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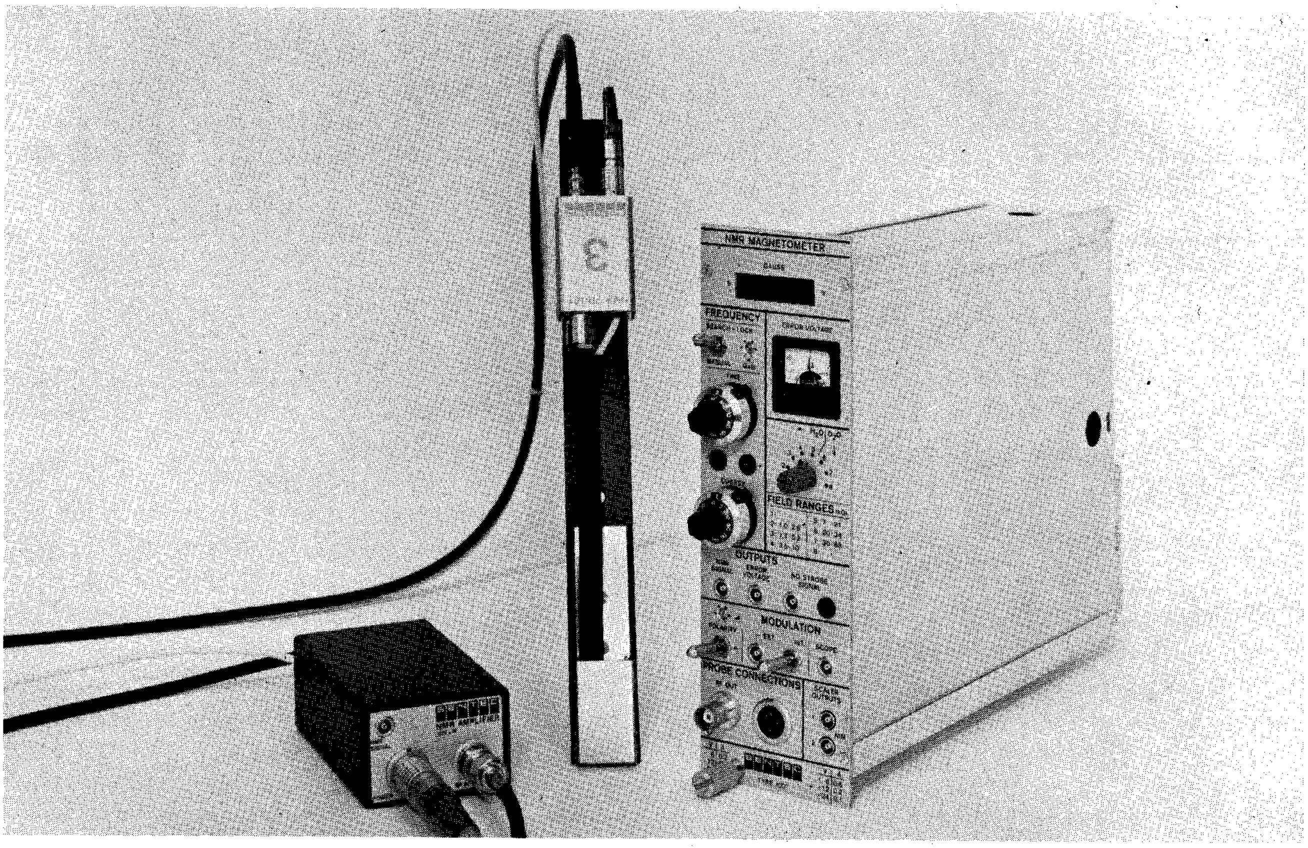
SENTEC

# NMR Magnetometer
## Type 1000



*NMR magnetometer with probe amplifier box and NMR probe.*

## SENTEC NMR Magnetometer type 1000

It is a low cost and easy to use instrument to measure magnetic fields in the range from 0.44 to 137 kGauss. Many of its features are available elsewhere only at much higher cost or not at all. They include:

- Field range 0.44-137 kGauss covered by 8 probes in 4 different styles
- 7 digit display in Gauss, resolution 0.01 Gauss
- Accuracy: $\pm 10^{-5}$ absolute, $\pm 5 \times 10^{-7}$ relative
- Automatic search and lock of NMR signal
- Automatic field tracking
- Automatic probe tuning, trigger threshold and timing of the NMR signal
- Double width NIM module plug-in includes internal oscillator, frequency counter and time base
- Error voltage output
- Connections for ext. scope and oscillator
- BCD output

The instrument was proven reliable and easy to use during many years and is in use in numerous leading laboratories and industries throughout the world.

SENTEC

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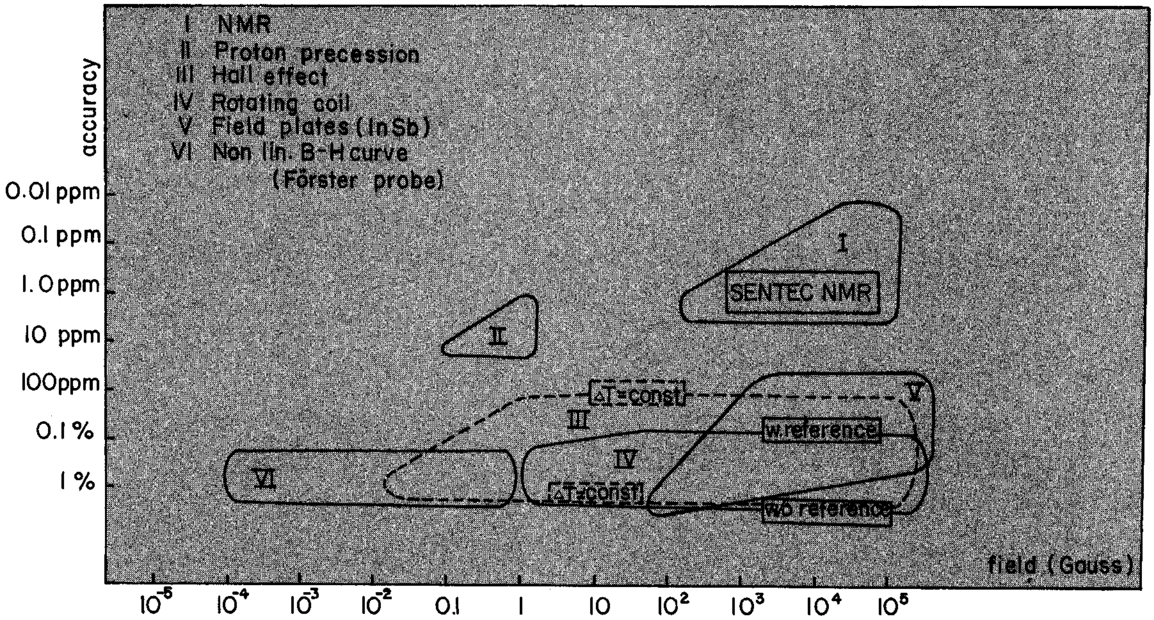


*Comparison of major field measuring techniques.*

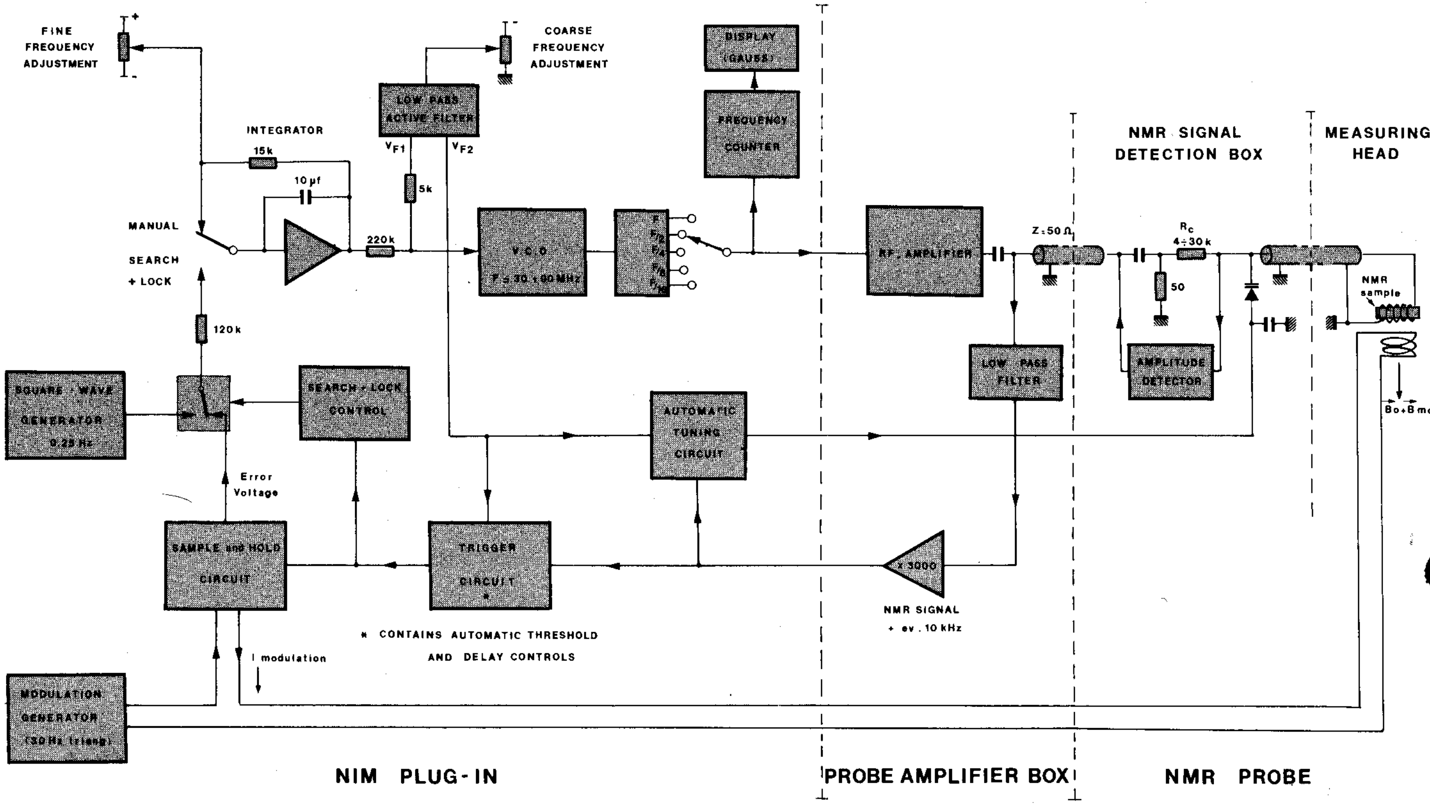
## General description

The design of the SENTEC NMR Magnetometer follows the CERN specifications* type 9298.

The NMR magnetometer consists of a dual-width NIM plug-in, which is the main unit, five $H_2O$ probes (for B = 0.44-21 kG) and three $D_2O$ probes (for B = 20-137 kG), and one probe amplifier box, the same for all probes. Each probe consists of a measuring head and a small box which contains the signal detection circuit. The maximum length of the two cables between the detection circuit and the measuring head is about 17 cm to guarantee the maximum field range, whereas the cables between the probe and the probe amplifier box may be a few metres long. From there to the main unit any cable length is allowed, provided the RF signal is not damped more than 6 dB. A block diagram of the magnetometer is given in the figure. The RF oscillator in the main unit has a frequency range of 30 to 90 MHz, which corresponds to the highest proton resonance field range of 7 to 21 kG. The other field ranges are obtained by dividing the frequency by 2, 4, 8 or 16 (f:4, f:2 and f:1 being used for the three $D_2O$ probes). This results in a very comfortable overlap of the eight field ranges. An internal frequency counter measures the frequency which is sent to the probe, the result being displayed in Gauss with a resolution of 0.01 G.

Coarse adjustement of the frequency is done manually with a 10-turn potentiometer. A second 10-turn pot-

*Block diagram of the NMR magnetometer.*



entiometer allows fine adjustment over 1 to 10% of full scale, depending on the coarse frequency setting and the type of probe ($H_2O$ or $D_2O$) used. In the "search and lock" mode, the unit sweeps the frequency up and down through the fine adjustment range until a NMR signal appears. Then it "locks" automatically to this signal, i.e. 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.

Automatic probe tuning and automatic trigger threshold and timing of the NMR signal processing circuits simplify the use of the magnetometer.

An error voltage, which is proportional to the difference between the frequency applied to the probe and the actual NMR frequency, is available at the front panel. This can be used for stabilizing a magnet in the following way: the NMR probe is connected to a stable reference frequency and the error voltage is used for correcting the magnet current. The reference frequency is generated by stabilizing the oscillator in the main unit with the RF Stabilizer 1007 or by a crystal oscillator.

---

* K. Borer, Nuclear Instrum. Methods **143**, 203 (1977) and K. Borer, G. Frèmont, CERN Report 77-19. (The magnetometer was developped by CERN, but CERN has no intention to give in any case any warranty of any kind whatsoever regarding the quality and performance of executed magnetometers.)

## Specifications

### Probes

| Probe | | Field range (kG) | Frequency range (MHz) | Error voltage sensitivity (V/G) | Homogeneity for tracking (ppm/cm) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Field range | | |
| No. | Type | | | | High | Middle | Low |
| 1003-1 † | $H_2O$ | 0.44-1.3 | 1.9-5.6 | 16 | 500 | 350 | 200 |
| 1003-2 | $H_2O$ | 0.87-2.6 | 3.8-11.3 | 8 | 600 | 400 | 300 |
| 1003-3 | $H_2O$ | 1.7-5.2 | 7.5-22.5 | 4 | 1200 | 800 | 500 |
| 1003-4 | $H_2O$ | 3.5-10.5 | 15-45 | 2 | 1300 | 1200 | 900 |
| 1003-5 | $H_2O$ | 7-21 | 30-90 | 1 | 750 | 450 | 280 |
| 1003-6 * | $D_2O$ | 20-34 | (7.5)-22.5 | 0.65 | ** | ** | 250 |
| 1003-7 * | $D_2O$ | 30-68 | (15)-45 | 0.32 | [illegible] | [illegible] | [illegible] |
| 1003-8 | $D_2O$ | 46-105 | 30-90 | 0.16 | [illegible] | [illegible] | [illegible] |

* For these probes the signal-to-noise ratio is small at the lower end of their frequency range, and automatic frequency tracking is only possible within the indicated field range.
** Not measured.
† Needs amplifier 1022.

**Absolute accuracy:** better than $\pm 10^{-5}$; can be improved by absolute calibration of the probes.

**Relative accuracy and stability:** $\sim \pm 5 \times 10^{-7}$.

> **Note:** The relative accuracy means the equality of the readings of different magnetometer units connected to the same probe in the same field. This accuracy and especially the stability depend on the signal-to-noise ratio safely above the limit for automatic frequency tracking.

**Signal-to-noise ratio** (in a highly homogeneous field): At min. of field range $\sim 10$ ($H_2O$), $\sim 5$ ($D_2O$). At max. of field range $\sim 100$ ($H_2O$), $D_2O$ not measured.

**Frequency tracking speed:** $\dot{f}/f$: up to 1%/sec. Time lag: min. 17 msec. Both depend on the loop gain, and the maximum tracking speed $(\dot{f}/f)$max. also on the setting of the modulation amplitude. Therefore, the frequency tracking speed and the time lag may be an order of magnitude worse than the optimum values given above.

**Loop gain at d.c.:** $> 10^5$ (worst case for $D_2O$ probes), typically $> 10^6$. Front panel potentiometer for max. 10 times attenuation of the loop gain.

