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(Revision of IEEE Std 1027-1984)

IEEE Standard Method for Measurement of the Magnetic Field in the Vicinity of a Telephone Receiver

Sponsor

Transmission and Access Systems Committee of the IEEE Communications Society

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Abstract: The methodology for measuring the magnetic field strength in the vicinity of a telephone receiver is described.
Keywords: magnetic field, telephone receiver

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Introduction

(This introduction is not a part of IEEE Std 1027-1996, IEEE Standard Method for Measurement of the Magnetic Field in the Vicinity of a Telephone Receiver.)

This standard replaces IEEE Std 1027-1984, IEEE Trial-Use Standard Method for Measuring the Magnetic Field Intensity Around a Telephone Receiver. Comments on this standard and suggestions for the additional material should be addressed to: Secretary, IEEE Standards Board, The Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08855.

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IEEE Standard Method for Measurement of the Magnetic Field in the Vicinity of a Telephone Receiver

1. Overview

This standard describes the methodology for measuring the magnetic field strength in the vicinity of a telephone receiver.

Recommended test equipment, including probe coils and test circuits, are described in clause 4. Magnetic field probe calibration is outlined in clause 5. Test procedures are described in clause 6. Annex A describes a suitable integrator circuit for linearizing the probe coil output voltage. Annex B gives the derivation of the relationship between the electrical output of the probe coil and the magnetic field strength. Annex C illustrates a method of generating a known magnetic field using Helmholtz coils.

1.1 Scope

Magnetic fields of analog and digital telephone receivers, as well as non-traditional telephone receivers, such as wireless devices, may be objectively measured using this standard. Receivers not connected to a telephone may be evaluated as well. Measurement of static fields, such as those created by permanent magnets, is not covered.

The methodology described in this standard is suitable for measurements in the range of 100 Hz to 10 000 Hz.

1.2 Purpose

The impetus for this work was derived from a need to specify the alternating magnetic field at selected locations around a telephone receiver required for satisfactory inductive coupling to hearing aids. It is also useful for other applications where knowledge of the magnetic field strength is required.

The results, thus obtained, may be used to evaluate or specify the magnetic field strength produced by a receiver on a standardized basis.

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The accuracy and reproducibility of measurements made in accordance with this standard will depend primarily upon the accuracy of the test equipment used, the care with which the measurements are conducted, and the inherent stability of the telephone or transducers, or both, under test.

Where a given set of measurements is repeated in the same laboratory and by the same operator, a relatively high degree of reproducibility should be obtained. When comparing measurements made by different laboratories, however, allowances should be made for the influencing factors mentioned above.

2. References

This standard should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply, but the impact on results should be determined.

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[1]

IEEE Std 269-1992, IEEE Standard Methods for Measuring Transmission Performance of Analog and Digital Telephone Sets (ANSI).

IEEE Std 1206-1994, IEEE Standard Methods for Measuring Transmission Performance of Telephone Handsets and Headsets (ANSI).

ITU-T Recommendation P.37-1993, Magnetic Field Strength around the Earcap of Telephone Handsets which Provide for Coupling to Hearing Aids.[2]

ITU-T Recommendation P.57-1993, Artificial Ears.

3. Definitions

3.1 ear reference point (ERP): The intersection of the receiver ear-cap axis with the external ear-cap plane (planar area containing points of the receiver-end of the handset which, in normal handset use, rest against the ear) as shown in figure 1.

3.2 frequency response: The ratio of the magnitude of the system output to the magnitude of the stimulus over a specified frequency range.

3.3 Helmholtz coils: A pair of coils so proportioned as to provide a known uniform magnetic field that may be used to calibrate a probe coil.

3.4 integrator: A device having an output proportional to the time integral of the input signal.

3.5 magnetic field strength: The magnitude of a time-varying magnetic field, that, when coupled to a coil, induces a voltage. The unit of magnetic field strength is amperes per meter (A/m).

3.6 probe coil: A coil (air or magnetic material core) used to sense an alternating magnetic field.

