



FIELD MEASUREMENTS, WEB PROCEDURES, AND ONLINE TOOLS FOR ASSESSING OCCUPATIONAL EXPOSURE TO NON-IONIZING RADIATION

Moreno Comelli

moreno.comelli@cnr.it

Institute of Applied Physics “Nello Carrara”

Italian National Research Council



CNR-IFAC

The Institute of Applied Physics "Nello Carrara" (IFAC) was established in March 2002 in Florence (previously IROE, Research Institute on Electromagnetic Waves).

IFAC has expertise in physical investigation methods for the development of devices and instruments, mathematical and computer methods for modeling and processing of data and images, with applications in:

- space, aerospace, and earth observation
- health, nanomedicine, and safety
- environmental monitoring and food quality
- cultural heritage





BRIC 2017-2025

- Collaborative Research Calls funded by INAIL (National Institute for Insurance against Accidents at Work)
- Involving several Italian institutions:
 - CNR-IFAC (“Nello Carrara” Institute for Applied Physics of the Italian National Research Council, Florence)
 - CNR-IFC Pisa
 - ISS (Italian National Institute of Health)
 - USL Siena
 - Policlinico San Matteo
 - University of Modena and Reggio Emilia



BRIC 2017-2025

- Activities focused on professional exposure related to AIMD (Active Implantable and Wearable Medical Devices) wearers
- Current project: Risk assessment and management deriving from exposure to new sources of electromagnetic fields for the protection of workers with active implantable medical devices

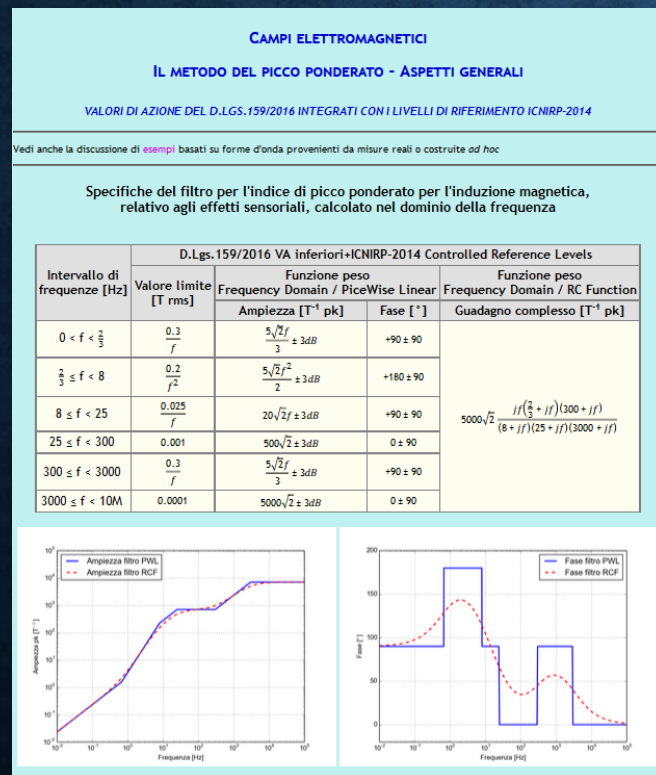


WEBNIR

- Web tools for the assessment of occupational exposure to Non Ionizing Radiation
- Web portal: <https://webnir.eu>
- 3 sections:
 - EMF (ElectroMagnetic Fields)
 - AIMD (Active Implantable and Wearable Medical Devices)
 - AOR (Artificial Optical Radiation)
- Updated with new technologies and implementation of new technical features (responsive site, multilingual, keyword search): <https://webnir2.ifac.cnr.it>
(switching off soon)

It makes available:

- Technical documents (web pages or PDFs)



INTRODUZIONE ALLA DOSIMETRIA ELETTROMAGNETICA:
LA VALUTAZIONE DELLE GRANDEZZE DOSIMETRICHE NEI SOGGETTI ESPOSTI¹

Daniele Andreuccetti, IFAC-CNR, Firenze

1. La dosimetria elettromagnetica

La dosimetria elettromagnetica è una disciplina tecnico-scientifica che si occupa di studiare i **meccanismi di accoppiamento** tra un **campo elettromagnetico** ed un **oggetto biologico** in esso immerso o, come si dice, **"esposto"** ad esso.

L'**accoppiamento** è il primo di una serie di fenomeni biofisici concatenati attraverso cui si realizza l'interazione tra un campo elettromagnetico ed un oggetto biologico e che comprende schematicamente i passi seguenti.

- Esposizione:** un oggetto biologico viene immerso in un campo elettromagnetico.
- Accoppiamento:** il campo elettromagnetico induce alcuni fenomeni fisici, caratterizzati da determinate grandezze fisiche, nei tessuti dell'organismo esposto; questi fenomeni hanno origine dall'azione delle forze del campo sulle cariche e sulle correnti elettriche presenti nei tessuti.
- Effetto biologico:** i fenomeni fisici indotti dal campo esterno provocano sempre una deviazione dalle condizioni di equilibrio elettrico a livello molecolare; per poter parlare propriamente di effetto biologico, si deve però verificare una variazione morfologica o funzionale in strutture di livello superiore (tessuti, organi o sistemi).
- Danno biologico o sanitario:** un effetto biologico non costituisce necessariamente un danno; perché questo si verifichi, occorre che l'effetto superi la capacità di compensazione di cui dispone l'organismo, che dipende anche dalle condizioni



WEBNIR

It makes available:

- Technical documents (web pages or PDFs)
- Interactive procedures

A backend interface allows the admin to insert data, automatically making available a frontend where the user can answer questions following a path according to the procedure.

Is the worker a carrier of AIMD?

YES
✓

NO
▼

Specify type, brand and model of AIMD

Type	Brand	Model	+
Pacemaker	Boston	Model 1	−

Continue
✓

LIST OF INSTRUMENTATION TABLE 1

As a first step in the risk assessment, a series of equipment that could be present in the workplace will be presented, for which the potential risk for workers with AIMD has already been assessed and it is therefore possible to carry out a simplified risk assessment. For each item reported in the source list, the user, in addition to indicating its presence by means of a check mark, must indicate whether it complies with specific indications on their method of use and operation, which will be shown on the screen from time to time.

Check whether the workplace contains equipment listed in [Table 1](#) of the CEI EN 50527-1 standard and whether the indications reported in the *Exceptions and Notes* column of the same Table are complied with.

Select the equipment of interest:

☐ Lighting fixtures ⓘ

☐ Computers and IT equipment ⓘ

☒ Computers, tablets, IT equipment including wireless communications ⓘ
☐ Comply / ☒ Does not comply with instructions

☒ Office equipment ⓘ
☒ Comply / ☐ Does not comply with instructions

☐ Smartphones, mobile phones and cordless phones ⓘ

☐ Two-way radios ⓘ



WEBNIR

It makes available:

- Technical documents (web pages or PDFs)
- Interactive procedures
- Calculation applications

Shielding Calculation Mode

Calculation for known and fixed shield thickness, distance from source, frequency and material

Calculation as a function of frequency for various materials

Calculation as a function of shield thickness for various materials

Calculation as a function of frequency and screen thickness

Calculation as a function of frequency and distance from source

Calculation as a function of screen thickness and distance from source

Calculation as a function of distance from source for various materials

Material data

User-defined material

Name	σ	μ_r	$f_{1/2}$	α
				0

Archived materials

Name	σ	μ_r	$f_{1/2}$	α
Alluminio	3.77e+07	1.000022	0	0

Calculation parameters

Material Aluminum

Minimum frequency1Hz

Maximum frequency100Hz

Screen thickness50 μ m

Minimum distance1cm

Maximum distance100cm

Definizione della struttura dei sistemi di conduttori

Numero di sistemi1

1

Parametri generali della struttura n. 1





Nome della strutturaStruttura n. 1

Altezza da terra del conduttore piú basso20m

Distanza dall'origine, lungo il terreno10.0m

Utilizzo facoltativo di sostegni a massimo impatto

Tensione efficace nominale tra le fasi132 kV



Parametri dei conduttori della struttura n. 1

N. conduttori nella struttura (fino a 30)3

X (m)	Y (m)	I (A)	Fase (°)
-7.1	0	300	0
0	0	300	120
7.1	0	300	240

Replica questi parametri alla struttura n. ...

Posizione dei punti di calcolo lungo il piano di terra

Distanza iniziale-100.0mAltezza sul terreno1.5m

Passo1.0mPendenza del terreno0°

Numero di punti200

Ricerca valore di campo

Passo angolare3°Valore cercato3.0 μ T



- [illegible]



EMF TOOLS

- General aspects
 - Consultation and comparison of regulatory limits
 - Interpolation of index measurements and calculation of the compliance distance with determination of the uncertainty
- Characterization of sources in the external environment
 - Calculation of the electric field generated by systems of indefinite rectilinear conductors
- Processing of data files from exposure measurements
 - Calculation of weighted peak indices for low and intermediate frequency magnetic field sources
 - Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements
 - Loading, recognition, and processing of measurement data files in the time or frequency domain
- Applications to support the reduction to compliance
 - Comparison of the electric field generated by systems of indefinite rectilinear conductors
 - Calculating the shielding effectiveness of an ideal screen



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS

Regulations list	Regulations comparison	Regulations filter	Instructions
ICNIRP Guidelines 1994 (Static magnetic fields)			▼
ICNIRP Guidelines 1998 (EMF up to 300 GHz)			▼
ICNIRP Guidelines 2009 (Static magnetic fields)			▼
ICNIRP Guidelines 2010 (LF)			▼
ICNIRP Guidelines 2014 (Movement in a static magnetic field)			▼
Raccomandazione 1999/519/CE			▼
Direttiva 2013/35/UE			▼
ICNIRP Guidelines 2014 + Direttiva 2013/35/UE			▼
ICNIRP Guidelines 2020 (100 kHz to 300 GHz)			▼

- Tab system
- Regulations grouped by document (ICNIRP guidelines...)



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS

ICNIRP Guidelines 2009 (Static magnetic fields)

ICNIRP. Guidelines on limits of exposure to static magnetic fields. Health Physics, Vol.96, N.4, April 2009, pp.504-514.

