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M. Placidi, G. Renzler and S. Tazzari : AN INSTRUMENT FOR MEASURING MAGNETIC FIELDS IN THE RANGE 0. 01 TO 20 GAUSS WITH PEAKING-STRIPS. -

(Nota interna: n. 296)

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1. INTRODUCTION -

It is well known that a voltage signal of the type shown in fig. 1 (continuous curve) can be magnetically picked-up from a peaking-strip excited by a sinusoidal magnetic field of fixed frequency.

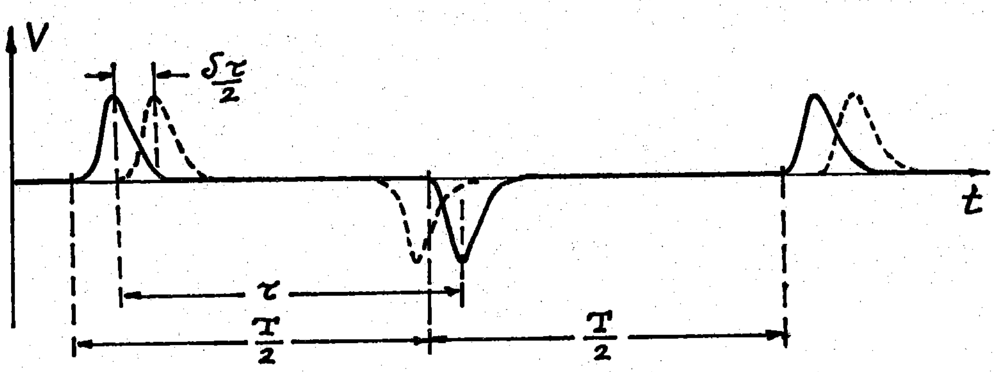


FIG. 1

1/T is the frequency of the exciting field. The amplitude of the peaks, besides depending upon from the peaker's mechanical characteristics(1), is a function of the amplitude and frequency of the exciting field itself.

An external, constant magnetic field, oriented along the peaker axis, $B_{//}$, has the effect of displacing the peaks as shown by the dotted line of fig. 1; let $\delta\tau(B_{//})$ be the variation of their relative distance in time, τ, in the presence of $B_{//}$. $\delta\tau$ is, with good approximation, a linear function of $B_{//}$.

An external, costant magnetic field normal to the peaker axis, $B_{\perp}$, has no effect on τ but affects both the shape and the amplitude of the peaks.

We propose an instrument for measuring the value of τ, and therefore of $B_{//}$. We will discuss its performance in connection with the measurement it was designed for, and namely the determination of the magnetic axis and asymptotes of the quadrupole magnets for ADONE. It is obvious, though, that the instrument can measure any kind of magnetic field within its range.

2. MEASUREMENT OF THE POSITION OF AXIS AND ASYMPTOTES OF A QUADRUPOLE MAGNET -

We recall that the magnetic field in a quadrupole at a distance $s = \sqrt{x^2 + y^2}$ from the magnetic axis z, has the following components:

$$B_x = ky ; \quad B_y = kx ; \quad B_z = 0$$

with constant k.

Therefore, in order to measure the position of the magnetic axis, or of an asymptote, to within Δs, it is necessary to measure a field component, $B_{//}$, to within

(1) $$\Delta B_{//} = k \, \Delta s$$

and the time distance τ of 1 to within

(2) $$\Delta\tau = k \, \Delta s \frac{\partial \tau}{\partial B_{//}} .$$

$\partial\tau / \partial B_{//}$ is, for a given frequency ν and amplitude H_M of the sinusoidal exciting field, a characteristic constant of the peaking strip. Its value, for our strips(x), is typically

(x) - The wire used was NILOMAG 771 μ-metal, diameter 3.6 mils.

$$\frac{\partial \tau}{\partial B_{/\!/}} = (6.8 \pm .1) \ \mu s/\text{gauss}$$

when $\nu = 1$ kH$_z$ and $H_M = 5.5$ gauss.

