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A HIGH RESOLUTION ABSOLUTE MAGNETIC FIELD MEASUREMENT SYSTEM

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Introduction

For adjusting good beam transport in the beam-switch yards it is necessary to know in high precision the magnetic fields of the bending magnets. This requires an instrument operating under the following bad conditions:

- high radiation level
- high ambient noise level
- long cabling from magnetic field probe to the instrument
- non optimum magnetic field homogeneity.

Commercially available high resolution absolute magnetic field measuring instruments are all based on the N.M.R.-principle. Considering those bad conditions, these instruments have the following disadvantages:

- an electronic oscillation or preamplifier circuit is necessary, located close to the field to be measured, thus exposed to a high radiation level
- weak signals, due to low probe efficiency (insertion loss $\geq$ 120 db) and limitation of input power (saturation)
- the probe signal decreases rapidly with decreasing field homogeneity.

A solution for this problem is the application of the E.S.R. principle, by means of a YIG-filter type probe. Compared with N.M.R. we have now,

- the electronic circuit is confined to only two microwave diodes, a step recovery and a detection diode
- much stronger signal, due to high probe efficiency (insertion loss < 10 db)
- at least one order less sensitive for field inhomogeneity.

Design consideration

The relation between field H and frequency f is

$$f = \frac{\gamma}{2\pi} H$$

For E.S.R. $\frac{\gamma}{2\pi}$ = 2,8 MHz/gauss.

The field range proposed to be measured is 1 to 12 Kgauss, corresponding a frequency range of 2,8 to 33,6 GHz. Directly operating these high frequencies would lead to extreme problems. Therefore we have introduced a step-recovery diode as harmonic generator. The whole probe is a combination of a YIG-filter, a harmonic generator and a detection diode. The power to be transported over a long distance (up to 100 m) can now be of relatively low frequency.
Fig. 1 shows a functional diagram. The indications in the blocks mean:

C.L.	Close Loop Switch
F.C.	Frequency Counter
V.C.O.	Voltage Controlled Oscillator
A.L.C.	Automatic Level Control
P.D.	Peak Detector
X	Multiplier
—\	low pass filter

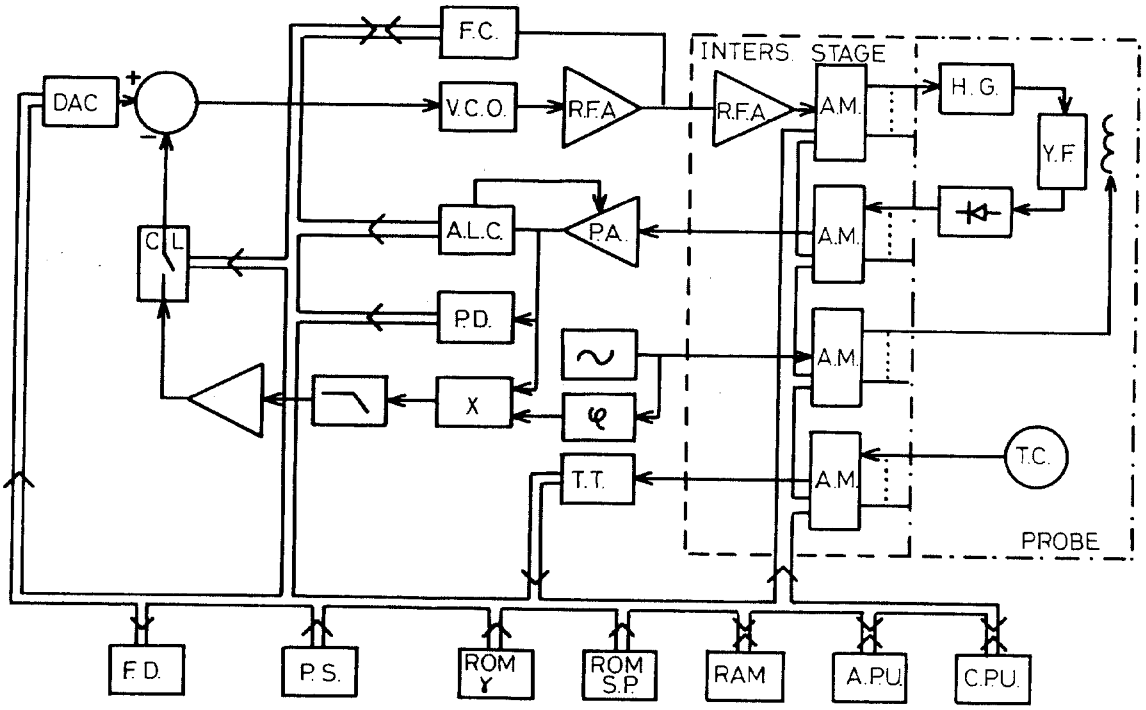

Fig. 1

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R.F.A.	Radio Frequency Amplifier
P.A.	Pre-Amplifier
∿	Magnetic field sweep oscillator (1000 Hz)
φ	Phase Shifter
T.T.	Temperature Transducer
A.M.	Analog Multiplexer
H.G.	Harmonic Generator (step recovery diode)
Y.F.	YIG-filter
T.C.	Temperature Censor
C.P.U.	Central Processing Unit
A.P.U.	Arithmatic Processing Unit
ROM S.P.	Memory System Program
ROM γ	Memory γ correction
P.S.	Probe Selection
F.D.	Field Display

The part of the diagram within the dashed-dotted line represents a probe. Analog multiplexers enable successive field measurement of several magnets. The part of the diagram within the dashed line represents an intersection stage. This stage has been adapted for two reasons:

- reducing the expensive probe cabling
- reducing the R.F.A. output power to an acceptable low level.