Download PDF: [\[INT\]](#) [\[EXT\]](#)

Code	Full name
ICNIRP2009BSTAT	ICNIRP Guidelines 2009 - Exposure limits for static magnetic fields
<div>Details</div>	
Short name	ICNIRP-2009 B-Stat
Type	Exposure limits
Quantity	Magnetic flux density
Metric	Static field or DC value
Subject	Population and workers
Effect	Undifferentiated
Level	Undifferentiated
Localization	Whole body exposure
Minimum frequency	0 Hz
Maximum frequency	0 Hz
Function	bstatico.icnirp2009
Reference document	ICNIRP Guidelines 2009 (Static magnetic fields)

- Limits not dependent on frequency are displayed in a table

Restriction	Value
Occupational exposure, spatial peak in the head or trunk	2 T
Occupational exposure, specific applications in a controlled environment where appropriate work practices are implemented to control the effects induced by movement, spatial peak	8 T
Occupational exposure, spatial peak for exposure of limbs only	8 T
Population exposure, spatial peak in any part of the body	400 mT
Prevention of potential indirect side effects resulting from exposure of persons with implanted electronic medical devices and implants containing ferromagnetic materials, and hazards from flying metal objects: much lower maximum levels may be appropriate, up to	500 μT



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS

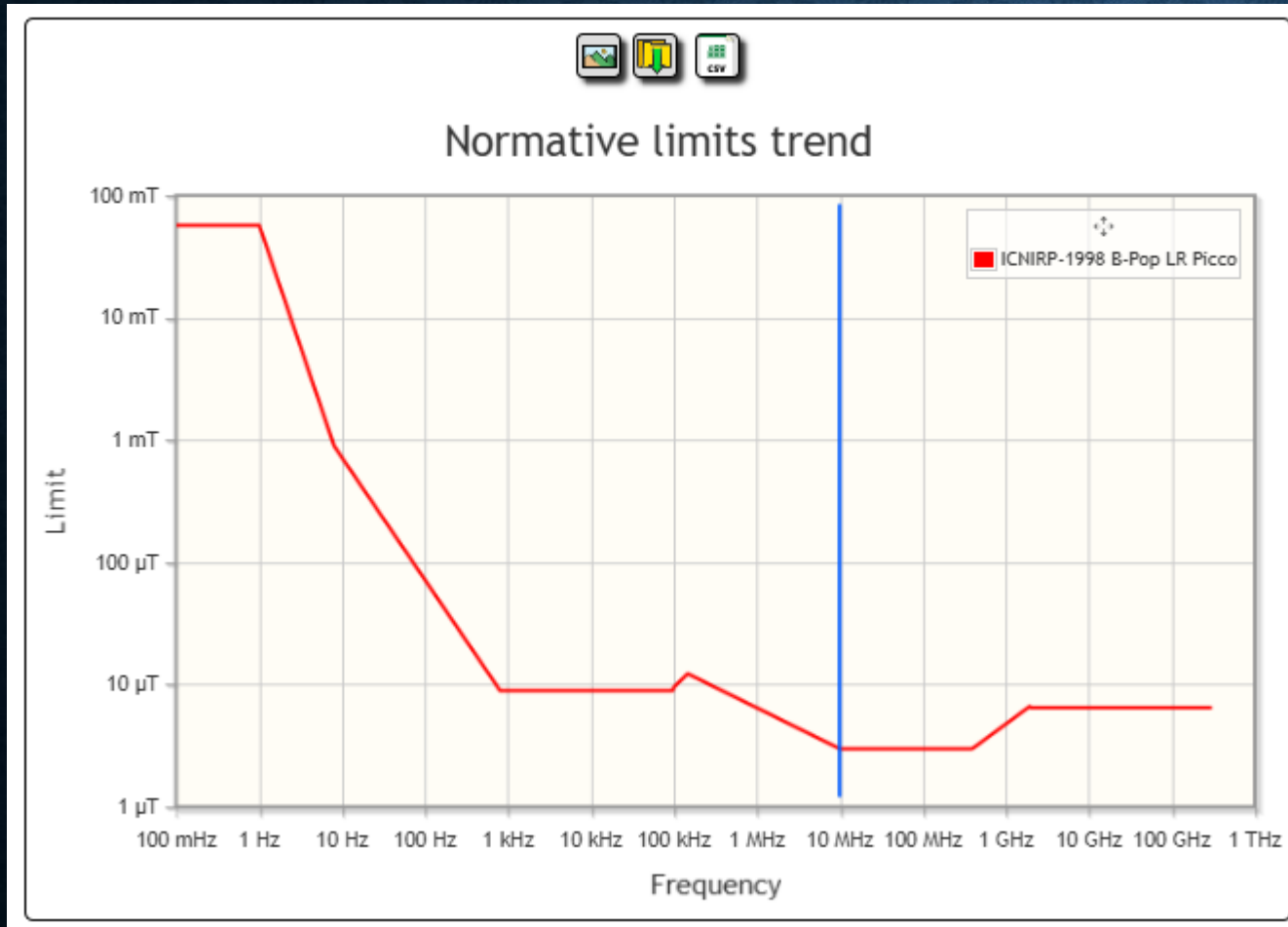
ICNIRP Guidelines 1998 - Magnetic induction - Limits for the general public - Peak reference levels [Details](#)

Short name	ICNIRP-1998 B-Pop LR Picco
Type	Reference levels, action values (AV), action levels (AL)
Quantity	Magnetic flux density
Metric	Peak value
Subject	Population exposures
Effect	Undifferentiated
Level	Undifferentiated
Localization	Whole body exposure
Minimum frequency	0 Hz
Maximum frequency	300 GHz
Reference document	ICNIRP Guidelines 1998 (EMF up to 300 GHz)
Calculate limit at specific values	Frequency <input type="text" value="300"/> <input type="text" value="GHz"/> <input type="button" value="Calculate"/>
Limit	

- Generic case: regulatory limit depends on the frequency
- User can calculate the limit at a specific frequency
- ...



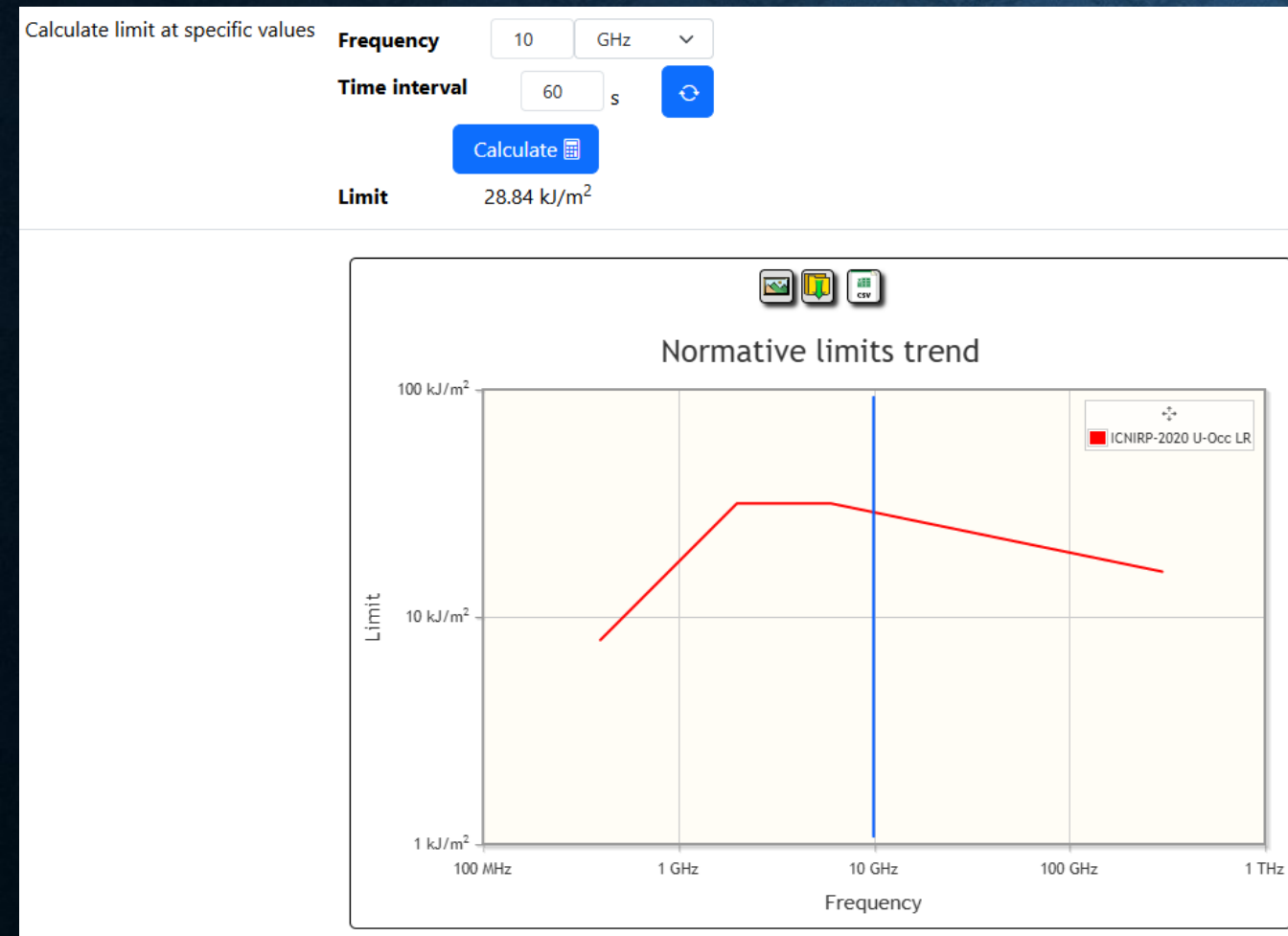
EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS



- Generic case: regulatory limit depends on the frequency
- User can calculate the limit at a specific frequency
- and plot limit trend vs. frequency



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS



- In the 2020 ICNIRP guidelines, limits can depend:
 - on time
 - on frequency
 - on time AND frequency
- Calculation is performed at a specific time interval and frequency value
- Limit trend vs. frequency is displayed at the chosen time interval



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS

Regulations list Regulations comparison Regulations filter Instructions

Functions selection

B (Magnetic flux density)

- 1999/519/CE B-Stim LR
- 1999/519/CE B-Term LR
- 1999/519/CE B LR Picco
- ICNIRP-2010 B-Occ LR
- ICNIRP-2010 B-Pop LR
- 2013/35/UE B-Stim VA-Inf
- 2013/35/UE B-Stim VA-Sup
- 2013/35/UE B-Stim VA-A
- 2013/35/UE B-Term VA
- ICNIRP-2014 B Picco-Picco LR
- ICNIRP-2014 Non-contr LR + 2013/35/UE B-Stim VA-Inf
- ICNIRP-2014 Contr LR + 2013/35/UE B-Stim VA-Sup
- 2013/35/UE B-Stim VA-Arti est. up fino a 0 Hz
- ICNIRP-2020 B-Occ-30min LR
- ICNIRP-2020 B-Occ-6min LR
- ICNIRP-2020 B-Occ LR Picco
- ICNIRP-2020 B-Pop-30min LR
- ICNIRP-2020 B-Pop-6min LR
- ICNIRP-2020 B-Pop LR Picco

DBDT (Time Derivative of Magnetic Flux Density (dB/dt))

- ICNIRP-2014 Non-contr LR
- ICNIRP-2014 Contr LR

DELTAB (Perceived change of Magnetic Flux Density)

- ICNIRP-2014 DELTAB/3s RB

E (Electric field)

- ICNIRP-1998 E-Stim-Occ LR
- ICNIRP-1998 E-Term-Occ LR
- ICNIRP-1998 E-Occ LR Picco
- ICNIRP-1998 E-Stim-Pop LR
- ICNIRP-1998 E-Term-Pop LR
- ICNIRP-1998 E-Pop LR Picco
- 1999/519/CE E-Stim LR