**Coarse-frequency adjustment**: 10-turn precision potentiometer.

**Fine-frequency adjustment:** 10-turn precision potentiometer.

**NMR signal ouput:** for scope inspection of the NMR signal. Negative pulses of 100 mV to 7V.

**Error voltage output:** sensitivity: see probe specifications. Maximum output voltage equal to the amplitude of the modulation signal at the scope output, i.e. ± 8 V at maximum modulation setting.

**Error voltage indicator**: Full scale corresponds to ± 10 ppm of the maximum field value of the range.

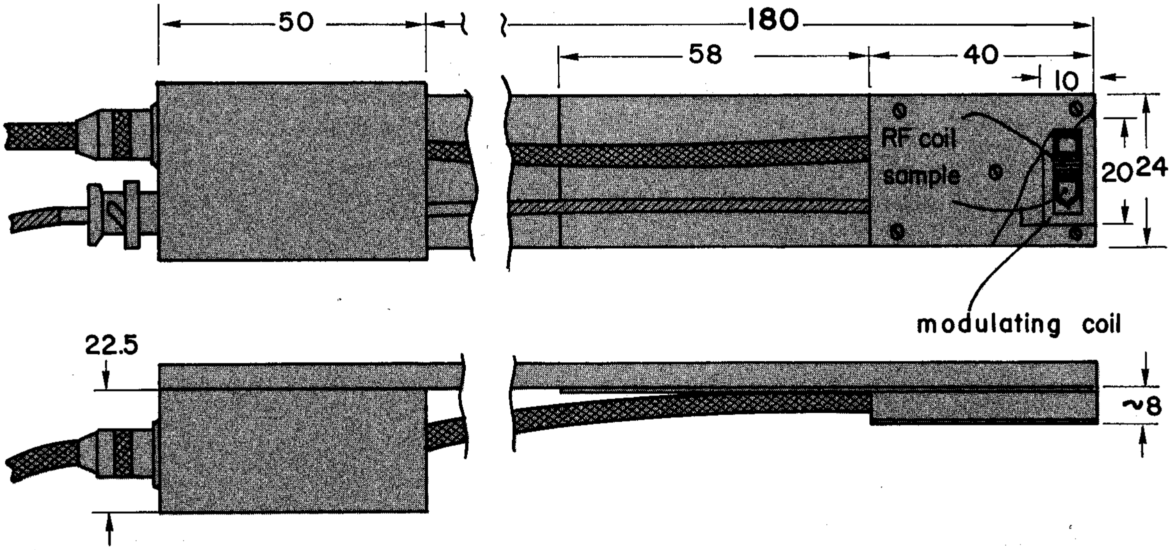
**Required homogeneity of the field:** The table with probe specifications gives the maximum field gradient (in ppm/cm) for which a signal-to-noise ratio results, which just allows automatic frequency tracking. The field gradient effect on the NMR can be compensated with an appropriate coil, see options.

**Field tracking range:** (= search-mode range = fine frequency adjustment range):

$H_2O$ probes: from 20% to 80% of the frequency range: $\sim \pm 5\%$, at the extremities of the frequency range: $\sim \pm 1\%$.

$D_2O$ probes: from 20% to 80% of the frequency range: $\sim \pm 1.5\%$, at the extremities of the frequency range: $\sim \pm 0.3\%$.

Two LEDs indicate the approach of the upper or lower limit of the frequency tracking range.



*Standard probe 1003*

**No strobe signal output:** CMOS switch to ground open in the absence of NMR signal:

— switch open: I = 5-500 nA at max. ± 20 V
— switch closed: 80Ω to 100Ω to ground at max. ± 20 mA.

**No strobe signal indicator:** LED is ON in absence of NMR signal.

**Modulation ouput:** Modulation signal is a 30 Hz triangular waveform. Amplitude adjustable with external potentiometer: max. ± 8 V, normal setting ~ ± 4 V. Calculation of $B_{mod}$: see "error voltage sensitivity".

**Ext. modulation:**

INT./EXT. front panel switch.
EXT. input: $Z_{in} \approx 25k\Omega$, voltage gain = 1, max. input = ± 8 V.

**RF output for NMR amplifier box:** Square wave of 0.8 V peak-to-peak amplitude into 50Ω.

**RF scaler output:** NIM standard signal.

**Internal frequency counter:** 7-digit LED display indicating the field strength in Gauss. Resolution: 0.01 G. Temperature stability: $3 \times 10^{-6}$ from 0° to 50° C. Timebase gate length: with $H_2O$ probes ~ 0.4 sec., with $D_2O$ probes ~ 0.6 sec.

**BCD output:** rear connector: Cannon 3503 1000

**NMR amplifier box:** Dimension 105 × 60 × 40 mm. RF input: 0.4 V peak-to-peak into 50Ω (sine or square wave). RF output: 5 V peak-to-peak square wave into 50Ω. NMR signal output: 1 kΩ output impedance, no noise filter.

**Power consumption:**

| | | |
|---|---|---|
| + 24 V 0.1 A | + 12 V 0.3 A | + 6 V 0.6 A |
| − 24 V 0.1 A | − 12 V 0.5 A | − 6 V 0.2 A |

## Options and accessories

The following accessories or options are available or under preparation, ask SENTEC about them:

| | |
|---|---|
| • Connection cables in non-standard length | |
| • Non-standard probes | |
| • Power supply with 6/12 NIM crate | 1020 |
| • Monitoring scope for NMR signal | 1024 |
| • Field gradient compensation coils | 1053 |
| • Probe multiplexer 6 or 8 way | 1005-6/8 |
| • CAMAC interface | 1006 |
| • Magnetic field stabilisation | 1007 |
| • Signal averaging | 1008 |

## Ordering information

| Description | SENTEC Nr. |
|---|---|
| NMR main unit (NIM module) | 1001 |
| Amplifier box (probe 2-8) | 1002 |
| Amplifier box (probe 1-8) | 1022 |
| 10 m cable (1001-1002) | 1001 B-10 m |
| 2 m cable (1002-1003) | 1002 B- 2 m |
| Transverse Probe | 1003-X |
| Axial Probe | 1013-X |
| Transverse Mini Probe | 1023-X |
| Axial Cylindrical Probe | 1033-X |

Probe range number X: see table of probes

1023 and 1033 have integral 2 m 1002 B cable

For America:

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**13, av. Ste-Clotilde**
**CH 1205 Geneva, Switzerland**
Tel. (022) 28 87 19, Tlx ch 421 254

**GMW**
**1060 Lakeview Way**
**Redwood City, CA 94062, USA**
Tel. (415)-368 4884

SENTEC

**SENTEC**

# NMR PROBES
## Type 1003 - 1013 - 1023 - 1033

B ⇑ Mod. 1003

B ⇒ Mod. 1033

B ⇒ Mod. 1013

B ⇑ Mod. 1023

## Probes for the SENTEC NMR Magnetometer type 1000

- 8 probes to cover 440 Gauss to 137 kGauss
- 4 different styles for different access to field
- all probes with leak proof, hermetically sealed $H_2O/D_2O$ samples
- automatically tuned LC circuit
- excellent signal to noise ratio (see overleaf)

Hundreds of these probes are in everyday use in numerous laboratories throughout the world.

**Probe Dimensions**

| Range | | Sample Active Vol. dia. × l (mm) | | Outside dimensions of Probe Head (mm) | | | | Dist. Sample to edge of Head (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Field (kGauss) | | | 1003 w × h | 1013 w × h | 1023 w × h | 1033 dia | 1003 | 1013 | 1023 | 1033 |
| 1* | 0.44– 1.3 | $H_2O$ | 7.0 × 6 | 24 × 10 | 24 × 17 | 16 × 10 | 18 | 8.0 | 5.0 | 10 | 7 |
| 2 | 0.87– 2.6 | $H_2O$ | 5.4 × 6 | 24 × 8 | 24 × 13 | 12 × 8 | 18 | 6.5 | 4.0 | 10 | 7 |
| 3 | 1.75– 5.2 | $H_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |
| 4 | 3.5 – 10.5 | $H_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |
| 5 | 7.0 – 21.0 | $H_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |
| 6 | 20 – 34 | $D_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |
| 7 | 30 – 68 | $D_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |
| 8 | 46 –137 | $D_2O$ | 4.4 × 5 | 24 × 8 | 24 × 13 | 12 × 7 | 18 | 5.5 | 3.5 | 10 | 7 |

* Probe No. 1 requires the amplifier Mod. 1022.

**SENTEC**

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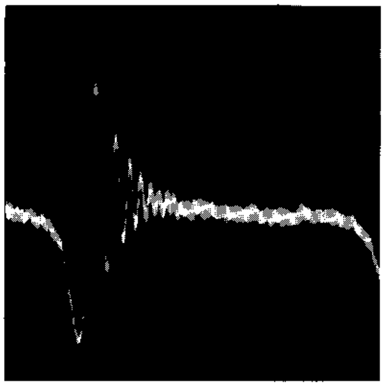
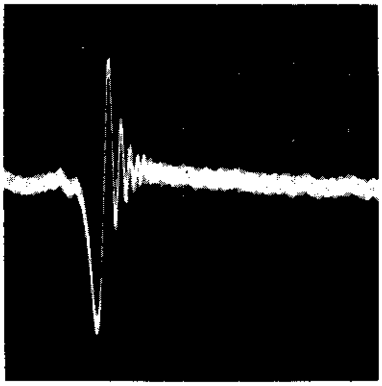
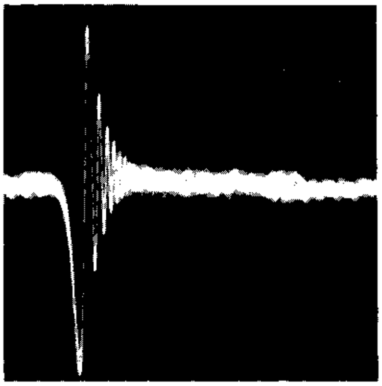
*1003-1: 440 G*



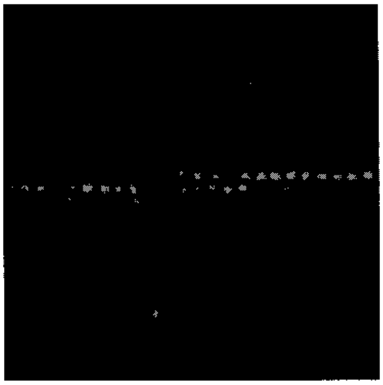
*1003-2: 870 G*



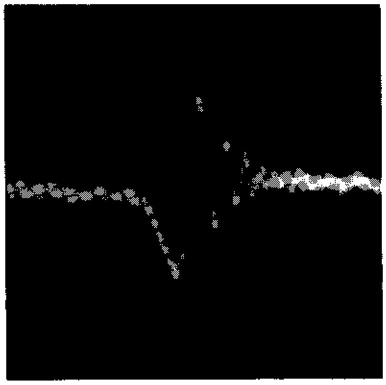
*1003-3: 1.75 kG*



*1003-4: 3.5 kG*



*1003-5: 7 kG*



*1003-6: 20 kG*

*Signals obtained in the minimum field for each probe: 100 mV/div. At the top of the range the signal is typically 1.5 to 5 Volts at comparable noise levels.*

All probes consist of a probe head (sample, RF and modulation coils) which is connected by a cable of approx. 17 cm to the detection box. This length cannot be increased without loss of range and or signal amplitude. The detection box may be placed in the magnetic field and is at a distance from the probe head where its small ferromagnetic components will not disturb the measurement. The cable 1002B between the detection box and the amplifier can be up to 10 m long, but should not be longer than necessary (recommended length 2 m). The amplifier can be up to 100 m away from the main unit 1001. Longer runs require repeaters.

The probes 1003 are economical "all around" probes for transverse fields permitting closest head-on approach to obstacles (vacuum chamber).

The probes 1013 are for magnetic fields which have only axial access.

The probes 1023 have smallest dimensions for insertion into narrow holes. The small size detection box (dia 14 mm) has the cable 1002B permanently attached.

The probes 1033 are for magnetic fields with axial access. The cylindrical shape of the probe with integral cables 1002B is best for access through small holes.

If no standard probe will fit your magnet, SENTEC can propose you a special probe to suit your needs. Composite multiple head probes are built to cover a larger field range. Let us know which way to pack the basic sample blocs: 20 mm long, 10 m wide and 5 mm high. Allow a few millimeters extra for shielding and packaging and specify the direction of the cable to the probehead.

**Ordering information:** Specify model and range number plus the cable length for type 1023 and 1033. E.g.: 1003-4, 1023-2-3 m.

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# THE

# SENTEC

# NMR* MAGNETOMETER

# TYPE 1000

CONTENTS :

( * NMR = Nuclear Magnetic Resonance )

GMW
ASSOCIATES
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## 1. GENERAL DESCRIPTION

The NMR magnetometer (fig. 1) consists of a dual-width NIM plug-in, which is the main unit, four $H_2O$ probes (for B=1-21 KG) and two $D_2O$ probes (for B=20-66 KG), and one probe amplifier box (the same for all probes).

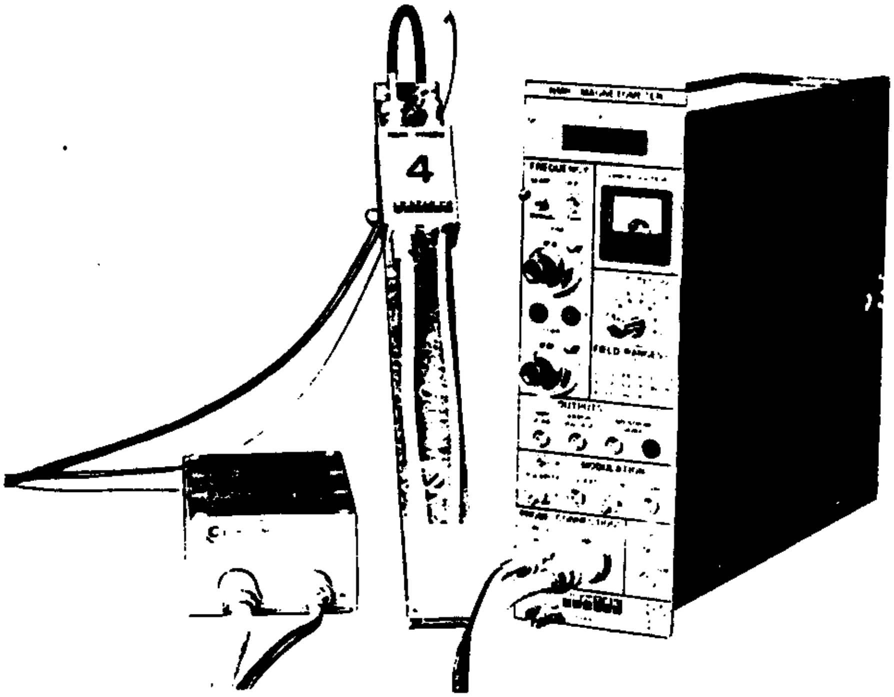


Fig. 1 NMR magnetometer with probe amplifier box and NMR probe

Each probe consists of a measuring head and a small box which contains the signal detection circuit. The maximum length of the two cables between the detection circuit and the measuring head is about 17 cm, whereas the cables between the probe and the probe amplifier box may be a few metres long. From there to the main unit any cables length is allowed, provided the RF signal is not damped more than 6 dB. A block diagram of the magnetometer, including probe and probe amplifier box is given in Fig. 2. The RF oscillator in the main unit has a frequency range of 30 to 90 MHz, which corresponds to the highest proton resonance field range of 7 to 21 kG. The other field ranges are obtained by dividing the frequency by 2,4 or 8; f:4 and f:2 being used for the two $D_2O$ probes. This results in a very comfortable overlap of the six fields ranges. An internal frequency counter measures the frequency which is sent to the probe, the result being displayed in gauss with a resolution of 0.01 G.