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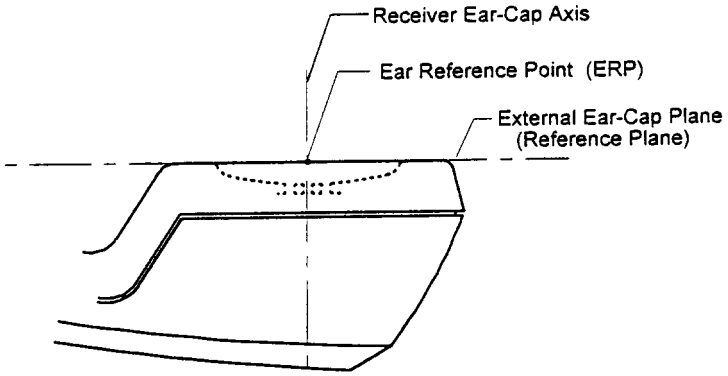


Figure 1—Ear reference point

4. Test equipment

4.1 General

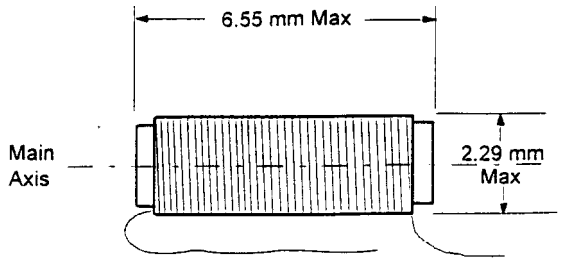
This subclause describes the requirements of equipment unique to evaluating a receiver's magnetic field strength. The extremely low-voltage levels and high impedances involved with the measurements require that special care be given to equipment selection and equipment cabling. For additional information concerning test equipment, refer to IEEE Std 269-1992 and IEEE Std 1206-1994.[3]

4.2 Probe coils

In place of the artificial ear microphone transducer, normally used in receiver testing, either of the following probe coils may be used to pick up the magnetic field generated by a typical receiver.

4.2.1 Coil with magnetic material core

A small coil with magnetic core material should be used where high sensitivity is required. The core material should be chosen to minimize the loss at frequencies up to 10 000 Hz. Individual calibration of the sensitivity vs. frequency characteristics of such a coil shall be performed as described in clause 5. A coil representative of this type is shown in figure 2. These dimensions shall be adhered to so as to assure consistency of measurement.



Resistance = 900 Ω
Wire size = 51 AWG
Inductance = 140 mH at 1000 Hz
Sensitivity ≈ -60.5 dB V/(A/m) at 1000 Hz

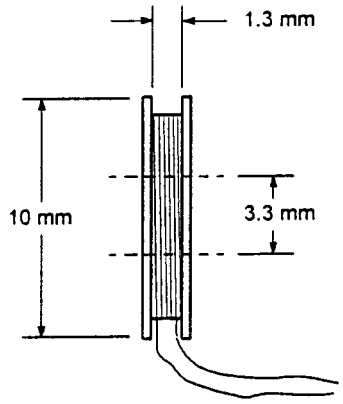
Figure 2—Probe coil with magnetic material core

[3]Information on references can be found in clause 2.

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4.2.2 Air-core coil

A small air-core type coil may be used for measurements where minimum disturbance of the field to be measured is important. An example of such a coil design is shown in figure 3.



Inside Diameter = 3.3 mm
Length = 1.3 mm
Coil = 2000 Turns of AWG No. 50
Polyurethane insulated copper wire

Figure 3—Air-core probe coil

4.3 Integrator

The electrical output voltage from the probe coil is proportional to the time derivative of the magnetic field strength. (Derivation of the relationship between the electrical output of the probe coil and the magnetic field strength is shown in annex B.) The probe coil output voltage exhibits a 6 dB per octave (20 dB per decade) rise with frequency for a constant magnetic field strength. It may be desirable to integrate this output voltage to determine the magnitude of the magnetic field strength as a function of frequencies other than 1000 Hz, where the coil is calibrated.

An integrator circuit suitable for a frequency range from 100 Hz to 10 000 Hz is shown in annex A.