Append Restore

Abbreviations and acronyms in function names

- Stim: stimulation effects
- Term: thermal effects
- Occ: occupational limit
- Pop: population limit
- Picco: Peak
- LR: Reference Limit
- VLE: Exposure Limit Value
- VA: Attention Value
- VA Limbs: Attention Value referred to limbs
- VA Inf: Lower Attention Value
- VA Sup: Upper Attention Value
- RB: Basic Restriction
- Contr: Controlled conditions
- Non Contr: Uncontrolled conditions
- Eint: Internal electric field
- Sens: Sensory (uncontrolled exposures)
- Sanit: Healthcare (controlled exposures)
- Testro: Head and trunk
- PWL: Piecewise Linear weight function
- RCF: RC Filter weight function

Parameters and plot building

Minimum frequency 0 Hz
Maximum frequency 300 GHz
Number of intervals 1000

Plot

Function	Mode	f _{min}	f _{max}	Quantity
× ICNIRP-1998 B-Stim-Occ LR	PWL	0 Hz	10 MHz	B
× ICNIRP-1998 B-Term-Occ LR	PWL	100 kHz	300 GHz	B
× ICNIRP-1998 B-Occ LR Picco	PWL	0 Hz	300 GHz	B
× ICNIRP-1998 B-Stim-Pop LR	PWL	0 Hz	10 MHz	B
× ICNIRP-1998 B-Term-Pop LR	PWL	100 kHz	300 GHz	B
× ICNIRP-1998 B-Pop LR Picco	PWL	0 Hz	300 GHz	B

Comparison of limits:

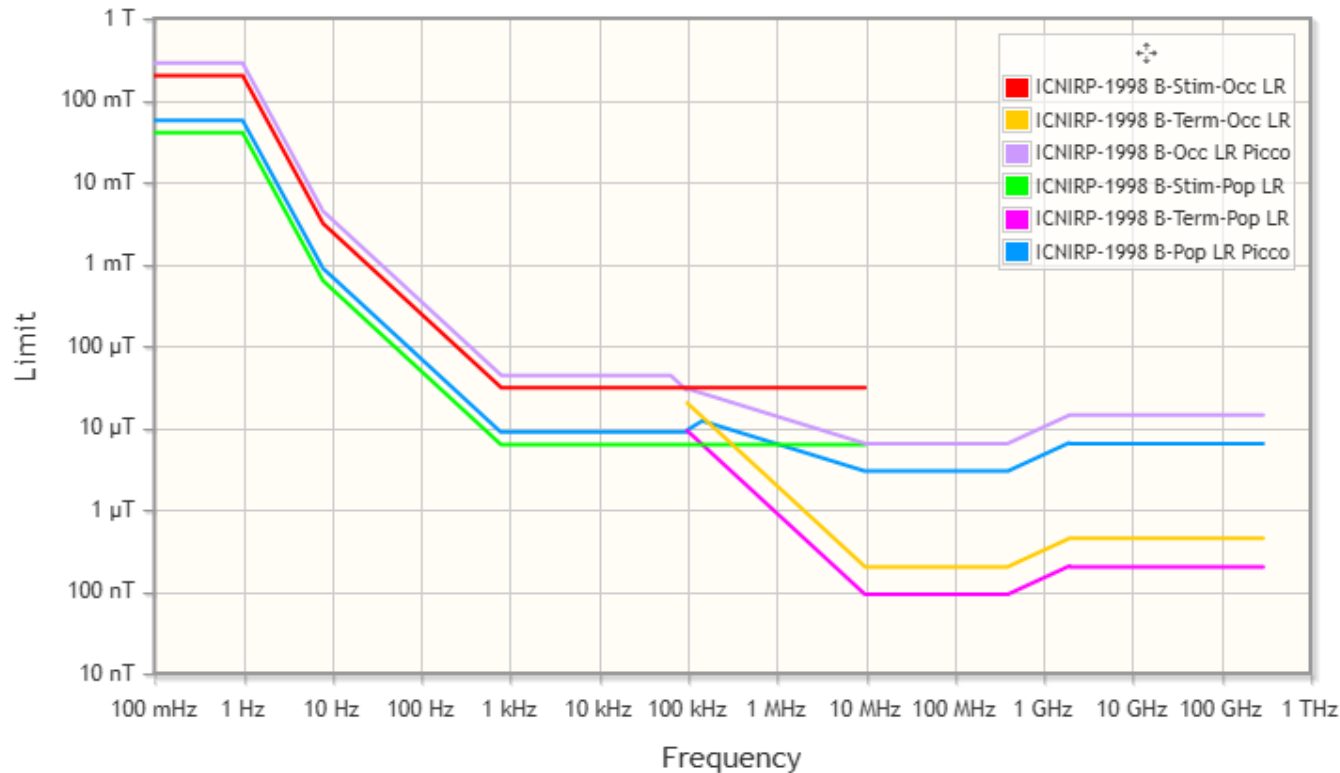
- The user can select a set of limits to compare
- They are first displayed in a table, where user can set their order (as they will appear in plot)



EMF TOOLS: CONSULTATION AND COMPARISON OF REGULATORY LIMITS



Limits for Magnetic flux density



Comparison of limits:

- The user can select a set of limits to compare
- They are first displayed in a table, where user can set their order (as they will appear in plot)
- and plot all of them (one physical quantity per graph)



EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT

2 sets of tools share a similar interface:

- Characterization of sources in the external environment
 - Calculation of the electric field / magnetic flux density generated by systems of indefinite rectilinear conductors
- Applications to support the reduction to compliance
 - Comparison of the electric field / magnetic flux density generated by systems of indefinite rectilinear conductors



EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT

Calculating E or B

- User can define up to 10 power lines
- Eventually chose one from a database
- Insert power lines electric and geometric data
- Geometric calculation parameters

Definizione della struttura dei sistemi di conduttori

Numero di sistemi

1

Parametri generali della struttura n. 1





Nome della struttura

Altezza da terra del conduttore più basso m

Distanza dall'origine, lungo il terreno m

Utilizzo facoltativo di sostegni a massimo impatto ☒

Tensione efficace nominale tra le fasi

Parametri dei conduttori della struttura n. 1

N. conduttori nella struttura (fino a 30)

X (m)	Y (m)	I (A)	Fase (°)
<input type="text" value="-7.1"/>	<input type="text" value="0"/>	<input type="text" value="300"/>	<input type="text" value="0"/>
<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="300"/>	<input type="text" value="120"/>
<input type="text" value="7.1"/>	<input type="text" value="0"/>	<input type="text" value="300"/>	<input type="text" value="240"/>

Replica questi parametri alla struttura n.

Posizione dei punti di calcolo lungo il piano di terra

Distanza iniziale m Altezza sul terreno m

Passo m Pendenza del terreno °

Numero di punti

Ricerca valore di campo

Passo angolare ° Valore cercato μT

Definition of the structure of conductor systems

Number of systems

Type of voltage

1

General parameters of structure no. 1

Name of the structure

Height above ground of the lowest conductor m



Distance from the origin, along the ground m

Parameter used in the case of bundle conductors:

☒ Radius of the circumference
☐ Spacing between subconductors

Optional use of maximum impact supports ☒

Rated effective voltage between phases

Before selecting the type of support, make sure that the voltage type is correct. If set to "Single-phase alternating" or "Continuous" Phase entry is disabled, and the voltage value is not automatically filled in.

Parameters of the conductors of structure no. 1

No. of conductors (up to 30)

X (m)	Y (m)	Tipo	V (kV)	Phase (°)	r (mm)	n	R / s
<input type="text" value="-7.1"/>	<input type="text" value="0"/>	<input type="text" value="F"/>	<input type="text" value="76.210"/>	<input type="text" value="0"/>	<input type="text" value="30"/>	<input type="text" value="1"/>	<input type="text" value="35"/>
<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="F"/>	<input type="text" value="76.210"/>	<input type="text" value="120"/>	<input type="text" value="30"/>	<input type="text" value="1"/>	<input type="text" value="35"/>
<input type="text" value="7.1"/>	<input type="text" value="0"/>	<input type="text" value="F"/>	<input type="text" value="76.210"/>	<input type="text" value="240"/>	<input type="text" value="30"/>	<input type="text" value="1"/>	<input type="text" value="35"/>

Replicate these parameters at structure no.

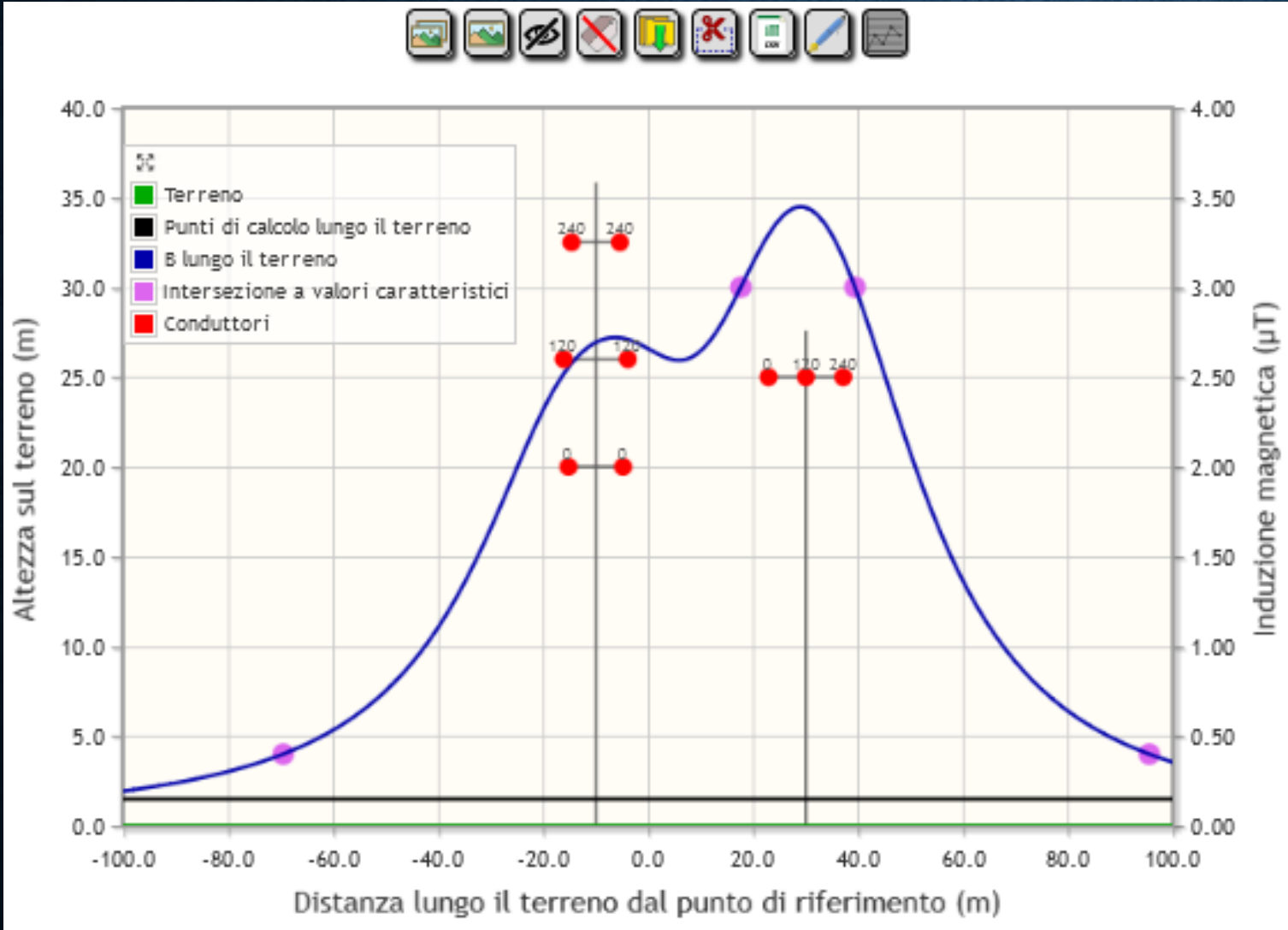
Position of calculation points along the ground plane