If we then take for k a value of 100 gauss/cm and we wish ΔS to be 10^{-3} mm, we get, from 2),

(3) $$\Delta \tau = 6.8 \cdot 10^{-8} \ s$$

In order to be able to extend the measurements to the maximum possible distance from the magnetic axis, it will also be necessary to minimize the effects of the trasverse field component, which amounts to making the measurement of τ as much as possible independent from the shape and amplitude of the peaker pulses.

3. APPARATUS -

The block diagram and circuit diagram of the apparatus are shown in figg. 2 and 3 respectively.

A 1 KHz oscillator (T1, T2) and a current amplifier (T3, 4, 5) supply the peaker's excitation winding with a current the peak value of which can be varied, up to $\sim$50 mA (corresponding to H_M 5.5 gauss), by means of P_6.

A pick-up coil picks-up the peaker pulses together with a sinusoidal noise at the excitation frequency. Since, because of the small dimensions of the coils, it is not possible to eliminate this noise directly, the pick-up output is fed into a band-stopping filter tuned on 1 KHz.

The filter also causes the pulses to be strongly derivated and it's output is fed into a 40 db amplifier (T6, 7, 8).

The amplifier drives a bistable circuit (T9, 10, 11) the switching occurring at the zero-crossing in order to strongly reduce time fluctuations due to shape and amplitude variations of the peaker pulses.

Input and output waveforms of the bistable circuit are shown in fig. 4

The bistable is a Schmitt circuit polarized in the center of the hysteresis region, so that, after an initial transient (fig. 4a), its output is the one shown in fig. 4b. The width ΔV_h of the hysteresis region can be varied by means of P_4.

The RC circuit that follows the Schmitt circuit is such that:

