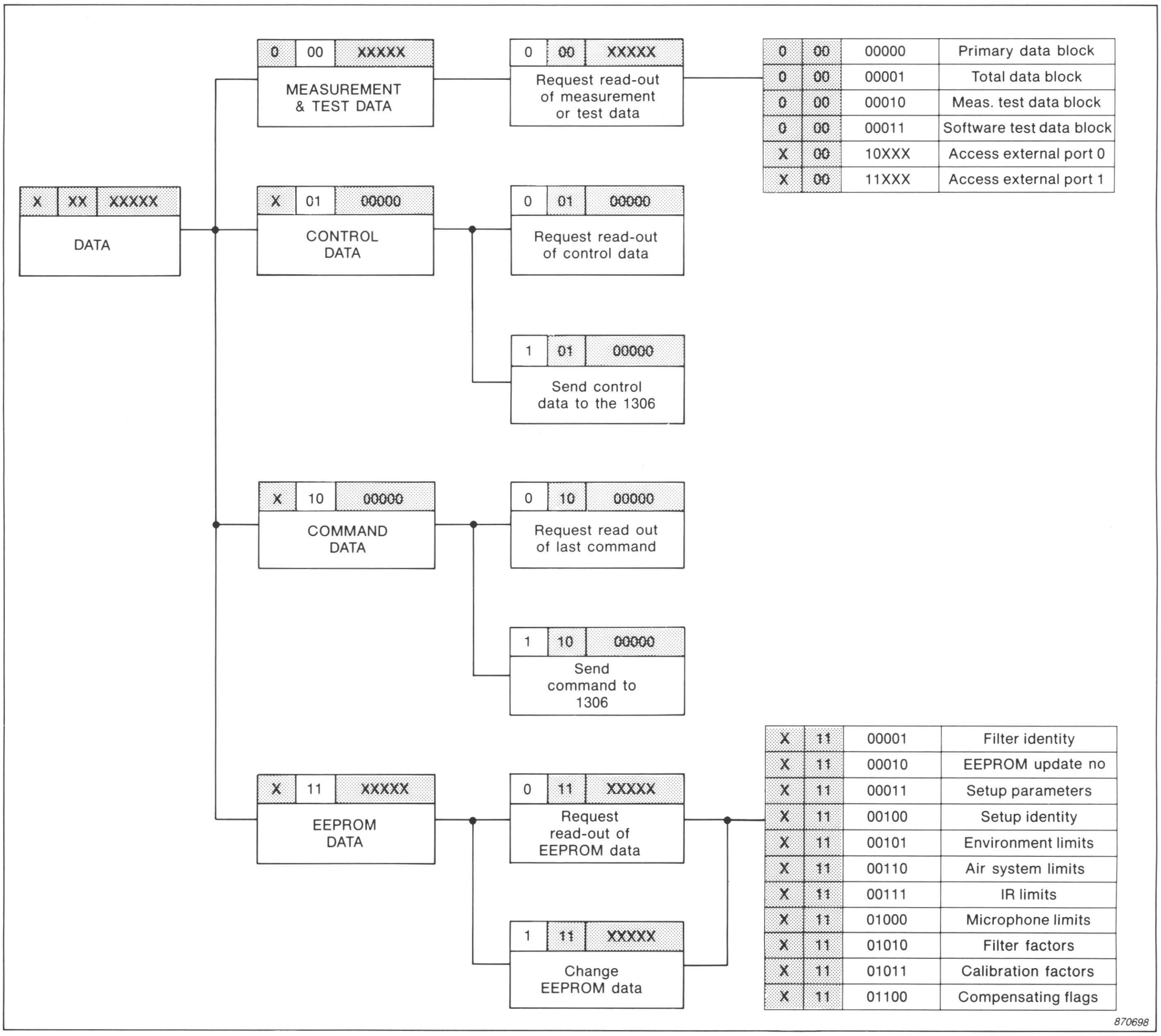

Fig. 4.1. Data transfers and corresponding instruction bytes

All data to and from the 1306 is transferred in the form of DDCMP data messages, as described in Section 3.2. All exchanges of data begin with a message from the control station, the first data byte of which must be a valid instruction byte. The instruction byte indicates the type and direction of the data transfer.

Data can be divided into four classes:

1. Control data for the 1306
2. Measurement and test data from the 1306
3. Commands to the 1306
4. EEPROM data

The first bit of the instruction byte indicates whether the control station is sending data to the 1306 or requesting data from it. The following two bits indicate which of the four classes of data is to be transferred, and the remaining bits are either used to further sub-divide the data types, or are set to zero.

Fig. 4.1 shows the types of data which can be transferred, and the corresponding values of the instruction byte. All valid instruction bytes are shown in the diagram — those which do not appear are not valid. When replying to a request for data, the 1306 returns the instruction it received as the first byte of the data field. If the first data byte of the received message was not a valid instruction, then the 1306 returns a message containing the single data byte 0FFH, indicating that it was unable to perform the instruction.

4.2. DATA FORMATS

All data is transmitted to and from the 1306 in the form of bytes. The 8 bits which make up a byte are transmitted sequentially, the least significant bit being transmitted first.

Three data formats are used by the 1306, consisting of one, two and four bytes. You only need to understand these if you are writing software for the 1306.

Single-byte format is normally used when each bit has an individual meaning, for example in the case of the error status flags. The computer can then process the data simply by testing each bit individually.

Two-byte (word) format is used to represent integer quantities. A two byte word can represent a value from 0 to 65 536, which can then be multiplied by a constant to give the required range. This constant can be less than one, enabling fractions to be represented. This format is used where only positive numbers need to be represented, for example in the case of the operating time of the monitor. The most significant byte is always transmitted first.

Four-byte (real) format is used to represent real numbers. These are represented in an exponential binary form, which is analogous to exponential decimal form (also known as scientific notation), and which conforms to IEEE standards.

In exponential decimal notation, a number is represented in the form $A \times 10^B$, where B is an integer and A is any number in the range 1,0000 to 9,9999 (for an accuracy of 5 significant figures). In exponential binary notation, the same number is represented as $C \times 2^D$, where D is a binary integer (the exponent) and C is a binary number in the range $1{,}0000_2$ to $1{,}1111_2$ (the significand). Since the first bit of C is always a '1', this '1' can be assumed, and does not need to be stored by a computer or similar device which is storing the number. Only the bits following the binary point need to be stored.

In the real data format used by the 1306, a sign bit, an exponent (8 bits) and a significand (23 bits) are used.

The **sign bit** indicates whether the number is positive (sign bit = 0) or negative (sign bit = 1).

The **exponent** indicates the order of magnitude of the number. An 8-bit exponent could normally represent values from 0 to 255. However, when the number is stored in the 1306, a bias of 127 is added to the exponent. This enables values from -127 to +128 to be represented.

The **significand** contains the significant bits of the number. Since zero is not considered to be significant, the first significant bit of a binary number is always a '1'. This '1' is automatically assumed, and only the bits following the binary point are represented by the significand, as explained above.

An example is given below, showing how a decimal number is converted to the real data format used by the 1306:

Decimal number:	178,125		
Exponential decimal:	$1,78125 \times 10^2$		
=	$1,3916 \times 2^7$		
Exponential binary:	$1,0110\ 0100\ 01 \times 2^{111}$		
Exponential binary: (Biased exponent)	$1,0110\ 0100\ 01 \times 2^{1000\ 0110}$		
1306 real data format	Sign bit	Biased Exponent	Significand
	0	1000 0110	0110 0100 0100 0000 0000 000

The resulting 32-bit number is then split into 4 bytes as follows:

First byte	0 1000 011 (sign bit + first 7 bits of exponent)
Second byte	0 0110 010 (last bit of exponent + first 7 of significand)
Third byte	0 0100 000 (next 8 bits of significand)
Fourth byte	0 0000 000 (last 8 bits of significand)

These bytes are then transmitted sequentially, starting with the first. The least significant bit is transmitted first in each case.

The following sections contain a detailed description of each type of data, and the format in which it is transferred.

4.3. CONTROL DATA

Control data specifies the alarm level and the time between gas concentration measurements (both described in Chapter 2). It also contains a 32-byte user data field, which can be used for storing general information. The data contained in this *block* is not affected by a "reset" of the 1306. Table 4.1 shows the format of the control data block. The meaning of each data field is as follows:

Byte No. (Hex)	Data
00 01 02 03	Alarm Level
04 05	Time between Measurements
06 to 25	User Data (32 Bytes)

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Table 4.1. The control data block

Alarm Level
A real value which specifies the alarm concentration level in mg/m^3. Before leaving the factory this parameter is set to 1 mg/m^3. When new control data is sent to the 1306 the new value of this parameter will replace the factory-set value. Its meaning is described in Chapter 2.

Time Between Measurements
A word value specifying the time between the completion of one gas concentration measurement and the start of the next, when the monitor is operating in normal mode. The time is stated in multiples of 0,1 seconds. The factory-set value of this parameter is 10 minutes. By sending new control data to the 1306 the value of this parameter can be changed.

User Data
A 32-byte data field which has no effect on the operation of the 1306. It is stored in the memory of the 1306, and read out whenever the control data is read. It can be used for storing general information (for example where the monitor is located, when it was initialized and who initialized it) or for storing a back-up copy of the control data.

Transfer of the Control Data Block

Control data can be both written to and read from the 1306 by the computer. Figs. 4.2 (a) and (b) show the transfer of control data to and from the 1306 respectively.

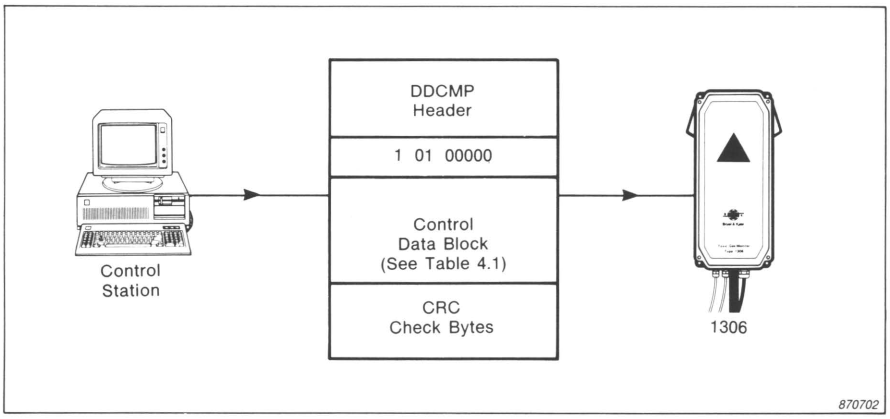

Fig. 4.2 (a). Sending control data to the 1306

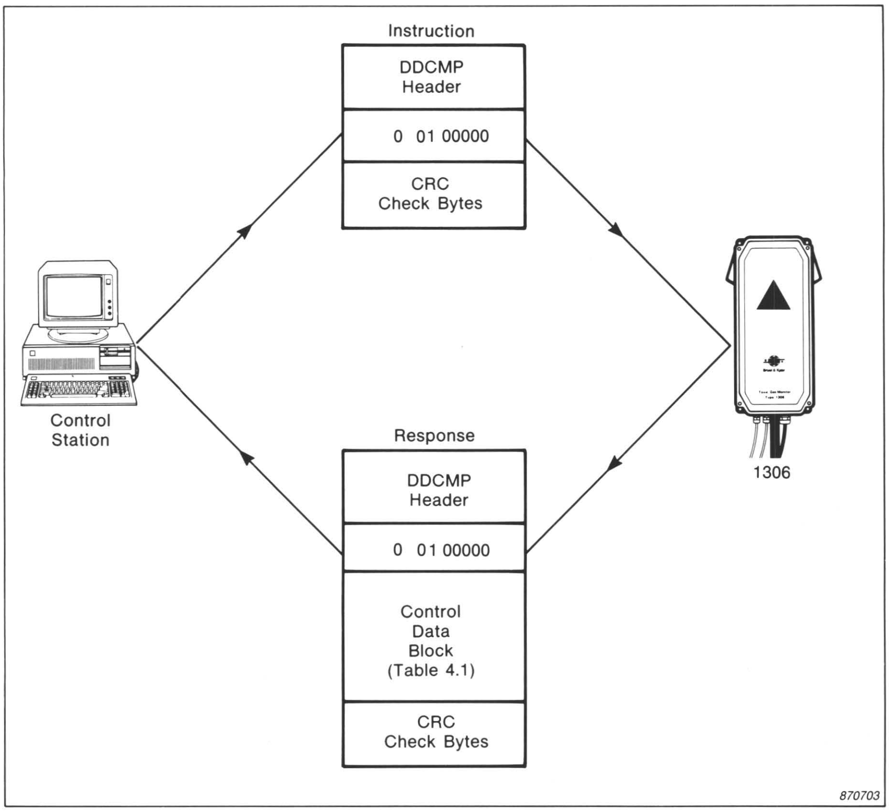

Fig. 4.2 (b). Reading back control data from the 1306

To send control data to the 1306, the user simply sends a data message containing the control data block in the format shown in Table 4.1. The instruction byte is set to '1 01 00000', indicating that data is being sent to the 1306 (see Fig. 4.2 (a)).

To read control data from the 1306, a data message containing only the instruction byte '0 01 00000' is sent to the 1306. The 1306 then responds by sending back the control data block in the format shown in Table 4.1, with the instruction byte also set to '0 01 00000' (see Fig. 4.2 (b)).