Initial distance m Height above ground m

Step m Terrain slope °

Number of points

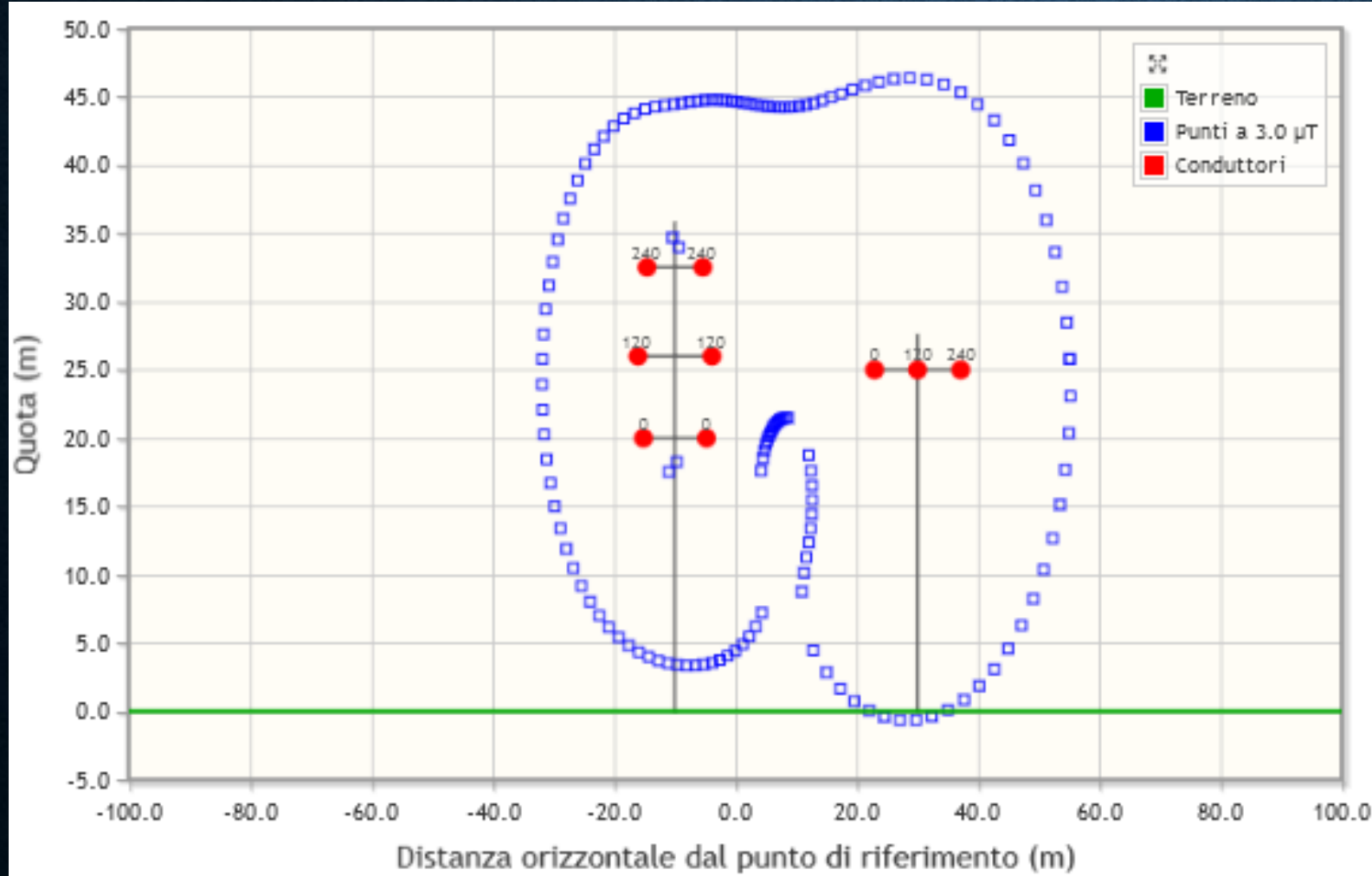
EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT



Magnetic flux density generated by systems of indefinite rectilinear conductors along a path parallel to the ground



EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT

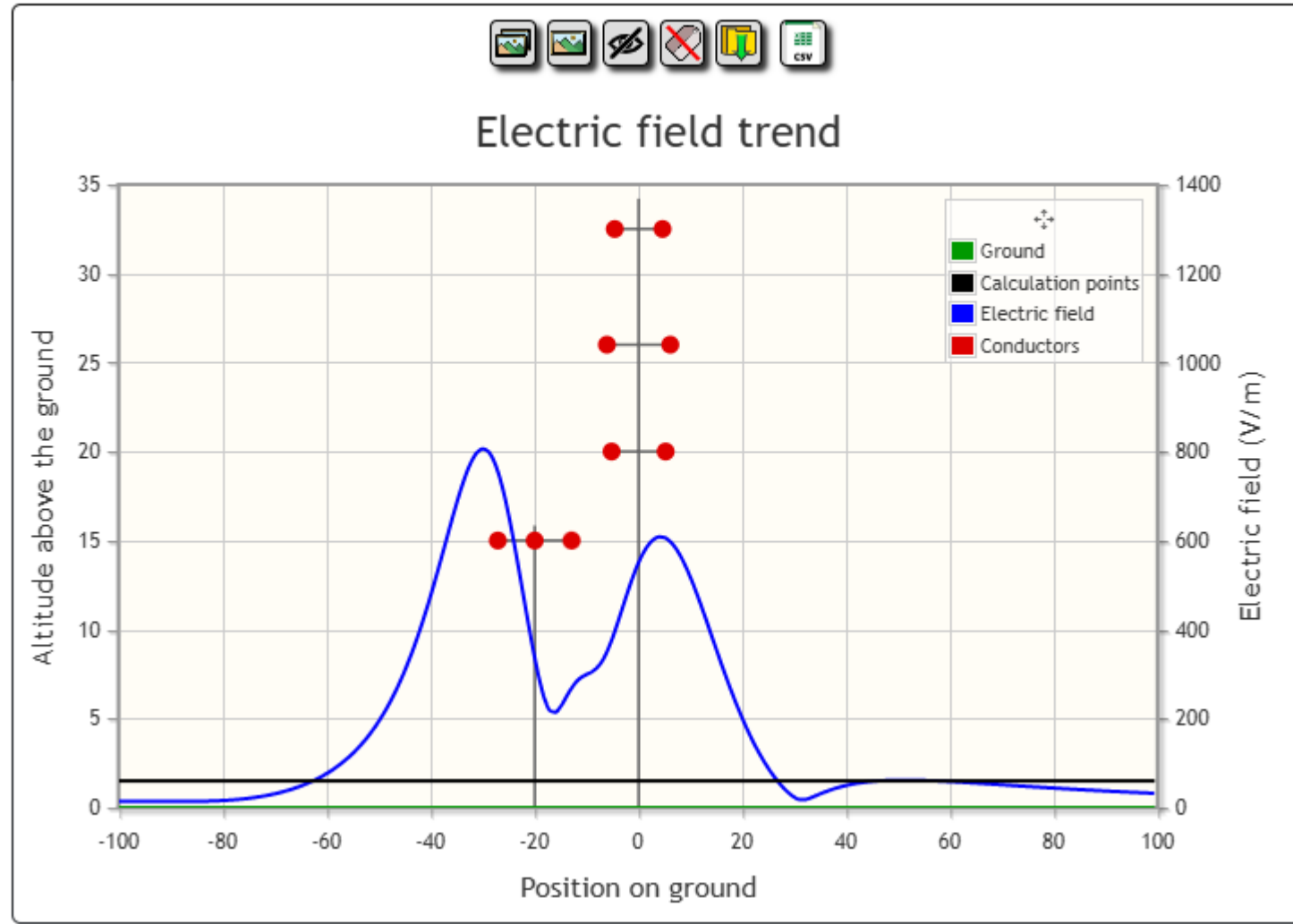


Position of points at a user-defined field value, around the wires



EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT

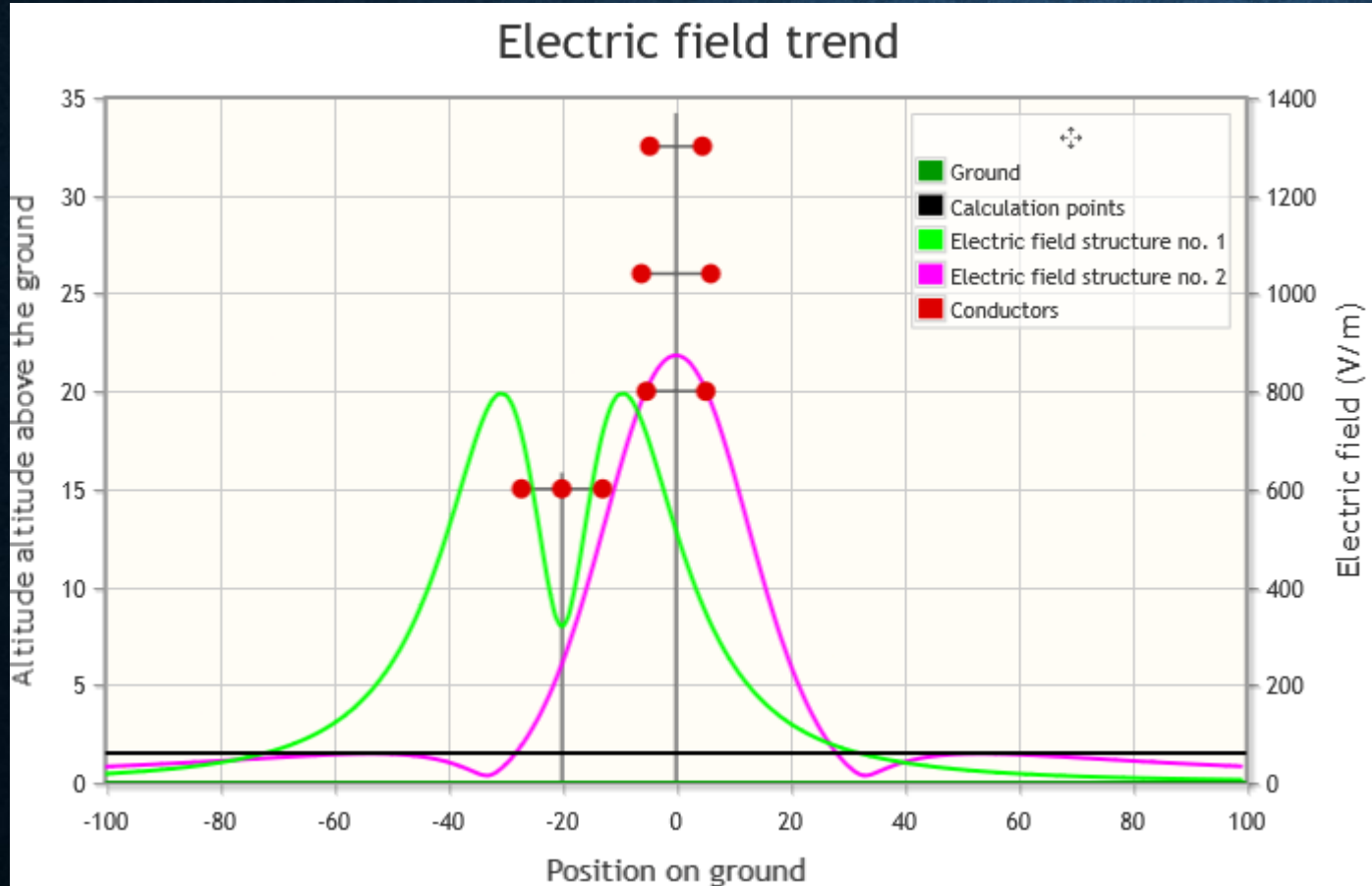
Peak value: 805.77 V/m at -30 m from origin.



