METROLAB Instruments SA

PT 2025

NMR TESLAMETER

User's Manual

Version 2.0

(Revision 1.0)

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CONTENTS

1 GENERAL DESCRIPTION

The PT 2025 NMR Teslameter System (Fig. 1) comprises the following:

- Bench-top main unit with RS 232C and (as an option) IEEE-488 interfaces
- At least one NMR probe
- A multiplexer if several probes are required

Each Probe consists of a measuring head and a detection circuit.

Probes model 1060 need an external amplifier (model 1030), the probe cable to the Amplifier is 7m long and the cable of the Amplifier to the PT 2025 may be up to 100 meters long.

Probes model 1062 have the amplifier integrated. They are connected directly to the PT2025. The cable of the probes model 1062 may be up to 100 meters long.

A block diagram of the Teslameter, including Probe and Amplifier, is shown in Fig. 2.

The radio frequency oscillator in the PT 2025 has a frequency range of 30 to 90 MHz, which corresponds to the highest proton resonance field range of 0.7 to 2.1 Tesla. The other field ranges are obtained by dividing the radio frequency (f) by 2, 4, 8 or 16; f/4, f/2 or f being used for the three ^{2}H probes. This results in a very comfortable overlap of the eight field ranges.

An internal frequency counter measures the NMR frequency which is sent to the probe, the result is displayed in Tesla with a resolution of 0.1 μT (1 mGauss) or in frequency with a resolution of 1 Hz.

Fig. 1
Model PT 2025 NMR Teslameter

COARSE frequency adjustment is done manually with a 10 turns potentiometer or via the interfaces.

FINE adjustment of the frequency is done with a second 10 turns potentiometer that allows precise adjustment of 1 to 5 % of full scale, depending on the COARSE frequency setting and the type of Probe (^{1}H or ^{2}H) used.

In the "automatic" mode, the unit sweeps the frequency up and down through the FINE adjustment range until an NMR signal is detected. Then it "locks" automatically to this signal, a feedback control adjusts the frequency such that it equals the NMR frequency of the connected probe.

The resulting frequency tracking, with any changes of the magnetic field at the Probe, is restricted to the FINE frequency adjustment range. Various other automatic controls simplify the use of the Teslameter: these are automatic trigger threshold and timing of the NMR signal processing circuits.

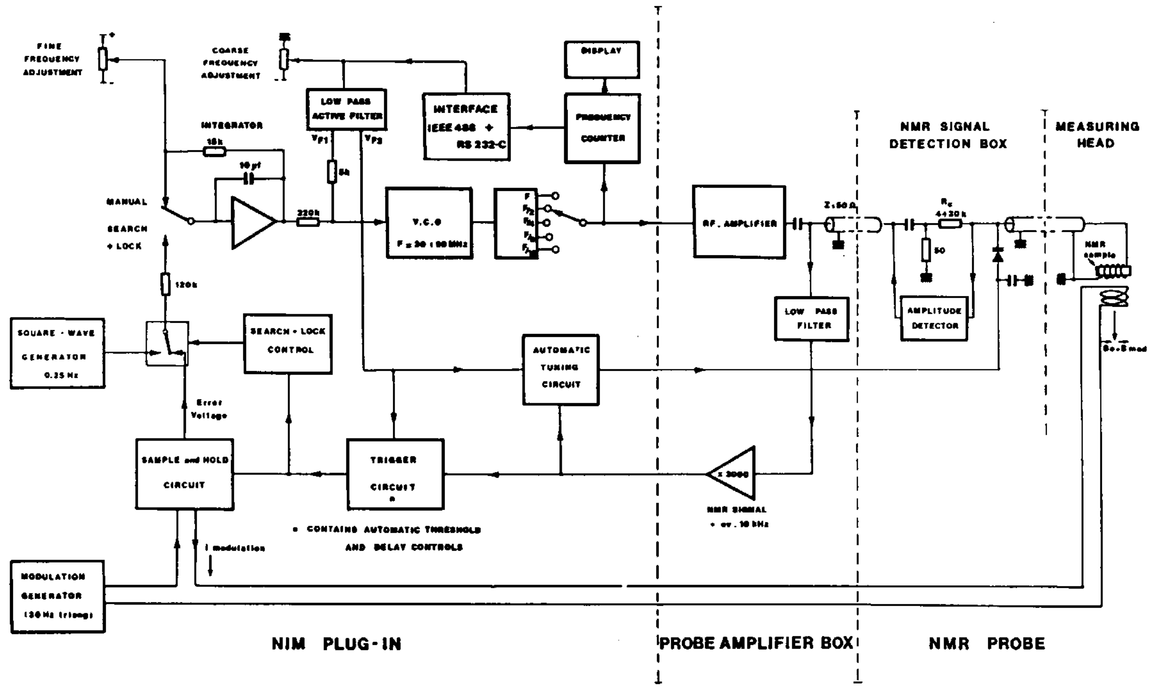


Fig. 2

Block diagram of the PT 2025 Teslameter

2 SPECIFICATIONS

2.1 PROBES

Probe N°	Field Range (Tesla)	Probe Type	Frequency Range (MHz)	Active Volume (Diam x L (mm)
1	0.043 to 0.13	^1H	1.9 to 5.6	7 x 4.5
2	0.09 to 0.26	^1H	3.8 to 11.2	5 x 4.5
3	0.17 to 0.52	^1H	7.5 to 22.5	4 x 4.5
4	0.35 to 1.05	^1H	15.0 to 45.0	4 x 4.5
5	0.70 to 2.1	^1H	30.0 to 90.0	4 x 4.5
6*	1.5 to 3.4	^2H	7.5 to 22.5	4 x 4.5
7*	3.0 to 6.8	^2H	15.0 to 45.0	4 x 4.5
8*	6.0 to 13.7	^2H	30.0 to 90.0	4 x 4.5

* For these probes, the signal-to-noise ratio is low at the lower end of their frequency range.

2.2 PT 2025 TESLAMETER

ABSOLUTE ACCURACY

Better than ± 5 ppm; this can be improved by absolute calibration of the probes.

RELATIVE ACCURACY

Approximately ± 0.1 ppm

STABILITY

Over fifty display readings in a 1.5 T superconducting coil, in stable laboratory conditions, the standard deviation is less than $\pm 5.0 \times 10^{-8}$.

Note: The specified value holds for a signal-to-noise ratio safely above the limit for automatic frequency tracking.

SIGNAL-TO-NOISE RATIO (IN A HIGHLY HOMOGENEOUS FIELD)

^{1}H probes:	at min. of field range: approximately 10 at max. of field range: approximately 100
^{2}H probes:	at min. of field range: approximately 5 at max. of field range: not measured

FREQUENCY TRACKING SPEED

Δf/f: up to 1%/sec

Time lag: min. 17 ms

Both depend on the loop gain and the maximum tracking speed (Δf/f) max, as well as on the setting of the frequency and the amplitude of the modulation. Therefore, the frequency tracking speed and the time lag may be of an order of magnitude poorer than the optimum values given above.

LOOP GAIN AT D.C.

Greater than 10^5 (worst case for ^{2}H probes); but typically greater than 10^6.

Front panel screwdriver adjustment for a maximum of 10 times attenuation of loop gain.

MANUAL FREQUENCY ADJUSTMENT

COARSE:	10 turns precision potentiometer.
FINE:	10 turns precision potentiometer; see "Field Tracking Range".

MAGNETIC ENVIRONMENT

The PT 2025 should not be used in magnetic environments over 0.1 Tesla. However, for the Amplifier 1030 and the Multiplexer - Amplifier 2031, the operational limit can be extended up to 1 Tesla.

REQUIRED HOMOGENEITY OF THE FIELD

The following table gives the maximum field gradients (in ppm/cm) for which the resulting signal-to-noise ratio just allows for automatic frequency tracking.

Probe N°	Field Range		
	High	Middle	Low
1	600	900	600
2	1200	1600	1200
3	1200	1400	1400
4	1500	900	800
5	250	600	350
6	240	280	280
7	300	180	160
8	50	120	70

Note: The field gradient effect on the NMR signal can, in some conditions, be compensated for with an appropriate external correcting coil.

FIELD TRACKING RANGE (IN AUTO MODE)

^{1}H probes: up to 70 % of the frequency range: > ± 5%
at the upper extremity of the frequency range: approx. ± 3%

^{2}H probes: up to 70 % of the frequency range:>±1.5%
at the upper extremity of the frequency range: approx. ± 1.0 %

Two LEDs indicate the approach of the upper (TOO HI) or lower (TOO LO) limit respectively, of the frequency tracking range.

NMR SIGNAL OUTPUT

BNC connector, located on the front panel, for scope inspection of the NMR signal. Output impedance: 10 kΩ + 10 nF to ground for noise filtering.

NMR signal: negative pulses of 100 mV to 5 V.

NMR LOCK INDICATOR

The LED is on in the presence of an NMR signal.

FIELD MODULATION OUTPUT

BNC connector, located on the front panel, for scope inspection of Probe field modulation waveform.

Output impedance: 1 kΩ.

Modulation signal is a 30 Hz to 70 Hz triangular waveform with an amplitude from 0 to ±8 V. Amplitude and frequency are adjustable with front panel screwdriver trimpots.

NMR FREQUENCY

BNC connector, located on the front panel, for scope inspection or external precision frequency counter.

It's a current square-wave of 0 to -16 mA amplitude (NIM level): 0 to -0.8 V amplitude if the input impedance of the measuring instrument is 50 Ω.

RADIO FREQUENCY OUTPUT FOR NNR AMPLIFIER

BNC connector, located on the rear panel, giving a square-wave of 0.8 V_{p-p} amplitude into 50 Ω.

SIGNAL OUTPUT FOR NMR AMPLIFIER

LEMO connector, located on the rear panel, used for NMR signal, Modulation and Amplifier power supply.

INTERNAL FREQUENCY COUNTER

9 digits LED display indicating the field strength in Tesla or NMR frequency in MHz.

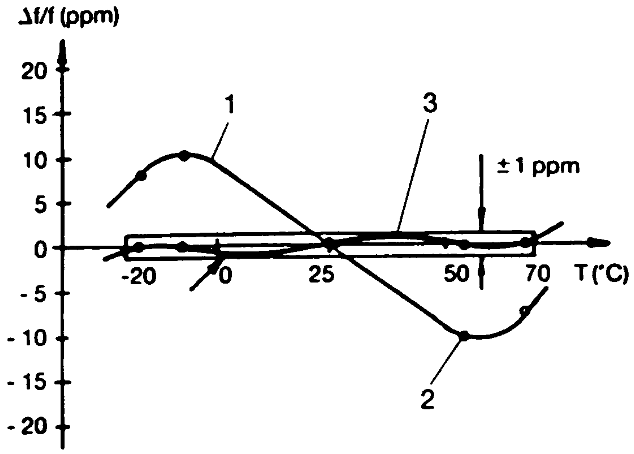
Resolution: 0.1 μT or 1 Hz.

TEMPERATURE COMPENSATED QUARTZ OSCILLATOR

<u>Stability</u>: ± 1 ppm within 10 to 40°C ambient temperature.

Refer also to the following picture which shows the 5 point compensation within the temperature range -20 to +70° C.

(1) Uncompensated curve; (2) Compensation point; (3) Compensated curve.



<u>Ageing</u>: < ± 1.0 x 10^{-7} / day

< ± 1.0 x 10^{-6} / month

< ± 2.0 x 10^{-6} / year

POWER REQUIREMENT

Voltage: 220 VAC or 110 VAC ± 10% (depending on the position of the line voltage selector).

Power: approx. 40 VA

Frequency: 50 or 60 Hz

Fuses: 0.8 Amp for 220 VACs; 1.6 Amp for 110 VAC(Slow Blow).

OPTIONAL HIGH STABILITY COUNTER (HS)
(OVEN CONTROLLED QUARTZ OSCILLATOR)

Warm-up: 5 minutes at 25° C.

Stability: < ± 5 ppb / ° C. within 10 to 40 ° C. ambient temperature.

Ageing: < ± 2 ppb / day after 30 working days.

3 USER'S GUIDE

- Ensure that the line voltage, which is indicated on the back panel of the PT 2025, corresponds to that of your location. A selector, situated just below the line voltage input, enables you to change the voltage accordingly. With the power cable removed, use a screwdriver to extract the fuse holder and replace it in the desired position.
- The main power switch situated on the back panel should be set to OFF.
- Either the 220 VAC or the 115 VAC power cord (whichever is required) should then be connected.
- The approximate magnitude of the field should be known or measured by external means (eg Hall Probe, value of magnet coil current etc.).
- Choose the relevant probe according to the magnitude of the field. Where the probe ranges overlap, it is recommended that the lower field range probe to use which will produce a larger NMR signal.
- If an amplifier 1030 is used, set correctly the Probe Select Switch: one position for probes 2 to 8 and the other position for probe 1 only.
- It is possible to place the probe detector circuitry within the magnetic field as this results in less than 1 ppm on the field value measured by the probe. Whereas the 1030 Amplifier may be used in high fields, the PT 2025 should only be used in fields of below 100 mT.
- The front panel outputs FIELD MODULATION and NMR 5IGNAL may be connected to the high impedance inputs of an oscilloscope: 2.0V/div, 0.2V/div respectively and an internal time-base of 5 ms/div.
- Set the MHz/TESLA toggle switch to the TESLA position.
- Set the MANUAL/AUTO switch to the MANUAL position.
- On powering up the Teslameter, a yellow LED situated on the front panel indicates which probe is in fact connected to the PT 2025
- If a scope is connected, then verify the d.c. value of the NMR signal output on the display. Depending on the frequency and the probe used, it should be between 0.1 to 1V. Should no positive d.c. voltage be registered at the NMR SIGNAL output, turn the COARSE control to maximum and then back to the required value.

  Note that the radio frequency oscillator may not start when set to a low frequency if the power has been turned off and on within a delay of approximately 15 seconds.
- Set the Modulation amplitude to its maximum value by using a screwdriver to turn the MODULATION AMPLITUDE trimpot fully clockwise.
- In certain cases (where high magnetic fields are to be measured) the stability of the measurement can be improved by reducing the Modulation amplitude.

- Set the Modulation frequency to 30 Hz. Again this can be done by using a screwdriver to turn the MODULATION FREQ trimpot fully anti-clockwise.

- For better stability, the frequency of modulation may be increased up to 70 Hz in high uniformity fields. The amplitude will decrease however when the frequency is increasing since the slope of the modulation signal is constant.

- The COARSE control must be adjusted until the Teslameter's field reading roughly corresponds to the magnitude of the field, then gradually turned until the NMR Lock LED flashes or remains lit. If an oscilloscope is connected to the front panel outputs (see above), the NMR signal should now be displayed on the screen. The FINE control can also be used if necessary.

- Set the MANUAL/AUTO toggle switch to the AUTO position. The Teslameter will scan the full range of the FINE control and "lock" on to the field. Should the Teslameter not "lock", then the modulation may be in the wrong polarity with respect to the measured field. In this case, reverse the FIELD ± toggle switch polarity.

- For optimum results the probe should be fixed in a position of high homogeneity, this being indicated by the "wiggles" and maximum amplitude of the NMR signal (refer to Fig. 3).

- The GAIN potentiometer of the frequency control loop should normally be turned fully clockwise (maximum gain for the highest precision measurement). Nevertheless a reduction of the loop gain may lead to a more stable field reading in the event of a poor signal-to-noise ratio or if there are rapid fluctuations in the field.

- Should the LEDs TOO HI or TOO LO appear faint, this implies that the Teslameter is "locked" but is not at the center of the field tracking range. In this case, turn the COARSE potentiometer very gently in the relevant direction until the LED is off.