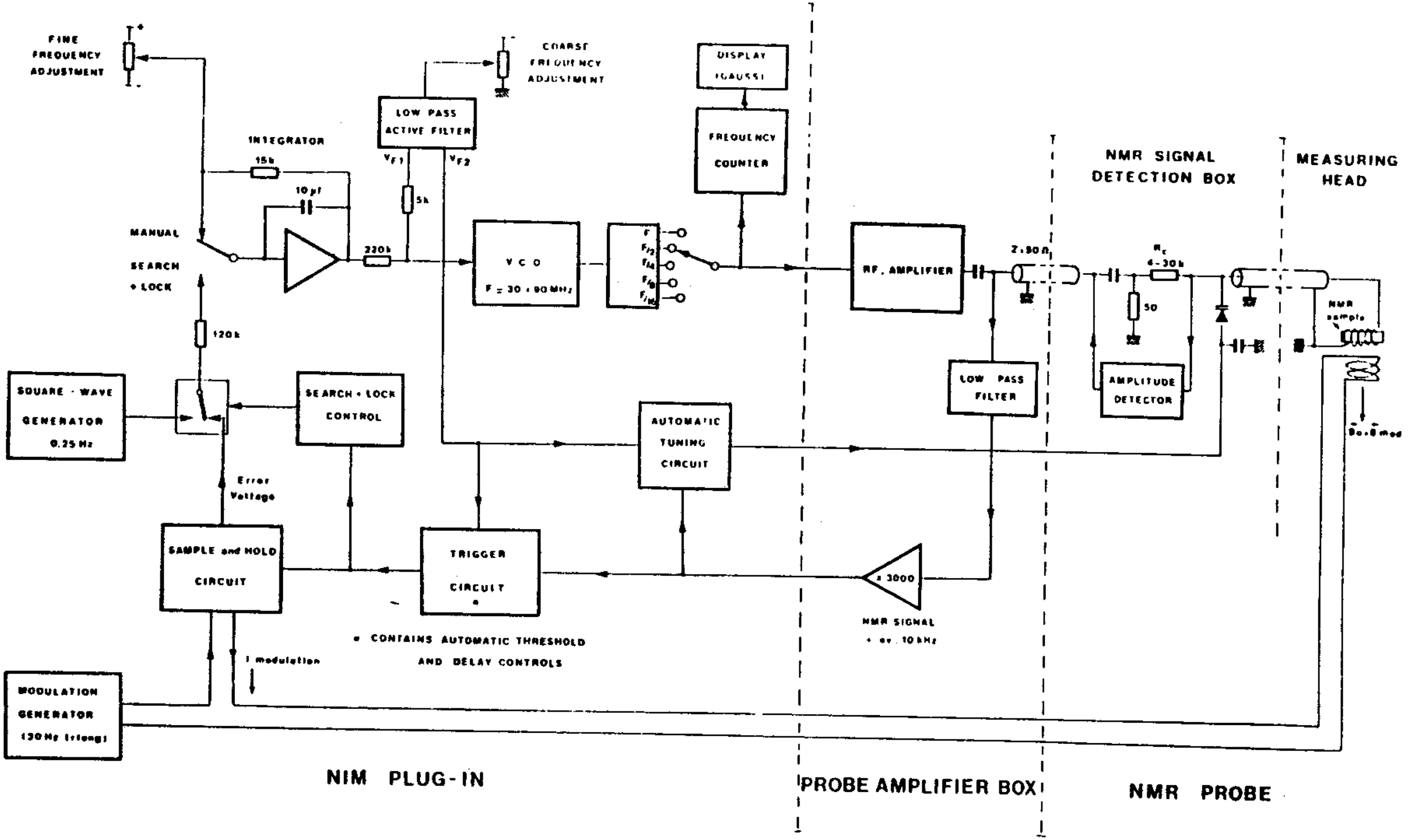


Fig. 2 Block diagram of the NMR magnetometer

Coarse adjustment of the frequency is done manually with a 10-turn potentiometer. A second 10-turn potentiometer allows fine adjustment over 1 to 10% of full scale, depending on the coarse frequency setting and the type of probe ($H_2O$ or $D_2O$) used. In the "search and lock" mode, the unit sweeps the frequency up and down through the fine adjustment range until a NMR signal appears. Then it "locks" automatically to this signal, i.e. 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.

Automatic probe tuning and automatic trigger threshold and timing of the NMR signal processing circuits simplify the use of the magnetometer.

An error voltage, which is proportional to the difference between the frequency applied to the probe and the actual NMR frequency, is available at the front panel. This can be used for stabilizing a magnet in the following way: the NMR probe is connected to a crystal-controlled oscillator instead of the oscillator in the main unit, and the error voltage is used for correcting the magnet current.

## 2. THEORY OF OPERATION

In the presence of a static magnetic field $B_0$, a nucleus with magnetic moment $\mu$ can take $(2I + 1)$ distinct energy states, I being the spin quantum number. The separation of these states is $\Delta E = \mu B_0/I$ . Transitions between levels can be induced by applying an alternating magnetic field perpendicular to the static field if its frequency equals the resonance frequency $f = \Delta E/h = \Gamma B_0$, with $\Gamma = \mu/hI$ . For magnetic fields of the order of 10,000 G the NMR frequencies lie in the RF region. For protons and deuterons $\Gamma$ is known very precisely 2) :

$$\Gamma_{p,H_2O} = 4257.608(12) \text{ Hz/G for protons in a cylindrical sample of } H_2O;$$

$$\Gamma_{d,D_2O} = 653.569(2) \text{ Hz/G for deuterons in a cylindrical sample of } D_2O .$$

For detecting the proton magnetic resonance*), a small water-filled coil is placed in the 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 one. 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 so-called spin-lattice relaxation time $T_1$. This is the reason why the protons continuously absorb energy from the alternating field if the coil is

---

*) The following explanations are also true for deuterons, except that $D_2O$ doped with $GdCl_3$ is used instead of $H_2O + NiSO_4$ (0.1m)

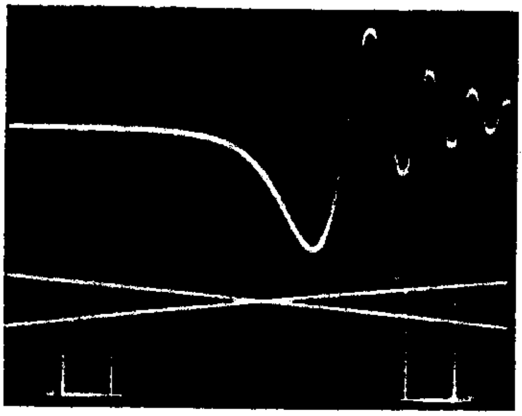
driven at the proton resonance frequency, thereby reducing slightly the quality factor Q of the coil.

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 with 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 to the proton resonance can be detected as a small amplitude variation of the RF voltage across the tank circuit.

This signal can be enhanced by adding a paramagnetic salt to the water. This reduces the relaxation time $T_1$ and therefore increases the steady-state energy absorption of the protons at resonance.

The modulating field $B_{mod}$ is produced by a small, flat coil in the NMR probes. Its frequency is 30 Hz and its amplitude 100 to 1000 ppm of $B_0$. The magnetometer electronics detects and amplifies the nuclear resonance signals of the LC circuit and measures the current in the modulating coil at the instant when the resonance occurs. A voltage-controlled oscillator produces the RF voltage. Its frequency is controlled by a high-gain feedback loop, such that the resonance occurs at the instant when $B_{mod}$ crosses zero. Therefore this frequency 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.

The field modulation in the NMR probes sweeps far too quickly through the resonance to obtain adiabatic conditions. Therefore, the observed signals have neither the form nor the width of the real proton or deuteron resonance curve. The width is several times the natural line width, and transient effects, like for example "wiggles", appear (Fig. 3). However, this fast modulation is convenient for practical reasons, and an accuracy better than 1 ppm is nevertheless achievable, using a symmetry criterium. This subject is discussed in more detail in Section 3.

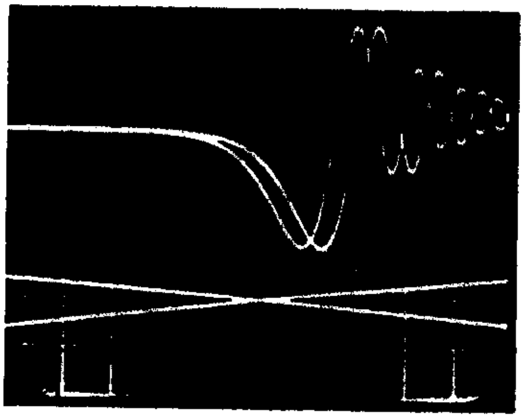


Resonance signal

Time scale: ∿ 0.4 msec/div.

Modulating field

"alignment" of the NMR-pulses in the frequency tracking mode



Resonance signal

Time scale: ∿ 0.4 msec/div.

Modulating field

"misalignment" resulting from a 1 ppm frequency error.

Fig. 3 NMR-signal and modulation field chopped y(t) display with $\vec{B} = 15$ kG. (The scope is triggered with the NMR-pulses, alternatively at upward and downward going modulation field.)

## 3. PRINCIPLE OF OPERATION OF THE NMR MAGNETOMETER

The measuring head contains a flat coil for modulating the field in a small glass tube, which contains either $H_2O$ or $D_2O$ and around which an RF coil is wound. The applied field modulation is a symmetric 30 Hz triangular wave form with an amplitude of a few hundred ppm of the field $B_0$.

The RF coil, a tuning diode, and the coaxial cable from the NMR signal detection box to the measuring head form a parallel LC resonant circuit. This resonant circuit is weakly coupled, by means of a resistor, to the output of an RF amplifier with stabilized output amplitude, and is automatically tuned to the applied frequency. If this frequency is chosen 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 the field modulation. This signal is amplified in the amplifier box and transmitted to the main unit.

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

The kind of field modulation has been chosen for the following reasons: i) the modulation amplitude of a few hundred ppm makes locking of the RF to the field easy; ii) the modulation frequency of 30 Hz was found to be a reasonable compromise between RF tracking speed and signal line width; iii) a triangular wave crosses through zero more slowly than a sine wave of the same frequency and amplitude, which reduces the spreading of the line width. Moreover, it can be easily generated very symmetrically, thus improving the accuracy of the magnetometer.

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. $B_{mod}(t + T) = -B_{mod}(t)$, 2T 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. 3). 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. This effect is eliminated by the automatic tuning of the probe.

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 $B_{mod} = 0$ and this is the criterion upon which the frequency control loop works.

The automatic tuning of the probe and the good symmetry of the field modulation are the basis for the high accuracy of the magnetometer. 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 being 8 V/G for the lowest and 0.3 V/G for the highest field range. This error voltage is integrated and then sent to the frequency control input of the RF 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. Therefore, for this optimum loop gain setting, the time lag of the frequency tracking is equal to the spacing of the NMR signals, which is roughly 17 msec. 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. During field mapping, for example, the amplitude may vary by a factor of ten and the width by a factor of four. Therefore the trigger level and the timing of the sample-and-hold circuit are adjusted automatically in the main unit in order to maximize the range of operation of the magnetometer. 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 the 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. 4). 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 delay of the strobe pulse is adjusted automatically by the magnetometer such that the above-mentioned 30 Hz component of the error voltage disappears.

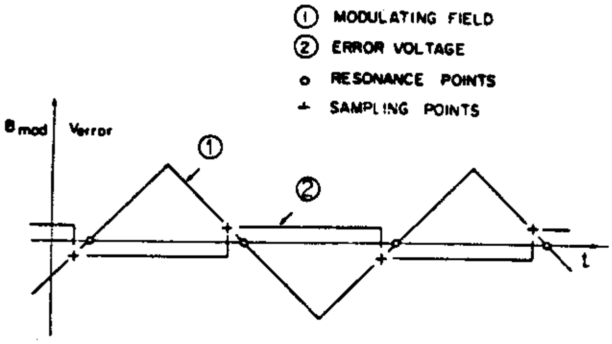


Fig. 4 A 30 Hz square-wave component in the error voltage indicates wrong timing of the sample-and-hold circuit. In the example shown, the sampling pulses are assumed to be early in respect to the nuclear resonance.

## 4. DETAILED CIRCUIT DESCRIPTION

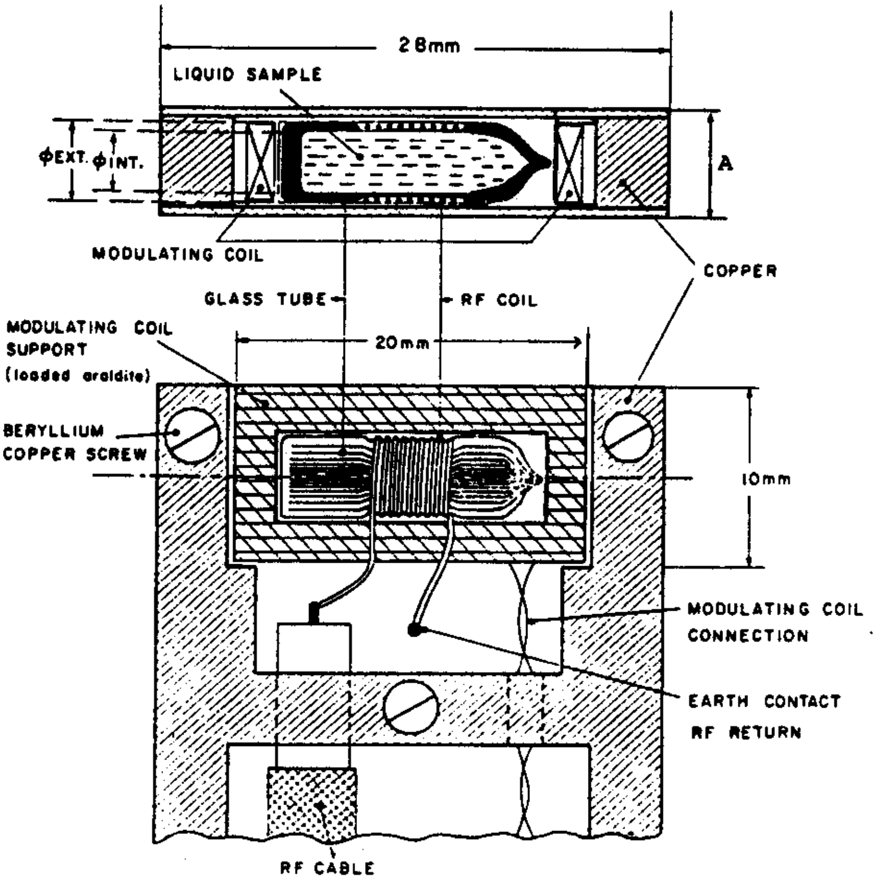
### 4.1 General remarks on the probes

Six probes are necessary for a field range of 1 to 68 kG. Each probe consists of a measuring head and a NMR detection box, which are interconnected by a short 50 Ω coaxial cable, which is part of the LC resonant circuit, and a screened cable with two wires for the modulation. The probe and the NMR amplifier box are interconnected with a four-wire cable (for the modulation, a negative supply, and the tuning diode bias voltage) and a 50 Ω double-screened coaxial cable which transmits both the RF and the NMR signals (+ any detected 10 kHz signal which is used for the automatic tuning).