Electric field generated by systems of indefinite rectilinear conductors



EMF TOOLS: CHARACTERIZATION OF SOURCES IN THE EXTERNAL ENVIRONMENT



Comparison of the electric field generated by systems of indefinite rectilinear conductors



ANALYSIS OF COMPLEX SIGNALS

- General aspects
 - Interpolation of index measurements and calculation of the compliance distance with determination of the uncertainty
- Processing of data files from exposure measurements
 - Calculation of weighted peak indices for low and intermediate frequency magnetic field sources
 - Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements
 - Loading, recognition, and processing of measurement data files in the time or frequency domain



ANALYSIS OF COMPLEX SIGNALS

STANDARD METHOD

1. Compliance with the limit is given by this formula, in which an evaluation is made for each frequency component in relation to the limit referred to that frequency.
2. It is a very conservative approach, as it is not said that all the components have a maximum at the same instant (extremely improbable situation)

$$I_{MS} = \sum_{i=1}^N \frac{A_i}{L(f_i)} \leq 1$$

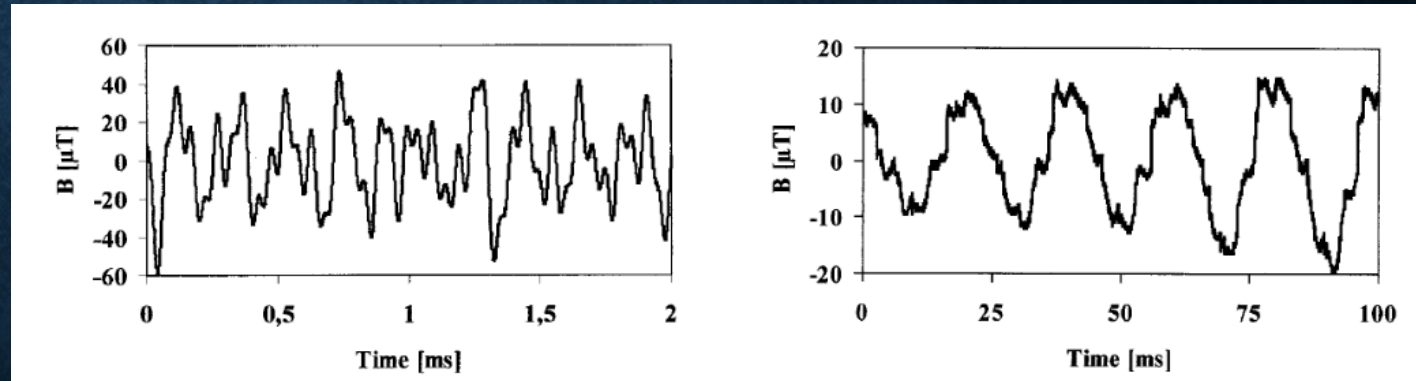


ANALYSIS OF COMPLEX SIGNALS

WEIGHTED PEAK METHOD (ICNIRP 2003-2010)

1. Differences in phases between different components are considered
2. Avoid overestimating the effect of the signal in an overly conservative manner
3. The approach can be shown to be valid for complex coherent and incoherent signals (complex non-sinusoidal waveforms, with or without phase coherence)

$$I_{WP} = \text{Max} \left| \sum_{i=1}^N \frac{A_i}{L(f_i)} \cos[2\pi f_i t + \vartheta_i + \varphi(f_i)] \right| \leq 1$$





INTERPOLATION OF INDEX MEASUREMENTS AND CALCULATION OF THE DISTANCE OF RESPECT

1) Select a text file (2 to 5 columns):

0.20, 99.99

0.40, 17.06

1.16, 1.04

1.20, 1.00

1.80, 0.24

2) Insert distance unit and errors

3) Choose a kind of graph (lin/log)

Presentation | **Data entry** | **Results** | **Instructions**

Choose the data file and enter the required data

Scegli file | Nessun file selezionato

☒ Percentage-based indices
☐ Unit-based indexes

Unit of measurement for position (in data-file) | m | v

Absolute error on position | 0 | m | v

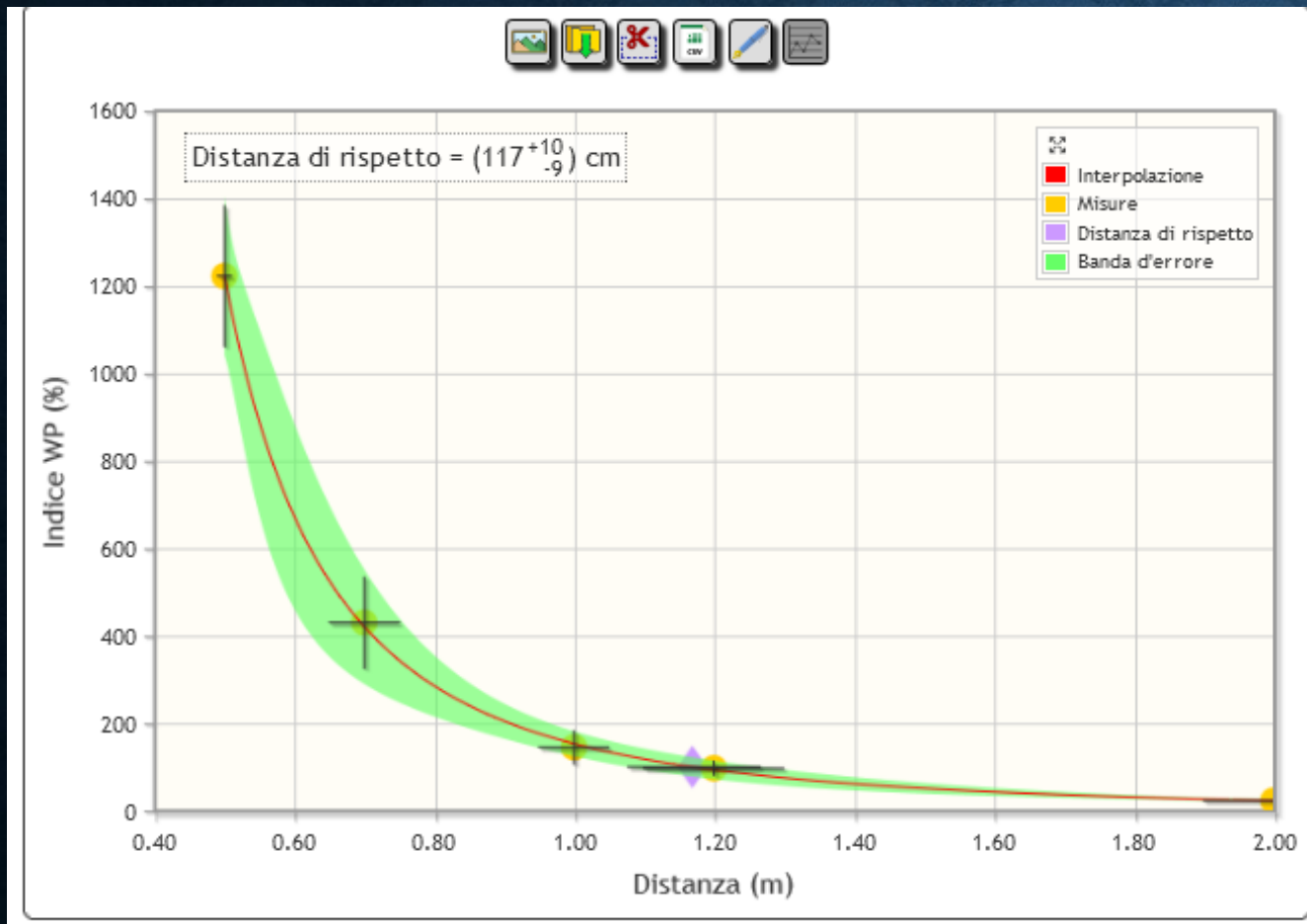
Absolute error on index | 0

Relative error on index | 0 | %

☒ Graph with linear ordinate axis
☐ Chart with logarithmic ordinate axis

Elaborate | **Reset**

INTERPOLATION OF INDEX MEASUREMENTS AND CALCULATION OF THE DISTANCE OF RESPECT



Interpolation with error bars and bands in a plot



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

3 applications:

- Motion in a static magnetic field: processing of perceived magnetic field measurements
- Calculation of weighted peak indices for low- and intermediate-frequency magnetic field sources
- Loading, recognition, and general processing of data files



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Motion in a Static Magnetic Field and

Calculation of Weighted Peak Indices:

- First procedures developed
- They are structured on the characteristics of specific measuring instruments, implementing specific scanning algorithms for the known output file format.



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements

- Assessment of occupational exposure due to an operator's movement in any non-homogeneous magnetic field
- Narda-Metrolab THM-1176 probe, attached to a specific point on the operator's body
- The probe is connected via USB cable to a PC running the probe management software



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements

Narda-Metrolab THM-1176 probe





PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements

- The subject is asked to perform movements typical of the various activities performed in relation to the task being studied, in areas where an intense static magnetic field is present
- During these movements, the instantaneous values of the magnetic induction vector detected by the probe are stored in a file on the personal computer
- The web tool allows processing of the data files



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Motion in a Static Magnetic Field - Processing of Perceived Magnetic Field Measurements

This instrument allows processing of magnetic field measurements that vary very slowly over time to derive the radiation protection parameters required by the ICNIRP-2014 “Guidelines for limiting exposure to electric fields induced by movement of the human body in a static magnetic field and by time-varying magnetic fields below 1 Hz”:

- the maximum ΔB variation in any 3-second interval
- the weighted peak index for stimulation effects.



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Calculation of weighted peak indices for low and intermediate frequency magnetic field sources

- A methodology for acquiring gradient magnetic field waveforms in the time domain has been developed.
- These waveforms are also essential for determining the weighted peak indices.