An alternative to electrical integration is to compensate for the 6 dB per octave rise in the probe coil response by post-processing using equation 2 of clause 5.1.

4.4 AC measuring device

The measuring device should be a root-mean-square (rms) voltmeter (or equivalent, such as a spectrum analyzer) capable of measuring levels from 0 to –110 dB V. The error limit should be within ± 0.5 dB for inputs with a crest factor up to 5:1 over the frequency range of 100 Hz to 10 000 Hz. The ac input impedance shall be at least 1 MΩ due to the high impedance of the probe coil.

If the measuring device is not sensitive enough it may be necessary to amplify the probe voltage output prior to the measuring device. This amplifier shall meet the input impedance and linearity requirements of the measuring device described above.

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4.5 Tracking filter

The output voltage from the probe coil is extremely low and the coils are very sensitive to stray fields. Use of a tracking filter or other frequency selective device is recommended.

4.6 Artificial ear

An artificial ear consists of a calibrated microphone and an acoustic coupler, which has an acoustic impedance similar to that of an average human ear over a given frequency band.

Refer to IEEE Std 1206-1994 and ITU Recommendation P.57-1993 for information on artificial ears.

4.7 Standard test circuits

Figure 4 shows the basic block diagram of a generic test circuit with the probe coil. Standard test circuits for analog or digital telephones measured with sinusoidal or wide band test signals are shown in IEEE Std 269-1992 figures 5B, 6B, 12B, and 13B. Refer to figure 1 of IEEE Std 269-1992 for suitable feed circuits for traditional telephones. Figure 3 of IEEE Std 1206-1994 illustrates a drive circuit for testing the handset as a discrete component.

The type of interface and feed circuits should be noted.

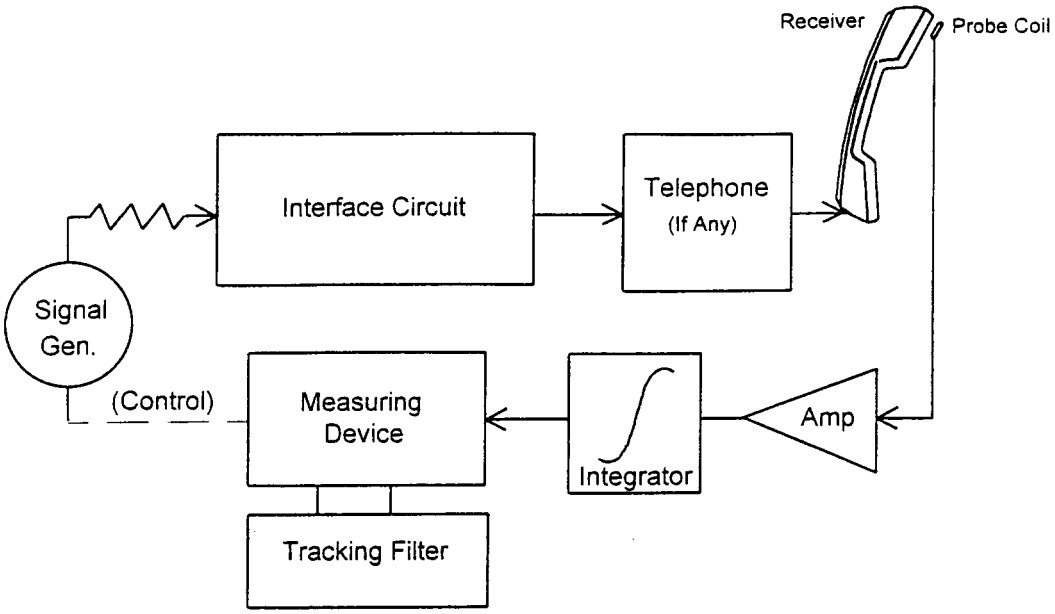


Figure 4—Generic test circuit

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5. Probe coil calibration

5.1 Sensitivity

It is possible to calculate the probe coil sensitivity from equation B.6 in annex B. However, for practical multi-layer coils, and certainly for coils with magnetic material cores, better accuracy can be expected by inserting the coil in a known magnetic field and measuring the output.