The level of the harmonics produced by H.G. decreases progressively with increasing frequency. So the level of the resonance peaks will decrease rapidly with increasing frequency (high magnetic fields). Therefore the Pre-amplifier has been provided with an automatic level control. The phase difference between the modulation field Hm and the drive to the multiplier can be adjusted by φ. A microprocessor expended with an arithmatic unit has been implemented to control the searching loops and the data flow as described below in "measurement procedure".

The gyromagnetic constant is not a perfect constant but depends on the field and the temperature. These effects will be corrected for by storing this dependence in R.O.M. modules. The instrument will be provided with an interface bus enabling automatic setting and control of the magnetic fields.

With a magnetic field H_1 corresponds a frequency f_1. The output frequency (g) of the V.C.O. can vary between 1.0 and 0.5 GHz. To obtain resonance g must have such a value that a harmonic of g equals f_1. The V.C.O. is swept by the DAC drive from high to low frequency starting at its maximum of 1.0 GHz. Let g_1 be the first and g2 the second value of g for which f_1 is a harmonic. Then the harmonic number is determined by the integer which is closely approached by

$$n = \frac{g_2}{g_1 - g_2}$$

and f_1 follows from $f_1 = ng_1$

Measurement procedure

The frequency g decreases by discrete steps Δg, corresponding the l.s.b. of the DAC. At the same time the magnetic field at the YIG-filter is modulated by a small amount H_m. This field modulation corresponds with a frequency interval Δf, according to

$$\Delta f = \frac{\gamma}{\pi} \hat{H}m$$

$\hat{H}m$ is the maximum amplitude of Hm. After some steps of the DAC, f_1 enters this interval. Then resonance peaks are generated. These peaks are detected by the Peak Detector, which stops the DAC. However the V.C.O. produces now a frequency different from g_1, because the field modulation Hm adds a small amount to the real field. To obtain the correct frequency g_1 the center of the resonance peaks must coincede with the zero crossings of the modulation field Hm. To obtain this, a phase locked loop is closed, initiated by the Peak Detector. After some settling time, g_1 can be measured and stored. Then the loop is unclosed and the DAC proceeds stepping. With a step Δg corresponds a step $\Delta fg = n \Delta g$. To cover the whole frequency range it is necessary that $\Delta fg < \Delta \hat{f}m$.

In the next DAC steps, resonance peaks corresponding the same harmonic number will be generated. The number of these successive resonances are given by

$$\frac{\Delta fm}{\Delta fg} = \frac{\hat{n}}{\bar{n}}$$

$\hat{n}$ is the harmonic number, corresponding the maximum field to be measured ($\hat{n} = 34$ for 12 Kgauss).

Measuring many times the same g_1 must be avoided. Therefore after the first resonance the next successive resonances must be ignored. This means the DAC proceeds stepping but the p.l.l. will not be closed. When there are again DAC steps without resonances, f_1 has left the Δfm interval. For the next resonance the system is again active. That means the DAC is stopped and the p.l.l. is closed, resulting in measuring g_2.

It is checked if $g_1 \neq$ the maximum V.C.O. frequency (1GHz). If this is not true, a next value g_3 is measured. Instead of g_1 and g_2 are then used g_2 and g_3 for the calculation of the magnetic field. After calculation of the harmonic number the result is checked to approach as close as can be expected an integer.

Typical for YIG filters is the appearance of spurious peaks, much lower in amplitude than the main peak. Their level decreases in accordance with the main peak. To distinguish between spurious and main peaks the CPU is informed about the peak level. This information is deduced from the ALC.

Results

A single stage YIG filter has been designed. Provided with a step recovery diode and a detection diode in standard mounts, it was possible to measure magnetic fields upto 6 Kgauss. Over this frequency range the YIG filter isolation is better than 20 db, the insertion loss is less than 10 db and the bandwidth is typical 10 MHz. These features together with sufficient drive for the pre-amplifier enable 10^{-4} resolution for resonance frequency determination. The deviations of γ depending on the magnetic field showed to be within 10^{-3}. So without γ correction the accuracy of the field measurement would not be better than 10^{-3}. With correction by means of ROM memory this can be improved to at least 10^{-4}.

The YIG filter is formed by two coaxial lines coupled to the YIG ball by half circle coupling loops. Polycrystalline YIG balls have been used, because the YIG ball position is then indifferent with respect to the magnetic field direction. For extension to higher magnetic fields the YIG filter must be improved. Also the step recovery and detection diode in standard mounts are unsuitable for these higher frequencies. Probably the solution will be the integration of the three probe components in one probe by thin film techniques.

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