Figure 5 shows the mechanical drawings of the measuring head. It contains a small glass tube filled with the liquid NMR sample, $H_2O$ + 0.1 m $NiSO_4$ for fields between 1 kG and 21 KG, or $D_2O$ saturated with gadolinium chloride for fields between 20 KG and 68 KG. Both ends of the glass tube are sealed by fusion of the glass. The RF coil is placed midway along the tube, wound in a 5.5 mm long and 0.2 mm deep groove which improves the "filling factor".

The number of turns of the RF coil is defined for each probe by its highest operation frequency and the lowest attainable value of the capacitance of the LC resonance circuit. This capacitance is essentially the sum of the capacitances 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 lenght of 17 cm.

The number of turns of the modulating coil is chosen such that a field modulation of 100 ppm is produced by a current of a few tens of mA. 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 damping the "wiggles".



| PROBE No. | GLASS TUBE ϕ INT. mm | A mm | COIL TURN NUMBER RF | NMR SAMPLE |
|---|---|---|---|---|
| 1003-2 | 5 | 7 | 44 | $H_2O + NiSO_4$, 0.1 m |
| 1003-3 | 3 | 6 | 32 | " |
| 1003-4 | " | " | 15 | " |
| 1003-5 | " | " | 5 | " |
| 1003-6 | " | " | 32 | $D_2O + GdCl_3$ 0.1m |
| 1003-7 | " | " | 12 | " |

Fig. 5 Measuring head

## 4.2 The automatic probe tuning

The simplified circuit diagram is given in Fig. 6.

The bias voltage of the tuning diode in the probe is composed of the voltage $V_{F2}$ given by the coarse frequency adjustment and the output of an integrator (INT in Fig. 6). A square wave signal of 0.6 mV amplitude is superimposed on it, and modulates very weakly the capacitance of the tuning diode ($\Delta C/C \sim 10^{-4}$). This results in a 10 kHz amplitude modulation if the resonant circuit is slightly mistuned, being in phase or 180° out of phase with respect to the injected square wave, depending on whether the capacitance is too small or too large.

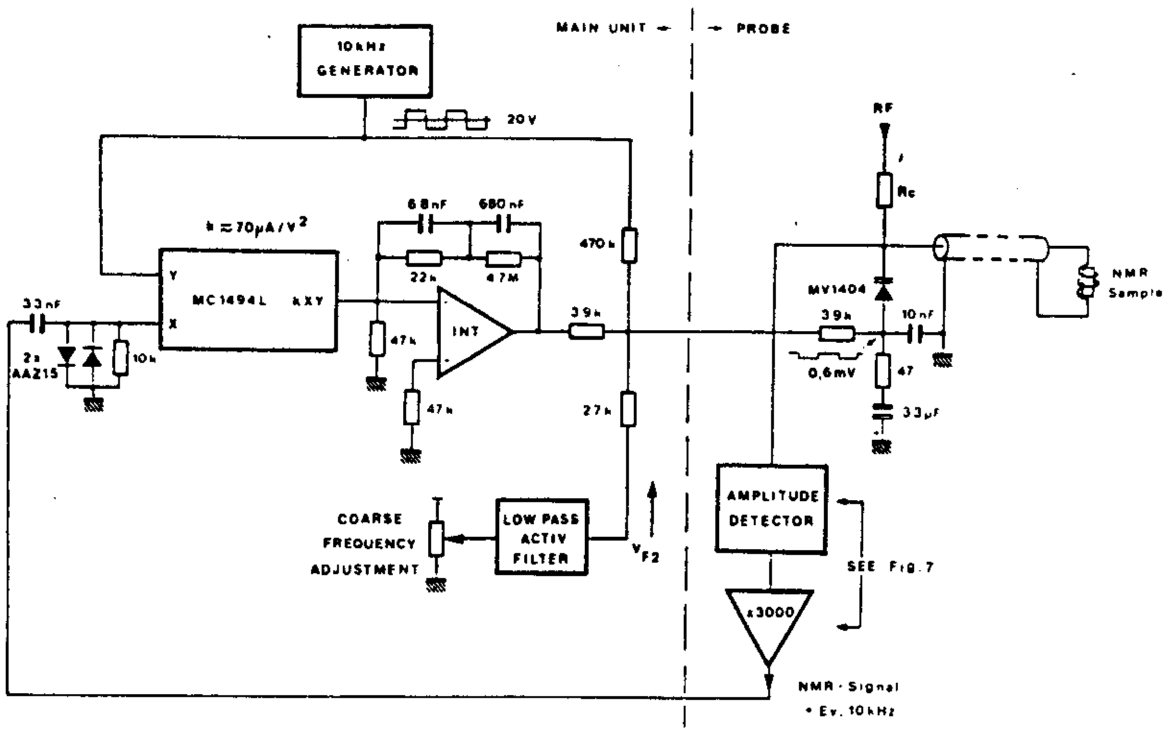


Fig. 6 Simplified circuit diagram of automatic tuning circuit

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 part is reduced by RC differentiation and diode clipping. 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 ∿ 90 dB attenuation for mudulating the varicap. This attenuation is split into two steps: ∿ 50 dB in the main unit and ∿ 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 the automatic tuning easily follows the fastest frequency variations in the search mode.

### 4.3. The NMR signal and RF amplifiers

A simplified circuit diagram of the NMR probe and NMR amplifier box is shown in Fig. 7. The NMR absorption signal is an amplitude variation of the RF 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 NMR amplifier box. The a.c. part of the detected voltage is amplified by a factor of

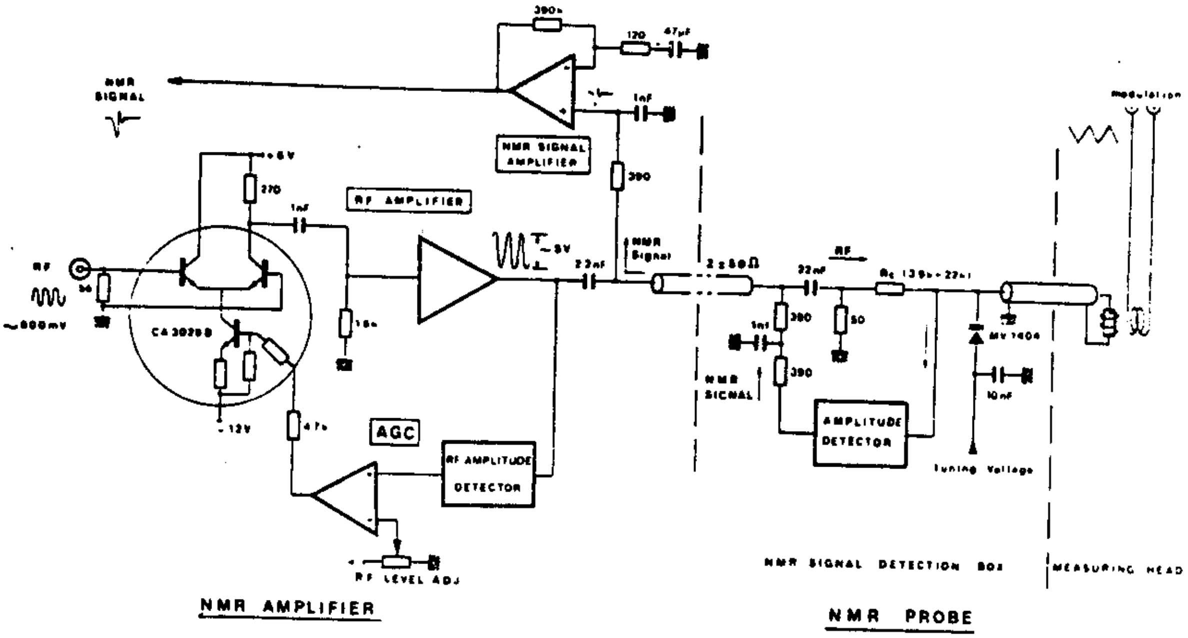


Fig. 7 Simplified circuit diagram of NMR amplifier and NMR probe

3000, whilst unity gain is provided for the d.c. component. The upper frequency limit is ∿ 20 KHz, i.e. higher than the 10 KHz frequency used for the 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 RF 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 main unit for scope inspection of the NMR signal. Its d.c. component indicates the RF voltage amplitude at the LC resonance circuit in the probe, which should be about 0.1 to 1 V depending on the 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 RF voltage must be extremely clean with respect to any spurious amplitude or frequency modulation and noise, otherwise the signal-to-noise ratio becomes bad. The wave form of the RF signal, however, is not important since the LC resonant circuit and the NMR sample in the probe are insensitive to any harmonics. In the NMR amplifier box the RF signal is amplified to about 5 V peak-to-peak. The RF 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 at the RF 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 of the input transistors, smooths any amplicude 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 operating at slightly different frequencies is used.

The output signal of the RF amplifier looks more like a badly shaped square wave than like a sine wave. This is of no disadvantage, since the probe is hardly sensitive to the wave form. For obtaining the best signal-to-noise ratio, the optimum RF voltage of the LC resonance circuit in the different probes is set by choice of the coupling resistor Rc.

### 4.4. Automatic trigger threshold and delay circuits

Figure 8 shows the diagram of the corresponding circuits.

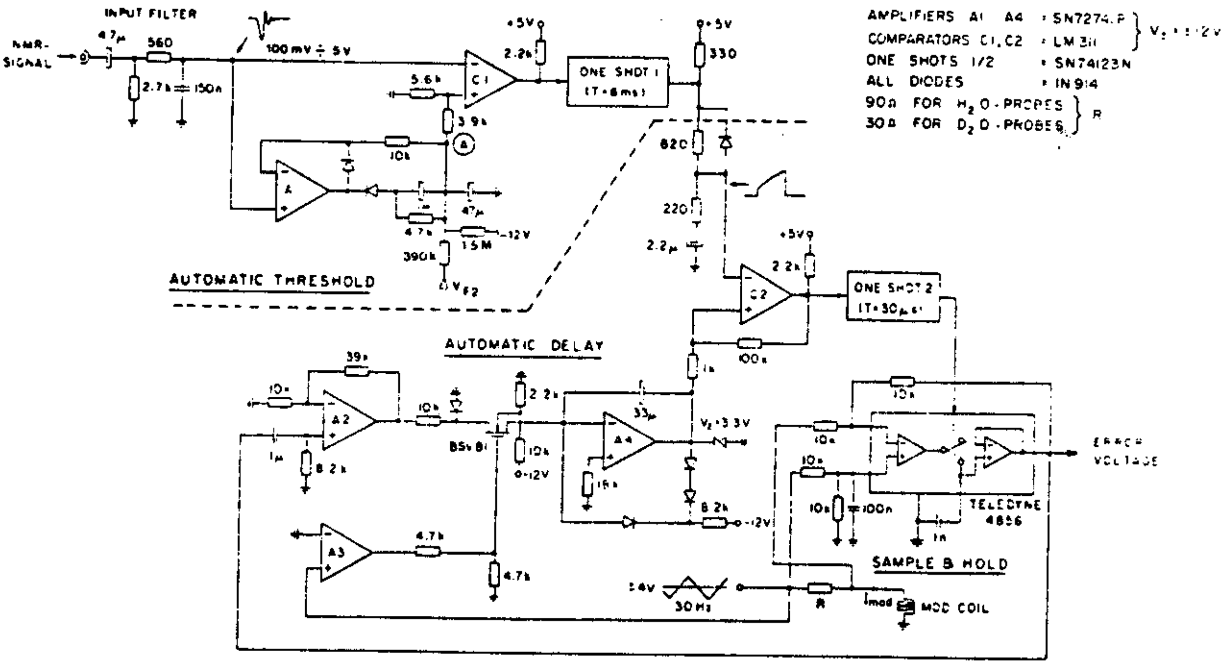


Fig. 8 Circuits for generating tne error voltage, including the automatic threshold and timing controls

The NMR signals are fed to the input of the comparator C1 via a filter network which eliminates the d.c. component and reduces the noise. 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 with no NMR signal, is kept safely above the noise level. Since the noise increases with the RF, the minimum threshold is derived from the coarse frequency adjustment ($V_{F2}$) and varies between 40 mV and 100 mV.

The modulating current $I_{mod}$ is sampled during the 30 μsec pulses produced by the one-shot 2 (shown in Fig. 8 ). The pulse width is not critical, but has to be long enough to allow the sample-and-hold amplifier to settle. The delay relative to the instant when the NMR signal crosses the threshold at C1 is determined by the voltage at the output of the integrator A4. This voltage is regulated so that no 30 Hz component appears at the error voltage output. If there is a signal in phase or 180° dephased relative to the modulation, it is amplified by A2 and integrated by A4 during only 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 the automatic delay is about 0 to 5 msec, which is, considering the fixed delay of 0.5 msec at the sample-and-hold input, equivalent to -0.5 msec to +4.5 msec. This is quite sufficient for all practical operating conditions of the magnetometer.

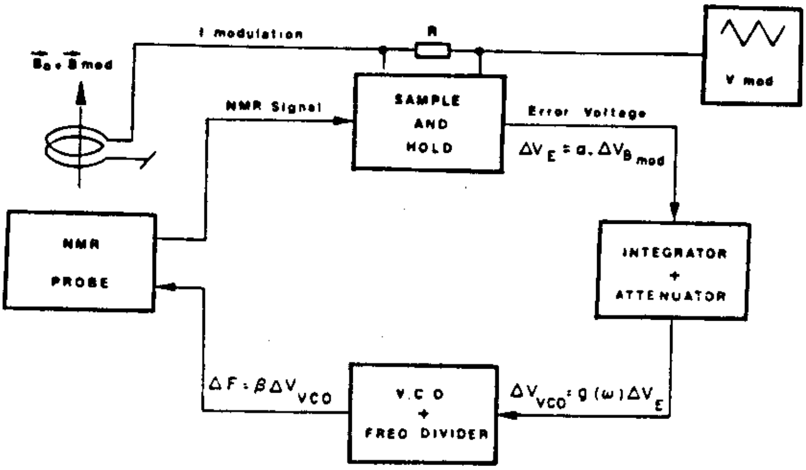
### 4.5. Frequency control and loop gain

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 about 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 RF screening and for avoiding thermal convection effects.

The various frequency ranges are obtained by division in steps of two. A long-tailed transistor pair produces two NIM outputs for external CAMAC or other counters. Using a well-filtered supply voltage for the output stage of the probe RF signal results in the necessary cleanness of the amplitude of the RF signal. Its square-wave-like shape does not cause any disturbance.

The frequency control-loop diagram is given in Fig. 9 The sample-and-hold circuit produces an error voltage $\Delta V_E$, proportional to the modulating field at the instant when the nuclear resonance occurs: $\Delta V_E = \alpha \Delta B_{mod}$. The frequency control voltage of the oscillator is derived from $\Delta V_E$ by integration and attenuation: $\Delta V_{VCO} = g(\omega) \Delta V_E$, which results in a frequency change of $\Delta F = \alpha\beta g(\omega) \Delta B$. By choosing an appropriate integration time constant and attenuation, $\Delta F$ reaches $\Delta B_{mod} \cdot \Gamma$ 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



$$\text{LOOP GAIN} = \frac{\Delta F}{\Gamma \cdot \Delta B} = \frac{1}{\Gamma} \cdot \alpha \cdot \beta \cdot g(\omega)$$

Fig. 9 Block diagram of frequency loop

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 $\beta$ by the same factor. This is compensated by the factor $\alpha$, i.e. the product $\alpha$ times $\beta$ is made constant for all field ranges between 1 kG and 21 kG (the $D_2O$ probes need some extra explanation, see below) by using an appropriate number of turns of the modulating coil of the different 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 $H_2O$ probes (at the same VCO setting). Hence the number of turns decreases roughly linearly with the decreasing field range of the probe, whilst $\alpha = \Delta V_E / \Delta B_{mod}$ increases inversely, R being constant. Therefore, switching the frequency range and changing corresponding $H_2O$ probes does not change the loop gain.