$$RC \gg (t_2 - t_o) = T$$

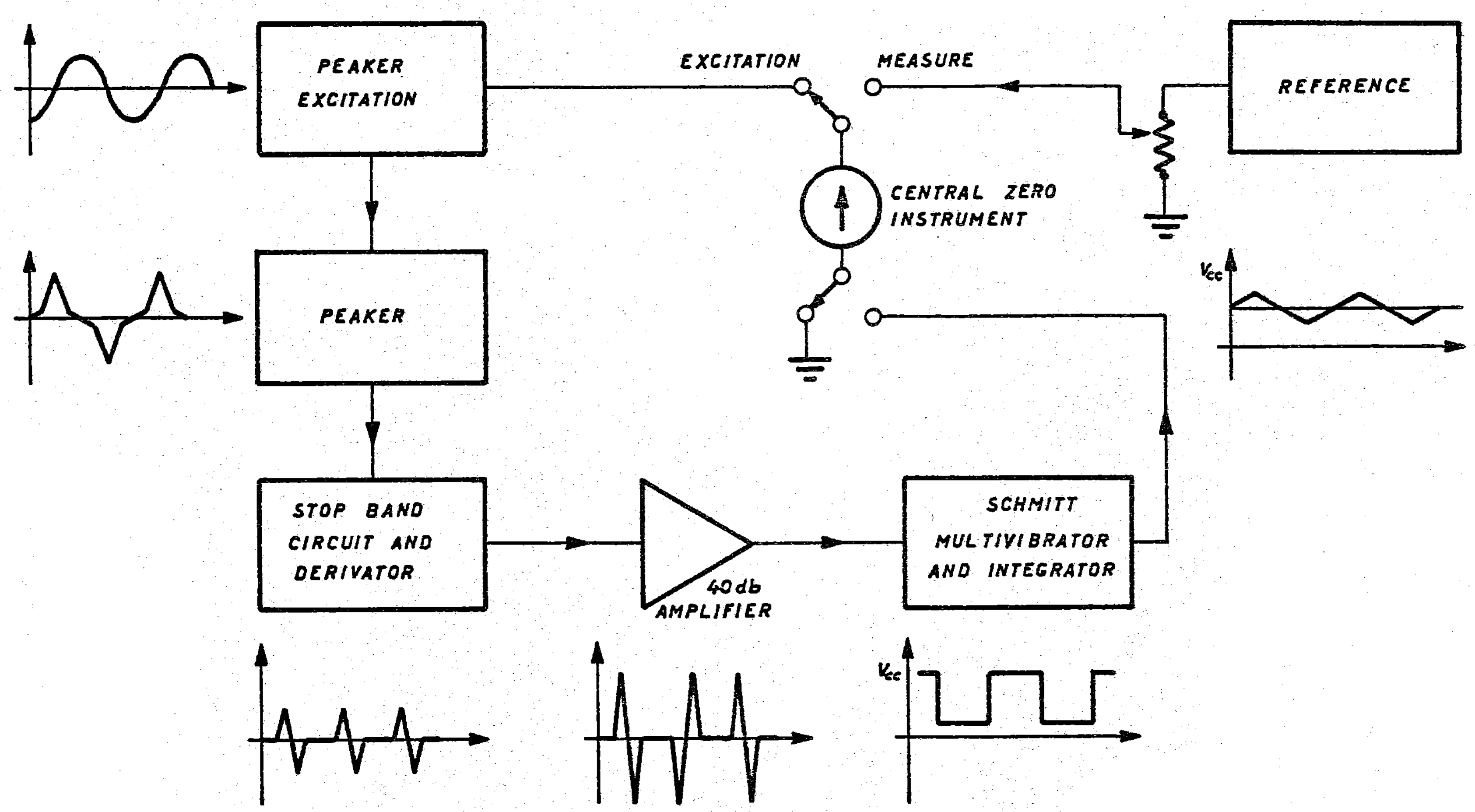
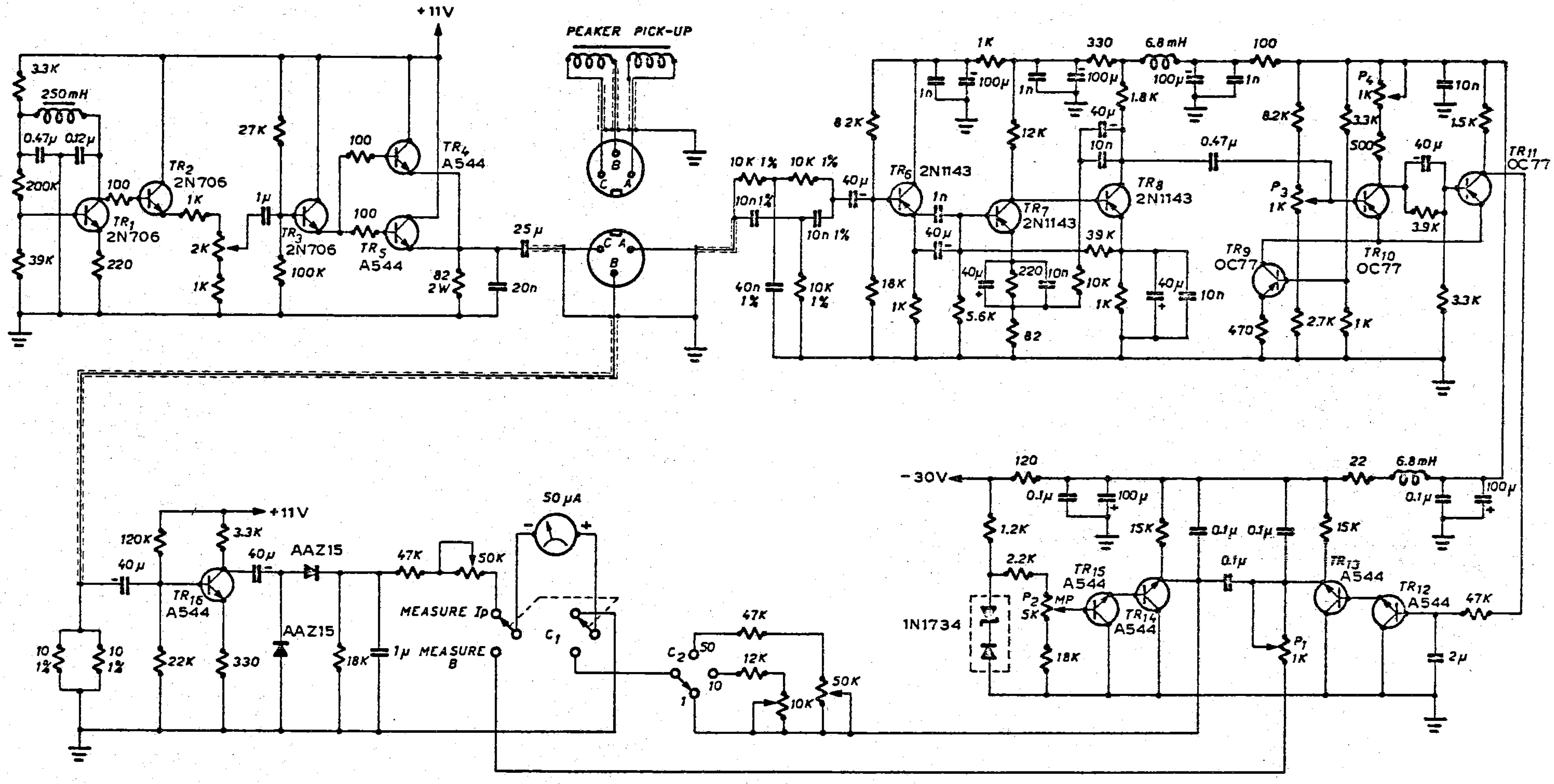