4.4. MEASUREMENT AND TEST DATA

This data can be sub-divided into five types

1. Primary Data Block
2. Total Data Block
3. Measurement Test Data Block
4. Software Test Data Block
5. External Port Request

4.4.1. Primary Data Block

This data block should be sufficient for normal operation of the 1306. It contains the last measured gas concentration, the actual time between measurements and the time to the next measurement, in the format shown in Table 4.2. The meaning of each data field is as follows:

Byte No. (Hex.)	Data
00 01 02 03	Gas Concentration
04 05	Actual Time between Measurements
06 07	Time to Next Measurement

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Table 4.2. The primary data block

Gas Concentration

A real value giving the last measured gas concentration in mg/m^3. This value is updated with a frequency dependent on the "actual time between measurements" (see below), and the time taken to make a concentration measurement. The gas concentration value is reset to zero when power to the 1306 is switched on, or when the 1306 receives a reset command (see Section 4.5).

The uncalibrated value of the gas concentration (expressed as the voltage output from the measuring microphone) can be found in the measurement test data — see **Raw gas value** in Section 4.4.3.

Actual Time Between Measurements

A 2–byte value, giving the time between the completion of one concentration measurement and the start of the next, in multiples of 0,1 seconds. It is set to a value of 6000 (10 minutes) before the Toxic-gas Monitor leaves the factory. This value can only be changed by sending new Control Data to the 1306 — it is not affected by a "reset" of the 1306.

When the 1306 is operating in normal mode, the "actual time between measurements" is equal to the "time between measurements" in the control data. When in intensification mode or alarm mode the actual time between measurements is reduced, as described in Chapter 2.

Time to Next Measurement

A 2-byte value giving the time remaining until the start of the next measurement, in multiples of 0,1 seconds. It is set to a default value of 150 (15 seconds) when power is switched on, or when the 1306 is reset.

This value is set to the same value as the 'actual time between measurements' when the gas concentration value is updated, and after that it is updated continuously.

Transfer of the Primary Data Block

The primary data block can only be read from the 1306. Fig. 4.3 shows the procedure. The control station sends a message containing the instruction byte '00000000'. The 1306 then returns a message containing the instruction byte, the primary data block (Table 4.2) and also the error status flags. These flags indicate whether any error has occurred which has affected the accuracy of the measurement, or prevented its successful completion. They are described in detail in Sections 2.10 and 4.7.

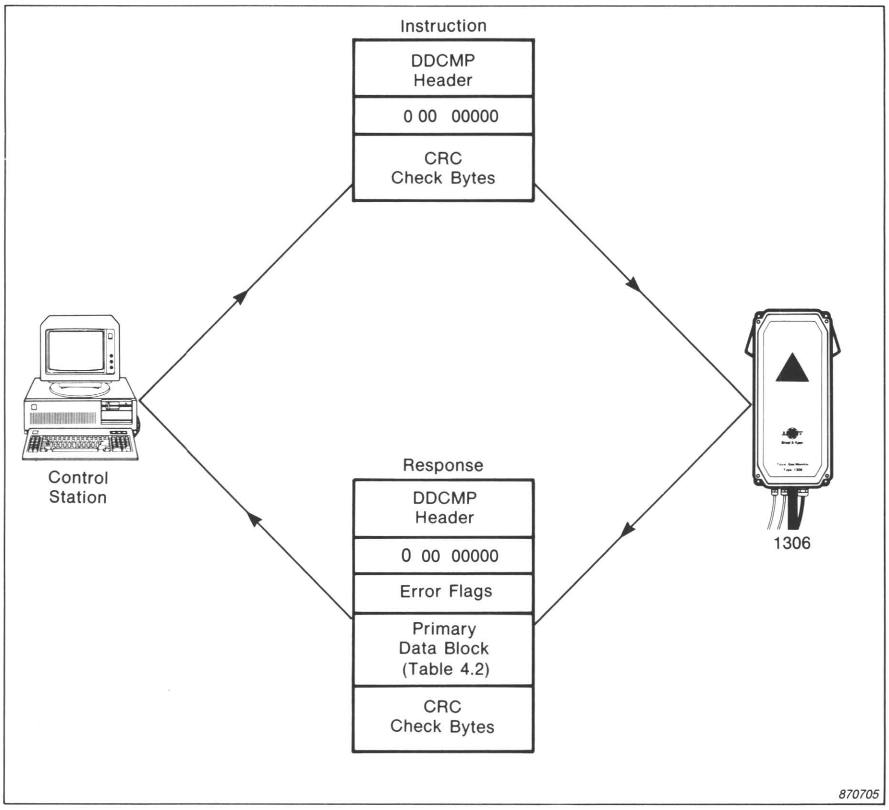

Fig. 4.3. Reading the primary data block from the 1306

4.4.2. Total Data Block

This contains all the information contained in the primary data block, plus some information about the environment, and the operation of the 1306. The format of the data block is shown in Table 4.3. The meaning of the first three data fields is described in Section 4.4.1. The meaning of the others is as follows:

Background Noise
This is given as a raw voltage (in volts). It is either the vibration noise or the chopper noise measured in the analysis cell — whichever is the largest (see **Vibration real value** and **Chopper real value** in Section 4.4.3. for details). Normally this value is under $2\mu V$. The background noise is reset to zero when power is switched on, or when the 1306 is reset. This value can be compared with the **Raw gas value** in the Measurement Test Data (see Section 4.4.3.) to see what contribution background noise has on the total signal measured in the cell during a gas measurement.

Temperature
A word value, giving the internal temperature of the 1306 in degrees Kelvin. It is reset to zero when power is switched on, or when the 1306 is reset.

Byte No. (Hex.)	Data
00 01 02 03	Gas Concentration
04 05	Actual Time between Measurements
06 07	Time to Next Measurement
08 09 0A 0B	Background Noise
0C 0D	Temperature
OE 0F	Power Supply Voltage
10 11	Total Operating Time

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Table 4.3. The total data block

If the temperature falls below –20°C or exceeds +70°C, then the temperature operating-error flag is set and the 1306 goes into power-down mode. When the temperature goes below +60°C or above –20°C again, the flag is cleared and the 1306 returns to power-up mode. If the temperature falls to below –5°C, then the IR source remains on continuously, in order to provide heat, rather than being switched off between measurements.

Power Supply Voltage
A word value giving the voltage on the power supply lines to the 1306, in millivolts (mV). It is reset to zero when power is switched on, or when the 1306 is reset.

If the supply voltage falls below 8,3 V, or exceeds 15 V, then the power supply operating-error flag is set and the 1306 goes into power-down mode. When the voltage goes below 15 V or above 9,3 V again, the flag is cancelled and the 1306 returns to normal mode. See Section 2.7.1 for further details.

Total Operating Time
A word value giving the total operating time of the 1306, in minutes, since the last reset. It is updated continuously by the 1306 until it reaches its maximum value after approximately 45 days (when all bits are set to '1') when it stops, but is not reset. Users can reset this value to zero by sending a "reset" command to the 1306.

Transfer of the Total Data Block

The total data block can only be read from the 1306. Fig. 4.4 shows the procedure. The control station sends a message containing the instruction byte '0 00 00001'. The 1306 then returns a message containing the instruction byte, the total data block (Table 4.3) and also the error status flags. These flags are described in detail in Section 4.7.

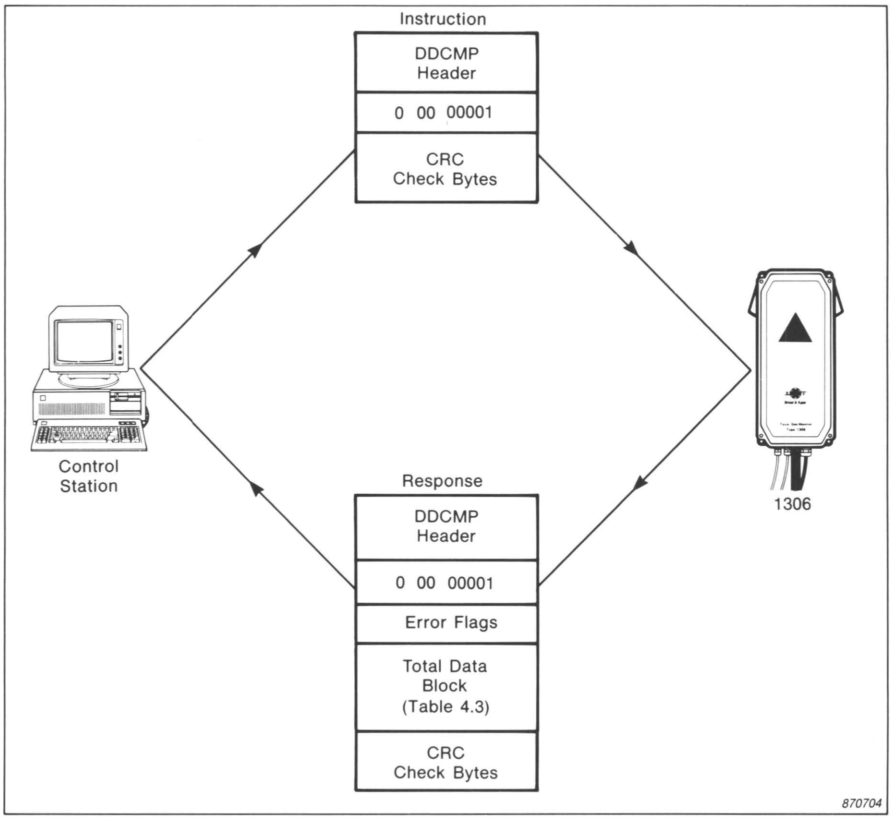

Fig. 4.4. Reading the total data block from the 1306

4.4.3. Measurement Test Data Block

This data block is intended for test use, mainly by service personnel. You do not need to use it during normal operation of the 1306, or to know its meaning in detail. However, if the 1306 develops a fault, then you can speed up the repair by reporting the measurement test data to the service engineers. If the error status flags indicate an error, then the measurement test data block gives more information about the type of error which has occurred.

The data block gives information about seven different measurements:

1. Gas concentration
2. Vibration noise
3. Air humidity
4. Pnuematics measurements (to check the air-shunt, air-filter, pump, and valves)
5. Chopper noise
6. Microphone 1
7. Microphone 2

All these measurements are made using the 1306's two built-in measuring microphones which are used to measure gas concentration. Fig. 4.5 shows a block diagram of the electrical part of the system. The output from each microphone is passed first through a preamplifier, and then through a summing amplifier, which has a variable gain. The signal is then passed through a 20 Hz filter to remove noise at frequencies other than 20 Hz (the chopper frequency, and therefore the frequency of the acoustic signal in the analysis cell). After the filter the signal is fed via a multiplexer to the analogue to digital converter (ADC), which converts it to a digital signal which can be further processed by the 1306. (The multiplexer selects which one of several possible input channels is con-

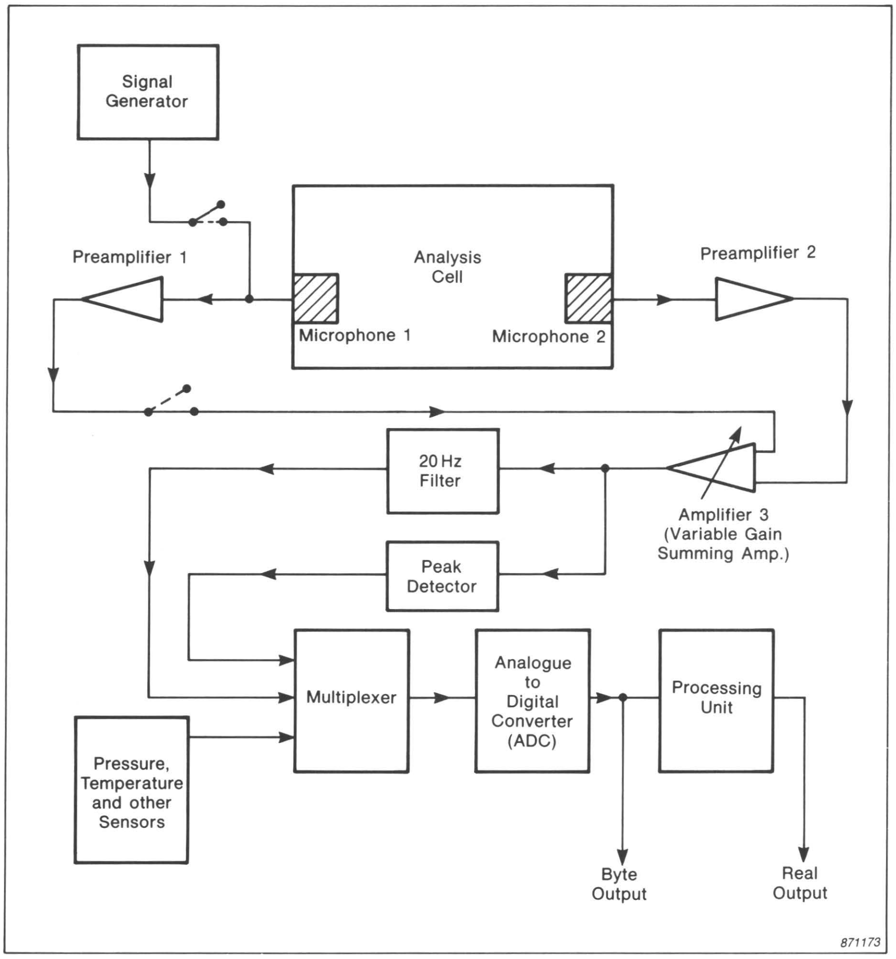

Fig. 4.5. The electronic part of the 1306

nected to the ADC at any given time). The system also contains a peak detector, so that peak values of the acoustic signal can be read out.