One way of establishing a known magnetic field is to use a pair of Helmholtz calibration coils as shown in annex C.

Metal parts, including fixtures for holding the probe coil, should not be near the Helmholtz coils during calibration. Connection to the probe coil should be made by twisted leads or a thin shielded wire. The Helmholtz coils should not be located near sources of magnetic fields such as transformers.

To calibrate, establish a known magnetic field at the center of the Helmholtz coils. A constant current should be maintained to the Helmholtz coils at all frequencies of measurement. Insert the probe coil in the field and align its main axis with the field by adjusting its position for maximum output. The coil sensitivity can then be determined at any frequency by using equation 1.

$$P(f) = 20 \log [V_p(f) / H_c] \quad (1)$$

where

$P(f)$ is the probe coil sensitivity vs. frequency in dB V/(A/m).
$V_p(f)$ is the output voltage of the probe coil in volts.
H_c is the magnetic field strength generated by the Helmholtz coils in amperes per meter (A/m).

$P(1000)$, the probe coil sensitivity at 1000 Hz, should be measured first.

The probe coil sensitivity ideally increases at a rate of 6 dB per octave with increasing frequency as expressed in equation 2 as follows:

$$P(f) = P(1000) + 20 \log(f / 1000 \text{ Hz}) \quad (2)$$

where

$P(1000)$ is the probe sensitivity at 1000 Hz in dB V/(A/m).
f is the frequency in hertz.

The sensitivity shall not deviate from this characteristic by more than ± 0.5 dB, as illustrated in figure 5.

5.2 Linearity

To check the system for amplitude linearity, vary the current through the Helmholtz coils to establish fields from –50 dB to 0 dB relative to 1 A/m in 10 dB steps. Check that the output varies in corresponding 10 dB steps ±0.5 dB.

5.3 Signal-to-noise ratio of the calibration system

Set the current in the Helmholtz coils to create a field of –50 dB relative to 1 A/m. Note the output reading of the probe coil. Turn off the current to the Helmholtz coils and ensure that the output drops at least 10 dB.

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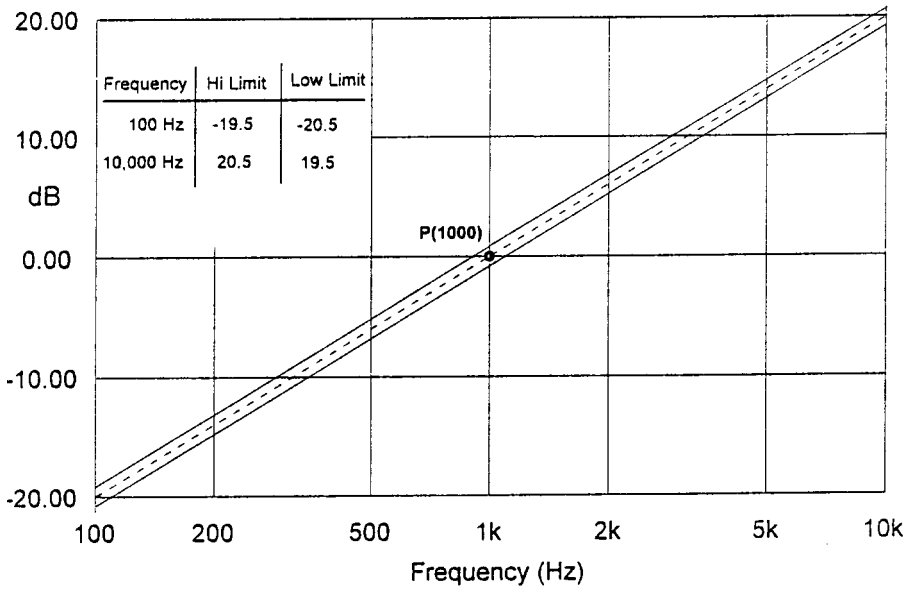


Figure 5—Probe coil sensitivity tolerance mask relative to sensitivity at 1000 Hz

6. Test procedure

6.1 General

Procedures are given in the following subclauses for measuring the magnetic field strength, frequency response, magnitude and direction, and distortion of the magnetic field. Refer to the standards that apply to the type of unit being tested for the proper receive test setup.