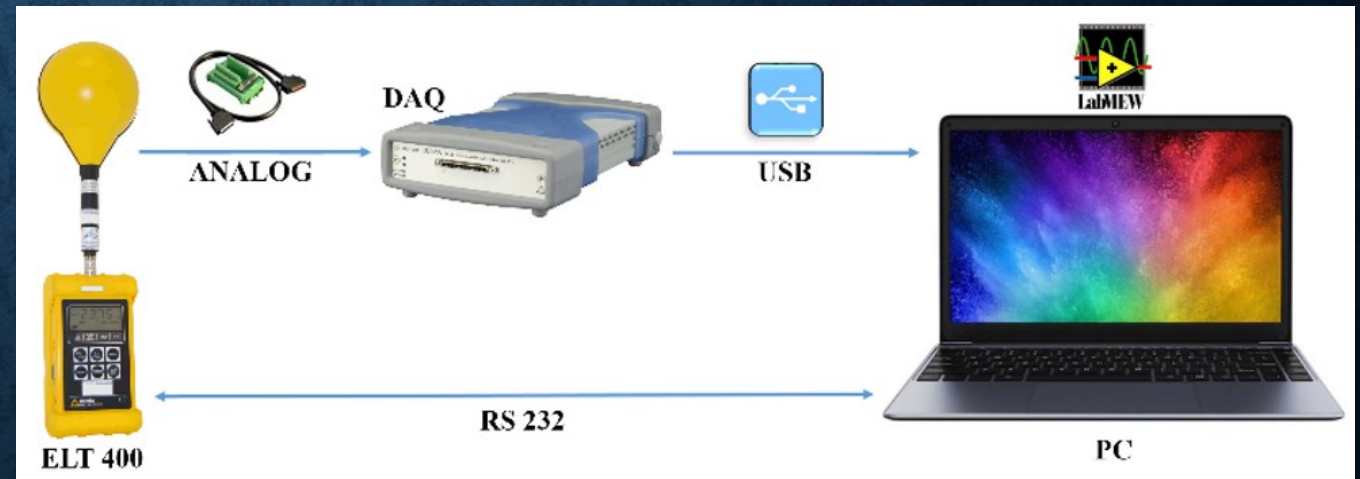


PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Calculation of weighted peak indices for low and intermediate frequency magnetic field sources

Measurement chain:

- Narda ELT-400 meter with 100 cm² probe
- Agilent U2351A data acquisition system (connected to the meter's analog output)
- PC connected to both the data acquisition system via a USB connection and the meter via a standard RS232 connection
- On the PC: data acquisition and chain management program, developed by ENEA in a LabVIEW environment.





PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Calculation of weighted peak indices for low and intermediate frequency magnetic field sources

- This web tool allows you to process the data files produced by that instrument chain, which therefore relate to low-frequency magnetic flux density measurements (not limited to gradient fields in MRI).
- The radiation protection parameters required by law are derived, including the weighted peak indices for stimulation effects referred to any regulatory limit (not just those for which the index is provided directly from the meter display).



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

This approach used in the 2 tools has been expanded in order to accept files of the most generic type possible, potentially produced by any measurement chain, as long as they are in an open format (text file or spreadsheet). 2 possibilities:

- Measurement chain already known to the system (stored in the database)
- Measurement chain not present in the database. The user provides the description of the data format.



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Loading, recognition, and processing of measurement data files in the time or frequency domain

Application structured in 3 sections (time domain, frequency domain, generic data), providing:

- Procedures developed for specific chains (divided into time and frequency domains)
- Generalized acquisition system for data files obtained from chains stored in DB
- Generalized acquisition for data files obtained from chains not stored in DB: the user must provide information about the structure of the data file



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Creating homogeneous format files

LabVIEW Measurement Writer_Version 2 Reader_Version 2 Separator Tab Decimal_Separator . Multi_Headings No X_Columns Multi Time_Pref Relative Operator BIONIR4 Date 2015/03/16 Time 16:26:32.33666133800615 ***End_of_Header***									
Channels 3	1	Block	B	Bx	By	Bz	Units	Temperature	Timestamp
Samples 50000	2	0	0.106400	0.027306	-0.069503	-0.075794	MT	36904	2016.09.21 16:25:25.413001461
Date 2015/03/16	3	0	0.081320	0.067809	-0.042217	-0.015255	MT	36904	2016.09.21 16:25:25.513001461
Time 16:26:32	4	0	0.075802	-0.029535	-0.012355	-0.068710	MT	36904	2016.09.21 16:25:25.613001461
X_Dimension 7	5	0	0.087258	-0.061387	0.022770	-0.004504			
X0 0.0000000	6	0	0.085305	0.049478	-0.004504				
Delta_X 1.0000									
End_of_Header									
X_Value Units:									
0.000000 0									
1.000000 0									
2.000000 0									

A	B	C	D	E	F	G	H	I	J	K
t(us)	X(uT)	Y(uT)	Z(uT)	ISO(uT)	t(us)	X(uT)	Y(uT)	Z(uT)	ISO(uT)	
2	0	0	0.1	0.14	327800	-2.79	-2.99	0.8	4.18	
3	10	0	0	0	327890	-3.09	-3.09	0.9	4.48	
4	20	-0.09	0	0.1	327700	-3.19	-3.19	1	4.83	
5	30	0	0.1	0.1	327710	-3.19	-3.39	1	4.77	
6	40	0	0	0	327720	-3.29	-3.59	1	4.98	
7	50	0	0	0	327730	-3.29	-3.59	1	4.98	
8	60	-0.09	0	0.14	327740	-3.49	-3.79	1.1	5.28	
9	70	-0.09	0.1	0.14	327750	-3.59	-4.39	1.1	5.79	
10	80	0	0.1	0.1	327760	-3.69	-4.79	1.1	6.16	
11	90	0	0.1	0.1	327770	-3.69	-4.89	1.2	6.26	
12	100	-0.09	0.1	0.14	327780	-3.79	-4.99	1.2	6.39	
13	110	-0.09	0.1	0.14	327790	-3.89	-5.09	1.2	6.53	
14	120	0	0	0	327800	-3.99	-5.09	1.3	6.61	
15	130	0	0.1	0.1	327810	-3.99	-5.29	1.3	6.77	
16	140	0	0	0	327820	-4.09	-5.59	1.3	6.9	
17	150	0	0	0	327830	-4.09	-5.59	1.3	7.06	
18	160	0	0	0	327840	-4.19	-5.89	1.3	7.2	
19	170	0	0	0	327850	-4.19	-5.79	1.3	7.28	
20	180	0	0	0	327860	-4.39	-5.89	1.4	7.49	
21	190	0	0	0	327870	-4.39	-5.99	1.5	7.59	
22	200	-0.09	0.1	0.14	327880	-4.49	-6.09	1.5	7.73	
23	210	-0.09	0.1	0.14	327890	-4.59	-6.09	1.5	7.79	
24	220	0	0	0	327900	-4.59	-6.19	1.4	7.85	
25	230	-0.09	0.1	0.14	327910	-4.69	-6.39	1.5	8.08	
26	240	-0.09	0.1	0.14	327920	-4.79	-6.49	1.6	8.24	
27	250	-0.09	0.1	0.14	327930	-4.69	-6.59	1.6	8.26	
28	260	-0.09	0.1	0.14	327940	-4.79	-6.69	1.6	8.4	
29	270	-0.09	0.1	0.14	327950	-4.79	-6.79	1.6	8.53	

Freq	Total	X	Y	Z	Limit
MHz	V/m	V/m	V/m	V/m	V/m
0.0000	0.0017	0.0010	0.0010	0.0010	---
0.0025	0.0017	0.0010	0.0010	0.0010	---
0.0050	0.0017	0.0010	0.0010	0.0010	---
0.0075	0.0017	0.0010	0.0010	0.0010	---
0.0100	44.600	25.796	25.625	25.828	87.000
0.0125	11.646	6.7344	6.7031	6.7344	87.000
0.0150	1.1999	0.6875	0.7031	0.6875	87.000
0.0175	0.1371	0.0938	0.0625	0.0781	87.000
0.0200	0.1449	0.0781	0.0938	0.0781	87.000
0.0225	0.1353	0.0781	0.0781	0.0781	87.000
0.0250	0.1539	0.0938	0.0781	0.0938	87.000
0.0275	0.1269	0.0781	0.0625	0.0781	87.000
0.0300	0.1747	0.0938	0.0781	0.1250	87.000
0.0325	0.2567	0.1094	0.0781	0.2188	87.000

1	tipo	TD			
2	deltat	0.100046			
3	tini	1591.95			
4	grandezza	B			
5	colonne 3		1	tipo	FD
6	0.0001045		2	grandezza	E
7	6.19e-5	4.98e-5	3	RBW	10000
8	1.26e-5	2.3e-5	4	colonne 3	
9	8.18e-5	4.62e-5	5	0	0.0017 0
10	6.99e-5	8.01e-5	6	2500	0.0017 0
11	2.85e-5	7.96e-5	7	5000	0.0017 0
12	7.62e-5	4.49e-5	8	7500	0.0017 0
13	6.12e-5	8.51e-5	9	10000	44.6 87
14	0.0001071		10	12500	11.646 87
15	8.0e-7	7.67e-7	11	15000	1.1999 87
16	7.1e-5	3.52e-5	12	17500	0.1371 87
17	9.62e-5	4.43e-5	13	20000	0.1449 87
			14	22500	0.1353 87
			15	25000	0.1539 87
			16	27500	0.1269 87
			17	30000	0.1747 87
			18	32500	0.2567 87
			19	35000	0.3175 87
			20	37500	0.3387 87
			21	40000	0.3086 87



LabVIEW Measurement

Writer_Version 2

Reader_Version 2

Separator Tab

Decimal_Separator .