- If the magnetic field changes slowly, the Teslameter will automatically follow the variations within the field tracking range (as given in the specifications). The position of the COARSE field setting in relation to the actual field is indicated by the LEDs TOO HI or TOO LO. In the MANUAL mode, these are off only when the FINE control is set to 5.0.

- The resonance frequency may be read in Hz by setting the MHz/TESLA switch accordingly. The 1 Hz digit will be relevant only in high uniformity fields.

- To ensure high precision during long-term measurements, a temperature stabilizer frequency meter of suitable stability may be connected to the NMR FREQ output located on the front panel. Verify that the input impedance of the frequency meter is 50Ω.

- To use the SEARCH mode of operation (see section 4.3 for details) push the SEARCH button. The REM/SEARCH LED is lit and the front panel functions are disabled. In this mode of operation, the FINE potentiometer must be in position 5.0. In particular field conditions, a different position may cause difficulties to lock the NMR signal. To stop the SEARCH mode, press again the SEARCH button.

Fig. 3
Typical NMR waveform, showing ringing or "wiggles".

4 PT 2025 OPERATING MODES

The PT 2025 has three operating modes, which are explained in this chapter. These three modes, called MANUAL, AUTO and SEARCH respectively, allow the user to measure field values under varying field conditions and can be used with or without the computer interface. The basic use of these three modes without the interface is now described, followed by details of what can be gained by using the interface commands.

4.1 THE MANUAL MODE

The MANUAL mode is the most basic mode of operation and gives the user full control of all the instrument functions. It may be useful in some very non-homogeneous fields that the AUTO mode does not ″lock″ on to the NMR signal.

Set the MANUAL/AUTO to the MANUAL position (i.e. the button is released). The radio frequency can be adjusted with the COARSE and FINE potentiometers.

The NMR signal can be found by slowly turning the COARSE potentiometer or, if necessary, the FINE one. The presence of the NMR signal will be indicated by the flashing of the NMR LOCK LED located to the left of the display.

Note: Noise can also cause the NMR LOCK to flash, if it is great enough to pass the threshold level.

If, however, the NMR signal is so small (due to the non-homogeneity of the magnetic field) that the detection level is not reached, the NMR LOCK will not light. In this case it is necessary to use an oscilloscope.

Connect channel 1 of the oscilloscope to the NMR SIGNAL BNC output (0.1 V/Div) and channel 2 to the FIELD MODULATION (5 V/Div). Set the time-base to 5ms/Div and trigger on channel 2 (FIELD MODULATION).

A precision of the order of 10^{-4} can be easily obtained if the NMR signal is made symmetrical in relation to the modulation signal (see below).

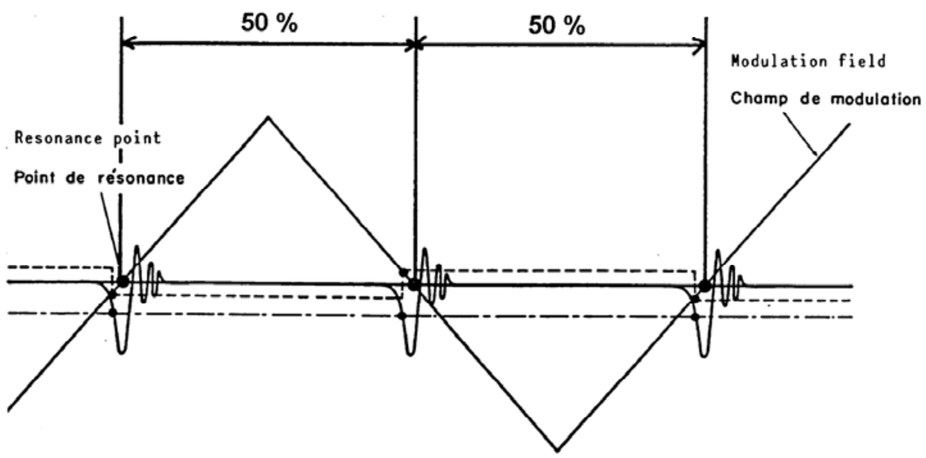


Fig. 4
NMR signal (upper) / Modulation signal (lower).

The LEDs TOO HI and TOO LO have no significance in the MANUAL mode and will only be off if the FINE potentiometer is set to 5.0.

If the NMR signal is sufficient to light the NMR LOCK LED then set the AUTO mode to ensure a stable "lock" condition. (See the following section).

4.2 THE AUTO MODE

To select the AUTO mode, push the MANUAL/AUTO button to AUTO (the button is depressed). In the AUTO mode, the PT 2025 sweeps the radio frequency over the whole range of the FINE potentiometer (the latter being disconnected). This represents a variation of ± 5 % of the frequency actually selected by the COARSE potentiometer. If the NMR signal appears within the range scanned, the PT 2025 will automatically "lock" on to the signal, providing that the polarity of the modulation as selected by the FIELD +/- is in accordance with that of the field (if the field sense is wrong select the correct sense). The LED NMR LOCK should then be permanently lit to indicate that the PT 2025 has found the correct field value.

The LEDs TOO HI and TOO LO indicate the position of the COARSE potentiometer in relation to the NMR frequency when the signal is "locked".

Example:

The field to be measured has a value of 1.02 T (probe 5). The PT 2025 is in MANUAL mode with the FINE potentiometer set to 5.0 and indicates 1.000 T. When the AUTO mode is selected, the PT 2025 will scan the field from 0.95 T (-5%) to 1.05 T (+5%). When the PT 2025 arrives at the field value of 1.02 T, it will "lock" on to the NMR Signal and the display will show the actual field value. The LEDs TOO LO will be lit, indicating that the COARSE potentiometer is too low. Increasing the COARSE very slowly until the TOO LO LEDs are off, will ensure that the NMR signal is centred within the scan range.

The magnetic field can be tracked within the range of ± 5% without losing the "locked" condition, providing the variation is not greater than 1%/sec.

If the NMR signal is too weak and the PT 2025 cannot "lock" on to it, the instrument must be returned to the MANUAL mode (refer to the previous section).

Note: For the 1H probes the sweep range is typically ± 5% but can be reduced to 3% at the upper end of the probe's range. For the 2H probes, the sweep range is reduced by a factor of 3 in comparison to the 1H probes.

4.3 THE SEARCH MODE

4.3.1 Introduction

In this mode the microprocessor takes control of all the front panel commands rendering them inoperative. Simultaneously, an automatic field search is activated. The entire range of the probe is scanned (from bottom to top) until the NMR signal is seen; at which point the PT 2025 "locks" on to the signal. Noise and interference signals are detected and by-passed by the search algorithm. Once the PT 2025 has "locked" on to a signal, the search algorithm can follow the field over the whole probe range. When connected to a computer and with the aid of the probe multiplexer, the PT 2025 can be programmed to search for and track a field over several probes.

4.3.2 Operation of the SEARCH Mode

The SEARCH mode is activated by pressing the LOCAL/SEARCH push button when the PT 2025 is under front panel control. The LED REMOTE/SEARCH will indicate the start of the field search. The front panel controls the sense of the field FIELD +/-. The multiplexer setting and the display format TESLA/MHz are taken into account at the start of the search; all other settings are ignored (the user is advised to set the FINE potentiometer to 5.0).

The microprocessor sweeps the radio frequency from the low end of the probe and waits to see if the NMR signal is seen. Once it has detected a signal, it must decide whether this is really the NMR signal, or if it is caused by some external interference. The algorithm rapidly rescans this zone to check for the reoccurrence of the NMR signal and if this is seen puts the PT 2025 into the AUTO mode to try to "lock" on to the NMR signal. (If the second occurrence is not seen the algorithm presumes that the signal was due to noise.)

Once in the AUTO mode the algorithm waits for five seconds and if the "locked" condition is not reached, changes the polarity of the field. After another period of five seconds the PT 2025 is either "locked" or the scan is continued as no signal was found.

Once in the "locked" state the PT 2025's search algorithm uses a servo control to avoid losing a signal from a drifting field. A variation of 1%/sec over the probe's range, increasing or decreasing, can be tolerated. Should the signal become "unlocked" the algorithm will restart the search from the present field value. A typical search may last for about 12 seconds depending on field value and polarity.

To quit the SEARCH mode the user must push the LOCAL/SEARCH button at which point the PT 2025 will return to front panel control.

During the search for the NMR signal, noise signals, which pass the detection threshold, will appear to be the first signs of the NMR signal. Providing the noise is of a random nature the search algorithm will ignore it; however this adds a delay of about four seconds to the search time. If the noise is not random but appears at a precise frequency (for example an external radio frequency beating with the internal radio frequency of the PT 2025), the algorithm will take about ten seconds to identify the noise signal (during this time the LEDs TOO HI and TOO LO will light up alternatively. Once the noise has been identified, the search will be continued.

4.4 USE OF THE THREE MODES VIA THE INTERFACE

The above explanation of the three modes of operation remains valid when using them via the computer interface. However more options are available in the SEARCH mode; these options are now described.

The MANUAL / AUTO mode is selected with the "An" message;

Where n = 0 for MANUAL
n = 1 for AUTO

This has exactly the same effect as the front panel button.

With regard to the SEARCH mode, the use of interface gives the user more possibilities than the front panel controls.

For example:

- Starting the search at a defined radio frequency.
- Performing a Search over several probes if a probe multiplexer is used.
- Changing the speed at which the search is performed.

The use of these functions is now outlined. If the value of the field to be measured is known approximately, the search time can be reduced if the search is started from a value close to that of the field to be measured.

When using the multiplexer with several probes (where the field value could be in one of several probes' ranges) the user may specify with the "Xn" message the number (n) of probes to be used in the search. If the PT 2025 does not find an NMR signal in the last probe's range, it restarts the search from the bottom of the first probe's range.

In poor field conditions, the rate at which the search is executed may need to be decreased in order to improve the "locking". This may be achieved with the "On" message. In this case n = 1 gives a fast search of 9 seconds per probe. Each increment in n causes the scan time to be increased by 3 seconds.

5 PT 2025 IEEE 486 INTERFACE

The PT 2025 Teslameter is equipped with a RS 232C and an IEEE 488 interfaces. The desired interface can be selected by using micro-switch "9" located on the back panel: "0" = RS 232C and "1" = IEEE 488.

Via these interfaces the user has control of the front panel functions and can access to the measured field value and the instrument status. The SEARCH mode may also be entered via the interfaces. Chapters 5 and 6 describe in detail the interfaces and their protocols.

In order to select the IEEE 488 interface, micro-switch "9" must be set to 1. This interface supports the following two modes:

- Listener / Talker (addressed mode)
- Talker only.

The PT 2025 can perform following functions:

SH1; AH1; T5; L4; SR1; RL1; PP0; DC1; DT1; C0E1.

The micro-switch configuration (on rear panel) to select one of the above two modes is now given.

Micro-switch N°	Comment
1 to 5	Device address in Listener/Talker mode or repetition rate when in Talker only mode (refer to section 5.4)
6	Must be 0
7	0 : Listener/Talker (addressed mode) 1 : Talker Only (section 5.4)
8	0 : suppresses the transmission of <CR><LF> as message terminator 1 : PT 2025 sends <CR><LF> to terminate messages
9	0 : selects RS 232 C interface 1 : selects IEEE 488 interface

In this document, the IEEE functions such as REMOTE and LOCAL are referred to as "Commands" and ASCII data sent to the PT 2025 when it is addressed as a Listener are referred as "Messages".

5.1 LISTENER/TALKER

Reading the Display (refer to section 5.1.3)

Switch No	Setting
1 to 5	Device address
6	0
7	0
8	1 / 0 *
9	1

* Refer to note in section 5.4.

In this mode, the PT 2025 can receive specific messages, which give the user full control of the instrument. To receive these messages the PT 2025 must be addressed as a **Listener**. The Teslameter also reacts to the standard IEEE 488 functions such as REMOTE or LOCAL etc.

It is also possible for the user to access certain data contained in the PT 2025, such as the field value or instrument status; in this case the instrument must be addressed as a **Talker**.

The following section describes the messages used in the IEEE 488 interface.

Note: The examples of the message sequences shown are for an HP 85 as bus controller.

5.1.1 IEEE 488 Commands

REMOTE

The PT 2025 is put into the REMOTE mode when the REN line of the IEEE 488 bus is set true and the instrument is addressed as a Listener. When the PT 2025 is put into the REMOTE state the front panel controls are disabled (with the exception of the LOCAL push button). The PT 2025 retains the same configuration as it had before the REMOTE state was selected, with the exception of the selection of the radio frequency.

Note: The DAC has a default value of 2048 which represents the middle of the frequency range.

When the PT 2025 is not in the REMOTE state, it cannot be addressed as a Listener.

GO TO LOCAL (GTL)

The IEEE 488 command GTL (Go to LOCAL) forces the PT 2025 into the LOCAL state; the PT 2025 is then configured by the front panel controls which become operational.

By pressing the LOCAL push button once, when the instrument is in the REMOTE state has the same effect as the Go To LOCAL command, as long as the button has not been disabled by the LOCAL lockout command (see below).

LOCAL LOCKOUT (LLO)

The IEEE 488 command LLO (LOCAL LOCKOUT) disables the LOCAL push button on the front panel of the PT 2025.

Only the GTL (LOCAL) command or a RESET can hence return the instrument to LOCAL (front panel) mode.

TRIGGER (GET)

The IEEE 488 command GET (Group Execute Trigger) forces a RESET of the PT 2025 time-base, thus starting a new measurement cycle. Note that if the PT 2025 is addressed as a Talker, it will return the field value with the letter “W” until a valid cycle has been completed (see section 5.1.3).

Before to its execution, a trigger command must be enabled with the T1 command (see section 5.1.2.10).

INTERFACE CLEAR (IFC)

This command (IFC) aborts the present communication and frees the bus. The PT 2025 is unaddressed.

Example:

ABORTIO 7

(7 is the address of the IEEE 488 bus in the HP 85).

DEVICE CLEAR (DCL)

This command (DCL) puts the PT 2025 into its initial state (as for a RESET). All communications are aborted and the "SRQ mask" is also set to its default setting.

Example:

CLEAR 708

(7 is the address of the IEEE 488 bus in the HP 85 and 08 is the address of the PT 2025 on the IEEE 488 bus).

5.1.2 The PT 2025 Addressed as a Listener

When the PT 2025 is addressed as a Listener, it can receive specific messages which permit the control of the instrument.

5.1.2.1 Preselection of the Radio Frequency

It is possible to preselect the radio frequency via the IEEE 488 interface, thereby in effect replacing the use of the COARSE potentiometer.

The selected value can be sent either in binary or in decimal form. (The value is then sent to a 12 bit digital/analog convertor in order to select the radio frequency.)

The range of the DAC is from 0 to 4095. Should a value greater than 4095 be received by the PT 2025, it will be interpreted as 4095.

DECIMAL FORMAT

Message format: **Cnnnn<CR><LF>**

C the ASCII character "C" signifies that the selected value is expressed in decimal.

n represents the preselected value given in ASCII characters from 0 to 9 inclusive. The user may perform leading 0 suppression on the selected value.

<CR><LF> the ASCII characters "carriage return" and "linefeed" respectively, must terminate the message.

Example:

OUTPUT 708; "C1068"&CHR$(13)&CHR$(10).

BINARY FORMAT

The binary format of the preselection of the radio frequency message is as follows :

Message format: **Bnn**

B the ASCII character "B" signifies that the preselected value is expressed in binary.

n represents a two bits selected value (0 to 4095 inclusive).