The measurements are described in more detail in Chapter 2. For each measurement the data block gives the unscaled measurement result, the gain of amplifier 3 during the measurement, the number of accepted samples and the variation between the accepted samples. All these are read out as byte values stated as the output from the ADC. The data block also gives the final calculated real value in IEEE real data format, as described in Section 4.2.

The data block also gives information about the current operating condition of the 1306 and the results of various self-tests, described in Chapter 2. All these results are read out as byte values.

All data is updated when the appropriate measurement or test is complete, and at the same time an update flag is set to ‘1’. Immediately after the data block is read out, all the update flags are cleared (reset to ‘0’). These update flags are read out with the data, enabling you to see whether the data has changed since the last read out.

Table 4.4 shows the format of the measurement test data block. A brief description of each data field follows — more detailed information can be found in the service manual, which is available separately.

Byte No. (Hex.)	Data	
00	Hardware status	
	Bit	Meaning
	0	Not used
	1	Not used
	2	Chopper motor 1 = on 0 = off
	3	IR Source 1 = on 0 = off
	4	Air pump 1 = on 0 = off
	5	Valve 1 1 = open 0 = closed
	6	Valve 2 1 = open 0 = closed
	7	Lid 1 = has been opened 0 = closed
01	Switches update flag	
02	Switch 1	
03	Switch 2	
04	Memory test **PROM test** Bit Address Range (Hex.) 0 0000 to 1 FFF 1 2000 to 3 FFF 2 4000 to 5 FFF 3 6000 to 7 FFF 4 8000 to 9 FFF 5 A000 to BFFF **RAM test** Bit 7 Bit 6 0 0 No errors 0 1 Single error 1 1 Multiple errors	
05	Test stop number	
06	Test sequence update flag	
07	Test sequence number	
08	Temperature update flag	
09	Temperature	

Table 4.4. The measurement test data block (part 1 of 7)

Hardware status

Gives information about the operation of the mechanical parts of the 1306. This byte is only "read" when the measurement test data is requested. Table 4.4 shows the purpose of each bit (bit 7 is the most significant bit, bit 0 is the least significant bit).

Switch 1 and Switch 2

Show how switches 1 and 2 are set. They are used to test that the switches are functioning correctly. The purpose of the switches is described in Vol. 2 — Installation and Maintenance. These bytes are updated approximately every 260 ms.

Memory test

Bits 0 to 5 — PROM test. The PROMs are tested every 15 s using a CRC system. Each bit represents an area of memory, as shown in Table 4.4. (bit 0 is the least significant bit). If any bit is set to '1', there is an error in this range. In this case the **software** operating-error flag is set, and measurements cannot take place.
Bits 6 and 7 — RAM test. The RAM is tested at start-up. These bits indicate if there is an error as shown in Table 4.4. (bit 7 is the most significant bit).

Test stop number

The last single step command sent (see Section 4.4). This indicates that the measurement will stop at a specific point. It is updated when a new command is received. If no command is sent to the 1306 to get it to revert to its normal mode of operation within 5 minutes of sending it a single step command, the byte is set to 0, the 1306 is reset and the soft error flag is set. If control data is sent to the 1306, the soft error flag can be cleared and the 1306 will start operating again.

Test sequence number

States what stage a measurement has reached. This byte is updated when each operation is completed, and so it enables you to follow a measurement. Section 4.4 lists the sequence numbers and corresponding operations.

Temperature

The internal temperature of the 1306. A read-out of zero corresponds to a temperature of –145°C, with each increment of 1 bit corresponding to an increase of 1°C. Thus a read-out of X corresponds to a temperature of (–145 + X)°C. The byte is updated approximately every 260 ms. If the temperature goes below –20°C or above +70°C then the 1306 takes protective action. This is described in Section 4.4.2.

Byte No. (Hex.)	Data
0A	Power supply update flag
0B	Power supply
0C	Spare ADC voltage update flag
0D	Spare ADC voltage
0E	Peak update flag
0F	Peak
10	Vibration update flag
11	Vibration unscaled value
12 13	Vibration number of samples
14	Vibration gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
15	Vibration deviation
16 17 18 19	Vibration real value

Table 4.4. The measurement test data block (part 2 of 7)

Power supply
The supply voltage after the input filter. The power supply to the 1306 is passed through this input filter to protect the 1306 from EMP's and other fluctuations in the power supply voltage. The byte is updated approximately every 260 ms. A read out of zero corresponds to 0,2 V, and after that each increment corresponds to an increase of 0,1 V. Thus a read-out of X corresponds to a voltage of (0,2 + 0,1X) V. If the supply voltage exceeds 15 V or falls below 8,3 V, the 1306 takes protective action, as described in Section 4.4.2.

Spare ADC Voltage
The voltage level on the spare input channel to the ADC. It is updated approximately every 260 ms.

Peak
The strongest peak, at the last microphone averaging. A value of 192 (0C H) or more indicates that an overload has occurred. In this case the sample will not be used in the measurement. The byte is updated at least every 18 seconds.

VIBRATION NOISE MEASUREMENT (bytes 10 H to 19 H)
The 1306 makes this measurement with the chopper and IR source switched off. In this way it measures the background vibration due to external sources, for example movement of the monitor on its mast during a storm. A measurement is made approximately every 18 seconds, except during gas concentration and chopper noise measurements.

Vibration unscaled value
The unscaled background vibration value, stated as the output from the ADC.

Vibration number of samples
The number of accepted sample periods. Set to 200 if all samples are accepted.

Vibration gain
The gain of amplifier 3 during the vibration measurement. One of four possible gains is indicated by the two least significant bits of this byte, as shown in Table 4.4.

Vibration deviation
The variation between the individual sample periods, in sets of 5. A small deviation indicates that the vibration level is constant during the course of the measurement.

Byte No. (Hex.)	Data
1A	IR source update flag
1B	IR source
1C	Gas update flag
1D	Gas unscaled value
1E 1F	Gas number of samples
20	Gas gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
21	Gas deviation
22 23 24 25	Raw gas value (C_m)
26	Humidity lamp update flag
27	Humidity lamp
28	Humidity update flag
29	Humidity unscaled value

Table 4.4. The measurement test data block (part 3 of 7)

Vibration real value (vibration noise)
The calculated vibration noise (in volts) when the infra-red light source is off and the chopper is not running.

IR source
The intensity of light emitted from the IR source. The value of this byte should lie within the range 61 to 89. If it is outside this range there is an error in the IR regulation or the IR source. In this case the **IR source** operating-error flag is set, and concentration measurements and chopper noise measurements cannot take place. The byte is updated after each concentration measurement.

GAS CONCENTRATION MEASUREMENT (bytes 1C H to 25 H)
All this data is updated when the 1306 makes a gas concentration measurement. The actual frequency of updating depends on the actual time between measurements (see section 4.4.1) and the time taken to make a measurement (approximately 40 seconds)

Gas unscaled value
The unscaled gas concentration value, stated as the output from the ADC.

Gas number of samples
The number of accepted samples in the gas concentration measurement.

Gas gain
The gain of amplifier 3 during the gas concentration measurement. One of four possible gains is indicated by the two least significant bits of this byte, as shown in Table 4.4.

Gas deviation
The variation between the individual sample periods.

Raw gas value (C_m)
The uncorrected raw signal measured by the microphones in the analysis cell when the infra-red light is on — measured in volts.

Humidity lamp
The 1306 tests the lamp during a normal gas concentration measurement. The data byte is set to 0 if the lamp is functioning correctly, or 255 (FF H) if there is no current through the lamp, in which case the **humidity lamp** warning flag is set and no humidity measurement is performed. Instead the calculation of the gas concentration is performed using the value of the humidity measurement made during the previous gas measurement sequence.

Byte No. (Hex.)	Data
2A 2B	Humidity number of samples
2C	Humidity gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
2D	Humidity deviation
2E 2F 30 31	Raw humidity value *(H_m)*
32	Pump pressure update flag
33	Pump pressure
34	Pressure offset update flag
35	Pressure offset
36	Pressure offset negative update flag
37	Pressure offset negative
38	Pressure v1 closed update flag
39	Pressure v1 closed
3A	Pressure v2 closed update flag
3B	Pressure v2 closed

Table 4.4. The measurement test data block (part 4 of 7)

HUMIDITY MEASUREMENT (bytes 26H to 31H)
This measurement is made after a normal gas concentration measurement.

Humidity unscaled value
The unscaled humidity concentration, stated as the output from the ADC.

Humidity number of samples
The number of accepted sample periods included in the humidity concentration measurement. Set to 100 if all samples are accepted.

Humidity gain
The gain of amplifier 3 during the humidity measurement. One of four possible gains is indicated by the two least significant bits of this byte, as shown in Table 4.4.

Humidity deviation
The variation between the individual sample periods, in groups of 5.

Raw humidity value (H_m)
The uncorrected raw signal measured by the microphones in the analysis cell when the humidity light is on — measured in volts.

PRESSURE TESTS (bytes 32H to 3DH)
Updated every 30 minutes.

Pump pressure
The pressure across the pump with open valves. A read-out of zero corresponds to a pressure of zero, and after that each increment corresponds to an increase in pressure of 2 mbar. This byte is updated after a concentration or chopper noise measurement. If the pressure is under 12 millibars, then the **pump** operating-error flag is set and the concentration measurement is terminated. If the pressure is over 110 mbar, the **air filter** warning flag is set. If one of these errors occurs after a gas concentration measurement, then the relevant error flag is set immediately. If it occurs during the self-tests (carried out every 30 minutes), then the test is repeated before the flag is set. When the error condition terminates, the relevant flag is cleared again.

Pressure offset
The offset for the pressure transducer on the pump. It is used to correct other measurements from the pressure transducer, so that a pressure offset of zero across the pump is read out as zero.

Pressure offset negative
As above, but indicates a negative pressure offset.

Pressure v1 closed and Pressure v2 closed
The pressure across the pump with valve 1 closed and valve 2 closed respectively. If in either case the pressure is under 120 mbar, the **pump** operating-error flag is set and the gas concentration measurement is terminated.

Pressure shunt
The pressure across the pump with valve 2 closed, one second after the pump has stopped. If this pressure is over 50% of **Pressure v2 closed** (see above), then the air shunt is blocked, and the **air shunt** warning flag is set.

Byte No. (Hex.)	Data
3C	Pressure shunt update flag
3D	Pressure shunt
3E	Mic 1 update flag
3F	Mic 1 unscaled value
40 41	Mic 1 number of samples
42	Mic 1 gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
43	Mic 1 deviation
44 45 46 47	Mic 1 real value

Table 4.4. The measurement test data block (part 5 of 7)

MICROPHONE 1 MEASUREMENTS (bytes 3E H to 47 H)
These are used to measure the amplification of preamplifier 1 (see Fig. 4.5). This is done by connecting the signal generator output (of known amplitude) to the input of the preamplifier. The 1306 makes these measurements every 30 minutes.

Mic 1 unscaled value
The amplification of preamplifier 1, stated as the output from the ADC. The value of this byte should lie within the range 46 to 79, and should be stable (that is, it should not vary significantly between read-outs). If not, then there is an error in the preamplifier.

Mic 1 number of samples
The number of accepted samples in the microphone 1 measurement. A small number indicates that an overload has occurred.

Mic 1 gain
The gain of amplifier 3 during the measurement. One of four possible gains is indicated by the last two bits of this byte, as shown in Table 4.4. The byte should normally be read out as 0, indicating a gain of 1. If a measurement is started with this gain, and concluded with another gain, then there is a fault in the microphone or preamplifier.

Mic 1 deviation
The variation in sets of 5 sample periods. The variation should be small, as the signal generator has constant amplitude.

Mic 1 real value
The measured signal generator level. This is used to see if the preamplifier is operating correctly.

MICROPHONE 2 MEASUREMENTS (bytes 48H to 51H)

Every 30 minutes the 1306 sends a test signal through the analysis cell to test the electrical amplification of preamplifier 2 (see Fig. 4.5) and the acoustical amplification through the analysis cell. It does this by using microphone 1 as a loudspeaker to transmit a test signal from the signal generator, and microphone 2 to receive the signal.

Byte No. (Hex.)	Data
48	Mic 2 update flag
49	Mic 2 unscaled value
4A 4B	Mic 2 number of samples
4C	Mic 2 gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
4D	Mic 2 deviation
4E 4F 50 51	Mic 2 real value

Table 4.4. The measurement test data block (part 6 of 7)

Mic 2 unscaled value

The total amplification, stated as the output from the ADC. This value should lie within the range 29 to 110, and should be stable. If not, then there is an error in the microphones.

Mic 2 number of samples

The number of accepted sample periods. A small number indicates that an overload has occurred.

Mic 2 gain

The gain of amplifier 3 during the measurement. One of four possible gains is indicated by the last two bits of this byte, as shown in Table 4.4. This byte should normally be read-out as 1, indicating a gain of 6. If a measurement is started this gain of one and concluded with another gain, then there is a fault in the microphone or preamplifier.