Magnetic field characteristics are affected by the test loop impedance, termination, loop current, and operating levels. The measurements should be made under test loop and level conditions representative of those conditions the receiver unit is expected to encounter in use. Records should be kept of parameters used in all measurements.

The measuring coil and associated cabling should not be located near magnetic fields. In addition, the room environment should be free of audible noises that may affect the measurements.

6.2 Conditioning of carbon transmitters

In telephone sets equipped with carbon transmitters, the resistance of the carbon transmitter may influence the receive sensitivity of the set. It is therefore necessary to follow a consistent procedure when testing telephone sets equipped with carbon transmitters. Refer to IEEE Std 269-1992, clause 6.1.1, for proper conditioning procedures.

NOTE—It may be satisfactory to replace the carbon transmitter with a resistor of the proper value when making the magnetic field measurements. In that case, the conditioning procedure described in IEEE Std 269-1992 does not apply.

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6.3 Receiver acoustic termination

Magnetic field measurements may be influenced by whether the receiver is sealed or unsealed. This effect will vary with frequency but is generally negligible.

6.4 Magnetic field measurement

6.4.1 Test circuits

Connect the telephone handset or headset to the appropriate circuit referred to in 4.7. For analog telephone sets connected to the switched network, magnetic field strength vs. frequency is dependent on the loop to which the telephone set is connected. Refer to the applicable performance specification, if any, for specific test loop requirements. Alternatively, IEEE Std 269-1992, 5.19, recommends a test loop to be used in testing analog telephones.

6.4.2 Test level

The test level should be determined by one of the two methods described in 6.4.2.1 and 6.4.2.2. The level and method used should be noted.

Special consideration should be given to test levels where passive or active limiting is present, such as varistors or automatic gain control (AGC). A volume control may also affect the measurement so its setting should be noted.

6.4.2.1 Preferred method—Specific sound pressure

The sound pressure method requires that the input voltage be set to produce a specified sound pressure level in an artificial ear. For a sinusoidal test signal, the drive level should be adjusted to produce a sound pressure level of –14 dB Pa in the artificial ear at 1000 Hz. For a continuous spectrum test signal, adjust the input voltage to produce –22 dB Pa total sound pressure in the artificial ear across the band from 100 Hz to 10 000 Hz. These levels are consistent with ITU Recommendation P.37-1993, but higher levels may be required if noise pickup is a problem.

This drive level shall be used for measuring the magnetic field strength at all frequencies.

6.4.2.2 Alternative method—Constant electrical input

An alternative method requires the use of a specific electrical input when measuring the magnetic field strength. For a sinusoidal signal, an open-circuit voltage of 0.316 V (–10 dB relative to 1 V) from a 900 Ω source is recommended for traditional analog telephones. The recommendation for a continuous spectrum test signal is –18 dB V open circuit across the frequency band 100 Hz to 10 000 Hz. Refer to IEEE Std 1206-1994, 5.3.1, for recommended drive levels for handsets and headsets tested as discrete components.

NOTE—The recommended voltage drive levels in this subclause will produce a sound pressure level of approximately –4 dB Pa in a nominal North American telephone.

6.4.3 Probe coil position and orientation

Generally the probe orientation is either axial (probe coil axis is parallel to the receiver earcap axis) or radial (probe coil axis is perpendicular to the earcap axis). It may be desirable to establish a plane of measurement 10 mm in front of, and parallel to, the receiver earcap plane as shown in figure 1. The position and orientation of the probe coil used should be stated for all measurements.

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There is a general industry trend toward smaller receivers, with the result that the radiating magnetic field approximates that of a point source. The magnetic field radiating from a magnetic point source may fall off rapidly with increasing distance. As a result, placement of the probe coil may be critical.