Example:

OUTPUT 708; "Bx1" (corresponds to 1329), or

OUTPUT 708;"B"&CHR$(4)&CHR$(12) (corresponds to1042).

<u>Note</u>: The 4 most significant bits of the 16 bit pattern given by these two digits are not used since the DAC has only 12 bits.

There is not a linear relationship between the selected value and the NMR frequency. Fig. 7 shows the typical relationship between the NMR frequency versus the DAC setting.

5.1.2.2 Select MANUAL or AUTO Mode

Message format: **An**

Where n = 0 for MANUAL mode
n = 1 for AUTO mode

This message selects the MANUAL or AUTO mode. When the PT 2025 is in AUTO mode it can "lock" on to the NMR signal and follow the field if it drifts within ± 5% of the value preselected by the DAC or the COARSE potentiometer. In AUTO mode, the FINE potentiometer is disconnected (for more details refer to section 4.2 AUTO mode).

Example:

OUTPUT 708; "A1" selects AUTO mode.

5.1.2.3 Select Field Sense

Message format: **Fn**

Where n = 0 or – (for negative fields)
n = 1 or + (for positive fields)

This message determines the sense of the field to be measured with respect to the orientation of the probe.

If the FIELD +/- is in the wrong sense, the PT 2025 does not "lock" on to the NMR signal.

Example:

OUTPUT 708; "F+" selects FIELD +, or

OUTPUT 708; "F1" selects FIELD +

5.1.2.4 Select Display

Message format: **Dn**

where n = 0 for MHz
n = 1 for Tesla.

This message determines whether the displayed value is given in Tesla or in MHz. It also affects the format of the measured value given via the interface.

Example:

OUTPUT 708; "D1" displays the value in Tesla.

5.1.2.5 Select Multiplexer Channel

Message format: **Pc**

Where c is either A, B, C, D, E, F, G or H and represents the appropriate multiplexer channel.

Example:

OUTPUT 708; "PE" selects channel "E" of the multiplexer.

5.1.2.6 Activate SEARCH Mode

Message format: **Hnnnn<CR><LF>**

Where nnnn is optional and can be any value between 0 and 4095 inclusive.

This message (H for Hunt) activates the automatic field-searching algorithm (see section 4.3). An optional start frequency can be supplied if the approximate field value is known. This has the advantage of reducing the search time.

If no DAC value is specified (i.e. H<CR><LF>), then searching starts at the minimum frequency (DAC = 0).

When the PT 2025 is in the SEARCH mode, it can still receive and interpret interface messages with the exception of An, Bnn, Cdddd and Fn, which would interfere with the search. They are therefore ignored.

The SEARCH mode can be made to work over several channels of the multiplexer to allow searching over larger field ranges (See the message "X").

Example:

OUTPUT 708;"H"&CHR$(13)&CHR$(10) activates searching at the lowest frequency for the selected probe, or

OUTPUT 708;"H934"&CHR$(13)&CHR$(1$) activates searching at the frequency corresponding to the DAC value of 934.

5.1.2.7 Quit SEARCH Mode

Message format: **Q**

When this message is received and the PT 2025 is in SEARCH mode, it inactivates the search in progress and leaves the configuration as it was at the instant the "Q" message was received.

5.1.2.8 Select Number of MUX channels Used in SEARCH Mode

Message format: **Xn**

where n is a number from 1 to 8 inclusive (X1 is selected on power up or RESET). This message tells the PT 2025 the number of multiplexer channels that are to be scanned in the SEARCH mode. When the PT 2025 enters the SEARCH mode, it starts its search on the channel that was last selected (either by the MUX switch when the instrument was put into REMOTE mode, or the last value received in the "Pc" message). If the signal is not found on this channel, the PT 2025 will follow on to the next channel and so on up to the number of channels given by the "Xn" message. When the last channel has been searched and no signal is detected, the search restarts on the first selected channel and the cycle is then repeated.

Example:

Consider that probes 3, 4 and 5 are respectively connected to channels B, C and D of the multiplexer.

Execute the following messages:

OUTPUT 708; "PB" selects channel "B"

OUTPUT 708; "X3" selects search over 3 channels

OUTPUT 708; "H"&CHR$(13)&CHR$(10) starts SEARCH mode.

The search will in this case start on channel "B" (probe 3) and if no NMR signal is found, it will continue on channel "C" (probe 4) and then on to channel "D" (probe 5). If the search fails to locate a field, the PT 2025 will start again the search on channel "B". If an NMR signal is detected the PT 2025 will "lock" on to it.

The SEARCH mode has been designed to follow the NMR signal even if it goes out of one probe's range by changing to the next channel. Suppose that the signal has been found on channel "C" (probe 4): if the field drifts to a value of less than 0.35 T, then the PT 2025 will select channel "B" and continue with probe 3 (the algorithm functions in both positive and negative drift conditions).

In this example the PT 2025 can therefore search and follow an NMR signal in a field ranging from 0.175 T (low end of probe 3) up to 2.10 T (high end of probe 5). In order to operate this scan correctly, it is necessary to ensure that the probes are connected in an ascending order vis-à-vis the multiplexer channels.

<u>Note</u>: If the first channel scanned is selected as "G" and the PT 2025 is programmed to search over 4 channels, then the sequence for scanning is "G", "H", "A" and "B".

5.1.2.9 Select the SEARCH Time

Message format: **On**

where n is a number from 1 to 6 (n = 3 on power up of RESET).

This message allows the speed of the search to be changed. The number 1 corresponds to the most rapid (i.e. 9 seconds to scan the field range of a probe). Each increase in n slows up the search by 3 seconds.

It may be necessary to slow the scan slope used in the PT 2025 under certain critical field conditions, for example if the NMR signal is diminished due to a non-homogeneous field.

It is possible to change the scan slope even when the search is in progress.

Example:

OUTPUT 708; "O2"

5.1.2.10 Enable/Disable Trigger

Message format: **Tn**

Where n = 0 disables the TRIGGER message (default value)

Or n = 1 enables the TRIGGER message.

When n = 0, the PT 2025 does not respond to the TRIGGER message. In order that the PT 2025 can accept the TRIGGER message, the user must send a "T1" message.

Example:

OUTPUT 708; "T1" the PT 2025 will respond to the TRIGGER message

5.1.2.11 Fast reading display

Message format: **Vn**

Where n = 0 or N (for Normal reading display rate)

n = 1 or F (for Fast reading display rate)

This message determines the display reading rate, i.e. Normal ~1 per second) or Fast (~10 per second). The last digit of the display is not visible and is not transferred to the computer. Therefore, the PT 2025 resolution is reduced by a factor 10.

5.1.2.12 SRQ Mask

Message format: **Mno**

M the ASCII character "M" indicates that the two following characters, constitute the byte mask for the internal status of the PT 2025.

n signifies the ASCII characters from 0 to 7 inclusive relating to the mask pattern, in octal, for bits 3, 4 and 5.

o the ASCII characters from 0 to 7 inclusive relate to the mask pattern, in octal, for bits 0, 1 and 2.

This message allows the user to set up a mask for the SRQ register in order to prevent the PT 2025 from interrupting the controller when a particular event occurs. On power up or RESET the default value for the mask is M00.

SRQ Mask register :

	bits		5	4	3			2	1	0
		n Value					o Value			
		0	M	M	M		0	M	M	M
M = Masked		1	M	M	A		1	M	M	A
A = Active		2	M	A	M		2	M	A	M
		3	M	A	A		3	M	A	A
		4	A	M	M		4	A	M	M
		5	A	M	A		5	A	M	A
		6	A	A	M		6	A	A	M
		7	A	A	A		7	A	A	A

Note: It is not possible to mask bits 6 and 7. On power up and RESET, both bits are active.

Example:

OUTPUT 708; "M00" gives all bits masked

OUTPUT 708; "M77" gives all bits active.

Note: See section 5.2 for more details on the SRQ register.

5.1.2.13 Request Instrument Status

Message format: **Sn**

Where n is 1, 2, 3 or 4

and indicates the status register to be read. The status registers are described in section 5.3.

Following reception of this message, when the PT 2025 is subsequently addressed as a Talker, it sends back to the controller the value of the status register as requested, instead of the last measured field value.

The message sent by the PT 2025 after a request for status has the following format:

Message format : Saa

where "S" is the ASCII character "S" meaning status

where "a" is the ASCII character forming a hexadecimal pair.

Example:

OUTPUT 708; "S3" request status reg. no. 3 ENTER 7$8;R$ addresses PT 2025 as a Talker DISP R$ R$ = "S35"

If switch "8" = 1 then the status will be followed by a <CR><LF>.

5.1.3 The PT 2025 Addressed as a Talker

Reading the Displayed Value

When the instrument is addressed as a Talker, it sends the displayed value according to the format described below. The EOI signal is set true before the last character is transmitted in order to indicate the end of the message.

The displayed value can be transmitted to the user in the following message format:

vdd.dddddddT<CR><LF>

vdd.ddddddF<CR><LF>

v — The ASCII character "**L**" (for "Locked") indicates that the Teslameter was "locked" during the measurement cycle and therefore the displayed value is valid.

The character "**N**" (for "Not Locked") indicates that the Teslameter has not seen an NMR signal during the measurement cycle and therefore the displayed value is invalid.

The character "**S**" (for Signal) indicates an occurrence of the NMR signal in the last measurement cycle; it may also indicate that the signal is present but that the PT 2025 is not in AUTO mode.

The character "**W**" (for Wrong) indicates that the data given has no significance and should be ignored (e.g. after a TRIGGER).

d — The displayed value is composed of an ASCII character between 0 and 9 inclusive; leading 0 suppression is performed.

. — Note that the decimal point is represented by the ASCII character "**.**" and is included in every message.

F — Represents the ASCII character "F" to indicate that the value pertains to an NMR frequency in MHz.

T — Represents the ASCII character "T" to indicate that the value is given in Tesla.

<CR><LF> — Represents the ASCII characters "carriage return" and "line feed" respectively. These characters are only transmitted if micro-switch "8" is set to 1. In all transfers the EOI (End Or Identify) is set true just before the last character of the message is sent.

Note: in the Fast reading display mode, the last digit of the display is not visible.

Reading of the Status Registers

When the PT 2025 is addressed as a **Talker** after having received a demand for a return of status (see section 5.1.2.13), it sends back the contents of the requested status register (refer to section 5.3).

The following examples demonstrate the sequences in which the measured value should be read and how to access status register 2:

Example:

```
100 ENTER 708; F$                 addresses as Talker
110 DISP F$
    F$ = "L82.125867F"
180 OUTPUT 708; "S2"              request status reg. 2
190 ENTER 708; F$
200 DISP F$
    F$ = "S45"
```

5.2 SERVICE REQUEST (SRQ)

An important feature of the PT 2025 is its ability to interrupt the controller when certain conditions occur.

5.2.1 How to Use the SRQ

When a service request is sent, the controller must firstly determine which instrument instigated the demand. This operation is carried out by a serial poll (spoll) of each device, connected to the bus, capable of generating a Service Request. When the instrument is "polled", it replies with the contents of its SRQ Status Register, which indicates if it is the originator of the Service Request and if so, the nature of the request. The above sequence supposes that the controller is programmed to receive the SRQ interrupts.

The Internal Status Register together with the Service Request (SRQ) Mask determine whether or not the Require Service (RQS) bit will be set by an interrupt. However, as soon as the Require Service bit is set, the PT 2025 puts the SRQ line of the IEEE bus true, which in turn causes an interrupt in the controller.

5.2.2 Setting the SRQ Mask

The SRQ Mask can only be applied to bits "0" to "5" of the SRQ Register. Each 1 in the SRQ Mask can be considered as a hole which allows the information in the "Internal Status Register" through to generate a Service Request.

Example:

bits	7	6 **RQS**	5	4	3	2	1	0
Internal Status Register	1	0	0	1	1	0	0	1
SRQ Mark Register	1	1	0	1	0	0	1	0
SRQ Status register	1	1	0	1	0	0	0	0

To create a mask, firstly determine which conditions must generate interrupts. In the following example, the bits corresponding to the NMR signal (bit "1") and the LOCAL push button (bit "4") will be active. Next, determine the octal code containing two digits for these conditions. Finally, output the "M" message followed by the two octal digits (see also section 5.1.2.12).

5.2.3 The SRQ Status Register

A Service Request is generated by the PT 2025 when bit "6" (RQS) is set to 1. This bit must be tested by the controller when it executes a serial poll. The remaining bits allow the controller to determine the nature of the Service Request, a "1" representing the active state. The status register is RESET to 0 after the controller has finished the serial poll. The bits have the following significance:

Bit:	7	6	5	4	3	2	1	0
	Power ON or RESET	RQS	NMR Lock	Front Panel LOCAL Button	Hard Error	Syntax Error	NMR Signal Seen	Data Ready
Decimal Value :	128	64	32	16	8	4	2	1

bit 7: power ON or RESET

This bit is set to 1 on power up, or on return of electric current after a power failure, or after having pressed the RESET button located on the rear panel.

bit 6: RQS (Require Service)

Set to 1 to generate a Service Request.

bit 5: NMR Lock

This bit is set when the instrument becomes "Locked". It is cleared after the serial poll or when the PT 2025 is no longer "Locked".

bit 4: Front panel LOCAL button

Pushing the LOCAL button situated on the front panel sets this bit.

bit 3: Hardware Error

This bit is set to 1 if the control program cannot read the display correctly (i.e. following a failure in the counter circuitry).

bit 2: Syntax Error

This bit is set to 1 if an incoming message does not conform to the formats described in this document.

bit 1: NMR Signal Seen

This bit indicates that there has been an occurrence of an NMR signal.

bit 0: Data Ready (masked on power up and on RESET)

Bit "0" is set to 1 after each measurement cycle. This bit can be used to inform the controller of the end of a measurement cycle without the need for the controller to continually scan the PT 2025.

After power up, this bit is masked. To use this function, the user must program the mask accordingly.

5.3 INSTRUMENT STATUS REGISTERS

The PT 2025 has four internal status registers which can be accessed by the user (see section 5.1.2.13). The format of these four registers is now given.

5.3.1 Status Register 1: Internal Instrument Status (1 byte)

This register is cleared after reading. Together with the SRQ Mask, it is used to form the SRQ Status Register.

Bit	7	6	5	4	3	2	1	0
	Power ON or RESET	N/A	NMR Lock	Front Panel LOCAL Button	Hard Error	Syntax Error	NMR Signal Seen	Data Ready

N/A = Not Applicable

bit 7: Power ON or RESET

This bit is set to 1 on power up, or on return of current after a power failure, or after having pressed the RESET button located on the rear panel.

bit 6: Unused

Always set to 0.

bit 5: NMR Lock

This bit is set when the instrument becomes "Locked". It is cleared by reading the Internal Instrument Status Register or when the PT 2025 is no longer "Locked".

bit 4: LOCAL push button

This bit is set by pushing the LOCAL button situated on the front panel.

bit 3: Hardware Error

This bit is set to 1 if the control program cannot read the display correctly (i.e. following a failure in the counter circuitry).

bit 2: Syntax Error

This bit is set to 1 if an incoming message does not conform to the formats described in this document.

The command generating a syntax error is ignored.

bit 1: NMR Signal Seen

Indicates that there has been an occurrence of an NMR signal since this status register was last read. This bit is the same as bit "3" in the internal status register "2".

bit 0: Data Ready

This bit is set to 1 after each measurement cycle and can be used to inform the controller of the end of a measurement cycle.