For the $D_2O$ 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 the $D_2O$ probes as for the $H_2O$ probes, and the resulting factor $\alpha$ 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 $H_2O$ probes and $D_2O$ probes at a given VCO setting, and the relative change of the probe frequency $\Delta f/f$ produced by $\Delta V_{VCO}$ does not depend on the frequency-dividing factor.

The signal-to-noise ratio is much smaller for the $D_2O$ probes than for the $H_2O$ probes. Therefore, for the $D_2O$ probes an additional attenuation factor of three is switched in the frequency control loop, in order to facilitate locking of the magnetometer 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 magnetometer is not influenced by the lower loop gain, which is still > $10^5$ at d.c.

## 4.6. FREQUENCY COUNTER

A seven-digit frequency counter with a special time-base measures the NMR frequency in gauss with a resolution of 0.01 G. About 3 measurements per sec are displayed in the case of the $H_2O$ probes, and ~ 1.6 per sec in the case of the $D_2O$ probes, the gate length being defined by the gyromagnetic ratios and the chosen predividing factors of 16 for the $H_2O$ probes and 4 for the $D_2O$ probes.

The frequency is built up with TTL (Schottky Low-Power) circuits. The data transfer signal for its display register and the reset signal are generated by the time-base circuit. A BCD output of the display register is available.

Figure 10 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 RF signal of the probe (risk of "beating"). The required gate lengths are 375798 μsec for the $H_2O$ probes and 612024 μsec for the $D_2O$ probes. The clock period of 10 μsec is too long for generating these times sufficiently accurately by simple countdown, therefore two one-shots for fine adjustment of the gate lengths (±40 ppm) have been added. One-shot 1 (3 to 30 μsec)

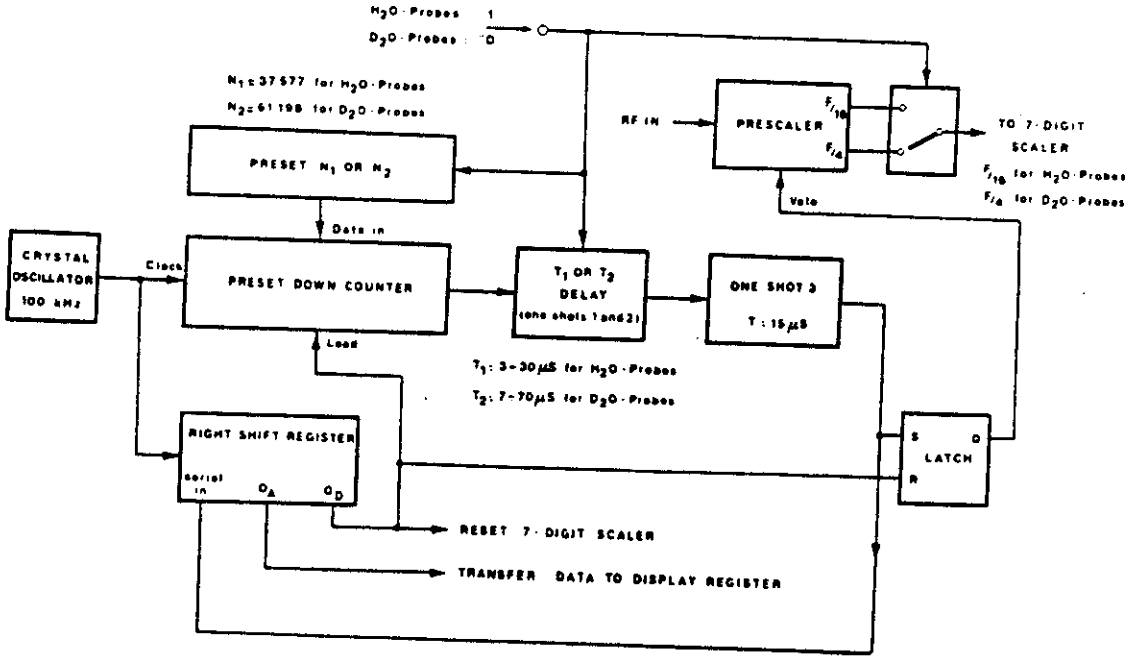


Fig. 10 Block diagram of the time base of the frequency counter

is used for calibrating the gauss reading of the $H_2O$ probes, and one-shot 2 (7 to 70 µsec) for the $D_2O$ probes. The stability of these one-shots (typically ≤ 1%) is not critical, since they add only a few 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.

Figure 11 shows a pulse sequence diagram of some lines in the time-base of the frequency counter.

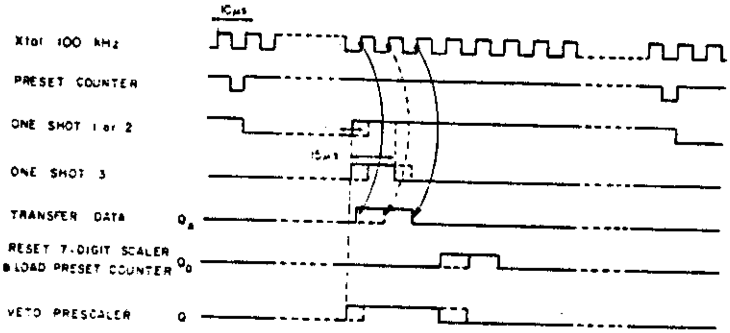


Fig. 11 Pulse sequence diagram of the time base of the frequency counter

## 5. SETTING-UP OPERATION OF THE SENTEC NMR MAGNETOMETER - TYPE 1000

- Read chapters 1 through 4 and 7 of this manual.

- Measure by other means (e.g., hall probe, value of magnet coil current...) the approximate magnitude of the field.

- Select the probe which corresponds to this magnitude of the field. In the overlapping regions, use preferably the probe with the lower field range, which will result in a bigger NMR signal.

- Insert the plug-in into a NIM crate supplying the following voltages : ± 24 V, ± 12 V, ± 6 V. Attention : the high quality ground (pin 34) must be wired in your crate!

- Connect the NMR amplifier box by means of the two appropriate cables (10 m length) to the NIM plug-in and the NMR AMPLIFIER box to the chosen PROBE by means of the 2 m long cables.

- The DETECTION BOX (very weakly magnetic) may be placed in the magnetic field and has a negligible effect (< 1ppm) on the field value measured by the probe.

- Connect both NMR signal and MODULATION output (SCOPE) to high impedance inputs of an oscilloscope (respectively 0.2 V/cm, 5 ms/cm; 2 V/cm, 5 ms/cm).

- Put toggle switch MANUAL/SEARCH + LOCK to MANUAL position, select position of FIELD RANGES corresponding to the probe used and switch on the power supply of the NIM crate.

- Check the DC value of NMR SIGNAL output on the screen of the scope. It should be about 0.1 to 1 V depending on the frequency and the probe used. If there is no positive DC voltage at the NMR SIGNAL output, check whether the selected field range at the NIM plug-in corresponds to the connected probe. If this is correct and there is still no positive DC voltage, set frequency COARSE to maximum and then back to the desired value.

  NOTE : turning the power off and back on within less then ≈ 1 minute may cause the RF oscillator not to start, if set to low frequency.

- Set the MODULATION signal amplitude at 8 V peak-to-peak for probes 4, 5, 6 and 7, or 16 V peak-to-peak for probes 2,3.

- Adjust the helipot COARSE until the field reading of the magnetometer corresponds to the magnitude of the field.

- Slowly turn the control of the helipot FINE until the NMR signal appears on the screen of the scope. At this moment, the red light NO STROBE SIGNAL should switch off.

- The toggle switch MANUAL/SEARCH + LOCK is placed in LOCK position. If the magnetometer doesn't lock, the modulation may be on the wrong polarity. Reverse the toggle switch POLARITY.

- For optimum performance, the probe should be fixed in a position of high field homogeneity which is indicated by "wiggles" and maximum amplitude of NMR-signal (see Fig. 12).

- When the magnetometer works correctly in LOCK, the needle of the meter should have very small deflections around zero, provided there are no fast fluctuations of the field (e.g. line frequency ripple).

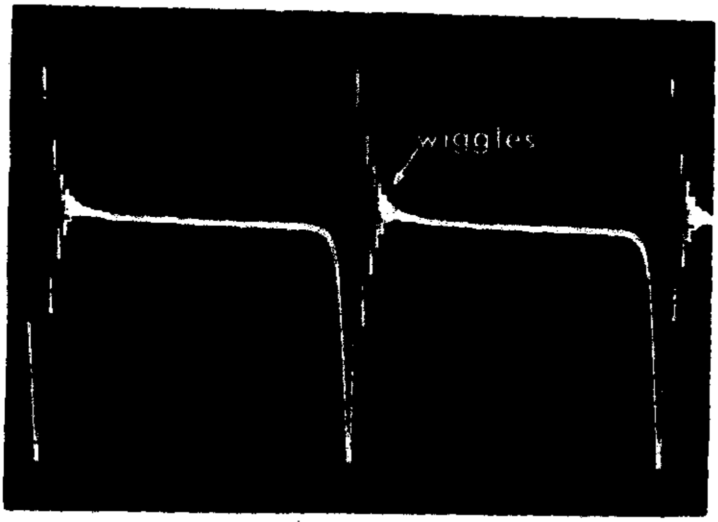


Fig. 12 Probe 1003-5, B = 18 kG, vertical = 1 V/div, horiz. = 3.5 ms/div

- If there is line frequency ripple in the field, a better stability may be obtained by using a modulation signal derived from the line voltage : toggle switch MODULATION to position EXT, 16 V peak-to-peak signal to the MOD-EXT input.

- The GAIN potentiometer of the frequency control loop should normally be fully clockwise (= max gain). However, if the signal-to-noise ratio is bad or if there are fast fluctuations in the field, reduction of the loop gain may result in a more stable field reading.

- If the magnetic field changes slowly, the magnetometer automatically follows the variations within the limited field tracking range given in SPECIFICATIONS. Two red lights situated between the two helipots FINE and COARSE indicate the position of the frequency setting inside the tracking range. Centering is possible by turning very slowly the COARSE control in the direction of the lit LED until both LED's are off.

- The output NO STROBE SIGNAL of the NIM plug-in is low impedance (CMOS switch to ground) only when an NMR signal is detected by the magnetometer.

## 6. ADJUSTMENT AND TEST PROCEDURES

### Instruments required

- NIM crate supplying the following voltages ± 24 V, ± 12 V, ± 6 V.
- Digital voltmeter: sensitivity 1 mV.
- Oscilloscope Tektronix type 465 or equivalent.
- Crystal oscillator 50 MHz with ECL level output: precision ≃ 1ppm.
- Pulse generator giving negative pulses
  - . amplitude 2 V
  - . frequency 60 Hz
  - . width 1 ms
- **Transformer giving line frequency sine wave 16 V peak-to-peak amplitude in 10 kΩ impedance.**
- Very homogeneous and short time stable magnetic field (gradient < 10 ppm/cm and $\dot{B}$ < 5ppm with f > 10 Hz) covering the field range 1-21 KG. Higher field strength will be useful for checking deuteron probes.

### Main unit printed circuit board

a) RF oscillator

- Remove the copper box covering the oscillator circuit on component side.
- Put front panel toggle switch MANUAL/SEARCH + LOCK to MANUAL position.
- Set the helipot FINE to 5.00 (LED's +, - are off).
- Set the helipot COARSE to maximum (10.00).
- Selector FIELD RANGES to position 5.
- Put slide-switch S4 (situated on printed circuit) to position INT.
- Set tap on printed circuit coil in order to have a field reading on display of ≃ 20.8 KG. This value will increase to about 21.2 KG when the box is put back.

  NOTE: For the lowest value of inductance of this coil, it may be impossible to obtain this reading. If this occurs the varicap MV 1404 (next to the printed circuit coil) must be replaced.

- Set the helipot COARSE at minimum. Adjust the potentiometer P8 (on printed circuit) in order to have a field reading around 7 KG.

b) Frequency ranges and outputs

- Check on counter display the field range for each position of the selector FIELD RANGES.
- Set the helipot FINE at maximum and then at minimum. The field value must respectively increase and decrease by a few percent. LED's + and - must respectively illuminate.
- RF output: signal amplitude ± 400 mV, roughly square wave.

- Scaler outputs: NIM level: 0, -800 mV roughly square-wave.

c) Modulation

- Put toggle switch MODULATION INT/EXT to EXT position.
- Connect DVM to output SCOPE.
- Adjust potentiometer P4 in order to obtain a zero reading on DVM ( ± 1 mV).
- Turn potentiometer (P6) above POLARITY switch on the front panel fully clockwise.
- Apply a line sine wave 16 V peak-to-peak to MOD. EXT input.
  Check that the same signal is obtained on SCOPE output.
- Put toggle switch MODULATION INT/EXT to INT position
- Check the signal at SCOPE output which must be a 30 Hz triangular waveform. Connect the right value resistor (10 kΩ -22KΩ ) in ADJ. (near IC 16) for maximum signal amplitude, ~ ± 10 V peak-to-peak, but safely below saturation.

d) Error voltage generator circuit

- Put toggle switch MODULATION INT/EXT on EXT position.
- Apply -2 V pulses of 1 ms duration and 60 Hz repetition rate into the NMR SIGNAL output.
- Connect a DVM to output ERROR VOLTAGE.
- Adjust P3 in order to obtain a zero reading on DVM ( ± 0.5 mV).

e) Integrator

- Apply negative pulses described in section (d) as above with toggle switch MODULATION IN/EXT still on EXT position.
- Position toggle switch MANUAL/SEARCH + LOCK to LOCK.
- Position slide-switch S5 on printed card to ADJ.
- Connect DVM to TP5
- Adjust P5 in order to obtain zero reading on DVM (± 5 mV).
- Return S5 to NORM.

f) Automatic delay circuit

- Remove pulses from NMR SIGNAL output.
- Position slide-switch S2 to ADJ.
- Position toggle switch MODULATION INT/EXT on INT position.
- Connect a DVM between ground and test point TP2

- Adjust P2 to obtain zero (± 0.5 mV).
- Return S2 to NORM.

g) Automatic tuning

- Position slide-switch S1 to ADJ.
- Connect the scope with a probe to test point TP1a.
- A 10 KHz signal appears on the screen.
- Minimize this signal (especially the square wave component) by adjusting P1a (top of component side of printed circuit )

  Notice: remaining peaks of a few hundred mV are normal.

- Connect the DVM between ground and TP1b.
- Slowly adjust P1b for reading less than ± 500 mV.
- Return S1 to NORM.

Frequency counter printed board

- Disconnect the 50 Ω cable (Lemo plug situated near the oscillator box).
- Inject in this plug from a Xtal oscillator, 50,000.00 KHz frequency with ECL level (-0.8 V, -1.6 V):
  - . Set selector FIELD RANGE at any position between 1 to 5 ($H_2O$ probes).
  - . Adjust the multiturn potentiometer Pp situated on bottom of printed board "counter" in order to read on display counter 11743.68 G.
  - . Set the selector FIELD RANGES at any position between 6 to 8 ($D_2O$ probes).
  - . Adjust the multiturn potentiometer Pd in order to read on display counter 76503.02 G.

Amplifier box

- Connect probe No. 5 to amplifier box and also the correctly adjusted NIM plug-in to amplifier box with only the signal cable.
- On NIM plug-in front panel:
  - . position toggle switch MANUAL/SEARCH + LOCK to MANUAL.
  - . selector FIELD RANGES on position 5.
  - . set the helipot COARSE at maximum (21 KG).
- Remove the top cover of the amplifier box.
- Connect a DVM to the output NMR SIGNAL (Amplifier box front panel).
- Adjust the multiturn potentiometer Ph in order to obtain a zero reading on DVM (± 10 mV).

