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Technical report

Patrik Appelgren, Cecilia Nylander, Sten E Nyholm

Magnetic field measurement system for microwave frequencies

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Report title

Magnetic field measurement system for microwave frequencies

Abstract

This report describes a magnetic field measurement system used to characterize radiation sources at microwave frequencies in HPM research at FOI Weapons and protection. The measurement system consists of commercial components and is intended to be used as a reference when developing in-house made field probes and baluns.

Keywords

Magnetic field, measurement system, B-dot probe, pulsed microwave, HPM

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Rapportens titel (i översättning)

Mätsystem för magnetfältskomponenter vid mikrovågsfrekvenser

Sammanfattning (högst 200 ord)

Rapporten beskriver det system för mätning av magnetisk fältstyrka som används för karakterisering av strålkällor vid mikrovågsfrekvenser inom HPM-forskningen vid FOI Vapen och skydd. Mätsystemet består av kommersiella komponenter och är avsett att användas som referenssystem vid utveckling av egna fältprober och baluner.

Nyckelord

Magnetfält, mätsystem, B-dot prob, pulsad mikrovåg, HPM

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Notation

Symbol	Quantity	Unit
a, d, l	Linear dimensions	m
A_{eq}	Equivalent area	m^2
$\boldsymbol{B}$	Magnetic flux density	T
f	Frequency	Hz
$\boldsymbol{H}$	Magnetic field	A/m
L	Inductance	H
R	Resistance	Ω
t	Time	s
V	Voltage	V
X	Reactance	Ω
Z	Impedance	Ω
μ	Permeability	H/m
θ	Angle	radians

1. Introduction

To evaluate the properties and potential of warheads emitting high-power microwaves (HPM), the measurement of the electric and magnetic field components is fundamental. The measurement of HPM radiation poses special problems, since the radiation has a pulsed character, short duration, often a very high peak power, and can span a large frequency range. Hence, common commercial equipment for measuring continuous radiation is of limited use. Instead, sensors adapted for measuring transient signals, i.e. single radiation pulses, and with a wide spectral sensitivity must be used.

Often the radiation from a source can have a complex radiation pattern with several modes present. For a complete picture a large number of detectors are needed for measuring both the electric and the magnetic field components. This report describes a magnetic field measurement system based on commercial components. It can be used as a reference for relative calibration of simpler radiation measurement systems.

2. Magnetic field sensors

2.1. Single strand loops

Magnetic field sensors known as B-dot sensors or B-dot probes consist of a loop of conducting material [1,2,3]. The name B-dot is due to the mathematical dot-notation for the time derivative, $\dot{B} = \partial B / \partial t$, operating on the magnetic flux density $B = \mu_0 H$. The loops considered here are electrically small with a circumference less than one tenth of the measured wavelength. When a plane electromagnetic wave is incident on a loop, as shown in figure 1, an open-circuit voltage V_0 develops across the loop terminals, denoted 1 and 2 in figure 1. The induced voltage is proportional to the area encircled and to the time derivative of the magnetic field according to

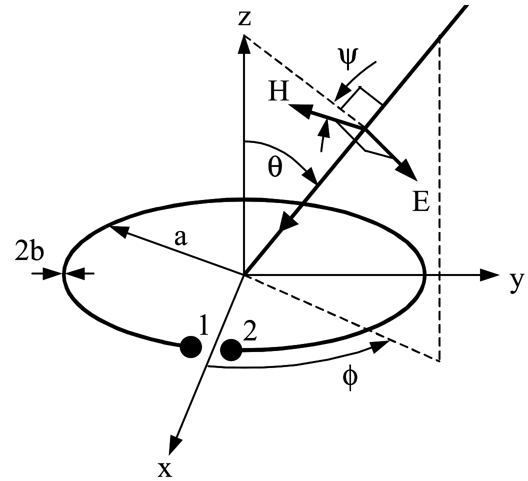

Figure 1. Plane wave incident on a loop.

$$V_0(t) = \vec{A}_{eq} \cdot \mu_0 \frac{d\overline{H(t)}}{dt} . \qquad (1)$$

Assuming a circular loop of radius a, we can rewrite Eq.(1) as

$$V_0(t) = \pi a^2 \cdot \mu_0 \frac{dH(t)}{dt} \cos(\psi) \sin(\theta) . \qquad (2)$$

A circuit containing a loop to detect the magnetic field must be terminated by a load over which the voltage can be measured by an oscilloscope or corresponding equipment. Figure 2 shows an equivalent circuit where Z_{in} is the input impedance of the loop and Z_{load} is the load impedance.

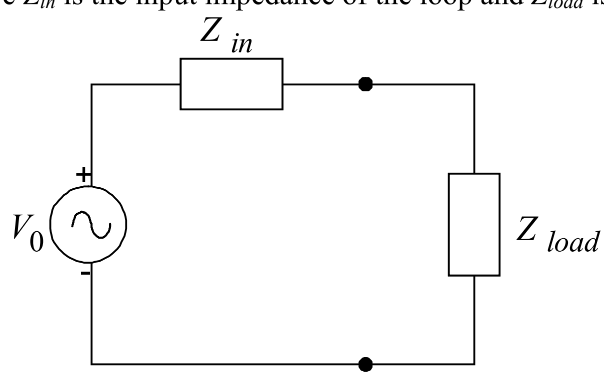

Figure 2. Equivalent circuit of B-dot sensor.