5.3.2 Status Register 2: NMR signal status (1 byte)

Bit	7	6	5	4	3	2	1	0
	N/A	N/A	N/A	N/A	NMR Signal Seen	NMR Signal State	TOO HI	TOO LO

N/A = Not Applicable

bits 7 to 4 : N/A

Always set to 0.

bit 3: NMR Signal Seen

This bit is set to 1 if the instrument detects the appearance of the NMR signal since this register was last read. This bit is only RESET by the reading of this register.

bit 2: NMR Signal State

This bit gives the state of the NMR signal at the time this register is read. A 1 indicates the presence of the NMR signal and A 0 the absence of the NMR signal.

bit 1: TOO HI

1 indicates that at the time of reading this register, one or several of the “TOO HI” LEDs were lit.

bit 0 TOO LO

1 indicates that at the time of reading this register, one or several of the “TOO LO” LEDs were lit.

Note: Bits “0” and “1” are useful to center the ± 5% scan window when the PT 2025 is in AUTO mode.

5.3.3 Status Register 3: Instrument Functions (1 byte)

Bits	7	6	5	4	3	2	1	0
	Fast Reading Display	MULTIPLEXER			SEARCH Mode	Field +/-	AUTO MAN. Mode	Display Tesla/ MHz

bit 7: Fast reading display

1 indicates that the PT 2025 is operated in the Fast reading display mode.

bits 6, 5, 4: Multiplexer channel

These three bits indicate which channel of the multiplexer is selected:

Bits:	6 5 4	Channel
	0 0 0	A
	0 0 1	B
	0 1 0	C
	0 1 1	D
	1 0 0	E
	1 0 1	F
	1 1 0	G
	1 1 1	H

bit 3: SEARCH mode

1 indicates that the SEARCH mode is active.

bit 2: Field +/-

This bit indicates if the field is positive or negative, with respect to the probe orientation.

1 indicates a positive field (+)

0 indicates a negative field (-)

bit 1: MANUAL / AUTO mode: state

This bit indicates whether the PT 2025 is in MANUAL or AUTO mode.

0 indicates MANUAL Mode.

1 indicates AUTO Mode.

bit 0: DISPLAY mode (data format mode)

1 indicates that the displayed value is given in Tesla.

0 indicates that the displayed value is given in MHz.

5.3.4 Status Register 4: DAC Status (2 bytes)

These two bytes give the contents of the DAC.

5.4 TALKER ONLY

This mode is used to connect the PT 2025 to a device (for example a printer) without the controller functions.

Micro Switch N°	Setting
1 to 5	Repetition rate (see table below)
6	0
7	1
8	1 / 0
9	1

Note: Micro-switch "8" should be set to 1 if the user wishes the PT 2025 to send "carriage return" and "line feed" at the end of every message. Setting this micro-switch to 0 suppresses, the "carriage return" and "line feed" characters. (To indicate the end of the message, the EOI signal is made true immediately prior to the transmission of the last character.)

In this mode, the Teslameter transmits the measured value at regular intervals (each measurement cycle lasting approximately one second) according to the message format described in section 5.1.3. The intervals between each value can be defined by using micro-switches "1" to "5" as shown in the following table:

Microswitches					**Interval**
5	4	3	2	1	
0	0	0	0	0	no message transmission
0	0	0	0	1	sends every measured value
0	0	0	1	0	sends every 2nd measured value
0	0	0	1	1	sends every 3rd measured value
0	0	1	0	0	sends every 4th measured value
0	0	1	0	1	sends every 5th measured value
0	0	1	1	0	sends every 6th measured value
0	0	1	1	1	sends every 7th measured value
0	1	0	0	0	sends every 8th measured value

0	1	0	0	1	sends every 9 th measured value
0	1	0	1	0	sends every 12 th measured value
0	1	0	1	1	sends every 16 th measured value
0	1	1	0	0	sends every 20 th measured value
0	1	1	0	1	sends every 27 th measured value
0	1	1	1	0	sends every 36 th measured value
0	1	1	1	1	sends every 48 th measured value
1	0	0	0	0	sends every 60 th measured value
1	0	0	0	1	sends every 80 th measured value
1	0	0	1	0	sends every 100 th measured value
1	0	0	1	1	sends every 150 th measured value
1	0	1	0	0	sends every 180 th measured value
1	0	1	0	1	sends every 240 th measured value
1	0	1	1	0	sends every 300 th measured value
1	0	1	1	1	sends every 420 th measured value
1	1	0	0	0	sends every 540 th measured value
1	1	0	0	1	sends every 720 th measured value
1	1	0	1	0	sends every 900 th measured value
1	1	0	1	1	sends every 1200 th measured value
1	1	1	0	0	sends every 1600 th measured value
1	1	1	0	1	sends every 2100 th measured value
1	1	1	1	0	sends every 2700 th measured value
1	1	1	1	1	sends every 3600 th measured value

5.5 SUMMARY OF THE IEEE COMMANDS AND PT 2025 MESSAGES

IN LISTENER/TALKER MODE

IEEE COMMANDS: LISTENER (REFER TO SECTION 5.1.1)

REMOTE (REN)	Allows the PT 2025 to accept messages via the IEEE 488 interface.
LOCAL (GTL)	Returns the PT 2025 to front panel control.
LOCAL LOCKOUT (LLO)	Blocks the function of the local push button.
DEVICE CLEAR (DCL)	
INTERFACE CLEAR (IFC)	
TRIGGER	Resets the PT 2025 internal counters to start a new measurement cycle.

MESSAGES TO THE PT 2025 : LISTENER

An	Select MANUAL (0) or AUTO (1) mode (section 5.1.2.2)
Bnn	Binary load DAC (12 bits) (section 5.1.2.1)
Cnnnn<CR><LF>	Decimal load DAC (12 bits) (section 5.1.2.1)
Dn	Display mode Tesla (1), MHz (0) (section 5.1.2.4)
Fn	Field sense + (1), - (0) (section 5.1.2.3)
Hnnnn<CR ><LF>	Select SEARCH Mode (section 5.1.2.6)
Mno	Program mask register (section 5.1.2.12)
On	Select SEARCH time (section 5.1.2.9)
Pc	Select multiplexer channel (section 5.1.2.5)
Q	Quit SEARCH mode (section 5.1.2.7)
Sn	Request status register (section 5.1.2.13)
Tn	Enable/disable TRIGGER message (section 5.1.2.10)

Vn	Fast reading display (section 5.1.2.11)
Xn	Select multiplexer range (section 5.1.2.8)

MESSAGES EMITTED BY THE PT 2025 : TALKER (REFER TO SECTION 5.1.3)

vdd. DddddddT Display format (Tesla)
vdd . ddddddF Display format (MHz)
Saa Status format

6 PT 2025 RS 232 C INTERFACE (DCE)

The PT 2025 Teslameter is equipped with an RS 232 C and an IEEE 488 interface. The desired interface can be selected by using micro-switch situated on the back panel:

"0" = RS 232 C

"1" = IEEE 488.

Via these interfaces the user has control of the front panel functions and can access the measured field value and the instrument status. The SEARCH mode may also be entered via the interfaces.

Chapters 5 and 6 describe in detail the interfaces and their protocols.

6.1 PROGRAMMING OF THE RS 232 C INTERFACE

To use this interface, micro-switch "9" must be set to 0. The remaining eight micro-switches are used to define the transmission characteristics as follows:

Micro-switch N°	Comment
1 to 3	Interval (refer to section 6.5)
4	0: 7 bit transmission/reception 1: 8 bit transmission/reception
5	0: without parity 1: with parity
6	0: even parity (if micro-switch "5"=1) 1: odd parity *If micro-switch "5"=0, then "6" has no meaning*
7	0: autonomous mode 1: conversational mode
8	0: 1 stop bit 1: 2 stop bits *
9	0: RS 232 C 1: IEEE 488

* Note: It is not possible to select a 8 bit transmission / reception with parity as well as 2 stop bits. All other combinations are acceptable.

6.2 CONNECTING THE RS 232 C INTERFACE

The PT 2025 is a DCE device; the connector for serial communications with the instrument is a sub-D 25 way female type.

We recommend the following pin-to-pin connections to the computer:

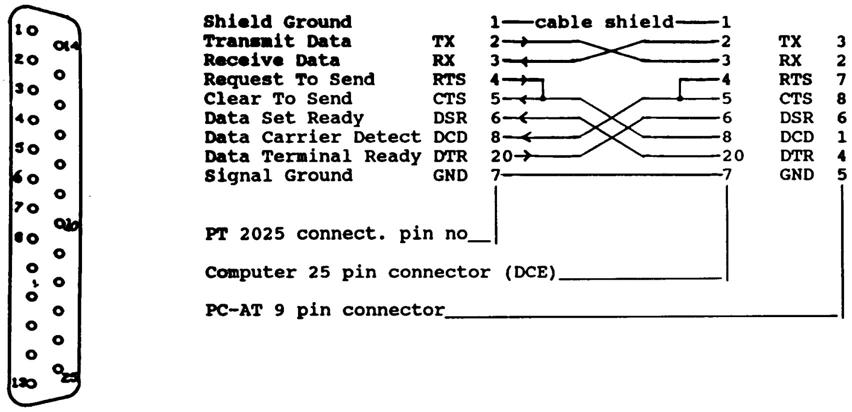


Fig. 5

RS 232 C connector pin-outs.

6.3 SETTING THE SPEED FOR THE RS 232 C INTERFACE

One of the following baud rates may be selected:

300

600

1200

*2400

4800

9600

19200

*Note: The PT 2025 is delivered with a baud rate of 2400

To change the baud rate, follow the procedure outlined below:

- Turn off the Teslameter.
- Unscrew completely the four retaining screws on the I/O module situated on the rear panel.
- Remove the I/O module by using the knurled screws as leverage.
- Chose the required baud rate by moving the jumper to the desired position (see Fig. 6).

- Reinstall the module in the Teslameter following the inverse procedure.

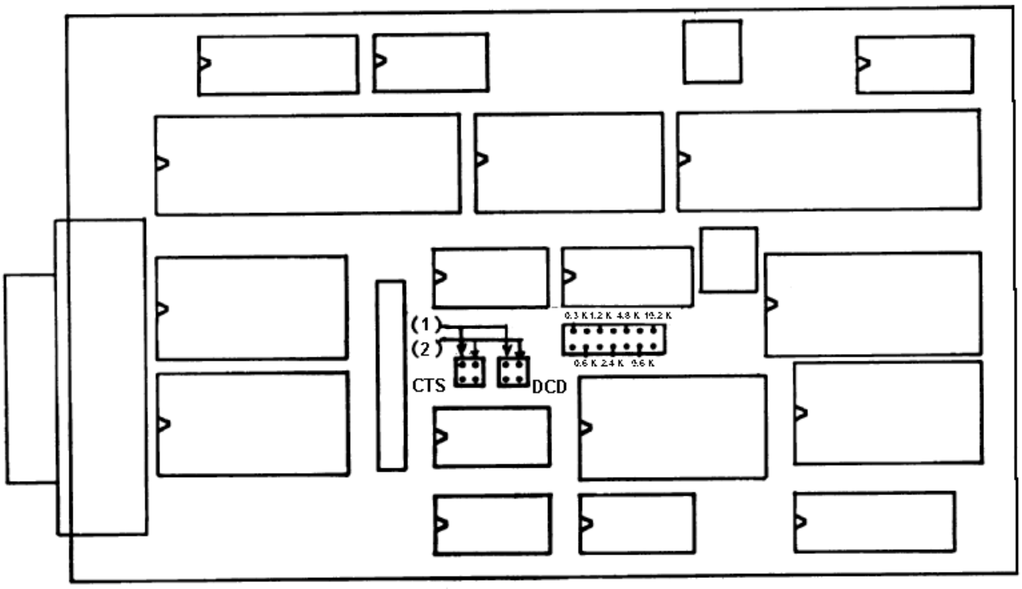


Fig. 6
Baud rate selection.

(1) HANDSHAKE

(2) NO HANDSHAKE

6.4 THE TWO OPERATIONAL MODES OF THE RS 232 C INTERFACE

The interface of the PT 2025 can function in two different ways.

The first is called "conversational" and allows the user to send messages to the PT 2025 as well as read the last measured field value or the internal instrument status registers.

The second method is called "autonomous": the PT 2025 is sending the last measured value to the RS 232 C interface at regular intervals (user defined with the micro-switches). In this mode, all incoming messages are ignored.

6.4.1 Conversational Mode

To select this mode, micro-switch "7" must be set to 1. The PT 2025 now awaits messages coming from the external device via the RS 232 C interface.

These messages are now described in detail.

6.4.1.1 Reading the Displayed Value (<ENQ>)

Message format: **<ENQ>** Code ASCII Hex 05

After the reception of the ASCII character <ENQ>, the displayed value is transmitted to the user in the following message format:

vdd.ddddddF<CR><LF>

vdd.dddddddT<CR><LF>

V The ASCII character "**L**" (for "Locked") indicates that the Teslameter was "locked" during the measurement cycle and therefore the displayed value is valid.

The character "**N**" (for "Not Locked") indicates that the Teslameter has not seen an NMR signal during the measurement cycle and therefore the displayed value is invalid.

The character "**S**" (for "Signal") indicates an occurrence of the NMR signal in the last measurement cycle; it may also indicate that the signal is present but that the PT 2025 is not in AUTO mode.

The character "**W**" (for "Wrong") indicates that the data given has no significance and should be ignored (e.g. after a TRIGGER).

d The displayed value is composed of an ASCII character between 0 and 9 inclusive; Leading 0 suppression is performed.

. Note that the decimal point is represented by the ASCII character "**.**" and is included in every message.

F	Represents the ASCII character "F" to indicate the value is in MHz.
T	Represents the ASCII character "T" to indicate that the value is converted into Tesla.
<CR><LF>	Represents the ASCII characters "carriage return" and "line feed" respectively. These characters are always transmitted at the end of a RS 232 C message.

Note: in the Fast reading display mode, the last digit of the display is not visible.

6.4.1.2 REMOTE

Message format: **R**

This message disables the front panel of the PT 2025 (with the exception of the LOCAL push button) and puts the instrument into the RS 232 C REMOTE mode. The instrument will now respond to the messages described in this chapter.
Messages issued prior to the REMOTE message will be ignored with the exception of the reading of the displayed value and the four status registers.
When the PT 2025 is put into the REMOTE state, the front panel controls are disabled (with the exception of the LOCAL push button). The PT 2025 retains the same configuration it had before the REMOTE state was selected, except for the preselection of the radio frequency.

Note: The DAC has a default value of 2048 which represents the middle of the frequency range.

6.4.1.3 LOCAL

Message format: **L**

This message forces the PT 2025 to the LOCAL state, the PT 2025 is configured by the front panel controls which becomes operational.

By pressing the LOCAL push button once, when the instrument is in the REMOTE state, has the same effect as the LOCAL message provided that the button has not been disabled by the LOCAL lockout message (see below).

6.4.1.4 LOCAL Lockout

Message format: **K**

Since this message disables the LOCAL push button on the front panel of the PT 2025, only the "L" message or a RESET can return the instrument to LOCAL (front panel) mode.

6.4.1.5 Selection of the Radio Frequency

It is possible to select the radio frequency via the RS 232 C interface, thus replacing the use of the COARSE potentiometer.

The selected value can be sent either in binary or in decimal form. (The value is then sent to a 12 bit digital / analog convertor (DAC) in order to select the radio frequency.)

As the range of the DAC is from 0 to 4095, all values greater than this, will set the DAC to its maximum setting.

6.4.1.6 Selection of the Radio Frequency (Decimal Form)

Message format: **cnnnn<CR><LF>**

C	the ASCII character "C" signifies that the preselected value is expressed in decimal.
n	represents the preselected value given in ASCII characters from 0 to 9 inclusive. The user may perform leading 0 suppression on the preselected value.
<CR><LF>	the ASCII characters "carriage return" and "line feed" respectively must terminate the message.