Mic 2 deviation

The variation in sets of 5 sample periods. The variation should be small, as the signal generator has constant amplitude.

Mic 2 real value

The measured signal transmission. This is used to see if the preamplifiers and microphones are operating correctly.

Byte No. (Hex.)	Data
52	Chopper noise update flag
53	Chopper unscaled value
54 55	Chopper number of samples
56	Chopper gain Bit 1 Bit 0 Gain 0 0 1 0 1 6 1 0 36 1 1 216
57	Chopper deviation
58 59 5A 5B	Chopper real value

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Table 4.4. The measurement test data block (part 7 of 7)

CHOPPER NOISE MEASUREMENTS (bytes 52 H to 5B H)

The 1306 makes these measurements with the IR source switched off and the chopper running. In this way it measures the background noise produced by the chopper. The result can be compared with the background noise produced by external vibration of the 1306 (i.e. the **vibration noise** measurement), which is made with the chopper switched off. If the noise with the chopper running is significantly greater, then the chopper is out of balance.

Chopper unscaled value

The unscaled noise value, stated as the output from the ADC.

Chopper number of samples

The number of accepted sample periods in the chopper noise measurement.

Chopper gain

The gain of amplifier 3 during the measurement. One of four possible gains is indicated by the last two bits of this byte, as shown in Table 4.4.

Chopper deviation

The variation in sets of 5 sample periods.

Chopper real value (chopper noise)

The calculated chopper noise (in volts) when the chopper is running and the infra-red light source is off. If this is significantly greater than the **vibration real value**, then the chopper is out of balance.

Transfer of the Measurement Test Data Block

The measurement test data block can only be read from the 1306 by the control station. Fig. 4.6 shows the procedure. The control station sends a message containing the instruction byte '00000010'. The 1306 then returns a message containing the instruction byte, the measurement test data block (Table 4.4) and also the error status flags. These flags are described in detail in Section 4.7.

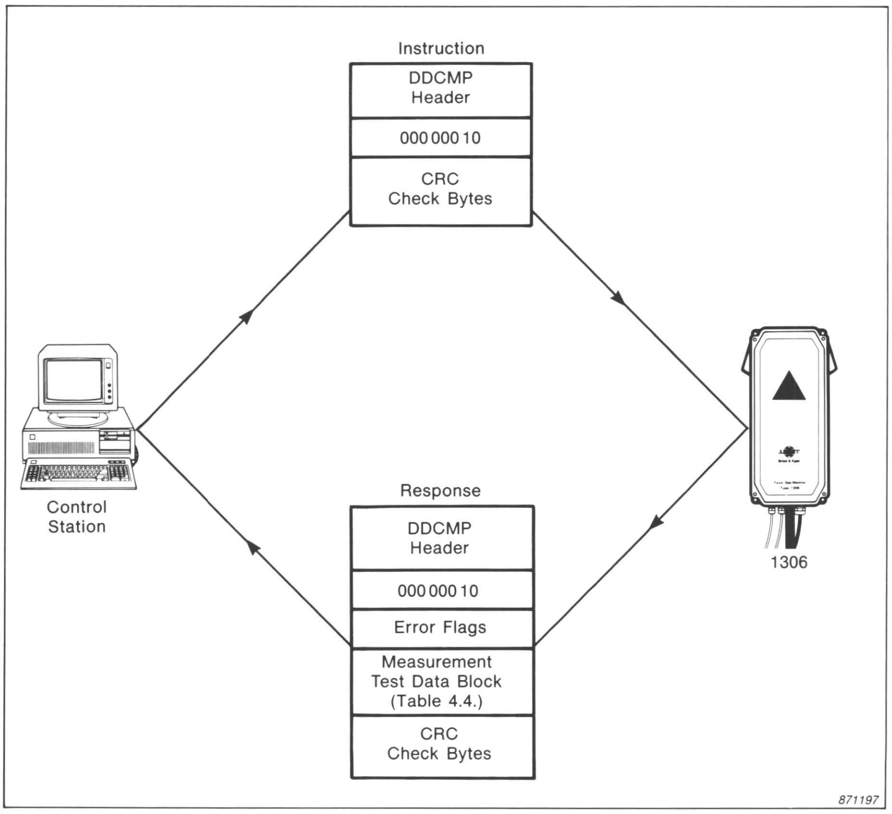

Fig. 4.6. Reading the measurement test data block from the 1306

4.4.4. Software Test Data Block

Byte No. (Hex.)	Data
00	Memory test time-out
01	ADC driver time-out
02	Concentration measurement time-out
03	Not used
04	Vibration measurement time-out
05	Not used
06	Not used
07	Transducer test time-out
08	Not used
09	Secondary measurements time-out
0A	DDCMP time-out
0B	Not used
0C 0D	Software error address
0E to 2D	Monitor identification text (32 bytes)
2E 2F	Software identification

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Table 4.5. The software test data block

This data block can be used by service personnel to locate possible errors in the software. It shows if any of the individual tasks performed by the 1306 has been active or passive for a long time, and also the address of any errors in the software.

Each of the 1306's individual tasks has a counter associated with it, known as a time-out counter. When each task begins, the appropriate time-out counter is preset to a value dependent on how frequently the task should be performed. All the counters are then decreased by one every 30 seconds. If any of them reaches zero, then the 1306 is reset, the soft error flag is set and the 1306 stops operating. To resume operation, send control data.

The software test data block shows the value of each of the time-out counters, and also the address of any software error which has occurred. Table 4.5 shows the format of the data block, while Table 4.6 shows the preset values of each of the counters.

Time-out Values

Time-out	Preset Value (decimal)	Preset time (mins.)
Memory test	4	2
ADC driver	10	5
Concentration measurement	222	111
Vibration measurement	10	5
Transducer test	65	32,5
Secondary measurements	10	5
DDCMP error	3	1,5

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Table 4.6. Preset values of the time-out counters

Transfer of the Software Test Data Block

The software test data block can only be read from the 1306 by the control station. Fig. 4.7 shows the procedure. The control station sends a message containing the instruction byte '00000011'. The 1306 then returns a message containing the instruction byte, the software test data block (Table 4.5) and also the error status flags. These flags are described in detail in Section 4.7.

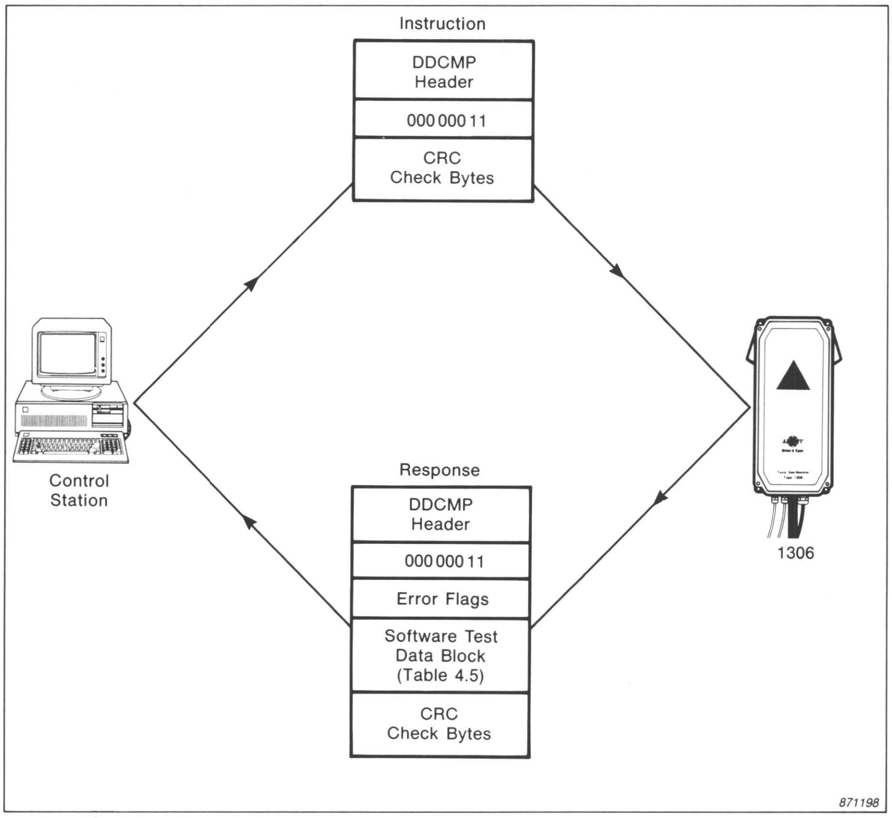

Fig. 4.7. Reading the software test data block from the 1306

4.4.5. Access External Ports

These instructions are provided to allow modifications to the 1306 by Brüel & Kjær Systems Development Department. It is possible to insert an extra circuit board into the 1306, which you can then communicate with using these instructions.

Two external ports are available, each of which has 8 possible addresses. The fifth bit of the instruction byte selects which of the two bytes is accessed. The last 3 bits select one of the 8 addresses within each port. You can read a data byte from each address, or write one to it. Read or write is selected by the first bit of the instruction byte: 0 = read, 1 = write.

The procedures for writing data to an external port, and reading data from it, are shown in Figs. 4.8 (a) and 4.8 (b) respectively.

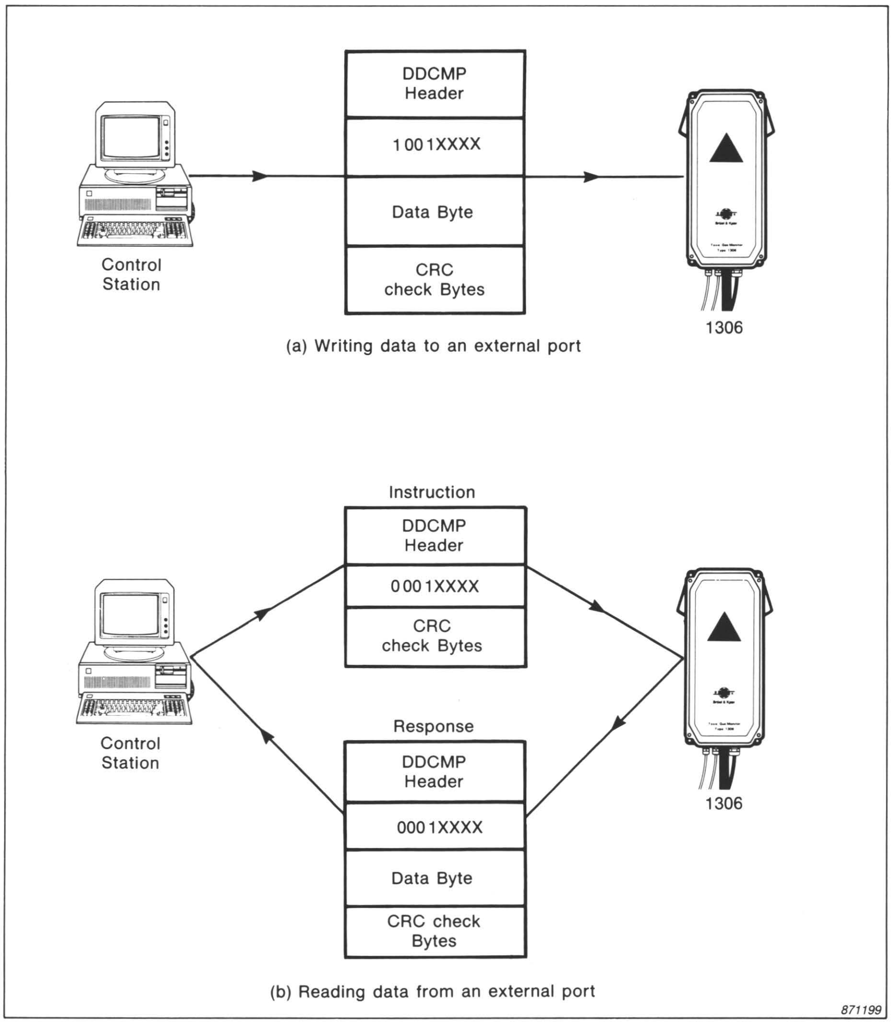

Fig. 4.8. Transferring data to and from an external port

4.5. COMMANDS TO THE 1306

4.5.1. Forced Commands

When operating normally (in normal, intensification or alarm mode), the 1306 makes gas concentration measurements and self-tests fully automatically. However, you can stop or start its operation, reset it, or force it to make a measurement by sending forced commands.

When the 1306 receives one of these commands it stops its normal operation and executes the command immediately. Once one of these commands has been sent, it is not possible to stop its execution, except with another forced command — see Section 4.5.3.

All commands are one byte long. Each command is listed below with the appropriate value of the command byte, in hexadecimal code.

1. **Power up / power down commands**

   These two commands are used to stop and start the operation of the 1306.

   00H Go into power-down mode.

Stop gas concentration measurements and *regular self-tests.*

01H Go into power-up mode.

Return to normal operation. If a *regular self-tests* would normally have been carried out during the time the 1306 was in power-down mode, then this test is started immediately after power-up. If the test is satisfactory, then a gas concentration measurement is automatically started. If no test is necessary (because the 1306 has been in power-down mode for less than 30 minutes), then a gas concentration measurement is started immediately after power-up.

2. Force a measurement

These four commands can be used to complete a measurement which would normally be aborted due to an error. Forced measurements cause the error status flags to be updated normally, but are unaffected by them. Therefore the 1306 cannot determine the measurements' quality or take protective action if required. If you make a forced measurement, you must take full responsibility for assessing its quality.