- Connect the RF cable with a 3 dB attenuator to the NIM plug-in and amplifier box.
- Connect the DVM to the test point Tpa, sensitivity 10 V.
- Adjust the multiturn potentiometer Pa for reading approximately +9 V at this point.

## Probes

### a) Electronic Test

- Connect a voltmeter between ground and Tp1b in NIM plug-in.
- Check that for each probe the voltage is less than ± 10 V over the corresponding field range (especially on the top of the range). If this voltage goes outside these limits, the varicap MV 1404, situated inside the detection box must be replaced.
- Check also d.c. voltage and noise level at NMR SIGNAL output on the NIM plug-in front panel, by means of an oscilloscope. Mean values are given in curves Fig. 13 + 14 and noise levels in chapter 7 (specifications).

### b) Test in magnetic field

With probe No. 5 inserted in the most homogeneous place in the magnetic field: $B \simeq 15$ KG, check in the lock mode operation:

- The NMR signal waveform (on NMR SIGNAL output); amplitude and symmetry according to the waveform Fig. 15
- The error voltage amplitude (on ERROR VOLTAGE output); < 100 mV peak-to-peak without any 50 Hz square wave component: see Fig. 16
- The stability of counter display: 1 least significant digit of variation.
- The zero position on ERROR VOLTAGE VU-METER.
- The NO STROBE SIGNAL indicator light must be off.

By varying slowly the field strength, $\dot{B} < 150$ G/sec, check the tracking mode operation:

- The magnetometer loop must remain closed.
- NMR SIGNAL display presents some asymmetry in time and amplitude (Fig.17) and the ERROR VOLTAGE signal a d.c. component seen also on the VU-METER: amplitude and polarity depends on the rate and the direction of the change of field.
- Change on counter display.

Check the NMR signal amplitude (curves on Fig. 18) and the locking over all the magnetic field range with each probe.

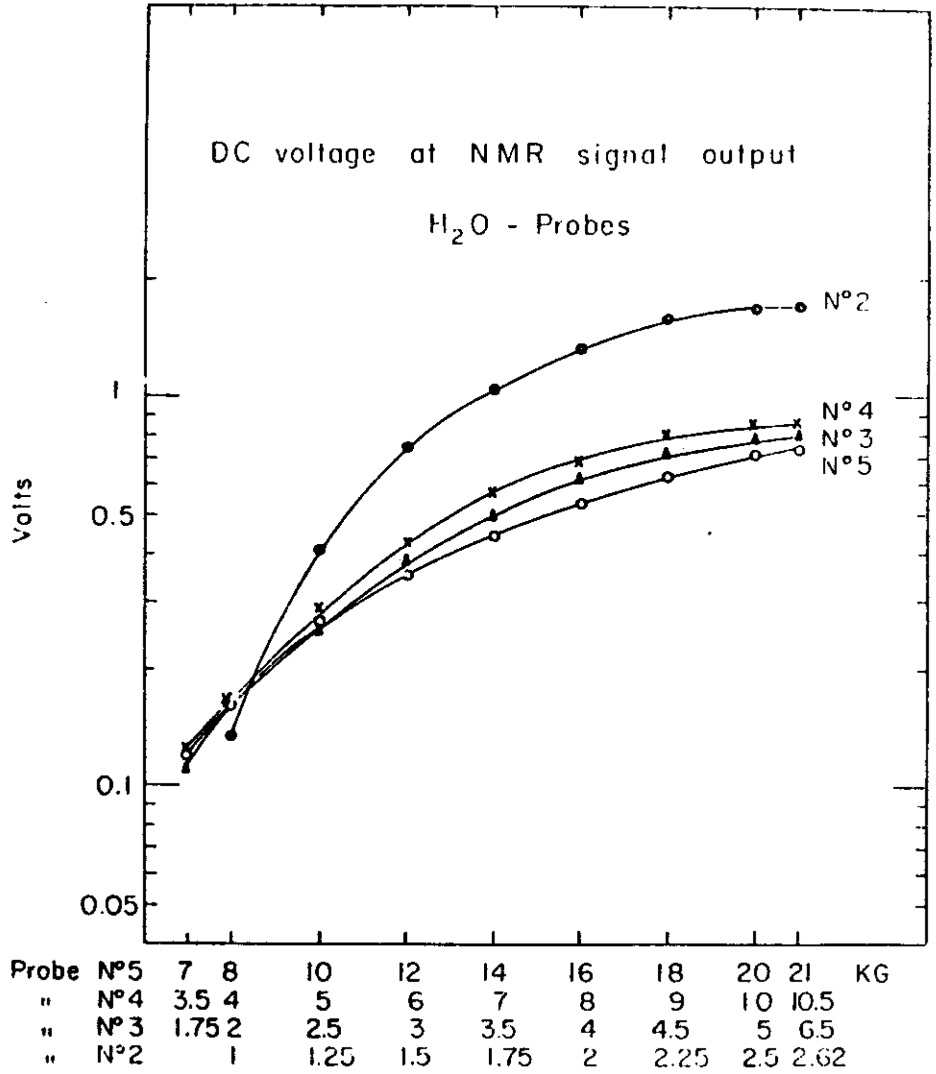


Fig. 13: d.c. voltage at NMR signal output $H_2O$ probes

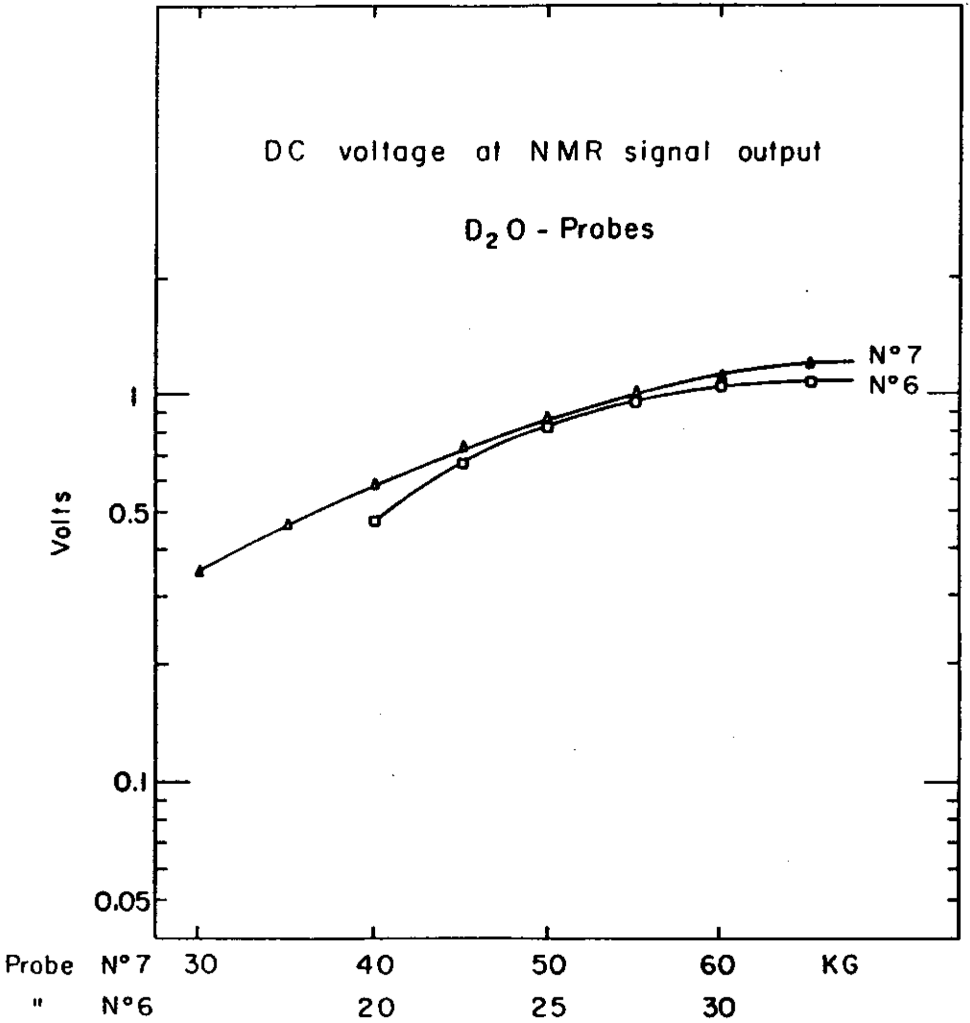
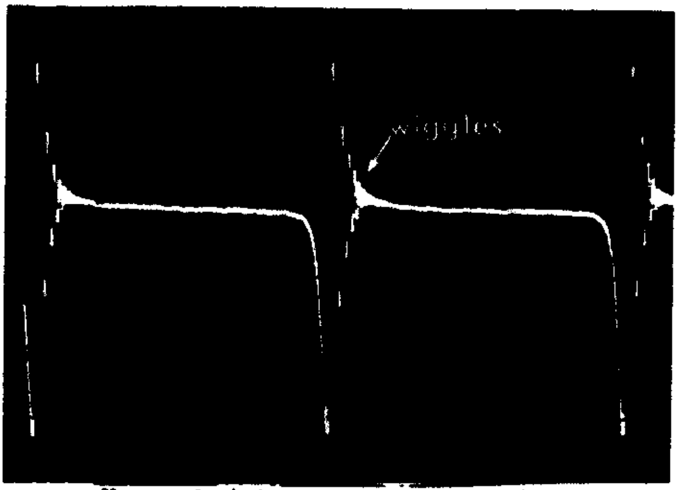


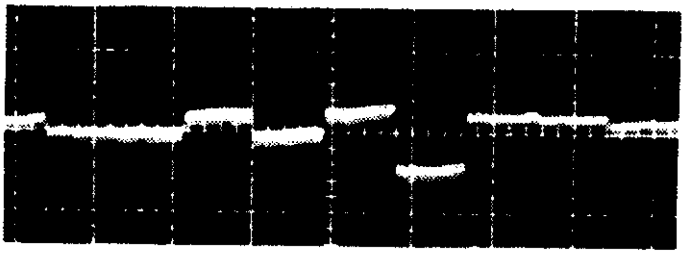
Fig. 14: d.c. voltage at NMR signal output $D_2O$ probes



B = 15 kG

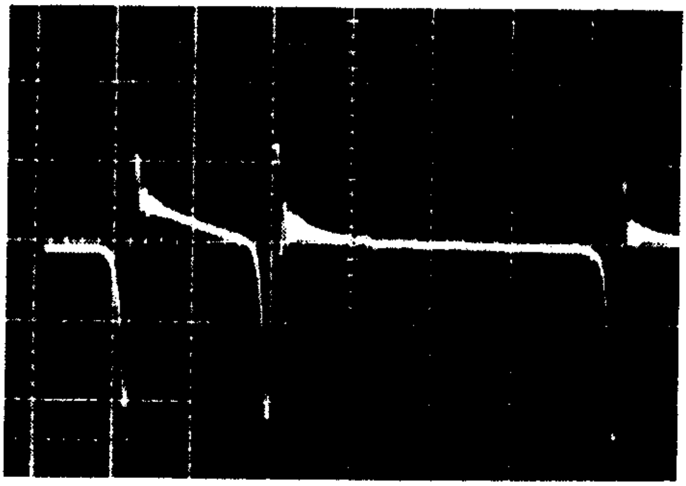
Vert: 1V/div Hor: ∿ 5 ms/div

Fig. 15 Display of NMR signals in frequency tracking mode, the field being steady



Vert: 50 mV/div Hor: 20 ms/div

Fig. 16 Error voltage display (same conditions as above)



$\dot{B}$ ∿ 85 G/sec

Vert: 1V/div Hor: ∿ 3,5 ms/div

Fig. 17 Display of NMR signals in frequency tracking mode with field variation at a rate 85 G/sec

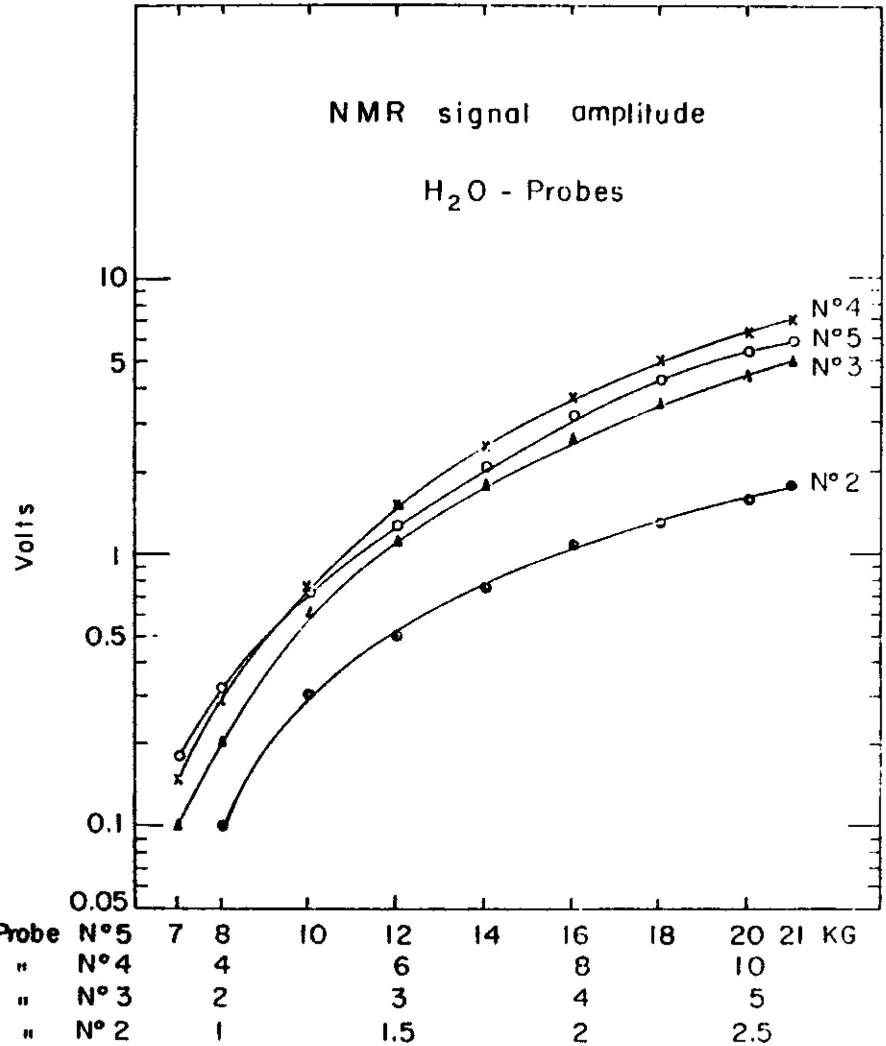


Fig. 18: NMR signal amplitude: $H_2O$ probes

## 7. SPECIFICATIONS

**Probes:**

| Probe No. | Field range (KG) | Probe type | Frequency range (MHz) | Error voltage Sensitivity (V/G) | Homogeneity for tracking (ppm/cm) Field Range | | |
|---|---|---|---|---|---|---|---|
| | | | | | High | Middle | Low |
| 1003-1 | (0.45-1.3) | $H_2O$ | (1.9-5.6) | a) | a) | a) | a) |
| 1003-2 b) | 1.0-2.6 | $H_2O$ | (3.8)-11.3 | 8 | 600 | 300 | 0 |
| 1003-3 | 1.7-5.2 | $H_2O$ | 7.5-22.5 | 4 | 1200 | 900 | 300 |
| 1003-4 | 3.5-10.5 | $H_2O$ | 15-45 | 2 | 1300 | 1300 | 700 |
| 1003-5 | 7-21 | $H_2O$ | 30-90 | 1 | 750 | 450 | 200 |
| 1003-6 b) | 20-34 | $D_2O$ | (7.5)-22.5 | 0.65 | a) | a) | 250 |
| 1003-7 b) | 30-68 | $D_2O$ | (15)-45 | 0.32 | a) | a) | a) |
| 1003-8 | (46-138) | $D_2O$ | (30-90) | a) | a) | a) | a) |

a) not measured

b) For these probes the signal-to-noise ratio is very small at the lower end of their frequency range, and automatic frequency tracking is only possible within the indicated field range.