Example:

C12<CR><LF> or C1028<CR><LF>

6.4.1.7 Selection of the Radio Frequency (Binary Form)

The binary format of the selection of the resonant frequency message is as follows:

Message format: **Bnn**

B	the ASCII character "B" signifies that the preselectedvalue is expressed in binary.
n	represents a two byte preselected value (0 to 4095 inclusive).

The right hand 12 bits of "nn" are sent to the DAC.

Example:

"B"&CHR$ (128)&CHR$ (255)

There is not a linear relationship between the preselected value and the NMR frequency. Fig. 7 shows the typical relationship between the NMR frequency versus the DAC setting.

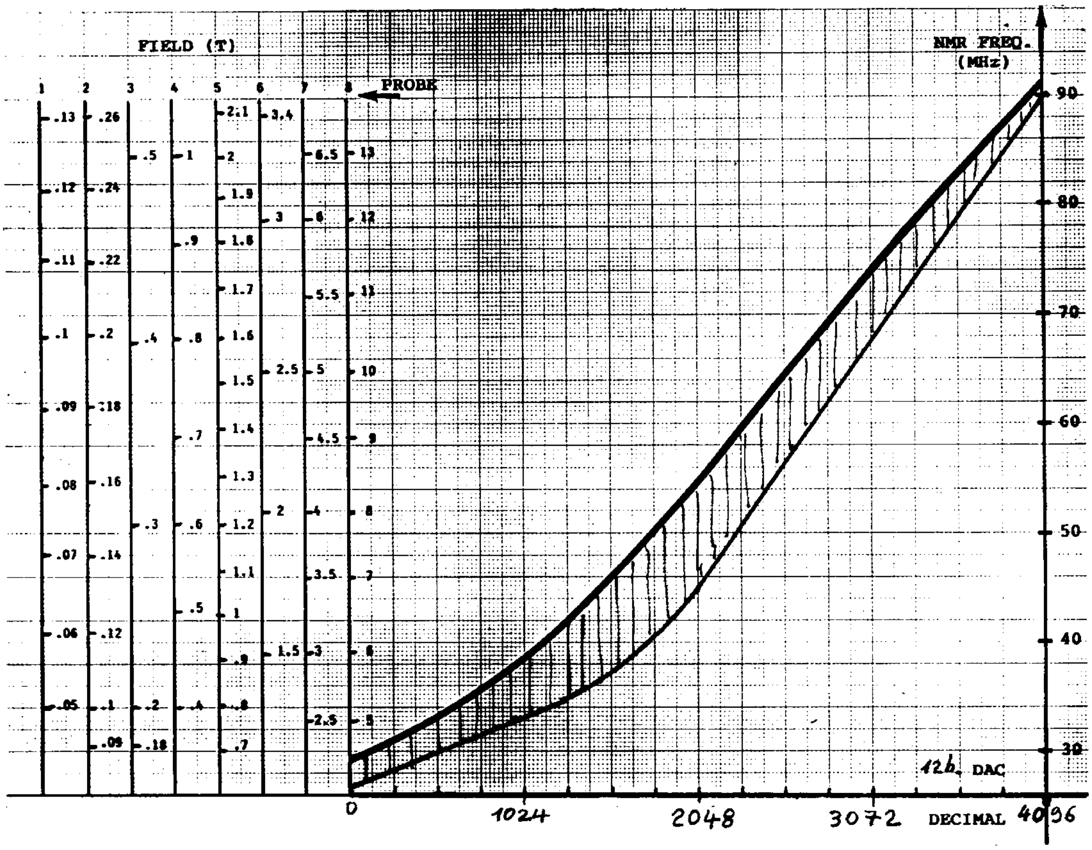


Fig. 7
NMR frequency versus DAC setting.

6.4.1.8 Select MANUAL or AUTO Mode

Message format: **An**

Where n = 0 for MANUAL mode
n = 1 for AUTO mode

This message selects the MANUAL or AUTO mode. When the PT 2025 is in AUTO mode it can "lock" on to the NMR signal and follows the field if it drifts within ± 5% of the value preselected by the DAC or the COARSE potentiometer. In the AUTO mode, the FINE potentiometer is disconnected (for more details see section 4.2 AUTO mode).

6.4.1.9 Select Field Sense

Message format: **Fn**

Where n = 0 or - (for negative fields)
n = 1 or + (for positive fields).

This message determines the sense of the probe with respect to the orientation of the field to be measured.

If the FIELD +/- is in the wrong sense, the PT 2025 does not "lock" on to the NMR signal.

6.4.1.10 Select Display

Message format: **Dn**

Where n = 0 for MHz
n = 1 for Tesla.

This message determines whether the displayed value given in Tesla or in MHz. It also affects the format the measured value given via the interface.

6.4.1.11 Select Multiplexer Channel

Message format: **Pc**

Where c is one of A, B, C, D, E, F, G or H and represents the appropriate multiplexer channel.

6.4.1.12 Activate SEARCH Mode

Message format: **Hnnnn<CR><LF>**

Where nnnn is optional and can have any value between 0 and 4095.

This message (H for Hunt) activates the automatic field-searching algorithm (see section 4.3). An optional start frequency can be supplied if the approximate field value is known. This has the advantage of reducing the search time.

If no DAC value is specified (i.e. H<CR><LF>) then searching starts at the minimum frequency (DAC = 0).

When the PT 2025 is in the SEARCH mode, it can still receive and interpret interface messages with the exception of An, Bnn, Cdddd, Fn, Xn and Pc which would interfere with the search. They are therefore ignored.

The SEARCH mode can be made to work over several channels of the multiplexer to allow searching over larger field ranges (refer to section 6.4.1.14").

6.4.1.13 Quit SEARCH Mode

Message format: **Q**

When this message is received and the PT 2025 is in SEARCH mode, it inactivates the search in progress and leaves the configuration as it was at the instant the "Q" message was received.

6.4.1.14 Select Number of MUX Channels Used in SEARCH Mode

Message format: **Xn**

Where n is a number from 1 to 8 inclusive

(X1 is selected on power up of RESET).

This message tells the PT 2025 the number of multiplexer channels that are to be scanned in the SEARCH mode.

When the PT 2025 enters the SEARCH mode, it starts its search on the channel that was last selected (either by the MUX switch when the instrument was put into REMOTE mode or the last value received in the "Pc" message). If the signal is not found on this channel, the PT 2025 will follow on to the next channel and so on, up to the number of channels given by the "Xn" message. When the last channel has been searched and no signal is detected, the search restarts on the first selected channel and the cycle is repeated.

Example:

Consider that probes 3, 4 and 5 are connected respectively to channels B, C and D of the multiplexer.

Send following messages:

"PB" starts search on channel "B"
"X3" searches over 3 channels
"H"&CHR$(13)&CHR$ (10) starts searching

The search will in this case start on channel "B" (probe 3) and if no NMR signal is found, it will continue on channel "C" (probe 4) and then on to channel "D" (probe 5). If the search fails to locate a field, the PT 2025 will recommence the search on channel "B".

If an NMR signal is detected, the PT 2025 will "lock" on to it. The SEARCH mode has been designed to follow the NMR signal even if it goes out of one probe's range by changing to the next channel. Suppose that the signal has been found on channel "C" (probe 4): if the field drifts to a value of less than 0.35 T then the PT 2025 will select channel "B" and continue with probe 3 (the algorithm functions in both positive and negative drift conditions).

In this example the PT 2025 can search and follow an NMR signal in a field ranging from 0.175 T (low end of probe 3) up to 2.10 T (high end of probe 5). **In order to operate this scan correctly, it is necessary to ensure that the probes are connected in an ascending order vis-à-vis the multiplexer channels.**

Note: If the first channel scanned is selected as "G" and the PT 2025 is programmed to search over 4 channels, then the scanning sequence would be "G", "H", "A" and "B".

6.4.1.15 Select the SEARCH Time

Message format: **On**

Where n is a number from 1 to 6 (n = 3 on power up of RESET)

This message allows the slope of the search to be changed. The number 1 corresponds to the most rapid (i.e. 9 seconds to scan the field range of a probe). Each increase in **n** slows down the search by 3 seconds.

It may be necessary to slow the scan slope used in the PT 2025 under certain critical field conditions, for example if the NMR signals were diminished due to a non-homogeneous field.

It is possible to change the scan slope even when the searching is in progress.

6.4.1.16 Reset NNR Time-base (Trigger)

Message format: **T**

This message forces a reset of the NMR time-base thus starting a new measurement cycle. Note that the NMR value will return the letter "W" until a valid cycle been completed.

6.4.1.17 Fast Reading Display

Message format: **Vn**

Where n = 0 or N (for Normal rate)

n = 1 or F (for Fast rate)

This message determines the display reading rate i.e. Normal (≈1 per second) or Fast (≈10 per second). The last digit of the display is not visible and is not transferred to the computer. Therefore, the PT 2025 resolution is reduced by a factor ≈10.

6.4.1.18 Request Status

Message format: **Sn**

where n is 1, 2, 3 or 4

and indicates the status register to be read. (The status registers are described in section 6.4.2).

Immediately after receipt of this message, the PT 2025 sends back the requested status in the format shown below:

Message format : Saa

where "S" is the ASCII character "S" meaning status

where "a" is the ASCII character forming a hexadecimal pair.

6.4.2 Instrument Status Registers

The PT 2025 has four internal status registers that can be accessed by the user (see section 6.4.1.18). The format of these four registers is now given.

6.4.2.1 Status Register 1 : Internal Instrument Status (1 Byte)

This register is cleared after reading.

Bit:	7	6	5	4	3	2	1	0
	N/A	Power ON or RESET	NMR Lock	Front Panel SRQ	Hard Error	Syntax Error	NMR Signal Seen	Data Ready

N/A = Not Applicable

bit 7: Unused

Always set to 0.

bit 6: Power ON or RESET

This bit is set to 1 on power up, or on return of current after a power failure, or after having pressed the RESET button located on the rear panel.

bit 5: NMR Lock

This bit is set when the instrument becomes "Locked". It is cleared by reading the Internal Instrument Status Register or when the PT 2025 is no longer "Locked".

bit 4: LOCAL push button

Pushing the LOCAL button situated on the front panel sets this bit.

bit 3: Hardware Error

This bit is set to 1 if the control program cannot read the display correctly (i.e. following a failure in the counter circuitry).

bit 2: Syntax Error

This bit is set to 1 if an incoming message does not conform to the formats described in this document.

The command generating a syntax error is ignored.

bit 1: NMR Signal Seen

Indicates that there has been an occurrence of an NMR signal since this status register was last read. This bit is the same as bit "3" in the Internal status register "2".

bit 0: Data Ready

This bit is set to 1 after each measurement cycle and can be used to inform the external computer of the end of a measurement cycle, without the need for the controller to continually scan the PT 2025

6.4.2.2 Status Register 2: NMR signal status (1 byte)

Bit	7	6	5	4	3	2	1	0
	N/A	N/A	N/A	N/A	NMR Signal Seen	NMR Signal State	TOO HI	TOO LO

N/A = Not Applicable

bits 7 to 4 : N/A

Always set to 0.

bit 3: NMR Signal Seen

This bit is set to 1 if the instrument detects the appearance of the NMR signal since this register was last read. This bit is only reset by the reading of this register.

bit 2: NMR Signal State

This bit gives the state of the NMR signal during the reading time of this register.

1 indicates the presence of the NMR signal

0 indicates the absence of the NMR signal.

bit 1: TOO HI

1 indicates that during the reading time of this register, one or several of the "TOO HI" LEDs were lit.

bit 0: TOO LO

1 indicates that during the reading time of this register, one or several of the "TOO LO" LEDs were lit.

Note: Bits "0" and "1" are useful to center the ± 5% scan window when the PT 2025 is in AUTO mode (see section 4.2).

6.4.2.3 Status Register 3: Instrument Functions (1 byte)

Bits	7	6	5	4	3	2	1	0
	Fast Reading Display	MULTIPLEXER			SEARCH Mode	Field +/-	AUTO/ MANUAL Mode	Display Tesla/ MHz

bit 7: Fast reading display

1 indicates that the PT 2025 is operated in the Fast reading display mode.

bits 6, 5, 4: Multiplexer channel

These three bits indicate which channel of the multiplexer is selected:

Bits:	6 5 4	Channel
	0 0 0	A
	0 0 1	B
	0 1 0	C
	0 1 1	D
	1 0 0	E
	1 0 1	F
	1 1 0	G
	1 1 1	H

bit 3: SEARCH mode

1 indicates that the SEARCH mode is active.

bit 2: Field +/-

This bit indicates if the field is positive or negative, with respect to the probe orientation.

1 indicates a positive field (+)

0 indicates a negative field (-)

bit 1: MANUAL/AUTO mode: state

This bit indicates whether the PT 2025 is in MANUAL or AUTO mode.

0 indicates MANUAL Mode.

1 indicates AUTO Mode.

bit 0: DISPLAY mode (data format mode)

1 indicates that the displayed value is given in Tesla.

0 indicates that the displayed value is given in MHz.

6.4.2.4 Status Register 4: DAC Status (2 bytes)

These two bytes give the contents of the DAC.

6.5 AUTONOMOUS MODE

This mode is used to connect the PT 2025 to a printer, without needing an external controller. To select this mode, micro-switch "7" must be set to 0. In this mode the Teslameter transmits the measured value at regular intervals according to the message format described in section 6.4.1.1 (all incoming messages are ignored). The intervals between each value can be defined by the micro-switches "1" to "3" as shown in the following table:

Micro-switches 3 2 1	Interval
0 0 0	no message transmission
0 0 1	sends every measured value
0 1 0	sends every 4th measured value
0 1 1	sends every 9th measured value
1 0 0	sends every 20th measured value
1 0 1	sends every 150th measured value
1 1 0	sends every 720th measured value
1 1 1	sends every 3600th measured value

6.6 SUMMARY OF THE RS 232 C MESSAGES

Message + Parameter	**Function**
An	Select MANUAL (0) or AUTO (1) mode (section 6.4.1.8)
Bnn	Binary load DAC (12 bits) (section 6.4.1.7)
Cnnnn<CR><LF>	ASCII load DAC (12 bits) (section 6.4.1.6)
Dn	Display mode Tesla (1), MHz (0) (section 6.4.1.10)
Fn	Field sense + (1), - (0) (section 6.4.1.9)
Hnnnn<CR ><LF>	Select SEARCH mode (section 6.4.1.12)
K	Set LOCAL lockout and disable front panel LOCAL button (section 6.4.1.4)
L	LOCAL Mode (puts PT 2025 under front panel control) (section 6.4.1.3)
On	Select SEARCH time (section 6.4.1.15)
Pc	Select multiplexer channel (section 6.4.1.11)
Q	Quit SEARCH mode (section 6.4.1.13)
R	REMOTE mode (section 6.4.1.2)

Sn	Request status register (section 6.4.1.18)
T	RESET NMR time-base (section 6.4.1.16)
Vn	Fast reading display (section 6.4.1.17)
Xn	Select multiplexer range (section 6.4.1.14)
<ENQ>	Read measured field value (section 6.4.1.1)

Messages sent by the PT 2025 :

vdd.dddddddT	Display format (Tesla)
vdd.ddddddF	Display format (MHz)
Saa	Status format

7 THEORY OF OPERATION

In the presence of a static magnetic field B_0, a nucleus with a magnetic moment μ can take (2I + 1) distinct energy states, I being the spin quantum number. The separation of these states is

$$\Delta E = \mu B_0 / I.$$

Applying an alternating magnetic field perpendicular to the static field induces transitions between levels if its frequency equals the resonant frequency.

$$f = \Delta E/h = \gamma B_0$$

with $\gamma = \mu / h \cdot I$.