Multi_Headings No

X_Columns Multi

Time_Pref Relative

Operator BIONIRA

Date 2015/03/16

Time 16:26:32.3366613388061523437

End_of_Header

Channels 3

Samples 50000 50000 50000

Date 2015/03/16 2015/03/16

Time 16:26:32.3366613388061523437 16:26:32.3366613388061523437 16:26:32.3366613388061523437

X_Dimension Time Time Time

XD 0.0000000000000000E+0 0.0000000000000000E+0 0.0000000000000000E+0

Delta_X 1.000000 1.000000

End_of_Header

X_Value Untitled (Extracted) X_Value Untitled 1 (Extracted) X_Value Untitled 2 (Extracted) Comment

0.000000 0.023041 0.000000 0.021973 0.000000 0.023651

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2.000000 0.022888 2.000000 0.021362 2.000000 0.022736

3.000000 0.023193 3.000000 0.021820 3.000000 0.023193

4.000000 0.023193 4.000000 0.021362 4.000000 0.023193

5.000000 0.022888

6.000000 0.024414

7.000000 0.023193

Catena da archivio

Struttura file

File utente

Istruzioni

Foglio di Excel

0

Numero di righe iniziali da saltare

13

Salta righe fino a

Progressivo colonne da saltare

2.6

Grandezze fisiche

f, Ex, Ey, Ez

Separatore tra i dati

Spazio

Caratteri risultato non valido

Salta la riga per risultato non valido

Sostituisci risultato non valido

0

Numero di ripetizioni delle colonne di dati

1

JSON

```

{
  "foglio": "0",
  "flag_salta_righe": "0",
  "num_righe_iniziali": "13",
  "stringa_salta_righe": "",
  "prog_col": "2.6",
  "intestazione": "f, Ex, Ey, Ez",
  "unita_msura": "MHz, Vm, Vm, Vm",
  "flag_separatore": "4",
  "non_valido": "-",
  "flag_sost": "1",
  "sostituzione": "0",
  "ripetizioni": "1",
  "flag_dominio": "2",
  "col_tempo": "1",
  "formato_tempo": "0",
  "col_frequenza": "1"
}

```

1	tipo	TD
2	deltat	0.100046
3	tini	1591.95
4	grandezza	B
5		3
6		0.045 2.51e-5 -5.48e-5
7	6.19e-5	4.98e-5 -0.0001193
8	1.26e-5	2.3e-5 -5.4e-5
9	8.18e-5	4.62e-5 -7.83e-5
10	6.99e-5	8.01e-5 -8.53e-5
11	2.85e-5	7.96e-5 -2.08e-5
12	7.62e-5	4.49e-5 -4.3e-5
13	9.12e-5	8.51e-5 1.81e-5
14	0.0001071	8.58e-5 -4.1e-5
15	8.0e-7	7.67e-5 8.0e-7
16	7.1e-5	3.52e-5 3.34e-5
17	9.62e-5	4.43e-5 -1.25e-5

The figure consists of four subplots arranged in a 2x2 grid, illustrating the relationship between magnetic field components and their spectra.

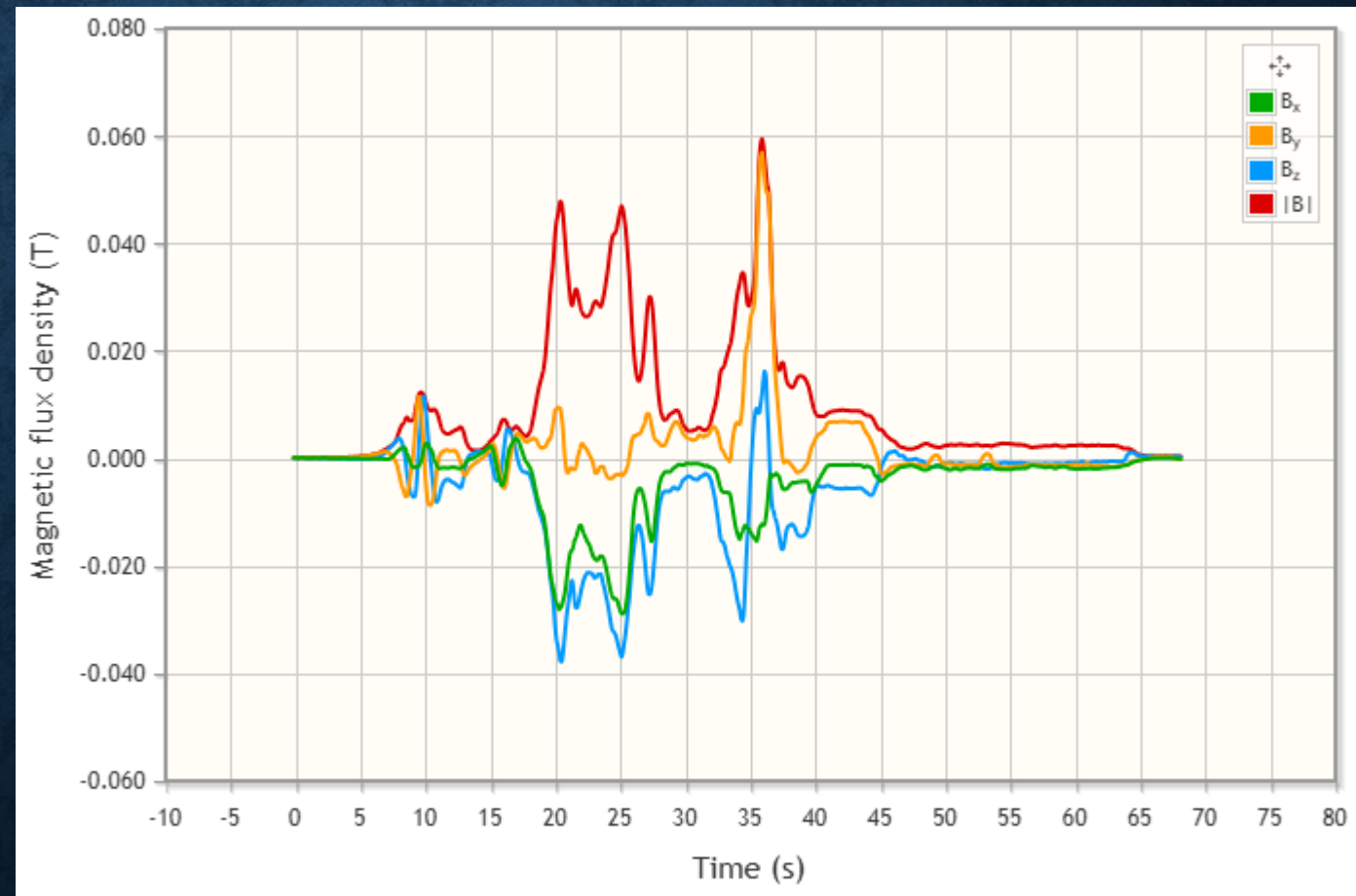
- Top-Left Plot:** Shows the magnetic field components B_x (red), B_y (yellow), B_z (purple), and the magnitude $|B|$ (green) as a function of frequency (Frecuencia (Hz)). The y-axis is labeled "Induzione magnetica (T)". The curves show oscillatory behavior, with $|B|$ having the highest amplitude.
- Top-Right Plot:** Shows the time derivative of the magnetic field, $dB/3s$ (red), as a function of time (Tempo (s)). The y-axis is labeled "dB/3s". The plot shows a sharp peak around 35 seconds.
- Bottom-Left Plot:** Shows the amplitude spectrum (Am) as a function of frequency (Frecuencia (Hz)) for the three components: Spettro X (red), Spettro Y (yellow), and Spettro Z (purple). The y-axis is labeled "Am". The spectra show a broad peak around 100 Hz.
- Bottom-Right Plot:** A zoomed-in view of the $dB/3s$ vs. Tempo (s) plot, showing multiple sharp peaks between 15 and 45 seconds.



PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Data output: components and module of H/B/E fields (condensed or all-data modes)


Data summary	
User file	magnet_2010.txt
Quantity	B (T)
Number of samples	683
Sampling period	100.1 ms
Overall duration	68.34 s
Maximum modulus value	59.40 mT @ 36.02 s
RMS value	15.67 mT