The voltage across the load is given by voltage division of the open-circuit voltage according to

$$V_{load}(f) = V_0(f) \cdot \frac{Z_{load}(f)}{Z_{in}(f) + Z_{load}(f)} . \qquad (3)$$

The input impedance Z_{in} is the sum of the antenna resistance and the antenna reactance. The antenna resistance is the sum of the radiation resistance, R_r, and the loss resistance, R_L, while the reactive losses is the sum of the inductive reactance of the loop, X_A, and the reactance of the loop conductor X_i. Eq.(3) can be expressed as

$$V_{load}(f) = V_0(f) \cdot \frac{Z_{load}(f)}{R_r + R_L + Z_{load}(f) + j\left(X_A(f) + X_i(f)\right)} . \qquad (4)$$

For a B-dot loop sensor of a size much smaller then the measured wavelength and terminated by a 50 Ω impedance, the main loss can be shown to be inductive, cf. e.g. Balanis [3]. This is exemplified by figure 3 which shows the ratio V_{load} / V_0 for different total loop inductances ignoring resistive losses in the sensor and having a purely resistive 50 Ω termination.

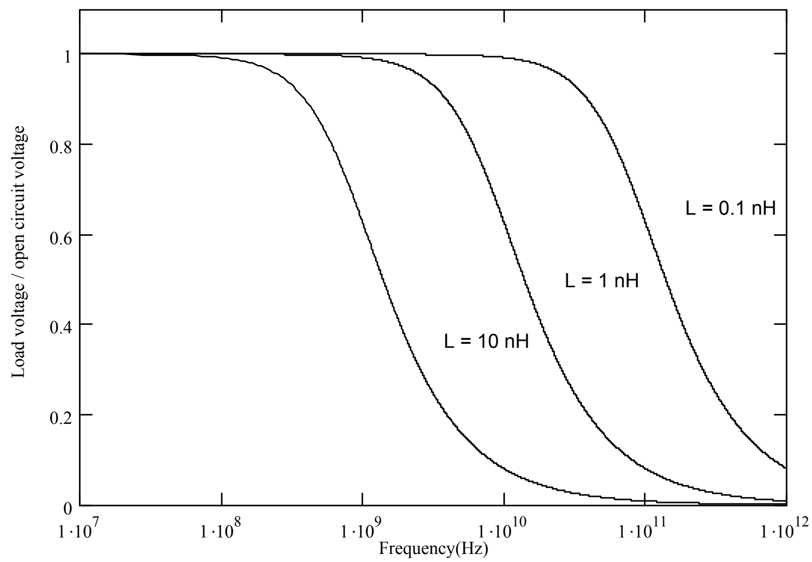

Figure 3. Reactive losses for different inductances.

In case the frequency of the field measured is so low that inductive losses can be ignored ($X_{tot}/R_{load} << 1$) the load voltage is equal to the open circuit voltage. This is the differentiating mode of the sensor. The magnetic field component normal to the loop is then obtained by integration of the load voltage signal

$$H(t) = \frac{\int V_{load}(t)dt}{\mu_0 \cdot A_{eq}}, \tag{5}$$

which for a sinusoidal voltage signal of frequency f_0 is written

$$H(t) = \frac{V_{load}(t)}{2\pi f_0 \cdot \mu_0 \cdot A_{eq}}. \tag{6}$$

At higher frequencies ($X_{tot}/R_{load} >> 1$) the sensor operates in its self integrating mode. The magnetic field is then proportional to the voltage signal

$$H(t) = \frac{V_{load}(t)}{\mu_0 \cdot A_{eq}} \cdot \frac{L_{tot}}{R_{load}}. \tag{7}$$

Between these pure modes the sensor operates in its transitional mode ($X_{tot}/R_{load} \cong 1$) and the magnetic field is obtained by

$$H(t) = \frac{V_{load}(t)}{2\pi f_0 \cdot \mu_0 \cdot A_{eq}} \cdot \sqrt{\left(\frac{2\pi f_0 \cdot L_{tot}}{R_{load}}\right)^2 + 1}. \tag{8}$$

2.2. Cylindrical loops

To avoid having a large inductive signal loss in a loop sensor the inductance can be reduced by extending the loop in its axial direction and form a cylinder [5,6]. The inductance of a very long cylinder, considered as a solenoid with a small thickness is given by [5]:

$$L_{cyl} = \mu_0 \frac{\pi a^2}{l} \tag{9}$$

where l is the length of the cylinder and a is the radius. For shorter coils and coils of not negligible thickness, Eq.(9) is multiplied with a correction factor K_L [7]. The correction factor is a function of length to diameter ratio and outer/inner radius ratio. The ratio *b/a* in figure 4 (from Knoepfel [7]) is the ratio between the outer radius of the solenoid and the inner radius of the solenoid. The ratio *h/2a* in figure 4 is the length to inner diameter ratio of the solenoid.