For magnetic fields of the order of 1 Tesla, NMR frequencies lie in the radio frequency region. For protons and deuterons, G is known very precisely:

Gp, ^{1}H = 42.57608(12) MHz/Tesla for protons,

Gd, ^{2}H = 6.53569(2) MHz/Tesla for deuterons.

For detecting the proton magnetic resonance, a small water-filled coil is placed in static field B_0, with its axis perpendicular to B_0. The magnetic moments of the protons in the water molecules point preferentially in the direction of B_0; i.e. the lower energy magnetic states are more populated than the higher ones. Therefore, if transitions are induced with an alternating field, those from lower to higher energy states are more frequent than the contrary. The protons absorb more energy from the alternating field than they supply to it, and the difference between the populations of the two energy states is reduced.

The thermal equilibrium populations are re-established due to spin-lattice interactions, at a rate described by the spin-lattice relaxation time T1. This is the reason why protons continuously absorb energy from the alternating field if the coil is driven at the proton resonance frequency, thereby reducing slightly the quality factor Q of the coil. A practical way of detecting this effect is to tune a parallel LC resonant circuit to the proton resonance frequency, using the water-filled coil as the inductor, and to apply to this tank circuit a stable sine wave of that frequency via a resistor. The resistor value chosen should be high compared to the resonance impedance of the tank circuit in order to avoid damping.

If the proton resonance frequency is now modulated by superimposing a modulating magnetic field parallel to the static field B_0, the reduction of the Q factor due the proton resonance can be detected as a small amplitude variation of the radio frequency voltage across the tank circuit.

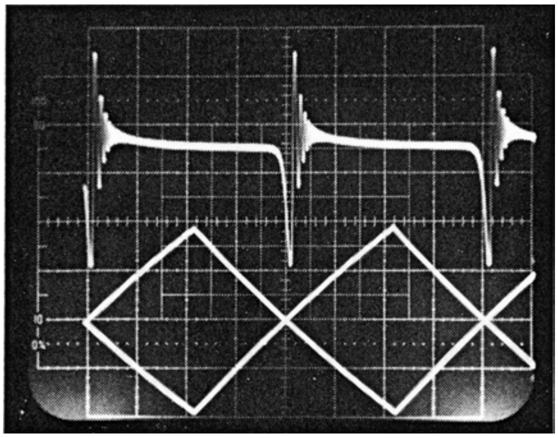
Adding a paramagnetic salt to the water can enhance the signal. This reduces the relaxation time T_1 and therefore increases the steady-state energy absorption of the protons at resonance. The METRO*LAB* probes contain either water doped with $NiSO_4$ (protons) or heavy water doped with $GdCl_3$ (deuterons).

A small, flat coil in the probes produces the modulating field B_{mod}. Its frequency is 30 Hz to 70 Hz and its amplitude 100 to 1000 ppm of B_0. The NMR electronics detects and amplifies the nuclear resonance signals of the LC circuit and measures the current in the modulating coil at the instant when resonance occurs.

A voltage-controlled oscillator produces the radio frequency voltage. Its frequency is controlled by a high-gain feedback loop to ensure that resonance occurs at the instant when B_{mod} crosses zero. Therefore, this frequency, f_0, equals the proton resonance frequency of B_0, and automatically follows any changes in B_0.

The LC circuit is automatically tuned to the applied frequency by means of a varicap diode.

In concluding these general remarks, it should be mentioned that the field modulation, in the NMR Probes, sweeps far too quickly through resonance to obtain adiabatic conditions. Therefore the observed signals have neither the form nor the width of a real proton or deuteron resonance curve. The width is several times the natural line width, and transient effects, for example "wiggles", appear (Fig. 8). However, this fast modulation is convenient for practical reasons, and an accuracy better than 1 ppm is nevertheless achievable, using a symmetry criterion.

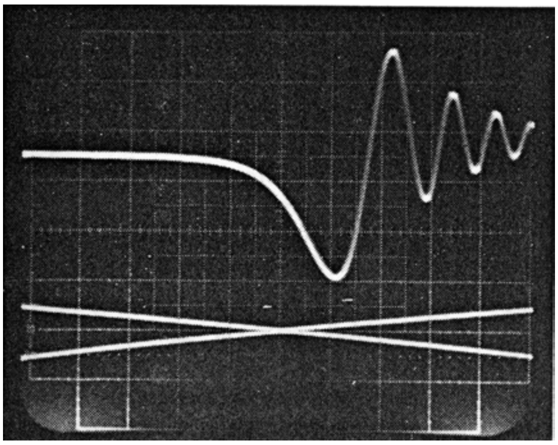


1 V/div

Time scale : 4 ms/div.

2 V/div.

a) "Alignment" of the NMR pulses in the frequency tracking mode

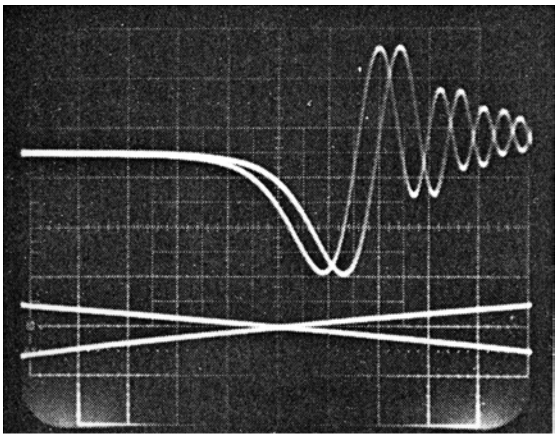


1 V/div

Time scale : 400 μs/div.

2 V/div.

b) Magnified display of the central part



1 V/div

Time scale : 400 μs/div.

2 V/div.

c) "Misalignement" resulting from a 1 ppm frequency error.

Fig. 8

NMR signal and modulation field chopped y(t) display with B = 1.5 Tesla.

8 PRINCIPLE OF OPERATION

The measuring head comprises a small glass tube which contains either ^1H or ^2H around which a flat radio frequency coil, for modulating the field width, is wound.

The applied field modulation, B_{mod}, is a symmetric 30 Hz to 70 Hz triangular waveform with an amplitude of a few hundred ppm of the measured field B_0.

The radio frequency coil, a tuning diode and the coaxial cable from the measuring head to the signal detection circuit, form a parallel LC resonant circuit. This resonant circuit is weakly coupled, by means of a resistor, to the output of a radio frequency Amplifier with a stabilized output amplitude, and is automatically tuned to the applied frequency. If the chosen frequency is close enough to the nuclear resonance frequency corresponding to the main field B_0, an absorption signal (i.e. amplitude variation) appears in the LC resonant circuit every time the resonance is crossed due to field modulation. This signal is amplified in the Amplifier and transmitted to the PT 2025.

A sample-and-hold circuit produces an "error voltage" which is proportional to the modulating field at the instant when nuclear resonance occurs. With this error voltage, the frequency of the radio frequency oscillator in the PT 2025 is regulated in such a way that nuclear resonance occurs exactly at the zero crossing of the modulation. This frequency is therefore equal to the nuclear resonance frequency of the field B_0, as seen by the protons or deuterons in the sample, but without modulation. It automatically follows all changes of B_0 within the range covered by the FINE frequency adjustment.

This kind of field modulation has been chosen for the following reasons:

- The modulation amplitude of a few hundred ppm facilitates the "locking" of the radio frequency to the field.
- The modulation frequency of 30 Hz was found to be a reasonable compromise between radio frequency tracking speed and signal line width. However the frequency can be increased up to 70 MHz if the field is very uniform.
- A triangular wave crosses through zero more slowly than a sine wave of the same frequency and amplitude, which reduce spreading of the line width. Moreover, it can easily be generated very symmetrically, thus improving the accuracy of the Teslameter.

The resulting line width is 10 to 100 ppm, depending on the measured field and the modulation amplitude setting. An accuracy better than 1 ppm can still be reached provided that the LC resonance circuit in the Probe is well tuned to the applied frequency and that the field modulation is symmetric in respect to zero; i.e. $B_{mod}(t + T/2) = -B_{mod}(t)$, T being the period of the modulation.

With both conditions fulfilled, the NMR signals become identical in form and size, and equally spaced in time, if the resonance occurs at the zero crossing of the modulation (Fig. 8).

If the LC resonance circuit in the Probe is slightly mistuned, a dispersion signal is mixed with the absorption signal, and the NMR signals at upward zero crossing of the modulation look different from those at downward zero crossing. Automatic tuning of the probe eliminates this effect.

It is therefore not necessary to know a priori at which point of the 10 to 100 ppm wide signal the applied frequency is equal to the proton resonance frequency. The criterion is simply that the time difference between any point of the NMR signal and the close-by zero crossing point of the modulation is equal for the upward-going as well as for the downward-going modulating field. Then the applied frequency is equal to the proton resonance frequency, of the field B_0, with $B_{mod} = 0$; this is the criterion upon which the frequency control loop works.

The automatic tuning of the Probe combined with the good symmetry of the field modulation form the basis for the high accuracy of the Teslameter.

To achieve a short response time of the frequency control loop, the sample-and-hold circuit mentioned above is used to produce an "error voltage", which indicates after each NMR pulse how far away the resonance was from zero modulation.

The sensitivity of the error voltage is 160 mV/μT (16 V/G) for the lowest and 1.6 mV/μT (0.16 V/G) for the highest field range.

This error voltage is integrated and then sent to the frequency control input of the radio frequency oscillator. By choosing the gain and the integration time constant appropriately, the error can be corrected entirely within the time between two consecutive NMR signals. For this optimum loop gain setting, the time lag of frequency tracking is equal to the spacing of the NMR signals, which is roughly 17 ms. The loop gain at d.c. is of the order of 10^6.

The size and width of the NMR signals depend strongly on the field strength and homogeneity of B_0. During field mapping, for example, the amplitude may vary by a factor of 10 and the width by a factor of 4. Therefore, the trigger level and the timing of the sample-and-hold circuit are adjusted automatically in the Teslameter in order to maximise its range of operation.

The trigger level is set automatically to about half the signal amplitude, the latter being measured with a special peak detector circuit, which is insensitive to possible occasional large, single parasitic signals.

The trigger point may be early or late with respect to proper proton resonance. In order to correct this, both the strobe pulse as well as the triangular wave voltage, proportional to the modulating field are delayed appropriately before being fed to the sample-and-hold circuit, which produces the error voltage.

Wrong timing does not change the mean value of the error voltage, but produces a 30 Hz rectangular signal superimposed on it and synchronous to the modulating field (See Fig. 9). It is, therefore, the speed rather than the accuracy of the field measurement, which would deteriorate, because a larger integration time constant would be needed. However, the Teslameter automatically adjusts the delay of the strobe pulse such that the above-mentioned 30 Hz component of the error voltage disappears.

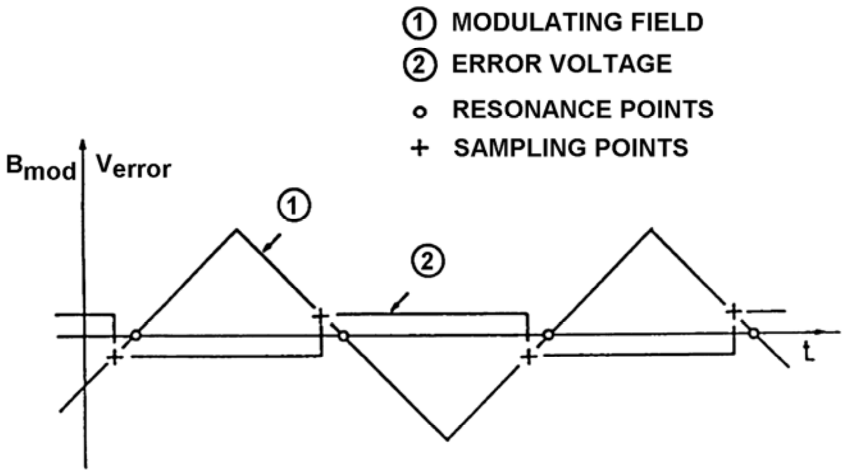


Fig. 9

A 30 Hz square-wave component in the error voltage indicates wrong timing of the sample-and-hold circuit. In the example shown, the sampling pulses are assumed to be early with respect to the nuclear resonance.

9 CIRCUIT DETAILS

9.1 PROBES

Eight probes are necessary for a field range of 0.043 to 13.7 Tesla. Each probe consists of a measuring head and NMR detection circuit, interconnected by a short 50 Ω coaxial cable, which is part of the LC resonant circuit and also a screened cable with two wires for modulation.

The probe and Amplifier are interconnected with a 5-wires cable (for probe identification, modulation, a negative supply and tuning diode bias voltage) and a 50 Ω double-screened coaxial cable, which transmits both the radio frequency and the NMR signals (plus any detected 10 kHz signal which is used for automatic tuning).

The measuring head of the probe contains a radio frequency coil wound around the NMR sample (active volume). The NMR sample is made of a solid material containing a large number of protons (^{1}H) for probes 1 to 5, or in the case of probes 6 to 8, a sealed glass tube containing D_2O (^{2}H).

The number of turns of the radio frequency coil is defined for each probe by its highest operating frequency and the lowest attainable value of the capacitance of the LC resonance circuit. This capacitance is essentially the sum of the capacitance of the coaxial cable and of the tuning diode. With the type of tuning diode used, a frequency range of a factor of three can be covered with a maximum cable capacitance of 17 pF, i.e. a maximum length of 17 cm.

The number of turns of the modulating coil depends on the field range of the probe, and is chosen such that a field modulation of 100 ppm is produced by a current of a few tens of mA. This number of turns is also important for the loop gain of the frequency control loop. The modulating field in the sample is not homogeneous. This does not harm the accuracy, as the resonance occurs when the modulating field goes through zero, but it has the welcome effect of dampening the "wiggles".

9.2 AUTOMATIC PROBE TUNING

Although for space reasons the circuits for generating the varicap voltage are located in the main unit, their operation is discussed in this section, as the automatic tuning is a very essential feature of the probes. The simplified circuit diagram is shown in Fig. 10.

The bias voltage of the tuning diode in the probe is composed of the voltage VF2 given by the COARSE potentiometer and the output of an integrator (INT in Fig. 10). A square-wave signal of 0.6 mV amplitude is superimposed on it and modulates very weakly the capacitance of the tuning diode (Δ_C/C = 100 ppm). This results in a 10 kHz amplitude modulation if the resonant circuit is slightly mistuned, being in phase or 180 degrees out of phase with respect to the injected square-wave, depending on whether the capacitance is too small or too large.

The amplitude modulation is detected and amplified by a factor of 3000 together with the NMR signal. The superposition of both is fed to the X input of an analogue multiplier, where the NMR portion is reduced by RC differentiation and diode clipping, the latter being necessary in order to avoid spurious signals when there are large and slowly decaying "wiggles".

The Y input of the multiplier is connected to the 10 kHz square-wave generator, which produces a bi-polar output signal of ± 10 V. The same signal is used with approximately 90 dB attenuation for modulating the varicap. This attenuation is split into two steps: approximately 50 dB in the Teslameter and approximately 40 dB in the probe, where a low-pass filter is placed for reducing the noise pick-up in the long interconnecting cables.