03H Force a gas concentration measurement

04H Force a vibration-noise measurement

05H Force a *regular* self-test.

06H Force an air humidity measurement

3. Reset the 1306.

07H Reset the 1306, that is, execute the start-up sequence

This command causes the 1306 to follow the same start-up sequence as it does when power is switched on. The sequence is:

1. Check the processor system and clear the results of the 1306's last measurement and self–test sequences from memory.
2. Carry out a hardware test, if enabled, and update the hardware status byte in the measurement test data (see Section 4.4.3).
3. Perform the *almost continuous* self-tests (see Section 2.7.1.).
4. If they are in order, perform the *regular* self-tests (see Section 2.7.2.).
5. If they are in order, perform the *gas-measurement sequence* self-tests (see Section 2.7.3.)

If all the tests are in order, start a gas concentration and a air humidity measurement and continue in normal, intensification or alarm mode, as appropriate.

Communication with the 1306 can begin after the start of the *almost continuous* self-tests, and the control data can then be sent.

4.5.2. Test Commands.

These commands are for test use. They enable service personnel to follow the operation of the 1306 more closely by stopping at a specific point, or by making a measurement or test one step at a time.

Test commands do not have immediate effect. When the 1306 receives a test command, it stores it in memory and continues operating normally until it has completed the operation specified by the command. At this point the 1306 either stops operating or repeats the specified operation continuously, until it receives another command (commands labelled **R** in the list below are repeated).

During normal operation the 1306 makes each measurement or test by carrying out the specified operations sequentially in the order given. The operation currently being performed is read out as **Test sequence number** in the measurement test data.

The last test command received by the 1306 is read out as **Test stop number** in the measurement test data block (see Section 4.4.3).

You can stop the 1306 operating for approximately five minutes using these commands. You can also make a measurement or test one step at a time, by sending test commands sequentially one after the other. After approximately five minutes, the time-out counters will automatically cause the 1306 to reset (see Section 4.4.4). The soft error flag is then set, and the 1306 stops operating. To return to normal operation, send control data, which clears the soft error flag. You cannot stop the execution of a forced measurement with a test command — see Section 4.5.3.

Sending one of the command bytes **10H, 20H** or **30H** causes the 1306 to return to normal operation. These commands have no effect unless a test command has previously been sent.

A list of test commands is given below. Users who wish to use these commands are advised to buy the Service Manual for the 1306 which gives a fuller description of each command.

Environmental Measurement

11H Temperature measurement
12H Power supply measurement
13H Spare ADC voltage measurement

When these operations are carried out during normal operation of the 1306, they have no effect on the **Test sequence number** in the measurement test data block. They only cause the **Test sequence number** to be updated if one of the above test commands has been given, causing the 1306 to stop operating at this point.

Vibration Measurement

15H Vibration measurement started, 20 Hz filter started
16H Vibration measurement active
17H Vibration measurement completed

Humidity measurement

19H		Humidity measurement started, 20 Hz filter started
1AH		Humidity measurement active
1BH		Humidity measurement completed
1CH		Humidity data update

Concentration measurement

21H		Concentration measurement started
22H		Valves open, pumped started, IR lamp on
23H		Pump running, IR lamp on
24H		Pump stopped, valve 1 closed
25H		Valve 2 closed
26H	*	Concentration measurement by software triggering
27H		Concentration measurement by index pulse triggering
28H		Concentration calculation started
29H		Concentration calculation complete
2AH		IR lamp off, chopper stopped
2BH		Concentration measurement complete
2CH		Continuous measurements, loops from **22H to 28H**
2DH		Continuous measurements of the same sample, loops from **25H to 28H**

* **Note:** The operation specified by command **26H** is not executed during normal operation of the 1306, or when the loop commands **2CH** or **2DH** are executed. During normal operation the ADC is triggered by a pulse generated by a detector sensitive to IR light (command **27H**). If this pulse is not available due to a fault, then the AD converter operating-error flag is set and the measurement is terminated. If a forced measurement is then ordered, it is made by triggering the ADC from a pulse generated by the software (command **26H**).

Pnuematic and chopper-noise tests

31H		Measurement task started
32H	R	Valves open (pressure transducer offset measurement)
33H	R	Pump started (air filter measurement)
34H	R	Valve 1 closed (valve 1 pressure test)
35H		Stop pump (normal run-down)
36H	R	Valve 1 open, valve 2 closed (valve 2 pressure test)
37H		Stop pump abruptly (to test air shunt)
38H		Close valves
39H	R	Measure generator signal (microphone 1 amplifier test)
3AH	R	Measure microphone received signal (microphone 2 acoustic test)
3BH		ADC interrupt test
3CH		Check all ADC bits can be set to 0
3DH		Check all ADC bits can be set to 1
3EH	R	Start chopper, measure chopper noise
3FH		Stop chopper, test sequence complete

Return to normal operation

10H **20H** **30H**

4.5.3. Order of Priority of Commands

The commands described in the previous two sections have different orders of priority. The commands are listed below in their approximate order of priority.

Command No.	Description	
07H	Reset (highest priority)	
03H		Force a gas concentration
04H	Forced	Force a vibration-noise measurement
05H	measurements	Force a regular self-test
06H		Force an air-humidity measurement
01H	Power up	
00H	Power down	
11H to **3FH**	Test commands (lowest priority)	

The reset command **07H** has the highest priority. The forced-measurement commands **03H, 04H, 05H and 06H** have roughly equal priority. There are, however, slight differences which are explained below:

Command **03H** can be interrupted by commands **04H** and **05H**
Command **04H** can be interrupted by commands **03H**, **05H** and **06H**
Command **05H** can be interrupted by commands **03H**, **04H** and **06H**
Command **06H** can be interrupted by commands **04H** and **05H**

A forced gas concentration measurement **03H** includes an air-humidity measurement **06H** , and so these two commands do not interrupt one another. Once a forced measurement command (**03H, 04H, 05H and 06H**) has been sent to the 1306, it can only be stopped by the reset command **07H**, or by another forced measurement command which has higher priority.

The power-up command **01H** and the power-down command **00H** have equal priority. If a forced measurement is ordered while the 1306 is in power-down mode, then it will return to power-up mode and execute the forced measurement and then return to power-down mode.

Test commands have the lowest priority, and they cannot stop the execution of any forced measurement commands.

4.5.4. Transfer of Commands

The computer can send a command to the 1306, or it can read back the previous command.

To send a command to the 1306, the control station sends a data message containing the instruction byte 11000000, followed by the byte 00H, followed by the command byte. This is shown in Fig. 4.9 (a).

To read the previous command, the control station sends a data message containing only the instruction byte 01000000. The 1306 then returns a data message containing the instruction byte, followed by the byte 00H, followed by the command byte. This is shown in Fig. 4.9 (b).

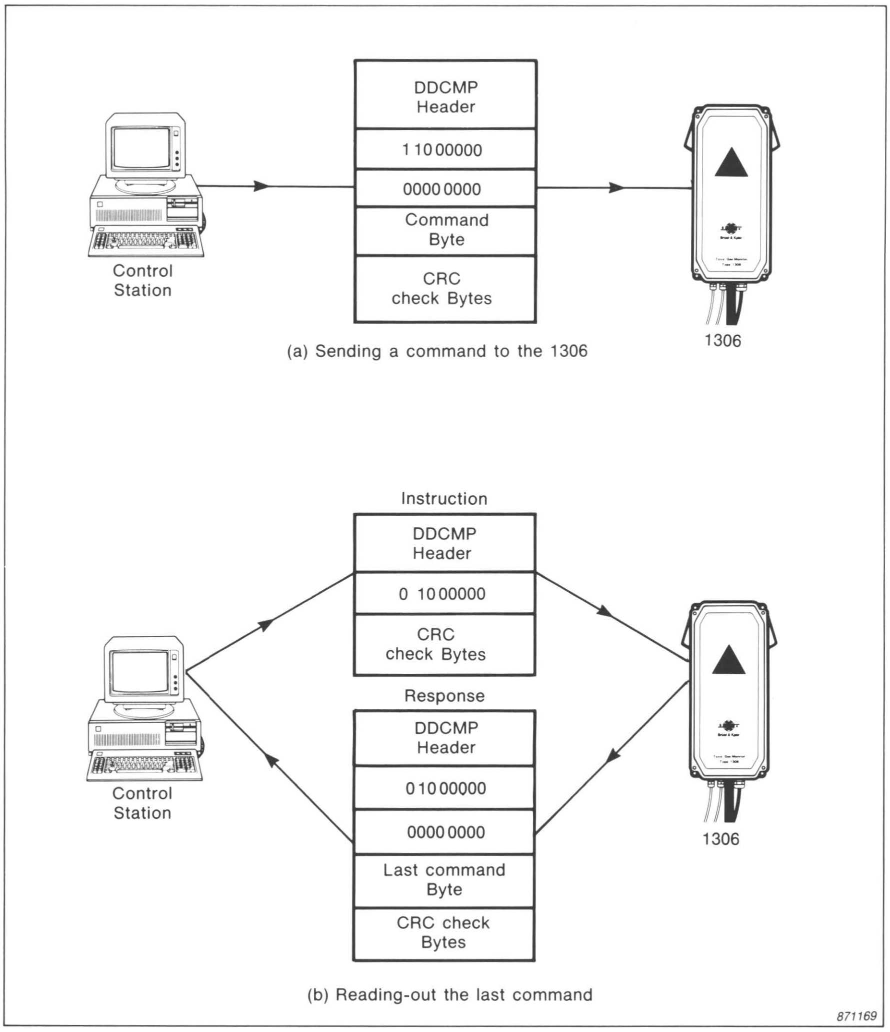

Fig. 4.9. Transferring commands to and from the 1306

4.6. EEPROM DATA

EEPROMs (Electrically Erasable Programmable Read Only Memories) are used by the 1306 to store data which is normally fixed in the 1306. The EEPROMS contain various data as shown in Fig. 4.1. Most of this data is fixed — the only data which normally needs to be changed is the optical filter factors, the optical filter identity and calibration factors, as described below.

4.6.1. Optical Filter Factors

These have to be changed when changing the optical filter. Table 4.7 shows the format of the optical filter factors. Correct values for each factor are supplied with the filter.

Reading-out the optical filter factors

To read out the filter factors, the computer sends a data message containing the instruction byte 011 01010. The 1306 responds by sending a message containing the instruction byte, and the filter factors in the format shown in Table 4.7. The last two data bytes read-out are an extra CRC check sum. This can be ignored.

Fig. 4.10 (a) shows the procedure for reading out the filter factors.

Byte No. (Hex.)	Optical Filter Factors
00 01 02 03	**T_b** (= Back temp. factor)
04 05 06 07	**T_f** (= Conc. temp. factor)
08 09 0A 0B 0C	**T_1** (= Hum. temp1 factor)
0C 0D 0E 0F	**T_2** (= Hum. temp2 factor)
10 11 12 13	**T_3** (= Hum. temp3 factor)
14 15 16 17	**k_2** (= Hum. sqr. factor)
18 19 1A 1B	**k_3** (= Hum. cub. factor)
2C 2D	2 CRC Bytes

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Table 4.7. Optical filter factors in the EEPROM

Changing the optical filter factors

To change the filter factors, the computer sends a data message containing the instruction byte 11101010, followed by the data, in the format shown in Table 4.7. The last 2 bytes of the data consist of an extra CRC check sum. This check sum is calculated as described in Section 4.6.4., and must be correct for the data to be accepted. If the CRC sum is not correct, then the 1306 returns the command byte FF H, indicating that the data could not be changed.

Fig. 4.10 (b) shows the procedure for changing the filter factors.

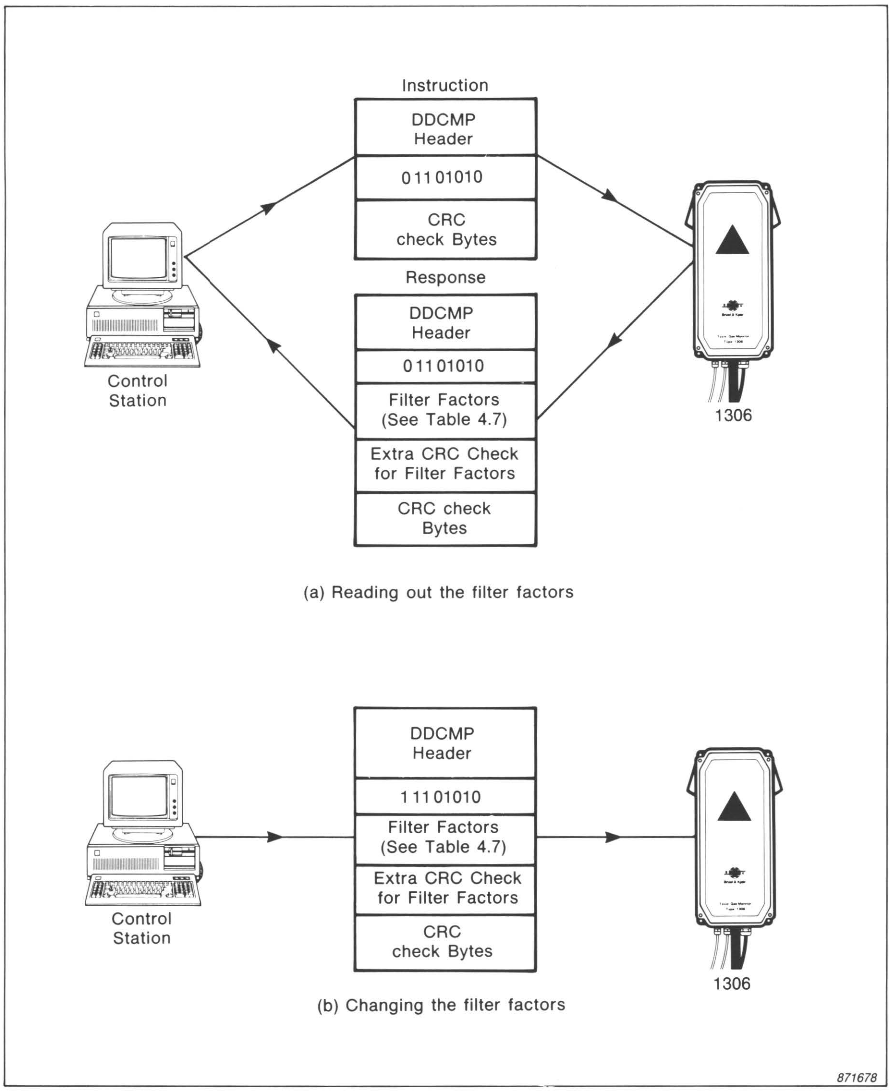

Fig. 4.10. Reading-out and changing the optical filter factors

4.6.2. Optical Filter Identity

These have to be changed when changing the optical filter. Table 4.8. shows the format of the optical filter identity block in the EEPROM. The 32 bytes of filter text can be used for storing general information (for example which optical filter has been installed, and when it was installed) or for storing a back-up copy of the filter factors (see Section 4.6.1.). The text in this block has no effect on the operation of the 1306.