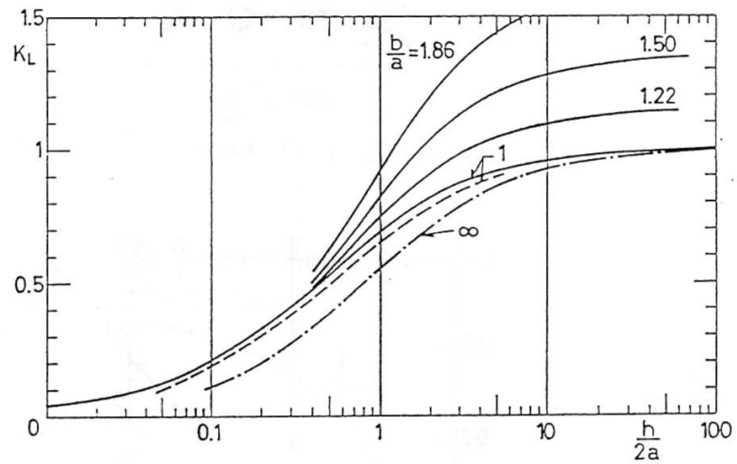

Fig. A1.10. The inductance correction factor K_L for various solenoids; the continuous curves refer to constant current density, the broken lines to the current distribution as determined by potential theory (see Fig. A1.9).

Figure 4. The inductance correction factor K_L for various solenoids [7].

By requiring the cylindrical sensor to have time constant τ, or an upper 3 dB frequency f_{3dB}, a condition for the inductance is obtained:

$$L_{cyl} = R_{load} \cdot \tau = R_{load} \frac{1}{2\pi \cdot f_{3dB}}. \tag{10}$$

Introducing a correction factor K_L into Eq.(9) and combining with Eq.(10) gives the expression

$$\mu_0 \frac{\pi a^2}{l} K_L = R_{load} \cdot \tau = R_{load} \frac{1}{2\pi \cdot f_{3dB}} \tag{11}$$

The response of the loop itself is limited by the rise time, given by

$$t_r = \frac{2\pi a}{c} \tag{12}$$

and represents the time it takes for an electromagnetic wave to travel around the loop. This means that the loop itself has a maximum frequency response given by Eq.(24). An optimum situation would be if the maximum frequency of the loop based on transit time and the frequency limitation of the inductance and termination were equal. Combining Eq.(11) with Eq.(24) the expression

$$\mu_0 \frac{\pi a^2}{l} K_L = R_{load} \frac{1}{2\pi \cdot \sqrt{2}\,\frac{1}{4t_r}} = R_{load} \frac{4a}{\sqrt{2}c} \tag{13}$$

is obtained, reducing to

$$\frac{a}{l} = \frac{4 \cdot R_{load}}{K_L \mu_0 c \pi \sqrt{2}}, \tag{14}$$

or

$$\frac{l}{a} = \frac{K_L \mu_0 c \pi \sqrt{2}}{4 \cdot R_{load}}. \tag{15}$$

A 50 Ω transmission line matching (R_{load} = 50 Ω) and a correction factor $K_L = 0.9$ gives a ratio $l/a \approx 7.5$ or $l/2a \approx 3.8$, assuming a negligible thickness of the solenoid.

The time response given by Eq.(12) assumes that the signal is introduced at the centre of the cylinder axis. This means that the transit time for a signal is longer if introduced at the farthest point of the cylinder, i.e. at one end of the cylinder. The transit time for that signal would be

$$t_r = \frac{2}{c}\sqrt{(\pi a)^2 + \left(\frac{l}{2}\right)^2}, \tag{16}$$

which for $l = 0$ is the same relation as Eq.(12). The high frequency limit would depend on the cylinder radius and length by

$$f_{\max} = \sqrt{2}\frac{1}{4t_r} = \frac{\sqrt{2}}{4 \cdot \frac{2}{c}\sqrt{(\pi a)^2 + \left(\frac{l}{2}\right)^2}} \tag{17}$$

Combining Eq.(11) and Eq.(16) gives a more accurate condition for the size of the sensor given either radius or length.

$$\mu_0 \frac{\pi a^2}{l} K_L = R_{load} \frac{4 \cdot \sqrt{(\pi a)^2 + \left(\frac{l}{2}\right)^2}}{\pi \cdot \sqrt{2} \cdot c} \tag{18}$$

Solving for the ratio l/a gives

$$\frac{l}{a} = \sqrt{2}\pi \sqrt{\sqrt{1 + \frac{{\mu_0}^2 c^2 {K_L}^2}{8{R_{load}}^2}} - 1} \tag{19}$$

The l/a ratio is 6.038 for a 50 Ω load when the transit time for a cylinder is accounted for. From figure 4 an outer radius of 1.22a of the cylinder would be required to have a $K_L = 1$ at $l/a = 6.038$. An inner radius of 2 mm requires an outer radius of 2.44 mm.

2.3. Bandwidth of a B-dot sensor

The bandwidth of a sensor is defined as the frequency at which the measured output voltage has dropped 3 dB (i.e. halved) compared to the open circuit voltage. Using the differentiating mode or self integrating mode expressions the error would be 29.3% at this frequency. For the B-dot sensor the 3 dB limit is obtained when

$$f_{3dB} = \frac{R_{load}}{2\pi \cdot L_{tot}} \qquad (20)$$

where R_{load} is the terminating resistance and L_{tot} is the total loop inductance. Eq.(20) corresponds to a time constant τ of the sensor according to

$$\tau = \frac{L_{tot}}{R_{load}} = \frac{1}{2\pi \cdot f_{3dB}} \qquad (21)$$

2.4. Rise time and frequency limits

The equivalent frequency of a signal corresponds to a rise time of the signal [2,4]. For a continuous wave the frequency f_{CW}, period time T, and rise time t_r (0 – 100%) relate according to