A positive or negative current is produced at the multiplier output whenever the resonance circuit is mistuned. This current is fed to the integrator INT, which changes the tuning diode bias voltage until the multiplier output current falls to zero, i.e. the 10 kHz signal at the X input disappears. The time constant has been chosen such, that automatic tuning easily follows the fastest frequency variations in the SEARCH mode. An appropriate feedback network of the integrator compensates for the effect of the low-pass filter in the probe on the frequency characteristic of the loop gain.

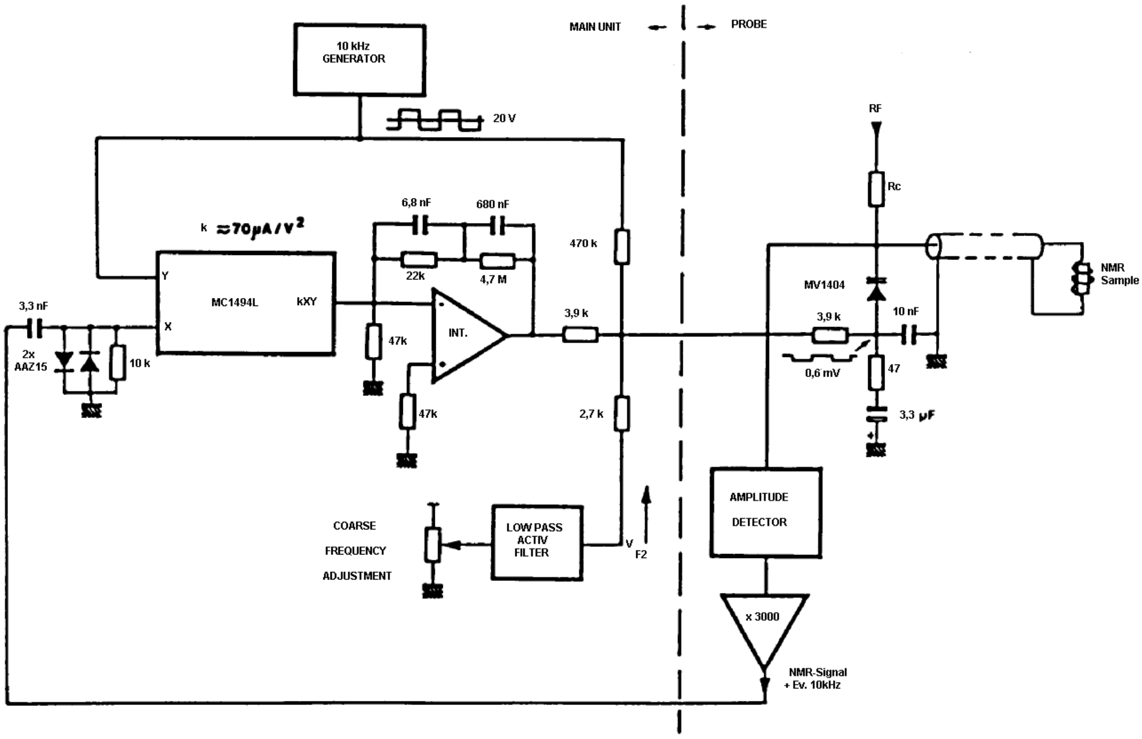


Fig. 10

Simplified circuit diagram of automatic tuning circuit

9.3 THE NMR SIGNAL AND RADIO FREQUENCY AMPLIFIERS

A simplified circuit diagram of the probe and Amplifier is shown in Fig. 11.

The NMR absorption signal is an amplitude variation of the radio frequency voltage of the LC circuit and is very small, typically of the order of 0.1 %. It is detected with two Schottky diodes and transmitted by means of an emitter follower through the coaxial cable and a low-pass filter to the Amplifier.

The a.c. portion of the detected voltage is amplified by a factor of 3000, while unity gain is provided for the d.c. component. The upper frequency limit is approximately 20 kHz, i.e. higher than the 10 kHz frequency used for automatic tuning.

After this Amplifier, the amplitude of the NMR signal may vary from about 100 mV, which is near the lower limit for "locking" the radio frequency to the field, to several Volts.

A slightly smoothed output (RC integration with 10 kΩ and 10 nF) is available at the front panel of the PT 2025 for scope inspection of the NMR signal. Its d.c. component indicates the radio frequency voltage amplitude at the LC resonance circuit in the probe, which should be about 0.1 to 1 V depending on frequency. For example, this checks very quickly whether the connected probe corresponds to the selected frequency range and whether the automatic tuning works properly.

Because of the weakness of the NMR signal, the radio frequency voltage must be extremely clean with respect to any spurious amplitude or frequency modulation and noise; otherwise the signal-to-noise ratio becomes poor. The waveform shape of the radio frequency signal, however, is not important since the LC resonant circuit and the NMR sample in the probe are insensitive to any harmonics.

In the Amplifier, the radio frequency signal is amplified to the level needed for the probe, which is about 5 V peak-to-peak. The radio frequency Amplifier consists of a fast differential amplifier with voltage-controlled gain, a common emitter stage and a push-pull output stage, which is able to drive a 50 Ω load at the required level.

With a typical input signal of 0.5 V peak-to-peak amplitude, the differential amplifier works in a switching mode rather than linearly. Its sensitivity to amplitude variations of the input signal is therefore reduced. Moreover, the signal output from the radio frequency Amplifier is measured with a diode detector circuit and compared with a clean, adjustable reference voltage. Any difference is amplified and fed back to the gain control.

This feedback control of the amplitude, in addition to the switching operation of the input transistors, smoothes any amplitude modulation of the input signal by a factor of 50 to 100. This helps, in particular, to reduce the very disturbing interference effects ("beating") when more than one probe operated at slightly different frequencies is used.

The output signal of the radio frequency Amplifier looks more like a badly shaped square-wave than a sine wave. As already mentioned, this is not a disadvantage, since the probe is hardly sensitive to the waveform. The output level is roughly the same for all frequencies. For obtaining the best signal-to-noise ratio, the optimum radio frequency voltage of the LC resonance circuit in the different probes is set by an appropriate choice of the coupling resistor RC to the radio frequency input.

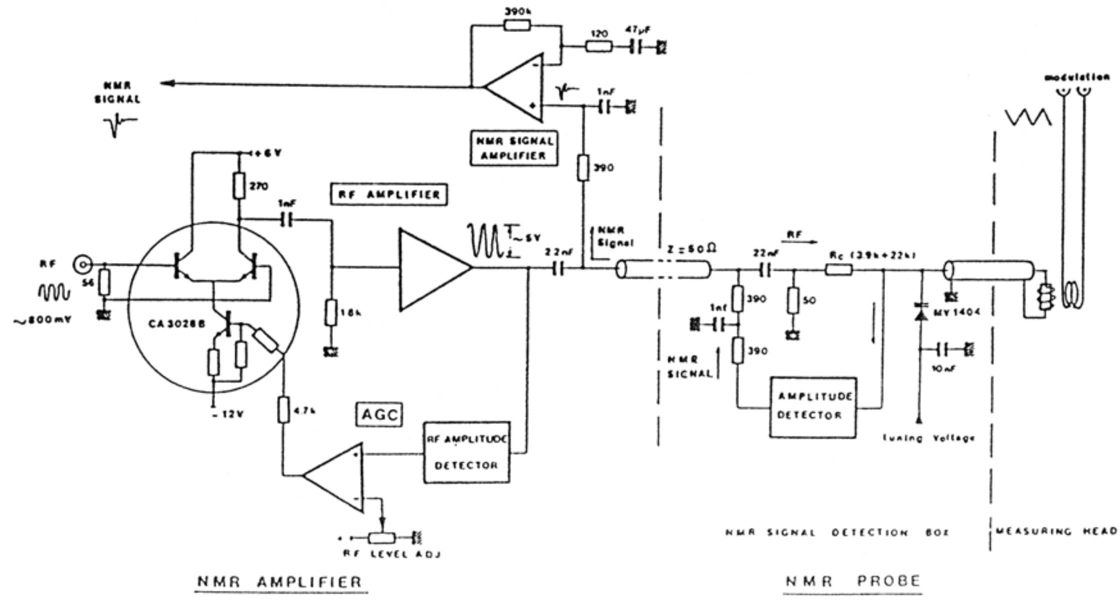


Fig. 11
Simplified circuit diagram of Amplifier and Probe.

9.4 AUTOMATIC TRIGGER THRESHOLD AND DELAY CIRCUITS

The NMR signals are fed to the input of comparator C1 via a filter network which eliminates the d.c. component and reduces the noise. (Fig. 12 shows the diagram of the corresponding circuits.)

The trigger level is set automatically to about half the signal amplitude: the threshold of comparator C1 is 0.6 times the voltage at point A, which is produced by the circuit around A1 in a charge pumping mode, and which is slightly less than the NMR signal amplitude. This kind of amplitude detection has the advantage of not being very sensitive to occasional large, single, parasitic signals, since the voltage at point A can change, at most, by 0.2 V per input pulse of any size.

The lowest trigger level, which is set without an NMR signal, is kept safely above the noise level. Since noise increases with the radio frequency, the minimum threshold is derived from the COARSE frequency adjustment (VF2) and varies from 40 mV to 100 mV.

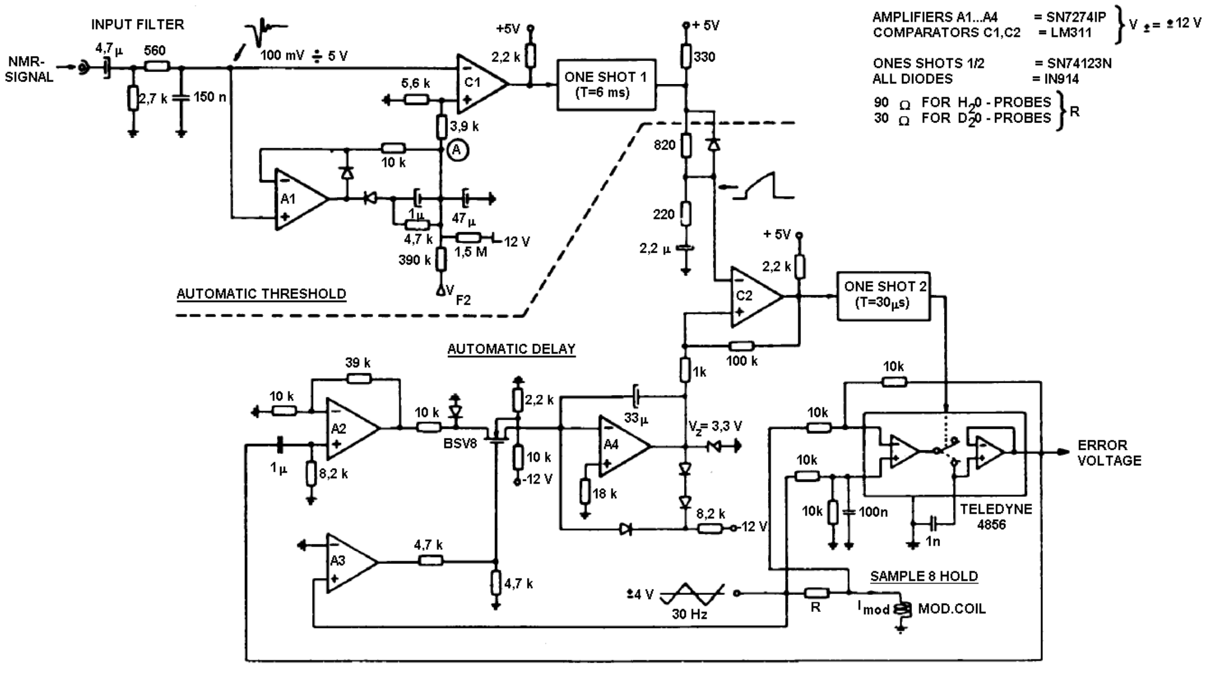


Fig. 12

Circuits for generating the error voltage, including the automatic threshold and timing controls.

The modulating current I_{mod} is sampled during the 30 μs pulses produced by one-shot 2 (shown in Fig. 12). The pulse width is not critical, but has to be long enough to allow the sample-and-hold amplifier to settle.

The voltage at the output of integrator A4 determines the delay relative to the instant when the NMR signal crosses the threshold at C1. This voltage is regulated so that no 30 Hz to 70 Hz component appears at the error voltage output. If there is a signal in phase or 180 degrees phase difference relative to the modulation, it is amplified by A2 and integrated by A4 only during the positive half waves of the modulation, the MOS-FET switch being controlled by A3. This results in a decrease or increase respectively of the output voltage of A4 and therefore, in a decrease or increase respectively of the delay, until the 30 Hz component disappears.

The three diodes and the zener diode limit the output voltage of A4 to values safely above the base line and below the top of the pulse at the inverting input of C2. The range of automatic delay is from 0 to 5 ms, which is, considering the fixed delay of 0.5 ms at the sample-and-hold input, equivalent to -0.5 to +4.5 ms. This is quite sufficient for all practical operating conditions of the Teslameter.

9.5 FREQUENCY CONTROL AND LOOP GAIN

The frequency control loop diagram is shown in Fig. 13.

As any frequency drifts of the voltage-controlled oscillator (VCO) are corrected by the frequency control loop, the problem of long-term stability of the VCO is not very critical. Any frequency modulation or noise above 1 Hz is, however, very harmful; therefore the following precautions are taken:

very careful filtering of the varicap bias voltage and of the supply voltage of the oscillator;

the oscillator is enclosed in a copper box for radio frequency screening and to avoid thermal convection effects.

The various frequency ranges are obtained by division in steps of two, using MECL 10.000 flip-flops. The selection of these ranges is done with MECL 10.000 gates. A long-tailed transistor pair produces the NMR frequency output (NIM level) for external CAMAC or other counters, whereas an MECL 10.000 gate is used as an output stage for the probe radio frequency signal. Using a well-filtered supply voltage for this gate, results in the necessary cleanness of the amplitude of the radio frequency signal. Its square-wave-like shape does not cause any disturbance.

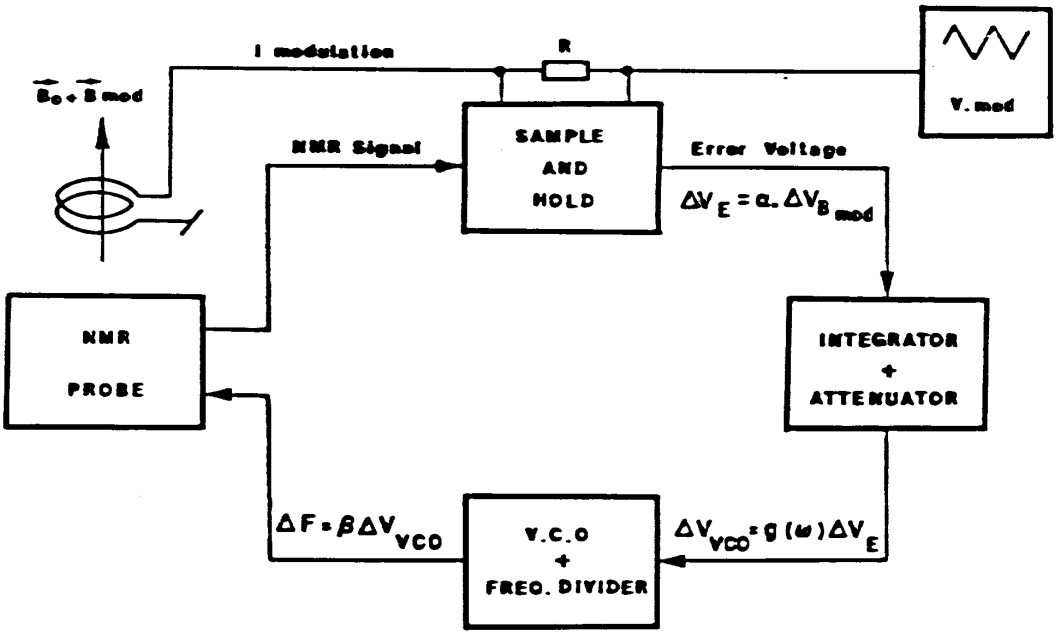
The sample-and-hold circuit produces an error voltage ΔV_E, proportional to the modulating field at the instant when the nuclear resonance occurs:

$$\Delta \mathbf{V_E} = \alpha . \Delta \mathbf{B_{mod}}$$

The frequency control voltage of the oscillator is derived from ΔV_E by integration and attenuation:

$$\Delta \mathbf{V}_{\mathbf{vco}} = \mathbf{g}(\omega).\Delta \mathbf{V}_{\mathbf{E}}$$

which results in a frequency change of $\Delta F = \alpha.\beta.g(\omega).\Delta B$



Loop gain = $\Delta F/\gamma.\Delta B = \alpha.\beta.g(\omega)/\gamma$

Fig. 13
Block diagram of frequency control loop.