Reading out the filter identity

To read out the filter identity, the computer sends a data message containing the instruction byte 01100001. The 1306 responds by sending a message containing the instruction byte, and the filter identity in the format shown in Table 4.8. The last two data bytes read-out are an extra CRC check sum. This can be ignored.

Fig. 4.11 (a) shows the procedure for reading out the optical filter identity.

Byte No. (Hex.)	Optical Filter Identity
00 to 1F	Filter text
20 21	2 CRC Bytes

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Table 4.8. Optical filter identity in the EEPROM

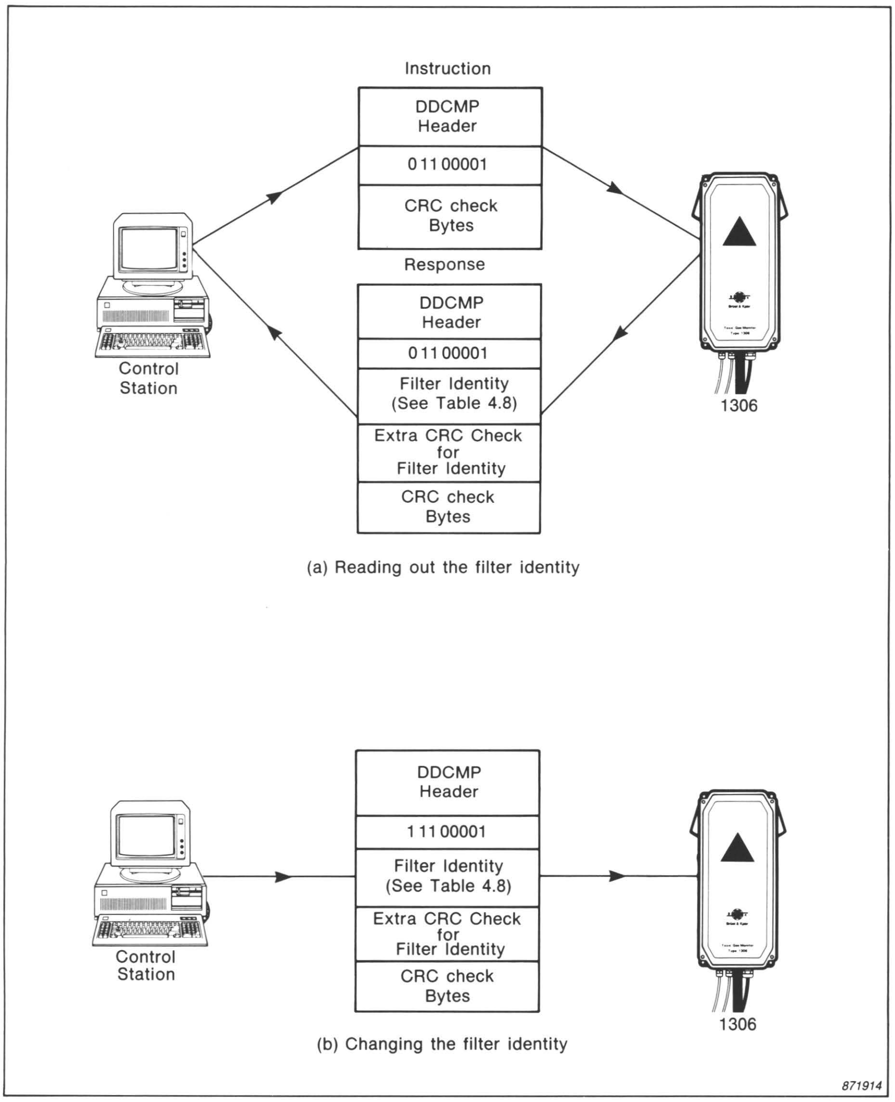

Fig. 4.11. Reading-out and changing the optical filter identity

Changing the filter identity

To change the filter identity, the computer sends a data message containing the instruction byte 11100001, followed by the data, in the format shown in Table 4.8. The last 2 bytes of the data consist of an extra CRC check sum. This check sum is calculated as described in Section 4.6.4., and must be correct for the data to be accepted. If the CRC sum is not correct, then the 1306 returns the command byte FF H, indicating that the data could not be changed.

Fig. 4.11 (b) shows the procedure for changing the filter identity.

4.6.3. Calibration Factors

These have to be changed when calibrating the 1306.

A single monitor can be calibrated using an IBM type XT, AT or PS/2 computer, and the program called `calibm.com` contained on the B & K Applications Diskette BZ 5003 supplied with the 1306. The use of this program is described in Volume 2 — Installation & Maintenance. All the necessary calculations are done automatically by the program.

If you have a system containing several monitors, and you wish to calibrate them without disconnecting them from the system, or if you wish to use a different type of computer, then you need to write your own calibration program. You then need to calculate the calibration factors, as described in Chapter 5.

Table 4.8 shows the format of the calibration factors. The meaning of each individual factor is explained in detail in Chapter 5.

Byte No. (Hex.)	Calibration Factors
00 01 02 03	C_{offset} (= Conc. offset)
04 05 06 07	f_c (= Volt to mg/m^3)
08 09 0A 0B	g_f (= Hum. gain factor)

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Table 4.9. Calibration factors in the EEPROM

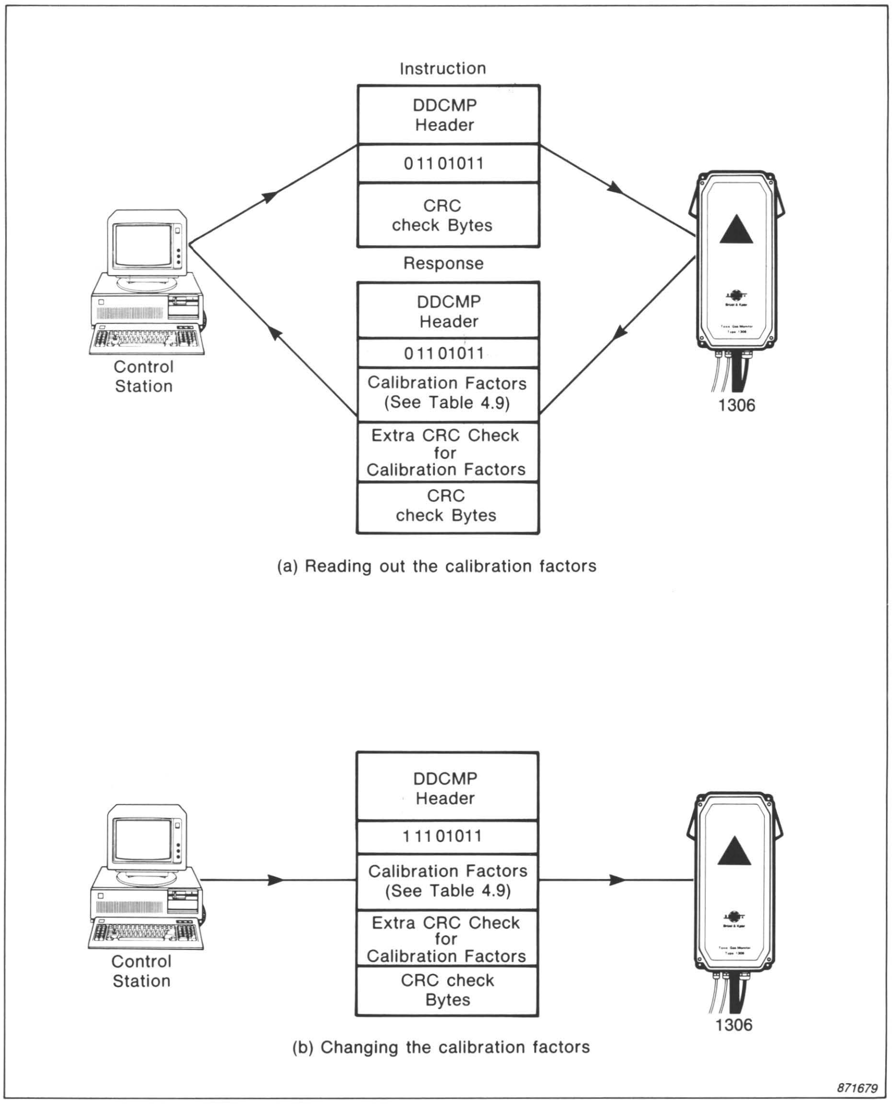

Fig. 4.12. Reading-out and changing the calibration factors

Reading-out the calibration factors

To read out the calibration factors, the computer sends a data message containing only the instruction byte 01101011. The 1306 responds by sending a message containing the instruction byte and the calibration factors, in the format shown in Table 4.8. The last two data bytes consist of an extra CRC check sum. This can be ignored.

Fig. 4.12 (a) shows the procedure for reading out the calibration factors.

Changing the calibration factors

To change the calibration factors, the computer sends a data message containing the instruction byte 11101011, followed by the calibration factors, in the format shown in Table 4.8. The last 2 bytes of the data consist of an extra CRC check sum. This check sum is calculated as described in Section 4.6.4., and must be correct for the data to be accepted. If the CRC sum is not correct, then the 1306 returns the command byte FF H, indicating that the data could not be changed.

Fig. 4.12 (b) shows the procedure for changing the calibration factors.

4.6.4. Calculating the CRC Check Sum

The CRC check sum is calculated in exactly the same way as the CRC check sum used in data transmission. The data bits to be transmitted are considered as the coefficients of a polynomial, which is then repeatedly divided by the CRC generator polynomial until a 16-bit remainder is left. This remainder forms the two CRC check bytes. The generator polynomial used is:

$$x^{16} + x^{15} + x^2 + 1$$

This is a standard method known as CRC-16. It is widely used in other systems, and is described more fully in Appendix C of the DDCMP standard, available from Digital Equipment Corporation. Two practical methods of implementing the system are described below.

Hardware method

The CRC sum can be calculated using a circuit containing Exclusive-OR (EXOR) gates and shift registers, as shown in Fig. 4.13.

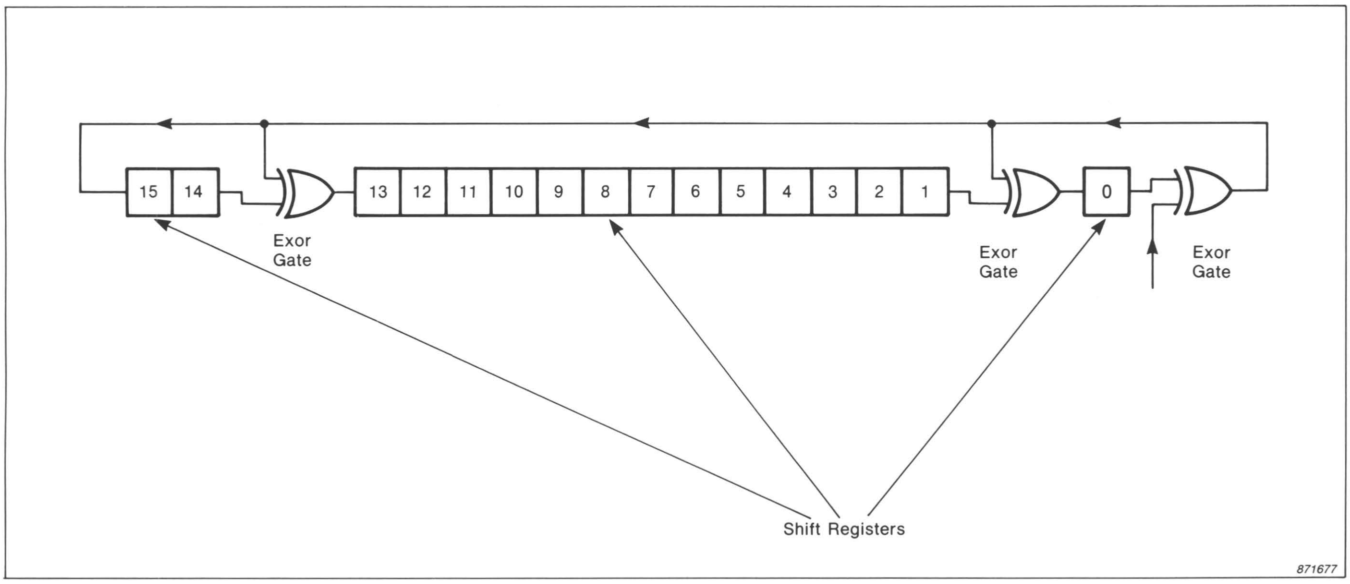

Fig. 4.13. Circuit containing Exclusive-OR(EXOR) gates & shift registers

Before data is sent, all bits in the shift registers are set to '0'. As each data bit is transmitted, it is simultaneously applied to the data input on the right of the diagram, and all the bits in the shift register are shifted one place to the right. As this process is repeated, the bits in the shift register change, not only in response to new data bits, but also in response to earlier bits which are fed back to the left of the shift register by the EXOR gates. Thus the contents of the shift registers at any time depend both on the current state of the input and on all the previous inputs. When all the data bits have been transmitted and fed to the input of the circuit, the 16 bits remaining in the shift registers form the 2-byte CRC check sum.