FIG. 2 - Magnetometer block diagram



TR$_{12}$ ÷ TR$_{15}$ - Mounted on a common copper radiator

FIG. 3

The final average voltage across C is therefore

(4) $$V_{av} = \frac{1}{T}\left\{V_2(t_1-t_o)+V_1(t_2-t_1)\right\} = \frac{t_1-t_o}{T}(V_2-V_1)+V_1$$

using the notations of fig. 4.

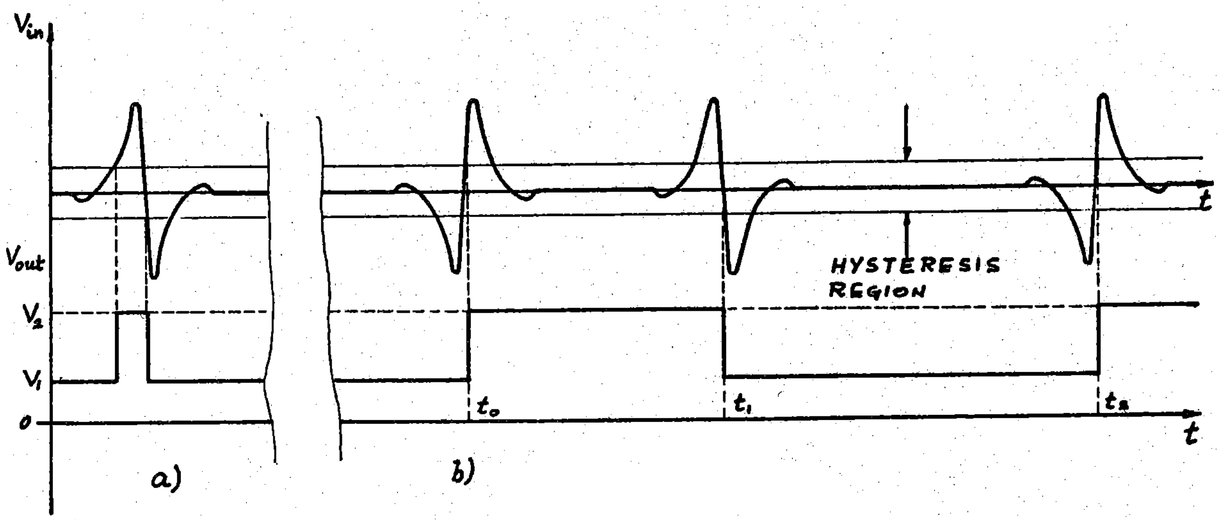


FIG. 4

One also gets:

$$\frac{\partial V_{av}}{\partial t_1} = \frac{V_2-V_1}{T} = \frac{\partial V_{av}}{\partial \tau}$$

For our circuit

(5) $V_2-V_1 = 15$ Volts; $T = 10^{-3}$ s; $\frac{\partial V_{av}}{\partial \tau} = 1.5 \cdot 10^4$ Volt/s

A microammeter is connected, through two double D. C. emitter-followers (T12, 13, 14, 15) between C and a reference voltage source. Besides integrating again over any residual ripple, it measures the difference between V_{av} and the reference, the reading being proportional to (t_1-t_o) and therefore to $B_{//}$.