6.4.4 Signal-to-noise ratio of test system

The measured field strength due to noise in the test system should be at least 10 dB below the lowest signal to be measured. Place the probe coil and receiver in the position to be used for receiver field strength measurements. Turn off the test signal and measure the remaining field strength in the same way and over the same frequency range used for receiver measurements.

6.4.5 Magnetic field strength

The magnetic field strength may be measured over a band of frequencies. (Some performance specifications use the probe coil output *V*p(*f*) directly, rather than the magnetic field strength.) The result is reported in dB relative to 1 ampere per meter (A/m).

The probe coil produces an electrical signal that is measured in dB relative to 1 V (dB V). This voltage is converted to magnetic field strength units by the use of equation 3 as follows:

$$H_r(f) = V_p(f) - P(f) \tag{3}$$

where

$H_r(f)$ is the receiver magnetic field strength at frequency (f) in dB A/m
$V_p(f)$ is the output voltage of the probe coil at frequency (f) in dB V
$P(f)$ is the probe sensitivity at frequency (f) in dB V/(A/m)

For example, the typical sensitivity of a probe is –60.5 dB V/(A/m) at 1000 Hz. Therefore, a reading of –80 dB V would indicate a magnetic field strength of: –80 dB V – [–60.5 dB V/(A/m)] = –19.5 dB A/m.

If only $P(1000)$ is known, $P(f)$ can be obtained through the use of equation 2.

If an integrator circuit is used, then $P(f)$ represents the sensitivity of the probe coil plus the integrator, therefore, $P(f) = P(1000)$.

6.4.6 Frequency response

Frequency response is the ratio of the magnitude of the magnetic field strength to the magnitude of the stimulus measured over a band of frequencies. Generally the stimulus is a voltage; therefore, the response is expressed in dB relative to 1 A per meter per volt, dB (A/m)/V.

The voltage reference point in the system used for calculation may be the same as is used for objective loudness calculations, although the voltage level may differ. Refer to IEEE Std 269-1992 for guidance on traditional analog and digital telephones. Other points of reference in the system may be used. The voltage used should be well defined as to its location in the system, its amplitude, and whether it is measured as an open or closed circuit. These conditions should be noted.

6.4.7 Magnitude and direction

To map the magnetic field, the three-dimensional magnetic field strength vectors should be determined at selected points in the vicinity of the receiver unit. This may be accomplished by placing the physical center of the probe coil at the point of interest and measuring the field in three mutually perpendicular directions by

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turning the probe coil. For traditional telephone receivers, the ERP is the reference point as shown in figure 1. If the ERP is not used, then the reference point should be clearly specified. The field magnitude and direction can then be established through vector addition.

Since there is an uncertainty of 180° in the vector measurements as described above, it will be necessary to use an oscilloscope or a phase meter to establish the “sense” of the field in each of the three directions.

Looking for symmetry in the field can usually save considerable measurement effort. As an example, many receiver units have fields that are symmetrical around an axis through the unit, so that after measuring the field in a plane along a radius, rotating this plane through 360° about the axis will completely map the field. The location and number of measurement points will depend on the purpose of the measurement.

6.4.8 Distortion

Harmonic distortion in the output is characterized by the appearance of harmonics of the fundamental frequency when the input signal is sinusoidal. Harmonic distortion may be measured using any of the standard methods described in IEEE Std 269-1992, 6.3.5. Special precautions may be required to measure distortion due to the low signal levels involved.

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Annex A

Integrator

(normative)

The circuit shown below implements an integrator suitable for use in converting the probe coil output voltage to a voltage proportional to the magnetic field strength as a function of frequency.