$$f_{CW} = \frac{1}{T} = \frac{1}{4t_r} \qquad (22)$$

For a double exponential pulse the equivalent frequency f_P relates to the rise time t_r according to

$$f_P = \frac{1}{4t_r} \qquad (23)$$

where t_r is the 10 to 90 % rise time of the double exponential pulse. A sensor required to have a fastest rise time t_r has a 3 dB frequency limit estimated by [2,4]

$$f_{3dB} = \sqrt{2}\frac{1}{4t_r} = \frac{0.35}{t_r} \qquad (24)$$

3. Commercial sensor Prodyn B-24

The commercial B-dot sensor used is a Prodyn B-24 (serial number 54), shown in figures 5 & 6, with specifications according to table 1 [8]. The data sheet for the B-24 is found in Appendix A.

Table 1

Equivalent Area (A_{eq} Differential)	9×10^{-6} m^2
Frequency Response (3dB point)	8.5 GHz
Rise time (t_r 10-90)	~ 0.041 ns
Maximum Output (peak)	± 500V
Output Connectors	SMA (male)

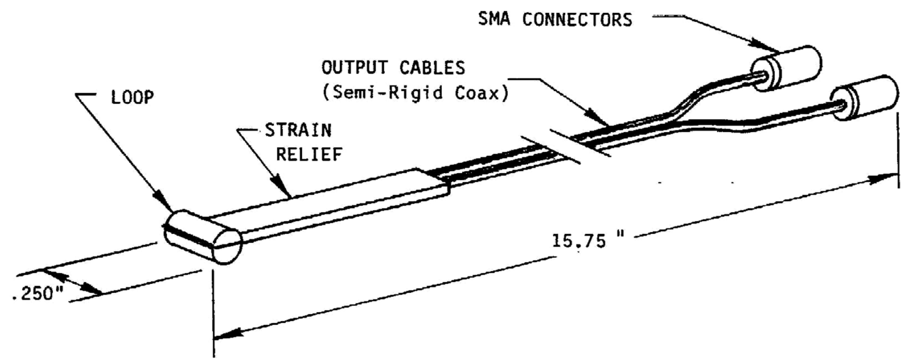

Figure 5. The Prodyn B24 sensor design [8].

The B-24 sensor is a cylindrical loop with differential output. The sensing cylinder consists of two half cylinders each connected to a 50 Ω transmission line giving opposite sign on the output signals. The sensor is then connected to a balun taking the difference of the two signals increasing the signal and reducing the noise. This sensor is used with a Prodyn Balun BIB-100G [9] and an HP8472B crystal detector diode [10], both described by Appelgren et al. [11]. The sensor head is encapsulated to provide breakdown resistance and environment protection.

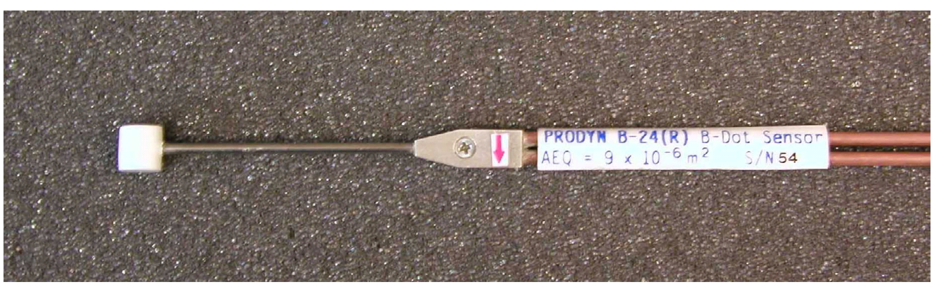

Figure 6. The Prodyn B24 sensor. The white cylinder is the sensor head .

The 3 dB frequency limit of the Prodyn B-24 is 8.5 GHz corresponding to a rise time of 0.041 ns using Eq.(24). The 3 dB frequency corresponds to a time constant

$$\frac{L}{R} = \frac{1}{\omega_{3dB}} = \frac{1}{2\pi f_{3dB}} = \frac{1}{2\pi \cdot 8.5 \cdot 10^9} = 1.87 \cdot 10^{-11}\,\text{s}. \qquad (25)$$

The sensing head consists of two half cylinders, each connected to a 50 Ω transmission line. The sensing loop has a diameter of 3.30 mm, corresponding to an enclosed physical area of 8.56 mm^2, which is close to the equivalent area given in the data sheet. No drawings of the sensor head are available. Some measured values are given in the measurement report (Appendix C). The width of the sensing loop is 3.56 mm and is assumed to be the height of the cylinder. The attenuation in the transmission lines has not been considered in the datasheets supplied by the manufacturer.

4. Measurement system

The magnetic field measurement system consists of a B24 sensor, a Prodyn balun, a LeCroy WaveMaster 8500 5 GHz oscilloscope, and coaxial cables connecting them, cf. figure 7.