Absolute accuracy: better than $\pm 10^{-5}$; can be improved by absolute calibration of the probes.

Relative accuracy and stability: $\sim \pm 5 \times 10^{-7}$.

Note: The relative accuracy means the equality of the readings of different magnetometer units connected to the same probe in the same field. This accuracy and especially the stability depend on the signal-to-noise ratio and therefore on the field intensity.

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)

| | | |
|---|---|---|
| $H_2O$ probes | at min. of field range | $\sim$ 10 |
| | at max. of field range | $\sim$ 100 |
| $D_2O$ probes | at min. of field range | $\sim$ 5 |
| | at max. of field range | not measured. |

Frequency tracking speed

$\dot{f}/f$: up to 1%/sec.

Time lag: min. 17 msec.

Both depend on the loop gain, and the maximum tracking speed $(\dot{f}/f)_{max}$ also on the setting of the modulation amplitude. Therefore, the frequency tracking speed and the time lag may be an order of magnitude worse than the optimum values given above.

Loop gain at d.c.: $> 10^5$ (worst case for $D_2O$ probes), typically $> 10^6$

Front panel potentiometer for max. 10 times attenuation of the loop gain.

Coarse-frequency adjustment: 10-turn precision potentiometer.

Fine-frequency adjustment: 10-turn precision potentiometer, range: see "Field tracking range".

Error voltage output: sensitivity: see probe specifications

Impedance = 1kΩ , connector: LEMO 00S250

Maximum output voltage equal to the amplitude of the modulation signal at the scope output, i.e. ± 8 V at maximum modulation setting.

Error voltage indicator

Full scale corresponds to ± 10 ppm of the maximum field value of the range.

Required homogeneity of the field:

In the table with probe specifications are given the maximum field gradients (in ppm/cm) for which a signal-to-noise ratio results, which just allows automatic frequency tracking.

The field gradient effect on the NMR can be compensated with an appropriate coil, see Options.

Field tracking range (= search-mode range = fine frequency adjustment range)

$H_2O$ probes: from 20% to 80% of the frequency range: ∿ ±5%
: at the extremities of the frequency range: ∿ ±1%

$D_2O$ probes: from 20% to 80% of the frequency range: ∿ ±1.5%
: at the extremities of the frequency range: ∿ ±0.3%.

Two LEDs indicate the approach of the upper or lower limit, respectively, of the frequency tracking range.

NMR signal output

For scope inspection of the NMR signal. LEMO connector: 00S250

Output resistance = 10 kΩ + 10 nF to ground for noise filtering.

NMR signal: negative pulses of 100 mV to 7 V (see Fig. 3).

No strobe signal output (LEMO 00S250)

CMOS switch to ground, open in the absence of NMR signal:

- switch open: I = 5-500 nA at max. ±20 V
- switch closed: 80 Ω to 100 Ω to ground at max. ±20 mA.

No strobe signal indicator

LED is ON in absence of NMR signal.

Modulation output

Lemo connector for scope inspection. (LEMO 00SL50)
Impedance = 1 kΩ.
Modulation signal is a 30 Hz triangular waveform.
Amplitude adjustable with external potentiometer: max. ±8 V, normal setting ∿ ±4 V.
Calculation of $B_{mod}$: see "Error voltage sensitivity".

Ext. modulation

INT./EXT. front panel switch.
EXT. input: Lemo connector 00S250, $Z_{in} \approx 25$ kΩ, voltage gain = 1, max. input voltage = ± 8 V.

RF output for NMR amplifier box

Square wave of 0.8 V peak-to-peak amplitude into 50 Ω . BNC connector.

RF scaler output

NIM standard signal (LEMO 00S250)

Internal frequency counter

7-digit LED display indicating the field strength in gauss.
Resolution: 0.01 G.
Temperature stability: $3 \times 10^{-6}$ from 0 to 50°C.
Time-base gate length:
- with $H_2O$ probes ∿ 0.4 sec.
- with $D_2O$ probes ∿ 0.6 sec.

BCD output

Rear connector: Hugues WSS 38

NMR amplifier box

RF input: 0.4 V peak-to-peak into 50 Ω (sine or square wave).
RF output: 5 V peak-to-peak square wave into 50 Ω.
NMR signal output: 1kΩ output impedance, no noise filter.
Dimensions: 105 x 68 x 43 mm.

Power consumption

| | | | |
|---|---|---|---|
| +24 V | 0.1 A | -24 V | 0.1 A |
| +12 V | 0.2 A | -12 V | 0.5 A |
| +6 V | 0.6 A | -6 V | 0.2 A. |

## 8. OPTIONS AND ACCESSORIES

A number of accessories and options are available or under preparation. They include:

### 1) Connection Cables in Non-standard Length

The length of the cable between the main unit and the probe amplifier box is only limited by the damping of the RF signal ( $<6$ db). If necessary a repeater can be inserted.

The cable between probe and amplifier box is limited to a few meter and should not be increased much, else the NMR signal becomes noisy.

The distance of 17 cm between the NMR detection box and the measuring head can be increased somewhat but this reduces the range covered by a given probe.

### 2) Non-standard Probes

As far as feasible SENTEC builds probes to customers specifications to fit special geometrical constraints.

### 3) Stand alone Power Supply

In case a NIM crate with power supply is not available, SENTEC will provide a stand alone power supply either in the form of a NIM crate (full or half width) or just for the NMR main unit, depending whether other NIM units might be needed or not.

### 4) Monitoring Scope for NMR Signal

For applications where no scope for observation of the NMR signal is readily available or one does not want to tie down an expensive lab. scope for that purpose, SENTEC offers a small, low cost scope, to go with the NMR unit.

### 5) Field Gradient Compensation

If field inhomogeneity is a limitation to the application of the NMR technique, this can frequently be overcome by compensation coils . This is particularly useful if the probe is to be mounted in a fixed place. If the gradient does not vary too much due to saturation in the magnet, it is best to supply the current for the compensation coils off the main magnet current. The detailed shape of the compensation coils depends on the size and direction of the field gradient relative to the probe. As an example one possible arrangement will be described here.

Two printed circuit coils are mounted, sandwich-fashion, close to the measuring head. The winding of these coils are arranged such that they produce fields parallel to $B_o$ but of opposite sign on opposite sides of the NMR sample, falling to zero at the centre of symmetry of the windings. A current of 100 mA produces a field gradient of about 3 G/cm and does not change the field reading if the NMR sample is situated in the centre of symmetry of the windings. In this way gradients of $B_o$ up to about 20 G/cm can be opposed and cancelled by choosing an appropriate current.

6) CAMAC Interface

A CAMAC device accepting data from up to two magnetometers contains internal synchronisation to avoid false data output in case of conflict between read commands (CAMAC) and data change (Magnetometer).

7) Probe Multiplexing

Up to four probes can be multiplexed to one NMR main unit.

8) Magnetic Field Stabilisation

As indicated the error voltage can be used to stabilize the magnetic field. On introducing the error voltage into the magnet power supply one has to careful about the time response to obtain a stable system. SENTEC can advise you on such problems.

To avoid the need of an external stable crystal oscillator (which is expensive) SENTEC can provide a field stabilisation unit containing a microprocessor that keeps the internal oscillator of the NMR main unit stable with respect to its crystal controlled time base.

9) Programming Unit for Field Sweeps

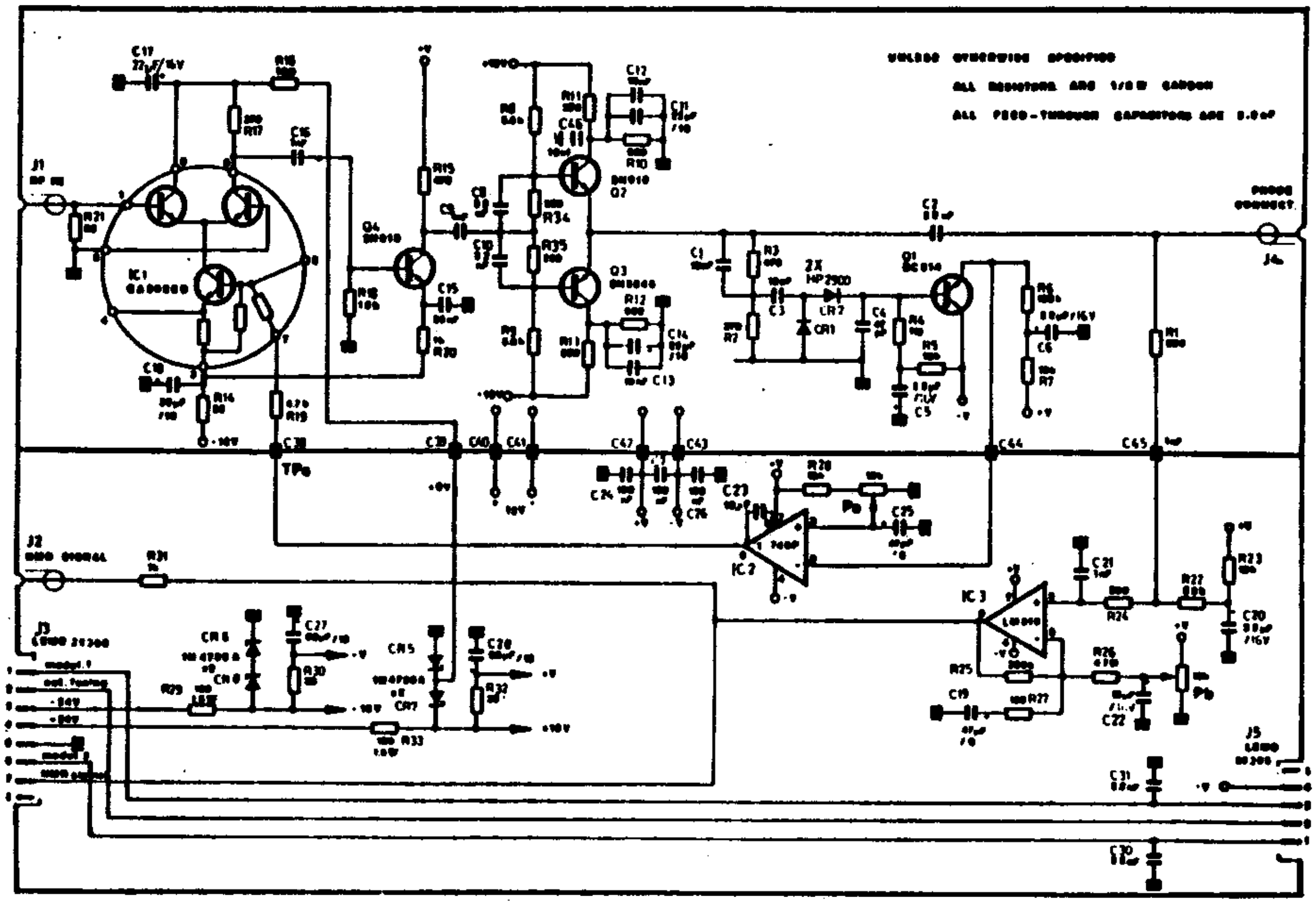
SENTEC is developping a unit based on the field stabilisation unit that permits programmed gradual changes of the field for applications like sweeps in mass spectometers.

10) Signal Averaging

If the NMR signal is weak and burried in the noise SENTEC can provide a signal averaging unit to enhance the signal-to-noise ratio.

# PROBE AMPLIFIER BOX

## CIRCUIT DIAGRAM



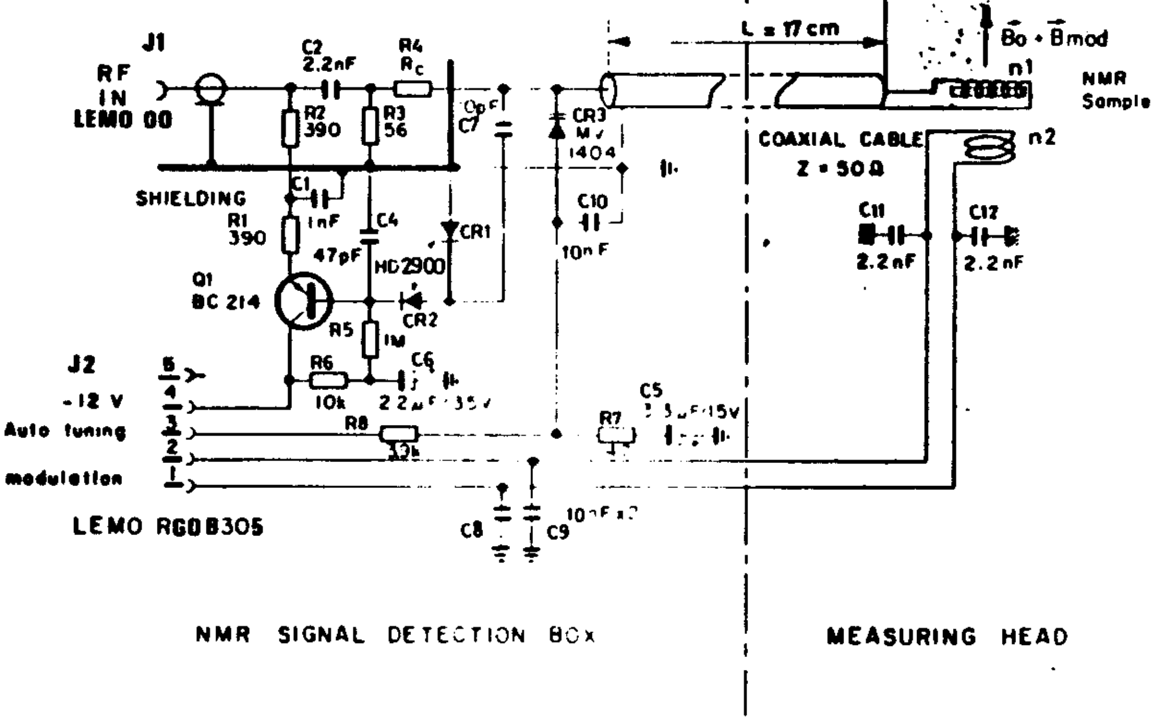
| | | |
|---|---|---|
| SENTEC APPAREILS DE MESURE | ECHELLE SCALE | DESSINÉ :<br>CONTROLÉ :<br>REMPLACE 13 S 00010 Apr 81 Wc<br>REMPLACE PAR<br>REDUCTION |
| 1002 NMR AMPLIFIER | 13-S-0003-1 | INDICE |

| DICE | DATE | NOM | ZONE | MODIFICATION |
|---|---|---|---|---|

# NMR PROBE

## CIRCUIT DIAGRAM

| PROBE No | $R_c$ | n1 | n2 |
|---|---|---|---|
| 2 | 33K | 48 | 8 |
| 3 | 15K | 30 | 19 |
| 4 | 15 K | 15 | 35 |
| 5 | 3K9 | 5 | 92 |
| 6 | 15K | 30 | 35 |
| 7 | 15K | 15 | 92 |



APPAREILS
DE MESURE

Improved, B type Apr. 83 we

1003-13-23 NMR SONDE

13-S-0004-1

## 10. REFERENCES

The SENTEC Magnetometer was developped originally at CERN by K. Borer and G. Frémont (1). Their availability for discussion was of great help during the initial production and testing, and for assembling this instruction manual. This manual follows largely the CERN report 77-19, but SENTEC assumes sole responsability for its content . Likewise CERN has no intention to give in any case any warranty of any kind whatsoever regarding the quality and performance of executed magnetometers.