Gain = 1 / (R1 × C2ω)

For w = 2π × (1000 Hz), GAIN ≈1 (0 dB)

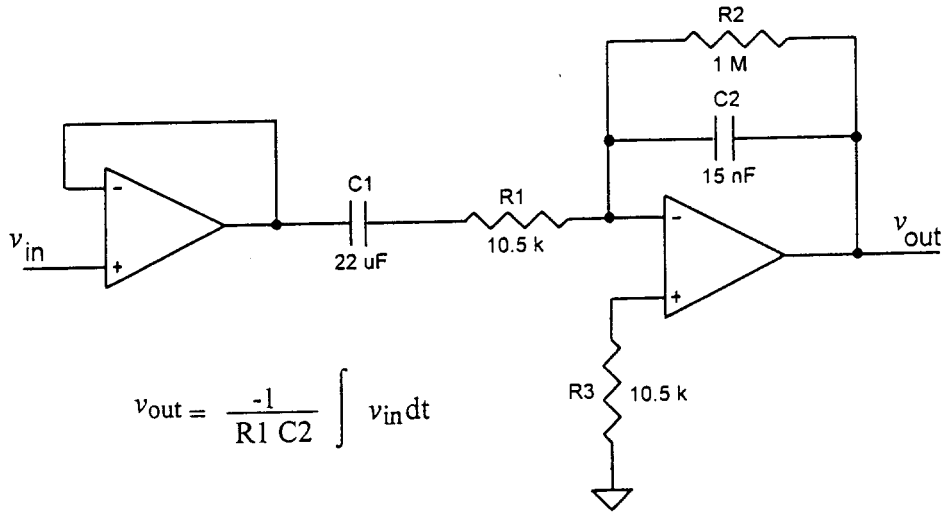


Figure A.1—Integrator

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Annex B

Coil output voltage derivation

(normative)

For a magnetic field strength of H amperes per meter, the magnetic flux density is

$$B = \mu H \text{ [Webers/m}^2\text{]} \tag{B.1}$$

where

μ is $4\pi 10^{-7}$ henry per meter, which equals the permeability of free space

For a coil of area S, the magnetic flux through the coil is

ϕ is B × S [Wb] (B.2)

Faraday's Law states that the electrical output from a coil placed perpendicularly to a varying field is:

$$v = N\, d\phi/dt \quad \text{[volts]} \tag{B.3}$$

where

N is the number of turns on the coil

Combining equations B.1, B.2, and B.3 for a coil placed perpendicular to the field gives

$$v = N\, \mu S\, dH/dt \text{ [volts]} \tag{B.4}$$

For a sinusoidally varying magnetic field, the magnetic field strength is

$$H = \hat{H} \sin(\omega t) \text{[A/m]} \tag{B.5}$$

where

$\hat{H}$ is the peak amplitude of the field, so

dH/dt *is* $\hat{H}\,\omega\cos(\omega t)$

Therefore, the electrical output from a coil placed perpendicular to a sinusoidal field of H amperes per meter is

$$v = N\mu S\omega\hat{H}\cos(\omega t), \text{ [volts]} \tag{B.6}$$

Equation B.6 shows that the output is proportional to ω, that is, proportional to frequency.

In order to plot magnetic field strength vs. frequency, it is desirable to have the probe coil followed by an integrator. The resulting output voltage from the integrator is proportional to the magnetic field strength and independent of frequency. An integrator suitable for use over the frequency range of 100 Hz to 10 000 Hz is shown in annex A.

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Annex C

Generation of a known magnetic field using Helmholtz coils

(normative)

Helmholtz coils consist of a pair of identical coils wound in series-aiding fashion, coaxially aligned and spaced a distance apart equal to their radius. The magnetic field at the center of such a pair of coils is axially directed with a strength given by [B1][4] as follows:

$$H_c = \frac{8NI}{r\sqrt{125}} \quad [\text{A/m}] \tag{C.1}$$

where

H_c is the magnetic field strength in amperes per meter
N is the number of turns per coil
I is the current in amperes
r is the coil radius in meters