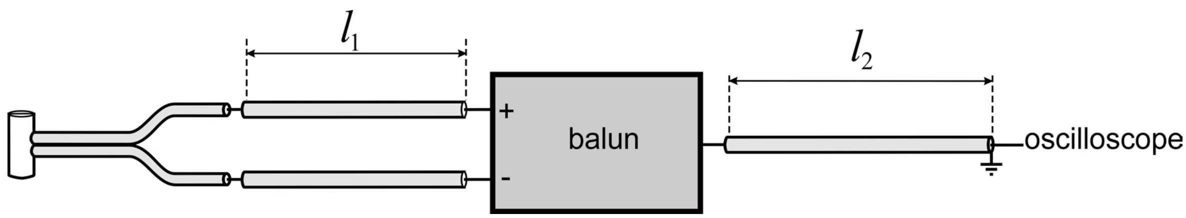

Figure 7. Magnetic field measurement system

Balun

The balun used together with the B24 sensor is a Prodyn Technologies BIB-100G, which accepts the two signals from the sensor and outputs the unbalanced difference signal. The BIB-100G has an attenuation of 8 dB and bandwidth 250 kHz - 10 GHz. These baluns are also used in the electric field measurement system, as described by Appelgren et al. [11] including specifications and calibration curves.

Coaxial cables

The signal attenuation in the connecting coaxial cables is usually frequency dependent, and must be accounted for in the evaluation of the measurement results. One high-frequency cable used is Habia Flexiform 405FJ [12,13], suitable for frequencies up to 20 GHz. This cable has an attenuation of 1.5 dB/m at 4 GHz. The attenuation in voltage amplitude is given by

$$\frac{V_2}{V_1} = 10^{-\alpha l/20} \tag{26}$$

where α is the attenuation in dB/m and l is the total cable length, i.e. the sum of the cable lengths before and after the balun ($l = l_1 + l_2$ in figure 7). It is important that the two cables from the sensor to the balun are of equal length.

Data reduction

Inserting $B = \mu_0 H$ into Eq.(8) and introducing attenuation factors for balun and cable we get

$$B_\perp(t) = \frac{V_{osc}(t)}{2\pi f_0 \cdot A_{eq}} \cdot 10^{-\frac{8}{20}} \cdot 10^{-\frac{\alpha \cdot l}{20}} \cdot \sqrt{\left(\frac{2\pi f_0 \cdot L_{tot}}{R_{load}}\right)^2 + 1} \tag{27}$$

where $B_\perp$ is the component of the B-field normal to the loop plane, and $V_{osc}(t)$ is the voltage signal as recorded on the oscilloscope.

If the spectral sensitivity for the frequency range of interest is available for sensor, cables and balun these components can be regarded as filters, each with their own transfer function. Recorded data are then reduced to field amplitudes by applying the inverse transfer functions.

Crystal detector option

A crystal detector diode can be inserted before the oscilloscope termination to measure the microwave power. This is useful for measuring microwaves of high frequency when time resolution of the signal is not required. Hence, an oscilloscope with a smaller bandwidth can be used in this configuration. The HP 8472B crystal detector has an input impedance of 50 Ω, sensitivity 0.1 mV/µW, and is documented in Appelgren et al. [11].

5. Calibration

Ignoring attenuation and using datasheet values in Eq.(27), the magnetic field *H(t)* relates to the measured signal according to

$$H(t) = \frac{V_L(t)}{2\pi f_0 \cdot \mu_0 \cdot A_{eq}} \cdot \sqrt{\left(\frac{f_0}{f_{3dB}}\right)^2 + 1} = \frac{V_L(t)}{2\pi f_0 \cdot \mu_0 \cdot 9 \cdot 10^{-6}} \cdot \sqrt{\left(\frac{f_0}{8.5 \cdot 10^9}\right)^2 + 1} \qquad (28)$$

5.1. Measurements with calibrated source

The balun has an attenuation of approximately 8 dB, which however has a large variation with frequency. A calibration of the B-24 with a balun was performed at the Swedish National Testing and Research Institute, SP (Appendix D). The sensor with balun was positioned in the far field in front of a horn antenna with known output. The frequency was swept between 1.15 and 8 GHz. The frequency was increased in steps of 250 MHz up to 4 GHz while the step size was 500 MHz above 4 GHz. Figure 8 shows the calibrated sensitivity (crosses) versus the theoretical (line) as given by Eq. (28). The sensitivity (V per A/m) deviates up to 50 % from the theoretical sensitivity.