When receiving data, the same circuit can be used. As the incoming data bits arrive, they are fed to the circuit's data input. When all the data bits have been input to the circuit, the contents of the shift registers should be the same as the received CRC check bits. These received CRC check bits are then fed to the circuit's input, where the EXOR gate compares each bit of the received check sum with the corresponding bit of the generated check sum. If there have been no errors, all the bits will be the same. Since an EXOR gate produces an output of '0' whenever both its outputs are the same, the output of the EXOR gate on the right will always be '0'. Thus a series of zeros will be fed through the circuit, and when all the CRC check bits have been received, all the bits in the shift registers should be '0'. If they are not, then an error has occurred in the data transmission.

Software method

The CRC sum can be calculated using a software algorithm. A routine which makes the calculation is included on the Applications Diskette BZ 5003, which is supplied with the 1306. The routine is written in IBM turbo-PASCAL, but could be modified for a computer which runs a different version of PASCAL.

The routine is implemented as a function, called 'CRC'. The source code is listed in the program DDCMP.INC. To call the function, the name 'CRC' is used in the same way as a normal variable name. It must be followed by two input parameters — an array containing the data bytes and an integer giving the number of data bytes. The routine then returns a 2-byte word variable which is the calculated CRC check sum.

The program CAL1306.PAS, which is also on the diskette BZ 5003, includes calls to the function which illustrate how it is used by the main program.

4.7. ERROR STATUS FLAGS

Whenever measurement or test data is read-out from the 1306, as described in Section 4.4, then the error status flags are also read-out. These flags are also referred to as the status report. They consist of two bytes of data which give information about the condition of the monitor and the reliability of the measurement. This information is the result of the self-tests which the monitor carries out at regular intervals, as described in Chapter 2.

The first byte of the error status flags consists of eight **warning flags**. If any of these flags is set to '1'. then all measurements and tests will be continued as normal. However, the flag indicates an error or abnormal condition which may affect the reliability of the measurements. Table 4.10 lists the warning flags, and gives a brief description of each one. Chapter 2 describes the self-tests in detail, and indicates the reliability of the measurement and the action to be taken if any of the warning flags is set to '1'.

The second byte consists of eight **operating-error flags**. If any of these flags is set to '1', it indicates that the 1306 was unable to make measurements or tests reliably, and so went into power-down mode. This could be caused by an internal error in the 1306 or by an abnormal external environment. Table 4.11 lists the flags, and gives a brief description of each. Chapter 2 describes the self-tests in detail, and suggests action to be taken if any of the flags is set to '1'.

Unless otherwise indicated in the tables, all the flags are set to '0' when power to the 1306 is switched on, and when the 1306 is reset. Some flags are also reset to '0' when control data is sent to the 1306. These are also indicated in the tables.

If the error status flags indicate an error, then the measurement test data block can give more information about the cause of the error. This data block is described in Section 4.4.3.

WARNING FLAGS	
Bit No.	**Name and description of the flag**
0 (LSB)	**Old Measurement** No new measurements have been made since the last read-out. This flag is set to '1' when measurement data is read-out, and reset to '0' when a new measurement is made.
1	**Extra Measurement** When making an initial measurement to determine the gain setting, the gas concentration was found to be either greater than the intensification level, or less than zero.
2	**Humidity Lamp** There is no current through the humidity lamp, indicating a fault.
3	**Air Shunt Blocked** With one valve closed, the pressure across the air shunt was decreasing too slowly after the pump stopped.
4	**Air Filter** Either one of the air filters is blocked, or the fine air filter has not been mounted correctly.
5	**Background Noise** The signal measured due to background noise (either chopper or vibration noise) is greater than half the total signal measured when the I.R. source is on.
6	**Lid Opened** The 1306's lid has been opened. This flag is set to '0' when control data is sent to the 1306.
7 (MSB)	**Reset** The 1306 has been reset, or there has been a power failure or software error. This flag is set to '0' when control data is sent to the 1306.

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Table 4.10. The warning flags. Bit 7 is the most significant bit, bit 0 is the least significant bit

OPERATING-ERROR FLAGS	
Bit No.	**Name and description of the flag**
0 (LSB)	**Software Error** A detected error in the software and/or the processor system, will cause this flag, and the "reset" warning flag, to be set (to"1"). This flag can be removed by sending control data to the 1306.
1	**Pump Error** The pressure difference across the pump is too low. There is a fault in either the pump or one of the valves.
2	**Microphone Error** There is an error in one of the microphones or preamplifiers. This flag is set to '0' when control data is sent to the 1306.
3	**Infra-red Source** The intensity of light from the infra-red source is either too low or too high.
4	**Chopper Frequency** The chopper is not running at the correct speed.
5	**Power Supply** The power supply voltage to the 1306 is either too low or too high.
6	**Temperature** The temperature inside the measurement chamber is too low or too high
7 (MSB).	**ADC error** The output of the analogue to digital converter (ADC) cannot be set to either its maximum or its minimum value (all bits '0' or all bits '1').

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Table 4.11. The operating-error flags. Bit 7 is the most significant bit, bit 0 is the least significant bit

5. CALCULATION OF CALIBRATION FACTORS

5.1. INTRODUCTION

Two Applications diskettes BZ 5003 are provided as accessories with the 1306. These diskettes contain exactly the same programs but differ in size. The 5 1/4 inch diskette is for use with either an IBM XT or an IBM AT computer, and the 3 1/2 inch diskette is for use with an IBM PS 2 computer. These diskettes contain several programs, one of which makes it possible to calibrate any single 1306 provided that it is connected to an AT/XT/PS 2 personal computer, and its address switch is set to 1.

The calibration program will automatically collect measurement data from the the 1306 during the calibration procedure. It will automatically calculate the new values of the calibration factors, compare them with the old values, and insert the new values into the EEPROM of the 1306 if requested to do so. A full description of the calibration procedure can be found in Volume 2 of this manual.

Software is available from Brüel & Kjær (Software for Toxic-gas Monitoring Type 7619) which enables *in situ* calibration of up to 31 Toxic-gas Monitors in a monitoring system. This software can be run on AT and PS 2 type IBM computers. Users who wish to use another type of computer to control their system, will have to write their own software to enable *in situ* calibration of monitors. This chapter provides all the necessary information to enable users to write their own calibration program.

5.2. ANALYSIS OF THE SIGNAL MEASURED IN THE ANALYSIS CELL

The signal measured in the analysis cell when the I.R. light source is on is a combination of the following signals:

- the signal produced by the absorption of IR light by the gas
- the signal produced by the absorption of IR light by water vapour
- the cell noise — this signal is produced by the imperfect reflection of light from the walls of the analysis cell. The absorption of light energy by the walls of the cell causes an increase in temperature, and therefore pressure, in the cell — thus contributing to the total signal measured.

These signals are all dependent upon the temperature of the air in the analysis cell. Therefore, the signal measured during a gas measurement has to be corrected for its temperature dependence, as well as for cell noise, and the signal produced by the absorption of the IR light by the water vapour in the cell.

5.3. CALCULATION OF THE GAS CONCENTRATION

The formula used to calculate the final concentration of the gas in the cell is:

$$\text{Final Conc.} = \Big[C_m - \big[C_{\text{offset}}\{(t_c - 293.3)\mathbf{T_b} + 1\}\big] - g_f\big[H_m\{(t_c - 293)\mathbf{T_1} + 1\} + H_m^2\mathbf{k_2}\{(t_c - 293)\mathbf{T_2} + 1\} + H_m^3\mathbf{k}_3\{(t_c - 293)\mathbf{T_3} + 1\}\big]\Big] \big[(t_c - 293)\mathbf{T_f} + 1\big]\big[f_c\big] \quad (1)$$

This formula can be represented simply as:

$$\text{Final Conc.} = \big[C_m - N_v - W_s \big]\big[T_{cf} \big]\big[f_c \big] \quad (2)$$

Where:

C_m = total signal measured in the analysis cell when the IR light is on
= Raw Gas Value (in the measurement test data)

N_v = is the cell noise

$$= \big[C_{\text{offset}}\{(t_c - 293.3)\mathbf{T_b} + 1\}\big] \quad (3)$$

W_s = water-vapour's signal contribution

$$= g_f\big[H_m\{(t_c - 293)\mathbf{T_1} + 1\} + H_m^2\mathbf{k_2}\{(t_c - 293)\mathbf{T_2} + 1\} + H_m^3\mathbf{k_3}\{(t_c - 293)\mathbf{T_3} + 1\}\big] \quad (4)$$

T_{cf} = $\big[(t_c - 293)\mathbf{T_f} + 1\big]$ = temperature compensation factor (5)

f_c = volt to mg/m^3 conversion factor

The various constants and variables used in the calculation of the final concentration of the gas are listed below:

Constants:

The following constants are dependent upon the optical filter installed in the 1306, and are stated on the chart supplied together with the optical filter. These constants are also stored in the Filter Factors block of the EEPROM of the 1306 (see Fig. 4.7) and can be read out (see Section 4.6.1.):

$\mathbf{T_b}$ = **back temp.factor**
temperature coefficient using a dry zero-gas

$\mathbf{T_f}$ = **Conc.temp.factor**
temperature coefficient using the gas to be monitored (called the calibration gas in the calibration procedure described in Volume 2 of the 1306 manual)

$\mathbf{T_1}$ = **Hum.temp 1 factor**
temperature coefficient describing the linear part of the signal produced by water vapour's absorption

T_2 = **Hum.temp 2 factor**
temperature coefficient describing the second degree part of the signal produced by water vapour's absorption

T_3 = **Hum.temp 3 factor**
temperature coefficient describing the third degree part of the signal produced by water vapour's absorption

k_2 = **Hum.sqr.factor**
second degree factor describing the unlinear relationship between humidity and the measured signal

k_3 = **Hum.cub.factor**
third degree factor describing the unlinear relationship between humidity and the measured signal

Variables:

After each stage of the calibration procedure the following variables can be read from the measurement test data block:

C_m = the total signal measured in the analysis cell when the I.R. light is on
= Raw Gas Value (in measurement test data)

H_m = the signal measured in the analysis cell when the humidity lamp is on
= Raw Humidity Value (in measurement test data)

t_c = the temperature of the air in the cell during a gas measurement
= Temperature (in measurement test data)

Calibration Factors (variables):

When the 1306 is calibrated initially by Brüel &Kjær these calibration factors are calculated from the measurement results recorded during the calibration procedure, and they are then stored in the Calibration Factors block of the EEPROM (Electrically Erasable Programmable Read Only Memory) of the 1306 (see Fig. 4.9). They can be read out (see Section 4.6.3).

The relationship between the total signal measured in the cell with the infra-red light on (C_m), the total signal measured in the cell with the humidity lamp on (H_m), the cell noise (N_v) and water-vapour's signal contribution (W_s) is illustrated in Fig. 5.1.

When the 1306 is calibrated again, new values of these factors have to be calculated and are used to replace those values already stored in the 1306's EEPROM (see Section 5.6.).

C_{offset} — the normalised cell noise using dry zero-gas
= **concentration offset factor**

g_f — the factor describing the dependence of the measured signal on the amount of water vapour in the analysis cell
= **humidity gain factor**

f_c — the volt to mg/m^3 conversion factor
= **conversion factor**

Practical details of the calibration procedure are fully described in Volume 2 of this manual. Using the measurement results recorded during the calibration procedure, new calibration factors can be calculated. The following section describes the calculation of these factors.