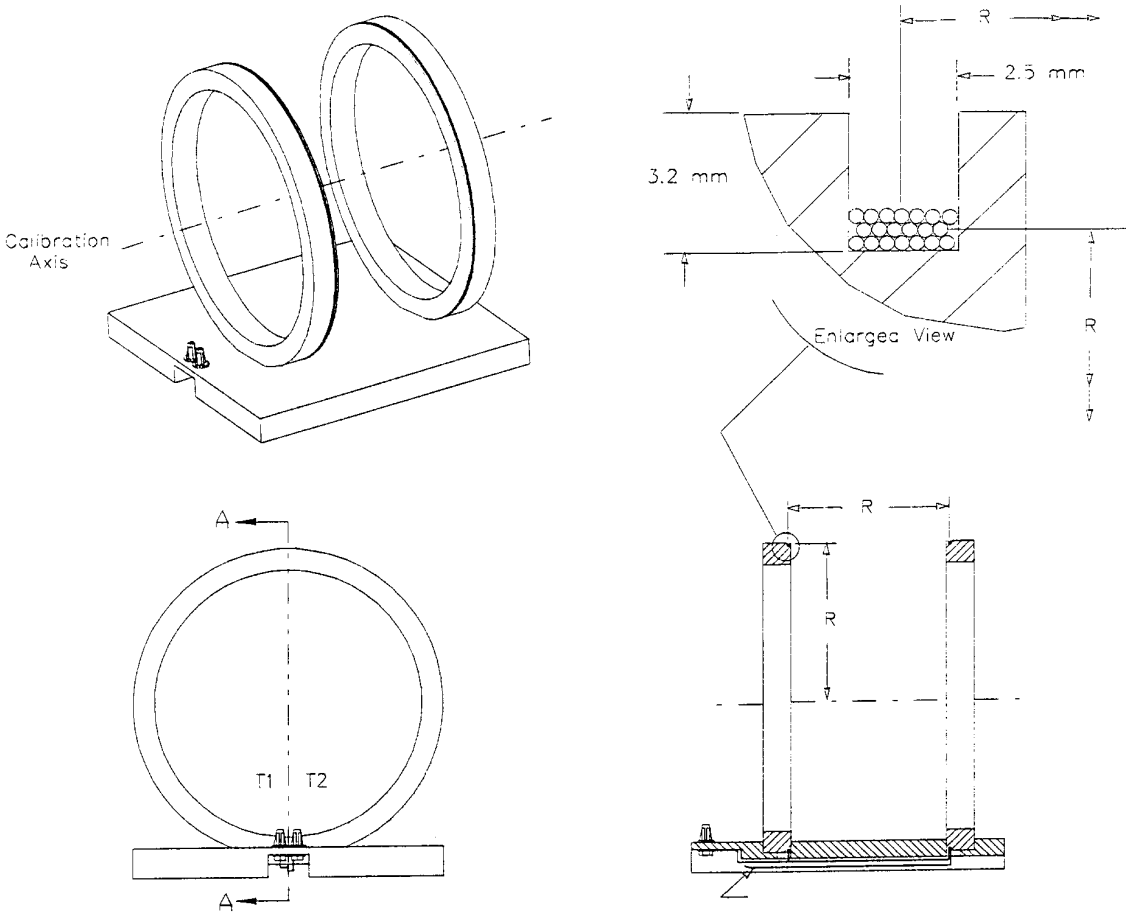
The above equation assumes that all the turns on each coil can be considered to lie in the same place and have the same radius.

The construction of a Helmholtz coil pair suitable for calibrating magnetic probe coils is shown in figure C.1. The coil parameters are such that the magnetic field strength is numerically equal to 100 times the current flowing through the coils. Thus, if a 100 Ω resistor is used to sense the current flow, the magnetic field strength is numerically equal to the voltage across this sensing resistor.

Nonmetallic materials should be used to construct the coil forms, base, and any supporting structure for locating probe coils that are to be calibrated. The method shown in figure C.1 of interconnecting the coils and bringing out the leads to binding posts on the end of the base minimizes any disturbing effects on the desired magnetic field.

[4]The number in brackets corresponds to that of the bibliography in annex D.

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R = 143 mm
N = 20 Turns, AWG No 24 Enameled Magnet Wire, Per Coil

Figure C.1—Helmholtz coils

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Annex D

(informative)

Bibliography

[B1] Winch, R. P., *Electricity and Magnetism,* Prentice-Hall, Englewood Cliffs, NJ, 1967, pp. 504–508.

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