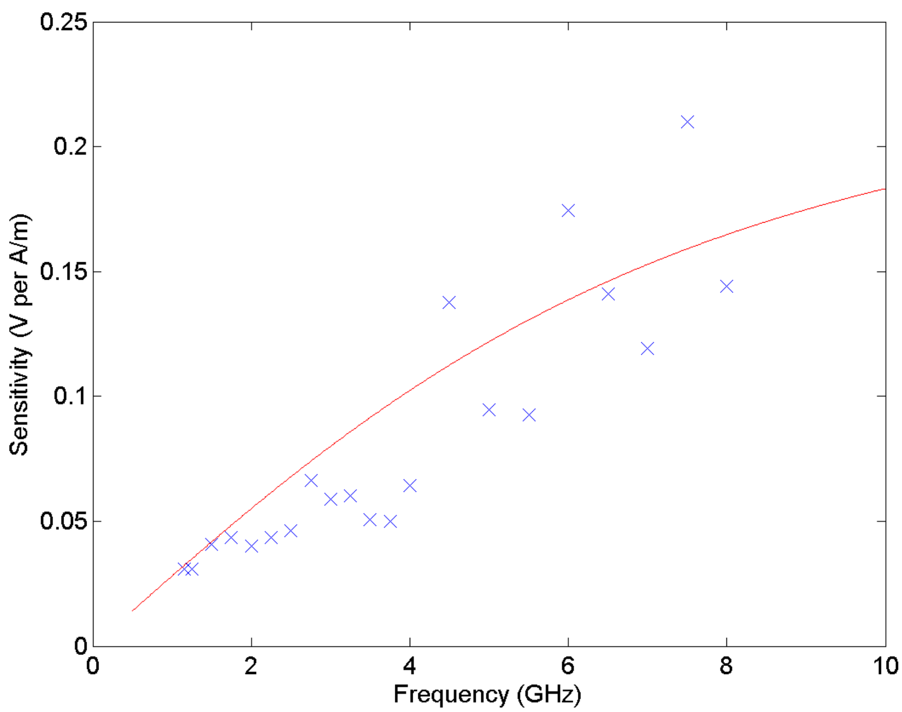

Figure 8. Calibrated (crosses) and theoretical sensitivity (line) of B-24 sensor.

The theoretical curve represents an average sensitivity in the frequency range measured, but the deviations are large at several frequencies. The sampling in this measurement is not dense enough to resolve the peaks and troughs, but shows that the accuracy in measurements with this system is not better than a few tens of percent.

5.2. Network analyzer measurements

The voltage reflection coefficient S11 was measured for the Prodyn BIB-100G balun together with the Prodyn B-24 B-dot probe, see Figure 9. In total, 401 points were measured in the range between 100 MHz and 8 GHz with a HP 8510C network analyzer.

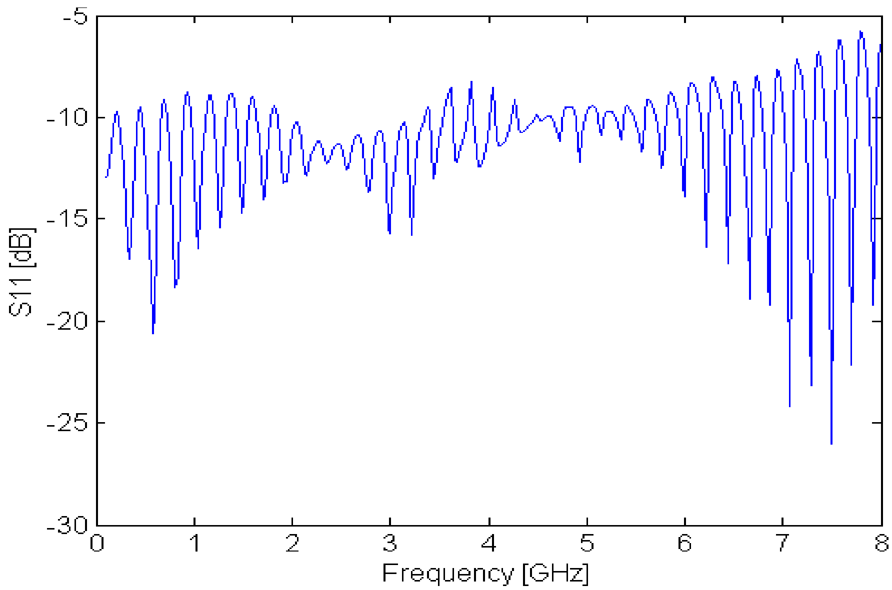

Figure 9. S11 parameter for B-24 with balun.

The input impedance Z_{in} of the balun and B-dot seen from the network analyzer can be calculated from the voltage reflection coefficient as [3]

$$S11 = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{29}$$

where Z_0 is the characteristic impedance of the measuring equipment, i.e. Z_0=50 Ω. The input impedance of the balun and B-dot can be seen in Figure 10.

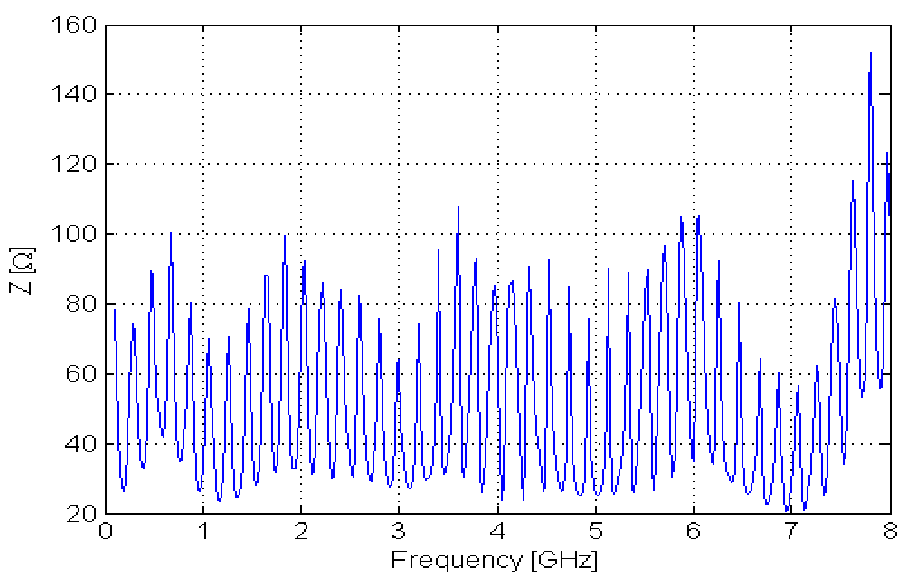

Figure 10. Input impedance for B-24 with balun.