(1) K. Borer, Nuclear Instrum. Methods 143, 203 (1977) and K. Borer and G. Frémont, CERN Report 77-19.

(2) E.R. Cohen and B.N. Taylor, J. Phys. Chem. Ref. Data 2, 718 (1973).
G.H. Fuller, J. Phys. Chem. Ref. Data 5, 885 (1976).

## NIM-UNIT

### PARTS LIST

| | | Quantity |
|---|---|---|
| **Integrated circuits** | | **Quantity** |
| Texas | SN 74LS02 | 1 |
| | SN 74LS14 | 1 |
| | SN 74LS74 | 1 |
| | SN 74LS123 | 1 |
| | SN 74LS145 | 1 |
| | SN 74LS151 | 4 |
| | SN 74LS190 | 1 |
| | SN 74LS191 | 4 |
| | SN 74LS221 | 2 |
| | SN 74LS248 | 1 |
| | SN 74LS290 | 7 |
| | SN 74LS375 | 7 |
| | SN 7402 | 1 |
| | SN 7472 | 1 |
| | SN 74122 | 1 |
| | SN 74145 | 1 |
| | SN 74194 | 1 |
| | SN 72741P | 10 |
| | SN 72748P | 2 |
| | TIL 081 ACP | 2 |
| Motorola | MC 1494L | 1 |
| | MC 1648L | 1 |
| | MC 10102P | 2 |
| | MC 10125P | 1 |
| | MC 10131P | 2 |
| | MC 10136P | 1 |

### PARTS LIST

| | | Quantity |
|---|---|---|
| **Integrated circuits** | | **Quantity** |
| National | LM 311N | 2 |
| | LH 0002-CH | 1 |
| RCA | RCA 3082 | 1 |
| Siliconix | DC 200 CJ | 1 |
| | DC 201 CJ | 1 |
| Hewlett Packard | HP 5082-7404 | 2 |
| Philbrick | Sample-hold type 4856 | 1 |
| **Quartz** | | |
| Vectron | type CO-231, 100 kHz, opt. 3 | 1 |
| **Diodes** | | |
| Philips | AAZ 15 | 4 |
| Motorola (1N 4446) | 1N 914 A | 11 |
| | 1N 5059 | 3 |
| | MV 1404 | 1 (must be selected ∿ 20% rejects) |
| | 1N 829A | 2 |
| Intermetal | ZPD 3.3 | 3 |
| | ZPD 3.9 | 2 |
| | ZPD 4.7 | 1 |
| | ZPD 5.6 | 1 |
| | ZPD 15 | 2 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Transistors** | | |
| Philips | BSV 81 | 1 |
| Texas | BC 214 | 1 |
| Philips | 2N 918 | 2 |
| Motorola | MPSA 64 | 1 |
| **Sockets** | | |
| OEC Transist. | CTO 18.4 | 3 |
| OEC ICs | CDF 108 | 14 |
| " " | CDF 114 | 16 |
| " " | CDF 116 | 31 |
| **Resistors** | | |
| Allen Bradley 1/8W 5% | | |
| | 15 Ω | 2 |
| | 47 Ω | 3 |
| | 56 Ω | 2 |
| | 220 Ω | 2 |
| | 270 Ω | 1 |
| | 330 Ω | 1 |
| | 560 Ω | 3 |
| | 680 Ω | 15 |
| | 820 Ω | 2 |
| | 1 kΩ | 12 |
| | 1.5 kΩ | 2 |
| | 1.8 kΩ | 1 |
| | 2.2 kΩ | 14 |
| | 2.7 kΩ | 1 |
| | 3.3 kΩ | 1 |
| | 3.9 kΩ | 3 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Resistors** | | |
| Allen Bradley 1/8W 5% | | |
| | 4.7 kΩ | 3 |
| | 5.6 kΩ | 3 |
| | 6.8 kΩ | 1 |
| | 8.2 kΩ | 1 |
| | 10 kΩ | 14 |
| | 12 kΩ | 1 |
| | 15 kΩ | 3 |
| | 18 kΩ | 3 |
| | 27 kΩ | 1 |
| | 33 kΩ | 2 |
| | 39 kΩ | 2 |
| | 47 kΩ | 3 |
| | 100 kΩ | 5 |
| | 120 kΩ | 3 |
| | 150 kΩ | 1 |
| | 180 kΩ | 1 |
| | 390 kΩ | 1 |
| | 470 kΩ | 5 |
| Allen Bradley 1/4W 5% | | |
| | 220 Ω | 1 |
| | 270 Ω | 8 |
| | 330 Ω | 1 |
| | 560 Ω | 2 |
| | 1.5 kΩ | 1 |
| | 2.2 kΩ | 1 |
| | 3.3 kΩ | 4 |
| | 6.8 kΩ | 1 |

# PARTS LIST

### Resistors

| | | Quantity |
|---|---|---|
| **Allen Bradley 1/4W 5%** | | |
| | 10 kΩ | 2 |
| | 120 kΩ | 1 |
| | 220 kΩ | 1 |
| | 1.5 MΩ | 1 |
| | 4.7 MΩ | 1 |
| **Allen Bradley 1/2W 5%** | | |
| | 100 Ω | 1 |
| | 120 Ω | 1 |
| | 390 Ω | 1 |
| | 1 kΩ | 1 |
| **Allen Bradley 1W 5%** | | |
| | 56 Ω | 1 |
| | 120 Ω | 1 |
| | 1 MΩ | 2 |
| **Sfernice 1/8W 1%** | | |
| | 1.47 kΩ | 2 |
| | 6.19 kΩ | 2 |
| | 9.09 kΩ | 1 |
| | 10 kΩ | 5 |
| | 13.3 kΩ | 1 |
| | 14.7 kΩ | 1 |

### Ceramic condensers

| | | Quantity |
|---|---|---|
| Philips | 1 nF | 2 |
| | 2.2 nF | 12 |
| | 10 nF | 11 |
| | 22 nF | 16 |
| Erie type Redcap | 100 nF 50 V | 7 |

# PARTS LIST

### Polyester metallized condensers

| | | Quantity |
|---|---|---|
| **Wima type FK3/MKS3** | | |
| | 2200 pF 100 V | 2 |
| | 3300 pF " | 2 |
| | 4700 pF " | 1 |
| | 6800 pF " | 1 |
| | 10 nF " | 3 |

### Plastic metallized condensers

| | | Quantity |
|---|---|---|
| Siemens type MKL | 1 µF 100 V | 1 |
| | 2.2 µF 100 V | 1 |
| | 4.7 µF 100 V | 1 |
| | 10 µF 100 V | 2 |

### Polystyren condensers

| | | Quantity |
|---|---|---|
| Siemens type B31110 | 1 nF | 1 |

### Polycarbonate metallized condensers

| | | Quantity |
|---|---|---|
| Advance Filmcap Ltd | 0.15 µF 63 V | 1 |
| | 0.47 µF 63 V | 2 |
| | 0.68 µF 63 V | 1 |

### Tantalum condensers

| | | Quantity |
|---|---|---|
| Union Carbide type J | | |
| | 4.7 µF 10 V | 1 |
| | 33 µF 10 V | 1 |
| | 100 µF 10 V | 2 |
| | 220 µF 10 V | 3 |
| | 22 µF 15 V | 1 |
| | 47 µF 20 V | 4 |
| | 10 µF 35 V | 1 |
| | 22 µF 35 V | 2 |

## PARTS LIST

| | Quantity |
|---|---|
| **Switches** | |
| Toggle-switch C+K type 7101 | 1 |
| " " " " 7201 | 2 |
| Rotary Erni type T 84P 613.000-3-3x8-U-12-1-5-1 | 1 |
| **Connectors** | |
| BNC Hubert-Suhner Type 22-BNC-50-0-3 | 1 |
| " " " " 11-BNC-50-3-50 C/133 | 2 |
| Lemo type RA 00S250 | 7 |
| " " F 00S250 | 2 |
| " " RPL00S250 | 4 |
| " " RP 00250 | 1 |
| " " RA 2307 (nylatron) | 1 |
| " " F 2307 (nylatron) screened cable ø 8 mm | 2 |
| Hughes type WSS 38 | 1 |
| AMP type 202515-5 | 1 |
| " " 202394-2 | 1 |
| Scotchflex type 3M-3416-0002 | 1 |
| Augat type 516-Ag-11D | 1 |
| **Knobs** | |
| Helipot type 2606-DUODIAL | 2 |
| Elma type 020-213 ø = 3 mm | 1 |
| " " 041-202 | 1 |
| " " 040-103 | 1 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Tantalum condensers** | | |
| Bosch type 0 678 901 | 2.2 µF 16 V | 1 |
| | 22 µF 16 V | 1 |
| | 47 µF 6.3 V | 1 |
| | 3.3 µF 20 V | 1 |
| | 1 µF 35 V | 1 |
| ITT type 20504 | 100 µF 10 V | 6 |
| **Ceramic feed-through condensers** | | |
| Philips type 2222(70)05222 | 2200 pF 100 V | 4 |
| **Potentiometers** | | |
| Beckman type 62PR | 10 kΩ | 4 |
| | 100 kΩ | 1 |
| Bourns type 3339P | 5 kΩ | 2 |
| Beckman type 89PR | 10 kΩ | 2 |
| | 20 kΩ | 2 |
| Contelec type T 84P | 10 kΩ | 2 |
| Helipot | 10 kΩ | 2 |
| **Switches** | | |
| Switch-slide Interdil, type 09 10000 03 | | 2 |
| " " " " 09 16201 04 | | 2 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Contacts** | | |
| Columbus type male No. 104 | | 6 |
| " " female No. 110 | | 6 |
| **Amperemeter** | | |
| Gossen type PQ 000-1002 | ±100 μA, zero central | 1 |
| **Polarized filter** | | |
| Omni-Ray type HRCP-7 red dark | 48 × 23 × 0.8 mm | 1 |
| **Interconnection cables** | | |
| Hubert-Suhner, type RG 223/U | | 10 m |
| Metrofunk (Berlin), type LiYCY 7 × 0.5/55 | | 10 m |

## AMPLIFIER BOX

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Integrated circuits** | | |
| RCA | CA 3028 B | 1 |
| National | LM 318 N | 1 |
| Texas | 72748 P | 1 |
| **Diodes** | | |
| Hughes | HD 5000 | 2 |
| Motorola | 1N 4735 | 4 |
| Intermetal | ZPD 5.6 | 2 |
| **Transistors** | | |
| Philips | 2N 918 | 2 |
| Motorola | 2N 3546 | 1 |
| Texas | BC 214 | 1 |
| **Sockets** | | |
| OEC | CTO 18.3 | 2 |
| | CTO 18.4 | 2 |
| | CTO 8 CS | 1 |
| | CDF 108 | 2 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Resistors** | | |
| Allen Bradley 1/8W 5% | | |
| | 22 Ω | 1 |
| | 56 Ω | 1 |
| | 120 Ω | 1 |
| | 220 Ω | 2 |
| | 270 Ω | 4 |
| | 390 Ω | 3 |
| | 470 Ω | 1 |
| | 680 Ω | 2 |
| | 1 kΩ | 2 |
| | 1.8 kΩ | 1 |
| | 4.7 kΩ | 1 |
| | 5.6 kΩ | 2 |
| | 10 kΩ | 2 |
| | 15 kΩ | 1 |
| | 33 kΩ | 1 |
| | 100 kΩ | 1 |
| | 390 kΩ | 1 |
| | 1 MΩ | 1 |
| Allen Bradley 1/4W 5% | | |
| | 33 Ω | 2 |
| | 220 Ω | 2 |
| | 4.7 MΩ | 1 |
| Sfernice wirewound 1,5W | | |
| | 180 Ω | 2 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Ceramic condensers** | | |
| Philips type 2222 632... | | |
| | 10 pF 63 V | 2 |
| | 47 pF 63 V | 1 |
| | 100 pF 63 V | 1 |
| Philips type 2222 629... | | |
| | 1 nF 40 V | 1 |
| | 2.2 nF 40 V | 6 |
| | 10 nF 40 V | 2 |
| | 22 nF 40 V | 1 |
| Erie type Redcap | | |
| | 100 nF 50 V | 3 |
| **Ceramic feed-through condensers** | | |
| Philips type 2222(70)05222 | | |
| | 2200 pF | 6 |
| Philips type 2222(70)05102 | | |
| | 1000 pF | 1 |
| **Tantalum condensers** | | |
| Union Carbide type J | | |
| | 68 μF 16 V | 2 |
| Bosch type 0 678 901 | | |
| | 47 μF 6.3 V | 2 |
| | 2.2 μF 16 V | 3 |
| | 15 μF 20 V | 1 |

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Potentiometers** | | |
| Bourns type 3339P-1-103 | | |
| | 10 kΩ | 2 |
| **Connectors** | | |
| Lemo type RA00S250 | | 1 |
| Lemo type F-0304 for shielded cable ∅ = 4.2 mm body in nylatron | | 2 |
| Lemo type RA0304 body in nylatron | | 1 |
| Lemo type F-2307 for shielded cable ∅ = 8 mm body in nylatron | | 2 |
| Lemo type RA 2307 body in nylatron | | 1 |
| Huber-Suhner type 22BNC-50-0-4 (UG-625-B/U) | | 2 |
| Huber-Suhner type 11BNC-50-3-50C/133 | | 2 |
| **Interconnection cables** | | |
| Hubert-Suhner type RG 223/U | | 2 m |
| Metrofunk (Berlin) type LiYCY 7 × 0.5/55 | | 2 m |
| **Metallic box** | | |
| POMONA-ITT (USA) model 3306 unpainted | | 1 |

## NMR PROBE

## PARTS LIST

| | | Quantity |
|---|---|---|
| **Diodes** | | |
| Hughes | HD 5000 | 2 |
| Motorola | MV 1404 | 1 (selected, 20% reject |
| **Transistors** | | |
| Texas | BC 214 | 1 |
| **Resistors** | | |
| Allen Bradley 1/8W 5% | | |
| | 47 Ω | 1 |
| | 390 Ω | 2 |
| | 1.5 kΩ | 1 |
| | 3.9 kΩ | 1 |
| | 10 kΩ | 1 |
| | 22 kΩ | 1 |
| | 1 MΩ | 1 |
| Allen Bradley 1/4W 5% | | |
| | 56 Ω | 1 |
| **Ceramic condensers** | | |
| Philips type 2222.632... | | |
| | 47 pF 63 V | 1 |
| Philips type 2222.629... | | |
| | 1 nF 40 V | 2 |
| | 2.2 nF 40 V | 5 |
| Bosch type 0 678 901 | | |

# PARTS LIST

| | | Quantity |
|---|---|---|
| **Ceramic condensers** | | |
| Bosch type 0 678 901 | 3.3 F 20 V | 1 |
| | 2.2 F 35 V | 1 |
| **Connectors** | | |
| Lemo type RA0304 nylatron | | 1 |
| Hubert-Suhner type 22-BNC-50-0-4 | | 1 |
| **Cables** | | |
| Habia type E 2607 STF2 | | 0.3 m |
| Hubert-Suhner type K04299/100 | | 0.3 m |