The helipot P_2 allows the zero of the instrument to be moved over a wide range of voltages.

Power is supplied by two different sources, of which one, supplying T_6 through T_{15}, stabilized to $\sim .01\%$, the other stabilized to $\sim .1\%$. The high degree of stabilization and the two double emitter followers are necessary since, taking $\Delta\tau$ from 3, one has:

$$\Delta V_{av} = \frac{\partial V_{av}}{\partial \tau} \Delta\tau \simeq 10^{-3} \text{ Volt}$$

and also, since $V_{av} \simeq$ 10 Volts

$$\frac{\Delta V_{av}}{V_{av}} \lesssim 10^{-4}$$

The whole circuit, except the power supplies and the peaker excitation circuitry, is enclosed in a styrofoam box in order to reduce short term temperature fluctuations. Long term temperature drift if not very relevant since it can be corrected by means of P_2.

Switch C_1 enables the peak excitation current, and therefore the peak excitation magnetic field, to be measured on the microammeter.

The sensitivity of the instrument can be reduced by a factor of 10 or of 50 by means of switch C_2.

4. PERFORMANCE -

Let i be the current flowing through the microammeter. One has:

$$\frac{\partial i}{\partial \tau} \simeq \frac{\partial V_{av}}{\partial \tau} \cdot \frac{1}{\rho} , \quad \rho = r_{p1} + r_i$$

r_i being the internal resistance of the instrument and r_{p1} the resistance of P1.

By proper adjustment of these values we obtained for our circuit the measured value:

$$\frac{\partial}{\partial \tau} = 10 \ \mu A / \mu s$$

Using a test magnet of known, variable field, curve o) of fig. 5, of i versus $B_{//}$ with $B_{\perp} = o$, was obtained. The slope is

$$\frac{\partial}{\partial B_{//}} = 68 \ \mu A/\text{gauss}$$

and stays constant up to about 30 gauss.

Repeating the calibration at different values of $B_{\perp}$ curves 1), 2), 3) of fig. 5 were obtained. The time jitter of the Schmitt circuit output was also measured as a function of $B_{\perp}$, and found to remain approximately constant, and compatible with the values we will later mention, up to about 1 kgauss transverse field. Beyond 1 kgauss it suddenly increases by a factor of about 10. The conclusion is that, up to 1 kgauss, the only effect of the transverse field is to lower the upper limit of the useful range of the instrument. Beyond 1 kgauss the lower limit is affected too.

To determine the lower limit of the range of the instrument experimentally, the value of the current i was recorded over a period of 17 hours of continuous operation, after about 1 hour warm-up and, with $B_{//} = B_{\perp} = o$. The total drift was found to be ~ 8 μA, corresponding to an average slope of .5 μA/h. The maximum short-term (10 m) fluctuation was .2 μA, corresponding to $\sim$ .003 gauss.

A $\pm$ 5% variation of the A. C. supply voltage caused an output variation of $\pm$ 0.4 μ A, and a $\pm$ 1% variation of the excitation frequency an output variation of $\pm$ 0.2 μ A.

If we assume that .4 μ A is the lower limit of the sensitivity of the apparatus we obtain, with $B_{\perp} = o$, the following results.