6. Concluding remarks

The magnetic field measurement system described can be used for free field measurements in the characterization of pulsed microwave sources. The B-dot probe and balun configuration can be used to directly sample one field component of the received radiation for pulses with frequency content up to about 8 GHz, or to the bandwidth of the oscilloscope used. It is also possible to measure the microwave power by using a crystal detector.

The B-dot probe and balun show a rather complex spectral sensitivity with many peaks and troughs in the frequency range of interest. Hence the detailed evaluation of a measurement can become very complicated if all spectral components are to be treated with full accuracy. Instead, simplified expressions may be used in the reduction of data.

A magnetic field measurement system built on a commercial B-dot probe and balun can be used as a reference for relative calibration of similar in-house made measurement systems.

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13. *ELFA Produktinformation, ELFA Artikelnr 55-929-28 Koaxialkabel Flexiform 405FJ*, 2001-01-03

Appendix A: Data sheet Prodyn B-24

DATA SHEET

MAGNETIC FIELD SENSOR ($\dot{B}$)
(Free Field)

MODEL B-24

DESCRIPTION

The PRODYN Model B-24 is a full loop magnetic sensor that measures the time rate-of-change of a magnetic field . This very small portable device was designed specifically for making high frequency free field measurements. For this type of measurement and because the sensor is fragile due to its size, it should be supported by dielectric materials and placed a minimum of two sensor diameters from conducting surface. The sensing area is encapsulated to provide breakdown resistance and protection from the environment. The sensor is a passive device, therefore, an external power source is not required.

The equation relating to the sensor is:

$$V_0 = \overrightarrow{A_{eq}} \cdot \frac{d\vec{B}}{dt} = \text{sensor output (in volts)}$$

where

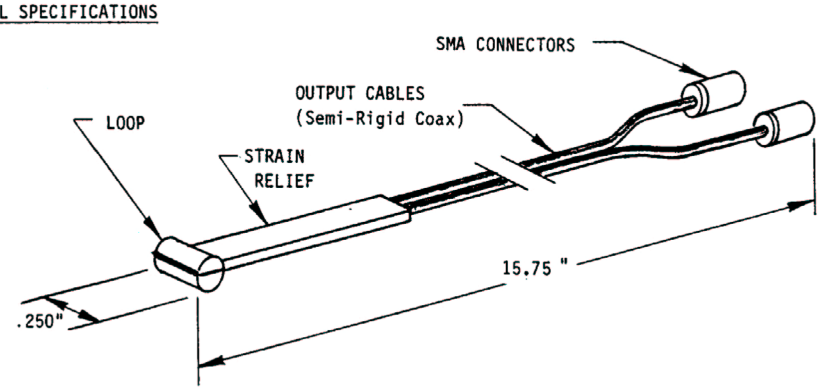
$\overrightarrow{A_{eq}}$ = sensor equivalent area (m^2)

$\vec{B}$ = magnetic flux density vector (teslas)

ELECTRICAL SPECIFICATIONS

Equivalent Area (A_{eq}, Differential)	9×10^{-6}
Frequency Response (3dB point)	~8.5GH$_z$
Risetime (t_r 10-90)	~.041 NS
Maximum Output (peak)	±500v
Output Connectors	SMA (Male)

PHYSICAL SPECIFICATIONS



Appendix B: B-24 Equipment test data

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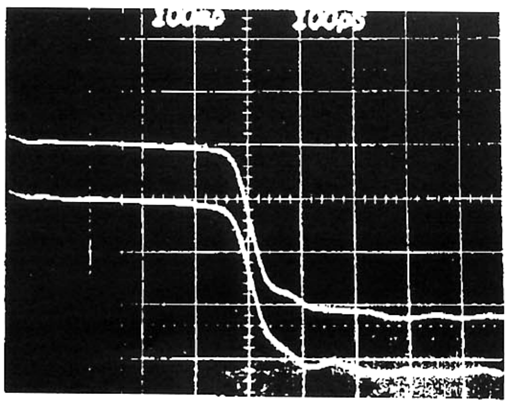
PRODYN TECHNOLOGIES

Equipment Test Data

Customer PPM



Equip. Description B-24(R)
Serial No. 54

"TDR" (TEK 7S12)
Picture Data

.1 NS/CM ρ/CM . .1

Picture Date 9/12/03

Remarks Upper left traces = 50Ω ref. to Sensing Loop. SMA(m) outputs

Equip. Description ____
Serial No. ____

Picture Data

____ /CM /CM = ____

Picture Date ____

Remarks ____

Equip. Description ____
Serial No. ____

Picture Data

____ /CM /CM = ____

Picture Date ____

Remarks ____

Appendix C: B-24 Measurement report

PRODYN TECHNOLOGIES
Precision EM Instrumentation

MEASUREMENTS REPORT

Customer Name: PPM   Customer P.O.: 1224   Date: 7/15/03

Job Number: P1358   Model/Part No.: B-24(R)   Serial No.: 54

Originated by: JAM   Measured by: [signature]

Description	Drawing Number	Drawing Dimension	Tolerance	Measurement Dimension	Date Measured	Pass (P) Fail (F)	
Sensing Loop:	86A0342						
Diameter		.130"	±.001	.130	081203	P	
Width		.140"	±.003	.140	081203	P	
Thickness		.008"	±.001	.008	081203	P	
Vertical Plane:	86A0343						
Width		.170"	±.003	.170	081203	P	
Height		.160"	±.003	.160	081203	P	
Thickness		.010"	±.001	.010	081203	P	

Appendix D: Calibration documents

Page 1 of calibration document.