By choosing an appropriate integration time constant and attenuation, ΔF reaches $\Delta B_{mod}/\gamma$ just when the next NMR signal appears, i.e. the frequency error which produced $\Delta V_E \neq 0$ is entirely corrected by this time. This is the optimum loop gain setting for fast frequency tracking.

Owing to the non-linearity of the oscillator frequency control curve, the optimum loop gain setting at a medium frequency is not valid for the full frequency range. The loop gain decreases in the worst case by a factor of five close to the upper and lower limits of the oscillator frequency range.

For all frequency ranges except one, the oscillator frequency is divided by a factor of 2^n which results in a reduction of β by the same factor. This is compensated for by the factor α, i.e. the product $\alpha.\beta$ is made constant for all field ranges between 0.045 and 2.1 Tesla by using an appropriate number of turns of the modulating coil of the different probes (see below for a further explanation of the ^2H probes). The number of turns is chosen such that at a given current in the modulating coil, the ratio of B_{mod} to B_0 is the same for all ^1H probes (at the same VCO setting). Hence the number of turns decreases roughly linearly with the decreasing field range of the probe, while $\alpha = \Delta V_E/\Delta B_{mod}$ increases inversely, R (the resistor of the modulation current sense) being constant. Therefore, switching the frequency range and changing the corresponding ^{1}H probes does not change the loop gain.

For the ^{2}H probes, the resistor R for limiting and measuring the modulating current is switched to a three times lower value (30 Ω instead of 90 Ω), in order to keep the necessary number of turns of the modulating coil below impracticable limits. The ratio of B_{mod} to B_0 at a given voltage drop over the resistor R is the same for both the ^{2}H and ^{1}H probes, and the resulting factor a compensates for the frequency division and the lower gyromagnetic ratio of the deuterons. To understand this point, the following argument may be helpful: the sensitivity of the error voltage to a frequency error in relative terms (e.g. ppm), is the same for all ^{1}H probes and ^{2}H probes at a given VCO setting, and the relative change of the probe frequency $\Delta f/f$ produced by ΔV_{VCO} does not depend on the frequency dividing factor.

The signal-to-noise ratio is much smaller for the ^{2}H probes than for the ^{1}H probes. Therefore, for the ^{2}H probes, an additional attenuation factor of three is switched in the frequency control loop in order to facilitate the "locking" of the Teslameter to the field. This reduces, by the same factor of three, the rate of the frequency variation in the SEARCH mode, the loop gain and the frequency tracking range. The accuracy of the Teslameter is not influenced by the lower loop gain, which is still greater than 10^5 at d.c.

9.6 FREQUENCY COUNTER

A eight and a half digit frequency counter with a special time-base measures the NMR frequency and displays it either in Tesla, with a resolution of 0.1 µTesla or in MHz, with a resolution of 1 Hz. When Field display has been selected, the counter gate is about 1 s with ^{1}H probes and about 1.5 s with ^{2}H probes; if Frequency display has been selected, the counter gate is 1 s, the gate length being defined by the gyromagnetic ratios and the chosen predividing factor of 4 for the ^{1}H probes. There are no predividing factors for the ^{2}H and the frequency display.

The frequency counter is built up with an ECL circuit for the first stage and high speed C-MOS circuits for the others. The data transfer signal for its display register and the reset signal are generated by the time-base circuit.

Fig. 14 shows a block diagram of the frequency counter time-base. A 100 kHz crystal oscillator is used as the clock frequency for generating the required gate lengths. This low clock frequency value has been chosen in order to avoid interference with the radio frequency signal of the probe (risk of "beating"). The required gate lengths are 0.93949464 s for the ^{1}H probes and 1.5300599 s. for the ^{2}H probes if field display has been selected, or 1.0000000 s in the case of Frequency display. The clock period of 10 µsec is too long for generating these times sufficiently accurately by simple countdown; therefore, three one-shots for fine adjustment of the gate lengths (±40 ppm) have been added.

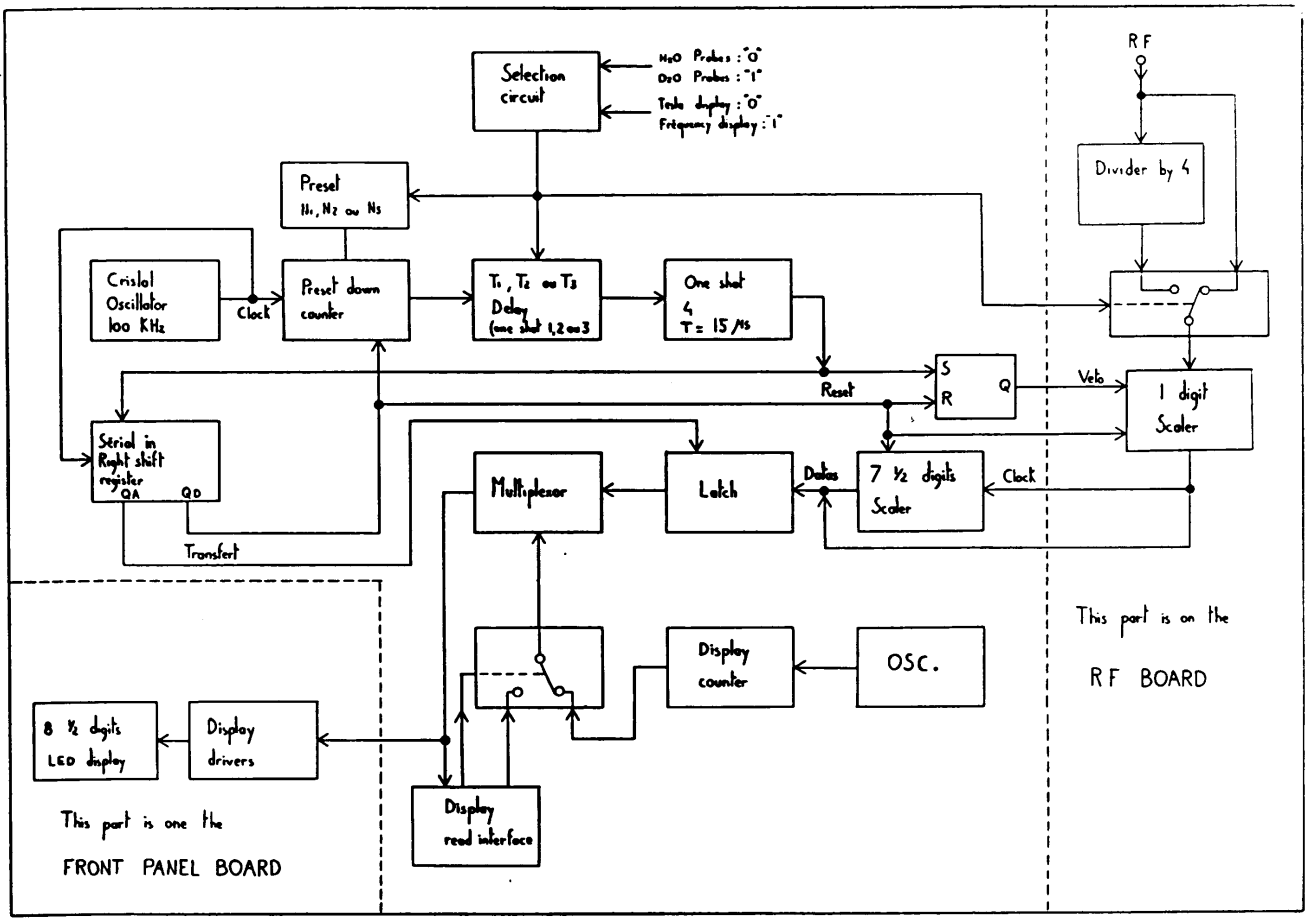


Fig. 14
Block diagram of the time base of the frequency counter.

One-shot 1 is used for calibrating the Tesla reading of the ^{1}H probes, one-shot 2 is used for calibrating the ^{2}H probes and one-shot 3 for calibration in MHz.

The stability of these one-shots (typically less than ± 1%) is not critical since they add only a small tens of ppm to the total gate width. This interpolation technique has also the advantage that the frequency tolerance of the 100 kHz crystal is relaxed.

Fig. 15 shows a pulse sequence diagram of some lines in the time-base of the frequency counter.

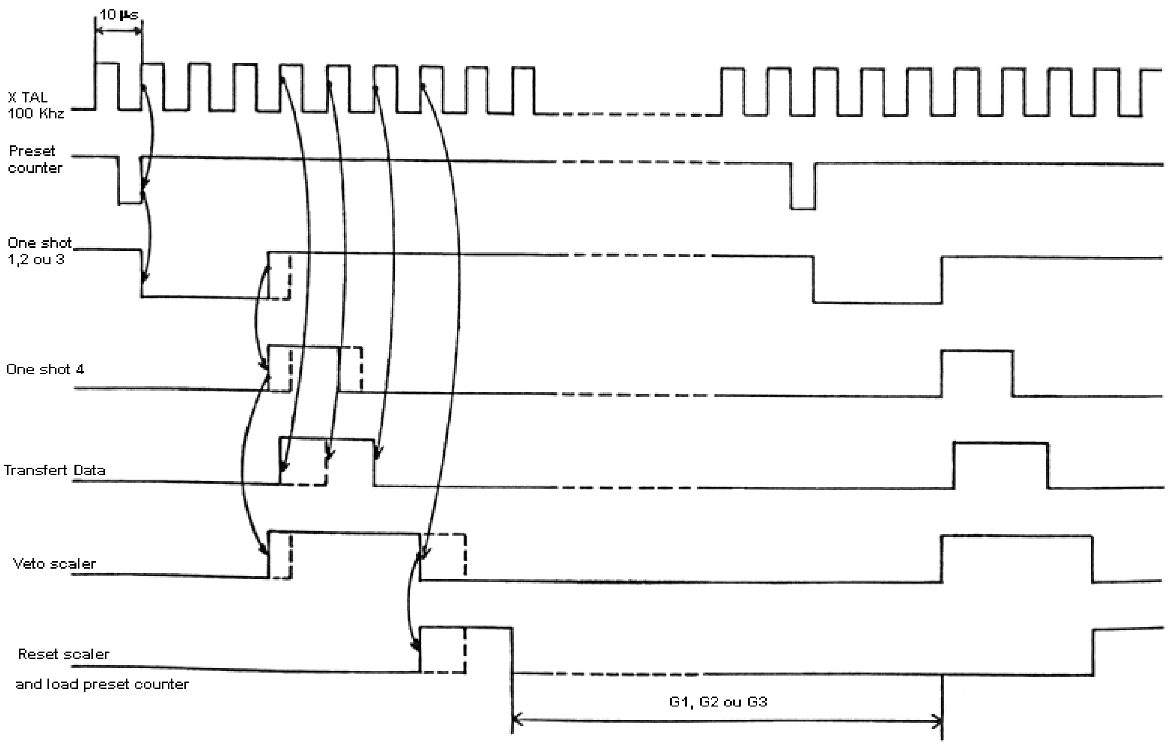


Fig. 15

Pulse sequence diagram of the time-base of the frequency counter

10 FAULT FINDING

The examples outlined below demonstrate:

- The types of problem that might occur
- The reason
- The solution

10.1 ABOUT AUTO MODE

Symptom: The Teslameter failed to generate a stable field or frequency reading whilst in AUTO mode (the NMR lock LED remained off).

Reason	**Solution**
Incorrect COARSE control setting	Revert to MANUAL mode and tune the COARSE control to achieve a field or frequency reading of within approximately 1 % of the known field. Change back to AUTO mode. In the event that the field or frequency reading is unknown, search the NMR signal output by using an external oscilloscope (sensitivity of approx. 100 mV/cm). Gradually tune the COARSE control until the NMR signal is observed then revert back to AUTO mode.
Incorrect field	Ensure that the FIELD ± switch position is polarity correct according to the measured field polarity, and that the probe range corresponds to the field about to be measured.
Incorrect probe type	The probe modulation field must be situated along the measured field direction (transversal or axial), despite the fact that the NMR probe gives a precise field or frequency reading independent of orientation. Verify that the arrow on the probe is in the direction of the measured field. Note that the field polarity is unimportant as it can be corrected by the FIELD ± polarity switch.
Incorrect probe modulation	Verify the triangular modulation waveform (approx. 30 Hz to 70 Hz) at the FIELD MODULATION OUTPUT, with the mode switch turned to MANUAL. If necessary, use a screwdriver to regulate the MODULATION AMP adjustment on the front panel until the correct signal amplitude is registered: H_20 probes - approx. 16 V peak-to-peak; D_2O probes - 8 V peak-to-peak
Amplifier box switch not in correct position	Set the switch to the correct position: one position for probe 1 and one position for probes 2 to 8.

Probe not tuned	In some conditions, the auto-tuning of the probe can take a few seconds. Turn the coarse field potentiometer to the top of the range for 2-3 seconds before returning to the actual field value.
Inadequate signal-to-noise level	Compare the signal at the NMR SIGNAL output with that shown in Fig. 1. A minimum signal of about 100 mV is required for the system to "lock". Should this signal level not be reached, it is possible that the field uniformity is inadequate. In some instances the next lower range probe may register a higher signal. It could also be worthwhile considering the use of Gradient Compensation Coils.
Faulty cable	Verify that the Probe-to-Amplifier and Amplifier-to-Teslameter cables are undamaged and securely in place.

10.2 ABOUT FIELD TRACKING

Symptom: Whilst in AUTO mode, the field tracking range was restricted.

FINE control not centred	The FINE control should be set to approximately 5.0 and the COARSE control adjusted if necessary.
When compared to the COARSE setting, the actual field remained either too high or too low	This is indicated by the LEDs TOO HI or TOO LO being lit. Gradually turn the COARSE control to high or low until both LEDs are extinguished.
Operating at the probe range's extremity	The tracking range is lower at the extremes of the probe ranges and so, where possible, use a different probe.

10.3 UNSTABLE VALUE

Symptom: Unstable field or frequency reading.

Unstable field	Verify the stability of the magnet power supply and magnet and the probe mounting.
Too low GAIN control setting	Turn clockwise the GAIN adjustment on the front panel to maximum, unless a poor signal-to-noise ratio prevents a stable "lock" at maximum gain.

10.4 EXTERNAL FREQUENCY METER

Symptom: An incorrect reading was registered by the external frequency meter.

The cable was unterminated from the NMR FREQUENCY output to the frequency meter	Use a cable with a 50 Ω termination at the frequency meter.