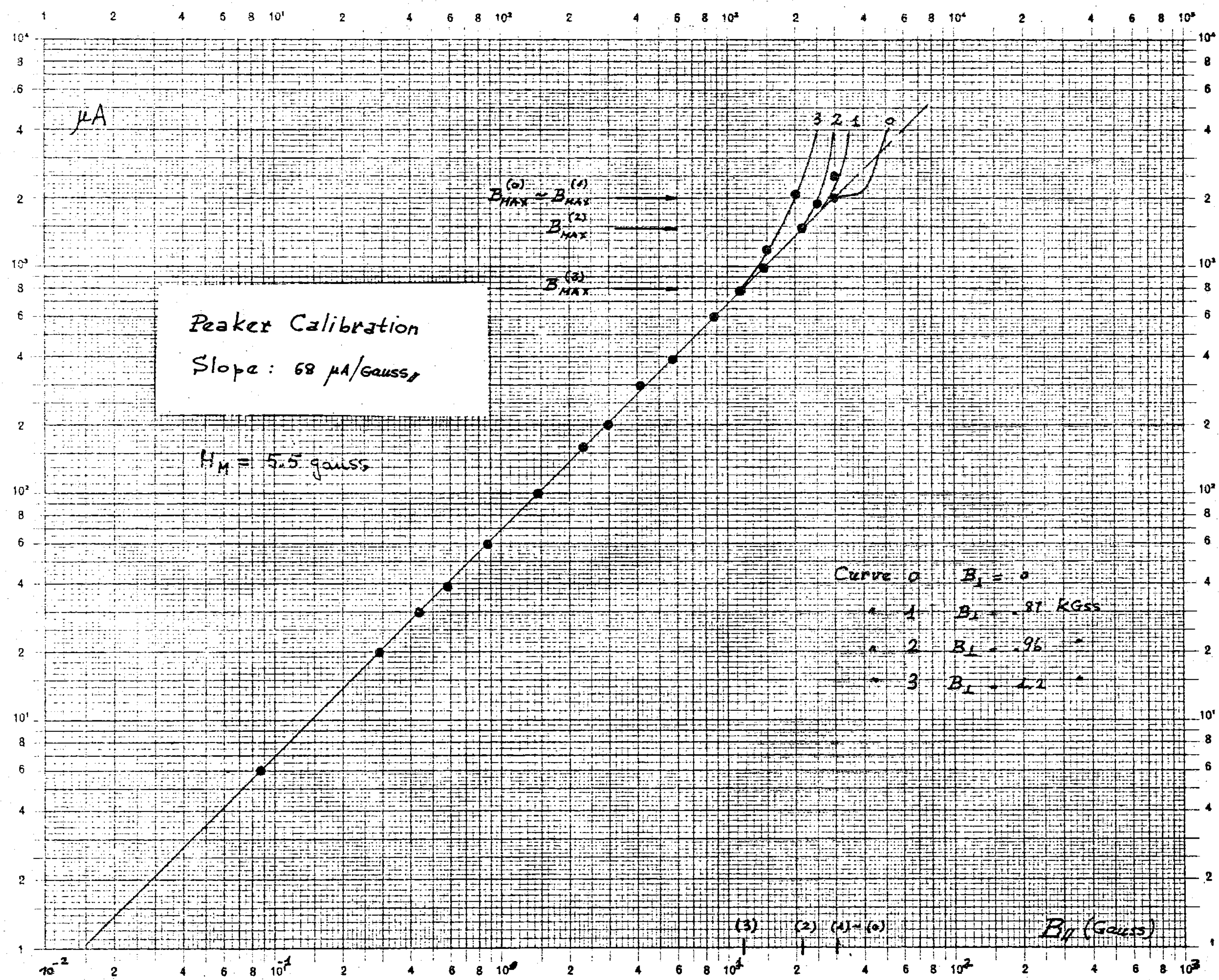
Useful range $\sim$ .006 $\div$ 30 gauss

$$\Delta \tau = \frac{\Delta i}{\partial i / \partial \tau} \simeq 4.10^{-8} \text{ s} \quad .$$

This value of $\Delta\tau$ is slightly better than the one required by 5).

It is our opinion that a better stabilization of the d. c. supply voltages could still be useful.

We would also like to emphasize again that the quoted results are to be thought of as strongly dependent from the peaking-strip used. It is however our experience that it is not difficult to build peaking-strips that, on the average, have characteristics similar to the ones we mentioned.



μA
Peaker Calibration
Slope : 68 μA/Gauss
H_M = 5.5 gauss
$B^{(0)}_{MAX} \simeq B^{(1)}_{MAX}$
$B^{(2)}_{MAX}$
$B^{(3)}_{MAX}$
3 2 1 0
Curve 0 $B_\perp$ = 0
" 1 $B_\perp$ = .87 KGss
" 2 $B_\perp$ = .96 "
" 3 $B_\perp$ = 1.2 "
(3) (2) (1)~(0)
$B_\parallel$ (Gauss)

FIG. 5

BIBLIOGRAPHY -

(1) - G. Diambrini-Palazzi: A magnetic differential probe. N. C. X, 3, (56).

ACKNOWLEDGEMENTS -

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