KALIBRERINGSBEVIS

RMP 01

utfärdat av Riksmätplats 01 / *CALIBRATION CERTIFICATE issued by a Swedish National Laboratory*

Patrik Appelgren
FOI
Grindsjön Research Centre
147 25 TUMBA

Handläggare, enhet/Handled by, department	Datum/Date	Beteckning/Reference	Sida/Page
Kristian Karlsson, Electronics	2004-02-24	F403094-B	1 (3)

Calibration of B-Dot field probe

Calibration object

B-Dot field probe: Prodyn, model B-24(R), S/N 54, ID: GR000595

Mission

To calibrate a B-Dot field probe in the frequency interval 1.15 GHz to 8 GHz.

Date of calibration

2004-02-18

Test environment

Temperature	before calibration:	21.9 °C
	during calibration:	21.9 °C
	after calibration:	21.7 °C
Humidity:	33 % ± 5 %	

Method of calibration

Calibration is performed in a known electric field according to SP method: SP 2781.

1GHz - 18GHz: The electric field is generated by a computable Standard Gain Horn (from Flann Microwave)

Traceability

Power measurements were performed with a power meter calibrated at Nederlands Meetinstituut, NMi.

SP Sveriges Provnings- och Forskningsinstitut, Box 857, 501 15 BORÅS, Tel 033-16 50 00, Telefax 033-13 55 02, E-mail info@sp.se, Org. nr. 556464-6874
SP Swedish National Testing and Research Institute, Box 857, SE-501 15 BORÅS, SWEDEN, Telephone +46 33 16 50 00, Telefax +46 33 13 55 02, E-mail info@sp.se, Reg. No. 556464-6874

Page 2 of calibration document.

KALIBRERINGSBEVIS
CALIBRATION CERTIFICATE

Datum/*Date*	Beteckning/*Reference*	Sida/*Page*
2004-04-24	F403094-B	2 (3)

Result

The generated H-field and measured voltage is provided in table 1 below.

Provided that the test antenna is placed in the far field, the E-field in front of an antenna can be calculated as (SP-method 2781):

$$E = \frac{\sqrt{30 P_{IN} G}}{R}$$

where:

P_{IN} = Power at the connector of the horn antenna.
G = Gain of the reference antenna
R= Distance between reference antenna and test object.

See figure 1 for test setup. The H-field can be calculated from the E-field:

$$H = E/\eta, \qquad \eta = 377$$

where η is the wave impedance in free space.

During the calibration the H-field at the test object was calculated and according to SP-method 2781 and the voltage over a 50Ω load at the port of the test object was recorded.

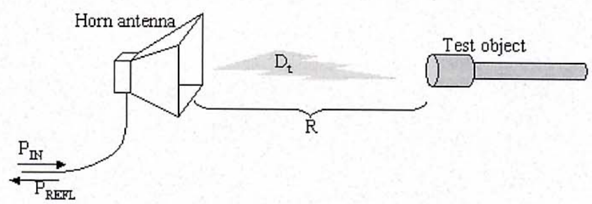


Figure1. Test setup within anechoic chamber.

Page 3 of calibration document.

KALIBRERINGSBEVIS
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Datum/*Date*	Beteckning/*Reference*	Sida/*Page*
2004-04-24	F403094-B	3 (3)

Table 1. Generated H-field and measured voltage (Prodyn B-24 (R))

Frequency [GHz]	Reference level [A/m]	Voltage at probe/balun connector [mV]
1,15	0,254	7,80
1,25	0,258	7,94
1,50	0,315	12,8
1,75	0,139	6,03
2,00	0,221	8,83
2,25	0,302	13,1
2,50	0,351	16,2
2,75	0,198	13,1
3,00	0,199	11,7
3,25	0,231	13,9
3,50	0,236	12,0
3,75	0,228	11,4
4,00	0,198	12,7
4,50	0,171	23,6
5,00	0,174	16,5
5,50	0,115	10,6
6,00	0,147	25,6
6,50	0,161	22,7
7,00	0,103	12,3
7,50	0,105	22,0
8,00	0,122	17,6

Uncertainties

The relation between generated H-field and voltage at the probe has a total measurement uncertainty of: +/- 0.7 dB (+/- 10 %)

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with EA Publication EA-4/02.

SP Swedish National Testing and Research Institute
Electronics - EMC
RMP01 HF

Jan Welinder
Technical manager

Kristian Karlsson
Technical Officer

Standard gain horn antennas (Flann Microwave) used and distance to sensor.

Frequency	**Horn**	**Distance**
[GHz]	[-]	[m]
1.15	6240	1.402
1.25	6240	1.402
1.50	6240	1.402
1.75	8240	1.510
2.00	8240	1.510
2.25	8240	1.510
2.50	8240	1.510
2.75	10240	3.414
3.00	10240	3.414
3.25	10240	3.414
3.50	10240	3.414
3.75	10240	3.414
4.00	12240	3.865
4.50	12240	3.865
5.00	12240	3.865
5.50	14240	3.934
6.00	14240	3.934
6.50	14240	3.934
7.00	14240	3.934
7.50	14240	3.934
8.00	14240	3.934