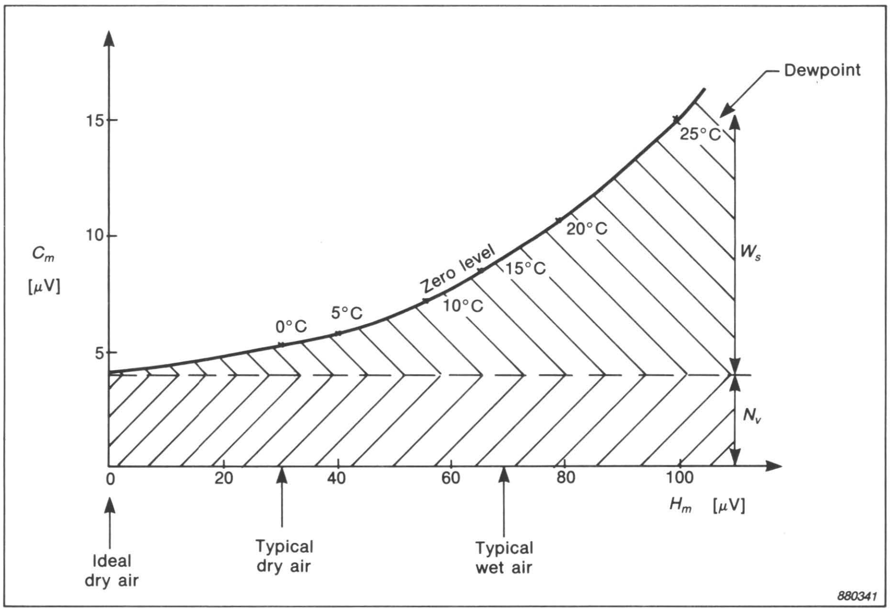

Fig. 5.1. Graph showing the relationship between the Raw Gas Value (C_m), Raw Humidity Value (H_m), cell noise (N_v) and water-vapour's signal contribution (W_s)

5.4. CALCULATION OF THE NEW CALIBRATION FACTORS

5.4.1. Calculation of the New Concentration Offset Factor (C_{offset})

During the calibration procedure a dry zero-gas (for example pure nitrogen which contains no water vapour) is supplied to the monitor and gas measurements are made until the gas concentration measured by the monitor stabilises. The measured signal is only produced by the cell noise — the gas does not absorb I.R. light and therefore does not produce a signal. In practice, the dry zero-gas used is seldom completely dry (see Fig. 5.1) and therefore the water vapour in it also contributes to the total signal measured in the cell when the infra-red light is on.

Using equation (2):

$$\text{Final Conc.} = \left[C_m - N_v - W_s \right] \left[T_{cf} \right] \left[f_c \right] = 0 \text{ (zero-gas)}$$

and substituting the known values:

$$C_m = N_v + W_s = C_{m(\text{dry zero-gas})}$$

Thus:

$$C_{m(\text{dry zero-gas})} - W_s = C_{\text{offset}} \left[(t_c - 293.3) \mathbf{T_b} + 1 \right] \tag{6}$$

Thus:

$$C_{\text{offset}} = \frac{C_{m(\text{dry zero-gas})} - W_s}{\left[(t_c - 293.3) \mathbf{T_b} + 1 \right]}$$

Where:

$C_{m(\text{dry zero-gas})}$ — this quantity can be read from the measurement test data = Raw Gas Value

t_c — this quantity can be read from the measurement test data = Temperature

$\mathbf{T_b}$ — this quantity can be read from the Filter Factors block in the EEPROM (see Section 4.5.1.).

W_s — this value can be calculated using equation 4 where:

H_m = the signal measured in the analysis cell when the humidity lamp is on = Raw humidity value (in measurement test data)

and the value of g_f can be read from the calibration factors in the EEPROM of the 1306 and the other constants can be read from the filter factors in the EEPROM of the 1306. Thus the new value of C_{offset} can be calculated.

5.4.2. Calculation of the New Humidity Gain Factor (g_f)

During the calibration procedure a wet zero-gas (for example pure nitrogen which is bubbled through a constant-temperature water bath) is supplied to the monitor and gas measurements are made until the gas concentration measured by the monitor stabilises. The measured signal is produced by the cell noise and the absorption of I.R. light by the water vapour in the cell — the zero-gas does not absorb I.R. light and therefore produces no signal.

Using equation (2):

$$\text{Final Conc.} = \left[C_m - N_v - W_s \right]\left[T_{cf} \right]\left[f_c \right] = 0 \text{ (zero-gas)}$$

Thus:

$$W_s = C_m - N_v$$

$$= C_{m(\text{wet zero-gas})} - C_{m(\text{dry zero-gas})}$$

Where:

$C_{m(\text{dry zero-gas})}$ — this can be calculated from the equation (6) above using the newly calculated value of C_{offset} and the value of t_c read from the measurement test data

$C_{m(\text{wet zero-gas})}$ — this is the Raw Gas Value which can be read from the measurement test data

Thus the value of W_s can be calculated.

Using equation (4) above,

$$W_s = \text{water-vapour's signal contribution}$$

$$= g_f\left[H_m\left\{(t_c-293)\mathbf{T_1}+1\right\}+H_m^2\,\mathbf{k_2}\left\{(t_c-293)\mathbf{T_2}+1\right\} + H_m^3\,\mathbf{k_3}\left\{(t_c-293)\mathbf{T_3}+1\right\}\right]$$

Where:

H_m — can be read from the measurement test data (Raw Humidity Value)

t_c — can be read from the measurement test data (Temperature)

$\mathbf{T_1}$, $\mathbf{T_2}$, $\mathbf{T_3}$, and
$\mathbf{k_2}$, $\mathbf{k_3}$ — can be read from the filter factors in the 1306's EEPROM

Thus the new value of g_f can be calculated.

5.4.3. Calculation of the New Conversion Factor (f_C)

During the calibration procedure a calibration gas (a gas of known concentration to which the 1306 is selective) is supplied to the monitor and gas measurements are made until the gas concentration measured by the monitor stabilises. The measured signal is produced by the cell noise, the water vapour in the cell and the calibration gas.

Using equation (2):

$$\text{Final Conc.} = \left[C_m - N_v - W_s\right]\left[T_{cf}\right]\left[f_c\right]$$

Thus:

$$f_c = \frac{\text{Final conc.}}{\left[C_{m(\text{calib. gas})} - N_v(\text{at } t_c{}^\circ\text{C}) - W_s(\text{at } t_c{}^\circ\text{C})\right]\left[T_{cf}(\text{at } t_c{}^\circ\text{C})\right]}$$

Where:

Final Conc. — is the concentration of the calibration gas

$C_{m(\text{calib. gas})}$ — this is the Raw Gas Value read from the measurement test data

The value of N_v(at t_c°C) can be calculated from equation (3). The value of W_s(at t_c°C) can be calculated from equation (4). The value of T_{cf}(at t_c°C) can be calculated from equation (5).

Where:

C_{offset} — has been newly calculated (see Section 5.3)

g_f — has been newly calculated

$\mathbf{T_1}$, $\mathbf{T_2}$, $\mathbf{T_3}$, and
$\mathbf{k_2}$, $\mathbf{k_3}$ — can be read from the filter factors in the 1306's EEPROM

H_m — this is the Raw Humidity Value read from the measurement test data

t_c — this is the Temperature read from the measurement test data.

Thus the new value of f_c (the volt to mg/m^3 conversion factor) can be calculated.

5.5. COMPARISON OF THE "OLD" AND "NEW" CALIBRATION FACTORS

The "old" values of the calibration factors can be read out from the EEPROM of the 1306 — see Section 4.6.3. Calculation of the "new" values of the calibration factors are described in the previous sections. The percentage change in each factor should then be calculated in the following way:

$$\text{Percentage change in } C_{\text{offset}} = \frac{C_{\text{offset}}(\text{new}) - C_{\text{offset}}(\text{old})}{C_{\text{offset}}(\text{old})} \times 100$$

$$\text{Percentage change in } g_f = \frac{g_f(\text{new}) - g_f(\text{old})}{g_f(\text{old})} \times 100$$

$$\text{Percentage change in } f_c = \frac{f_c(\text{new}) - f_c(\text{old})}{f_c(\text{old})} \times 100$$

The typical and the acceptable percentage change in each calibration factor is shown in Table 5.1.

Calibration Factors	Percentage Changes	
	Typical	Acceptable
C_{offset}	10%	up to 39%
g_f	10%	up to 29%
f_c	3%	up to 19%

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Table 5.1. Typical and Acceptable Percentage Changes in the Three Calibration Factors

Typical Percentage Changes:

If the percentage change in a calibration factor is "typical" the new value of the calibration factor can be accepted without question and inserted in the EEPROM of the 1306.

Acceptable Percentage Changes:

If the percentage change in a calibration factor lies in this region, the new value of the calibration factor should be checked by performing the calibration procedure again with new sources of calibrating gases (perhaps the original gases used during calibration were not analytically pure), and calculating the calibration factors again.

If the percentage change in the calibration factors still lies in this region it could indicate that the analysis cell has been contaminated, in which case it is recommended that the 1306 be serviced.

WARNING!

If the user decides to accept "non-acceptable" percentage changes in the calibration factors he/she should be aware that, although the 1306 will still be able to measure gas concentrations accurately, the lower detection limit of the 1306 will be compromised — that is, the 1306 will not be able to detect very low gas concentrations.

5.6. TRANSFER OF THE NEW CALIBRATION FACTORS TO THE 1306's EEPROM

If the percentage change in the calibration factors falls in the "typical" or "acceptable" regions the new calibration factors can be sent to the calibration factors block in the EEPROM of the 1306. This procedure is explained in detail in Sections 4.6.3. of this manual.

6. SERVICE AND REPAIR

The Toxic-gas Monitor Type 1306 is designed and constructed to provide the user with many years of reliable operation. However, should a fault occur which impairs the correct function of the instrument, the 1306 will automatically go into its power-down mode of operation. For repair consult the separate Service Manual for the 1306 (available on request from Brüel & Kjær), or consult you local Brüel & Kjær service representative. Under no circumstances should repair be attempted by persons not qualified in the service of electronic instrumentation.

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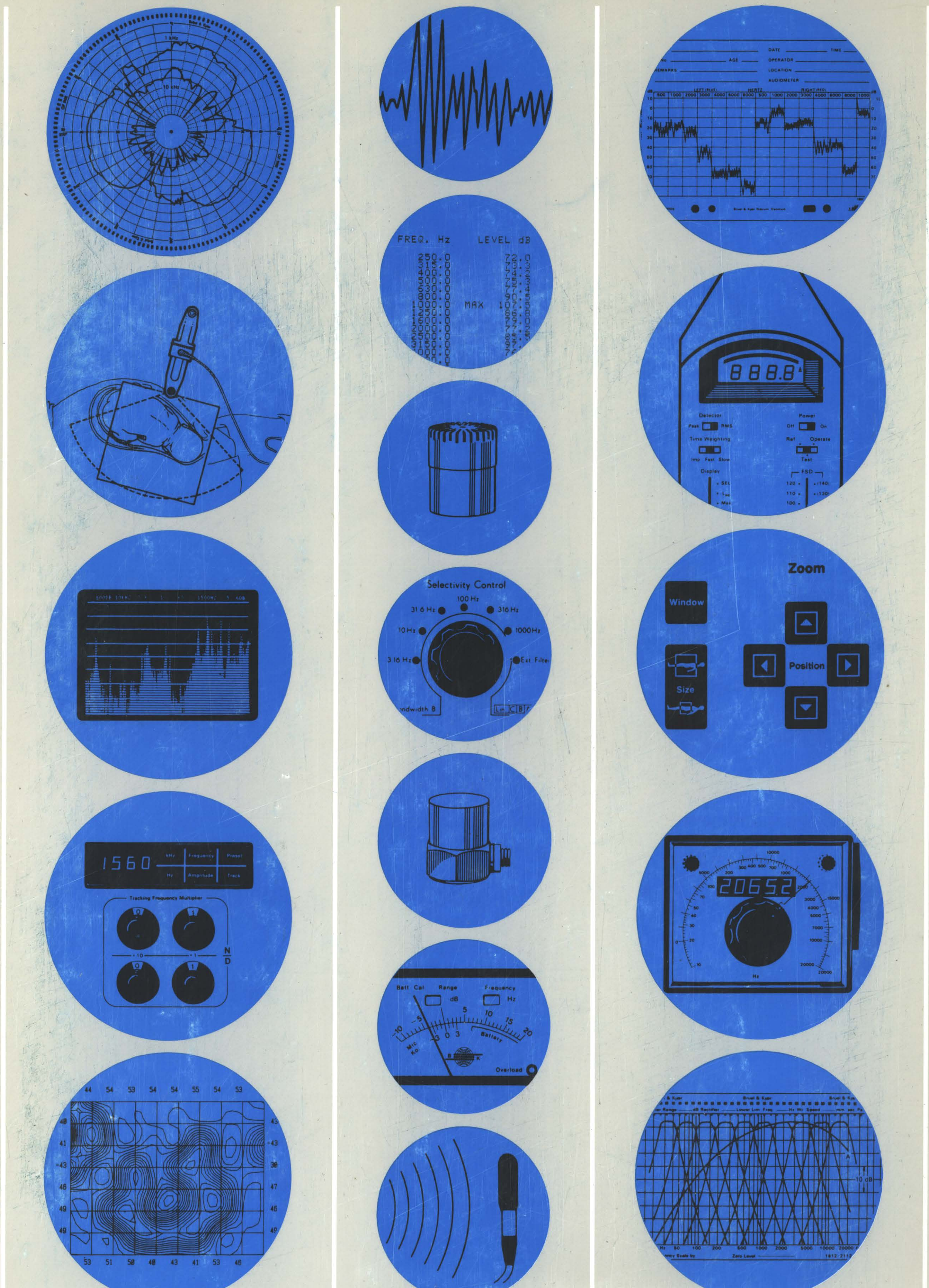

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