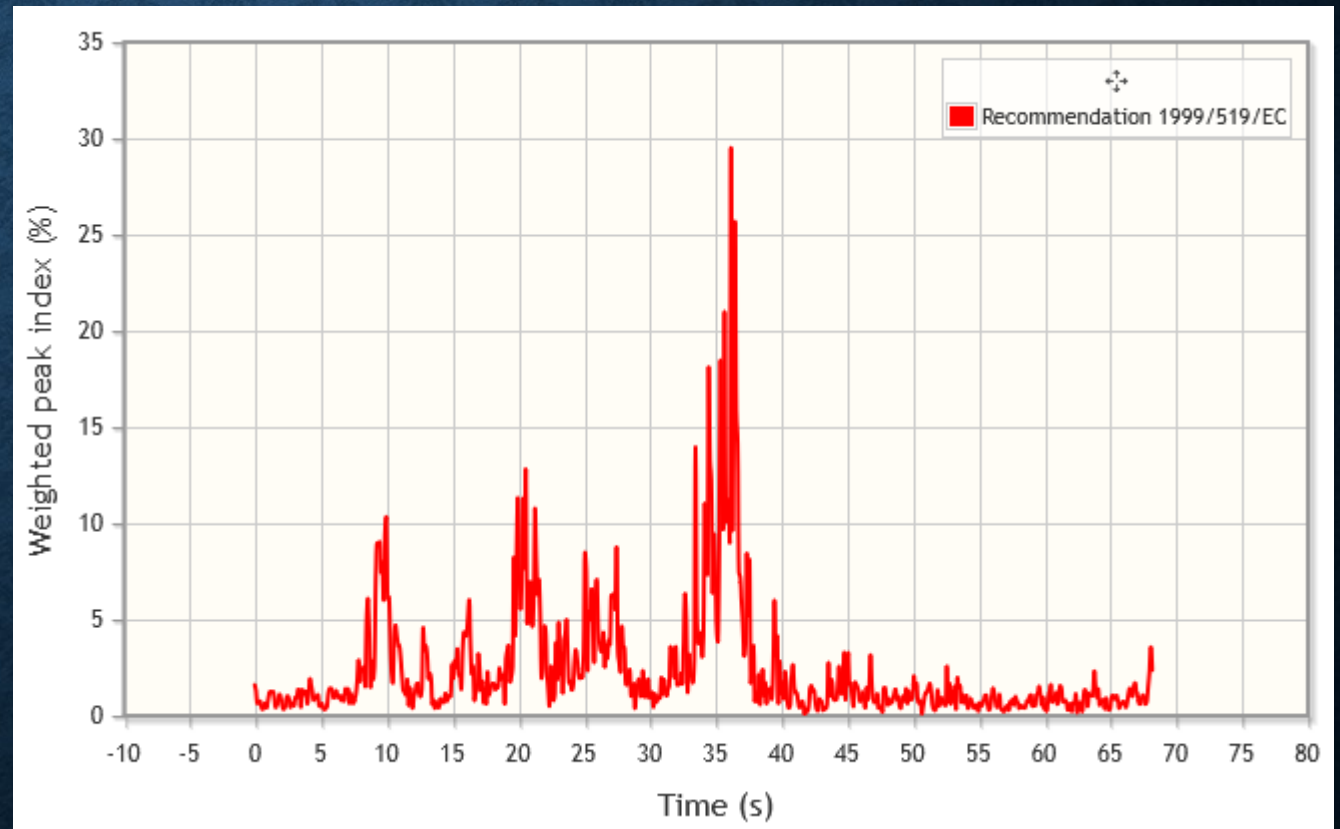




PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

Data output: wheighted peak indices, according to different regulations

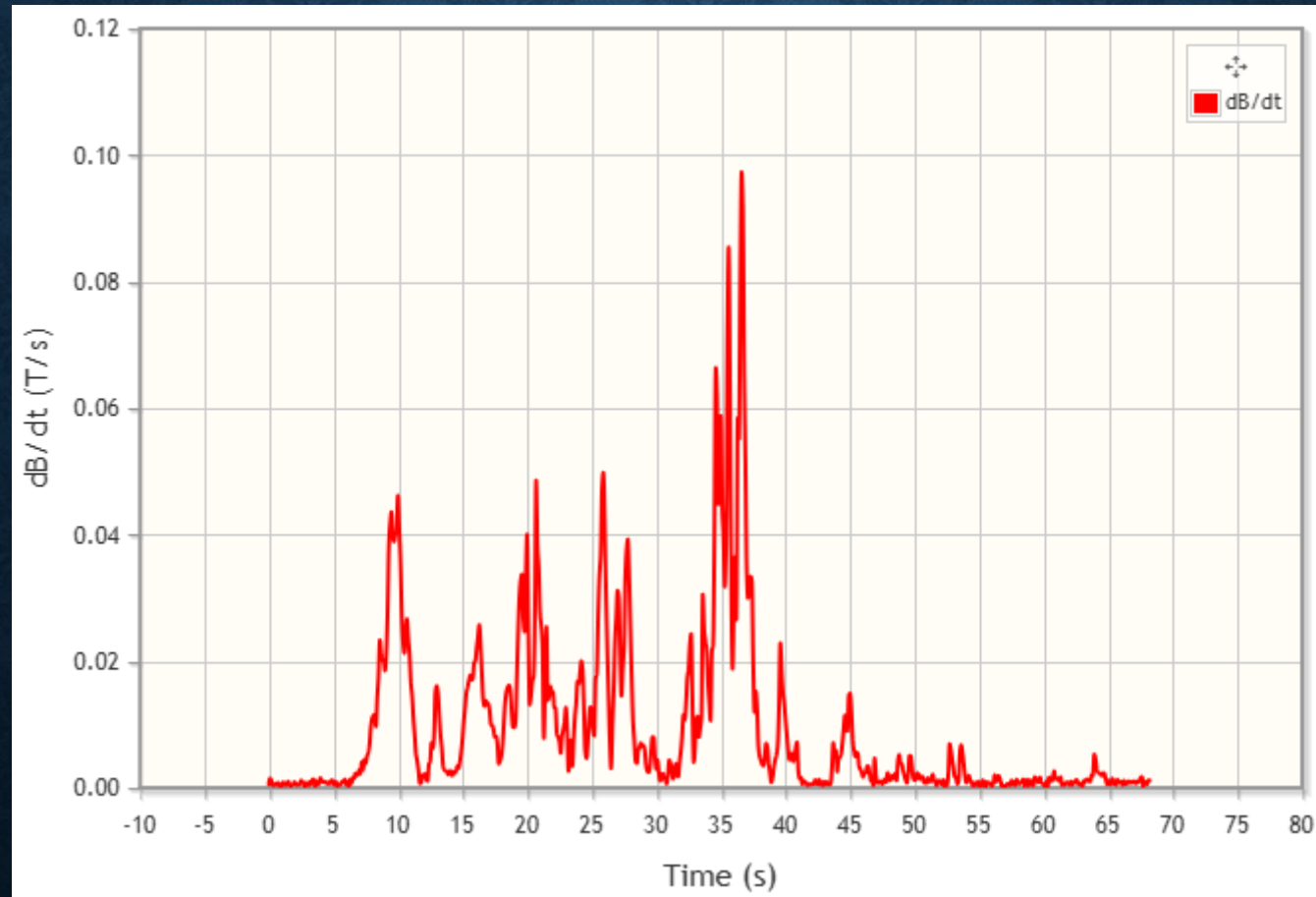
Weighted peak indices 	
Standard file format: wp202509051335381757072138338.txt	
Recommendation 1999/519/EC	29.5%
ICNIRP 1998 Workers	5.9%
ICNIRP 2010 Workers	7.7%
D.Lgs. 81/2008 Lower AV	7.7%
D.Lgs. 81/2008 Upper AV	3.7%
Legislative Decree 81/2008 AV in limbs	1.2%





PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

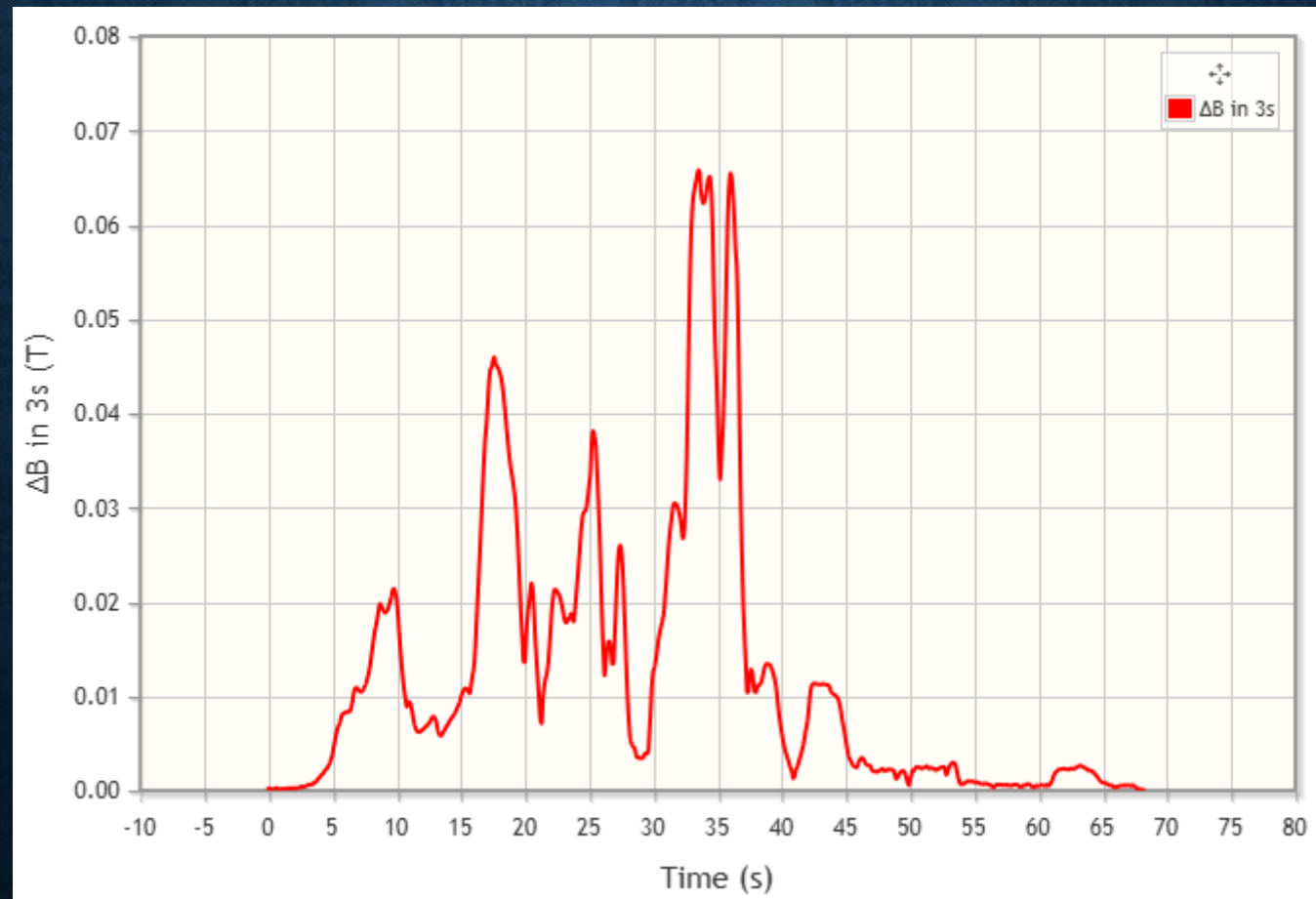
Data output: trend of dB/dt





PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

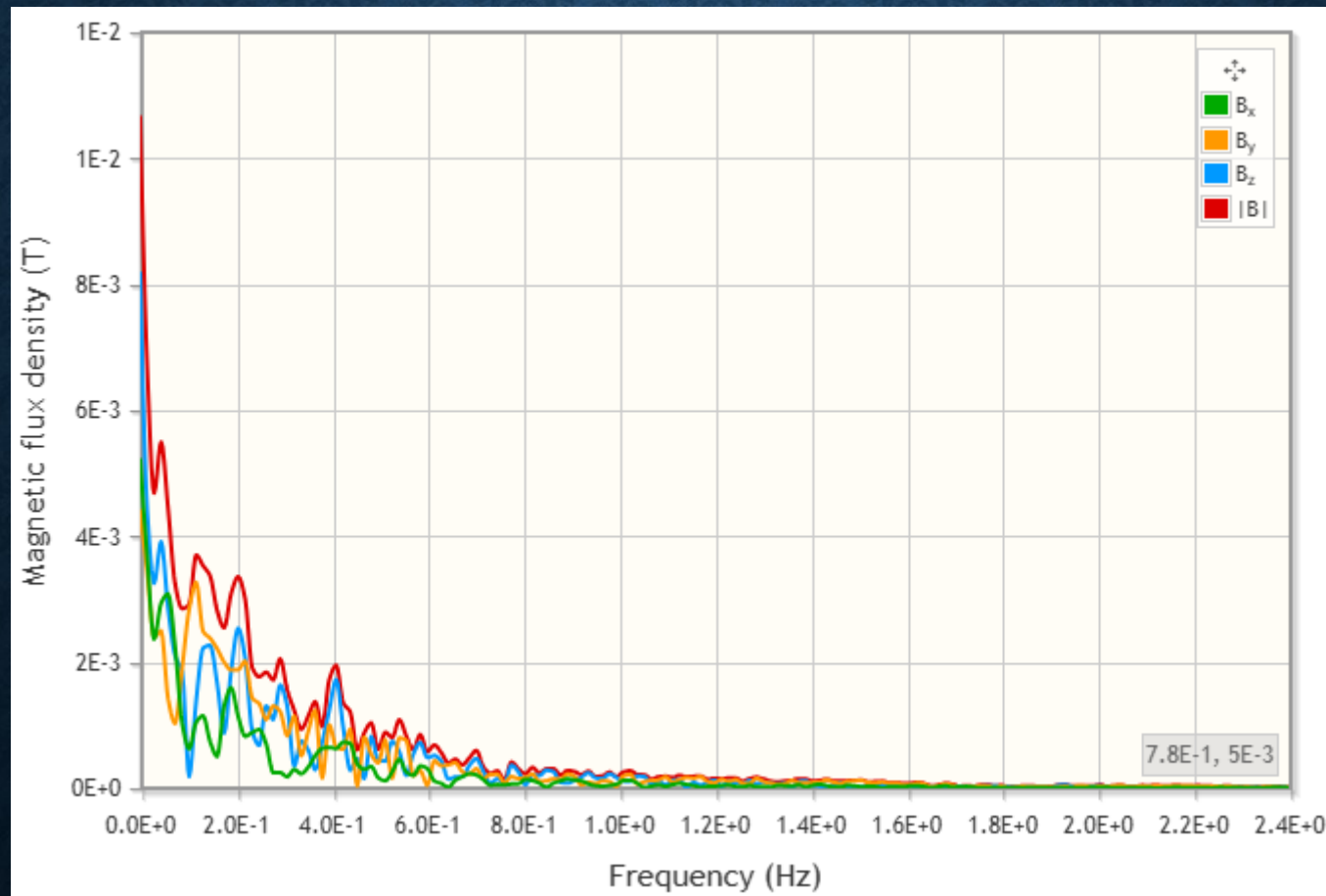
Data output: Max $\Delta B/3s$ and its trend over time





PROCESSING DATA FILES FROM EXPOSURE MEASUREMENTS

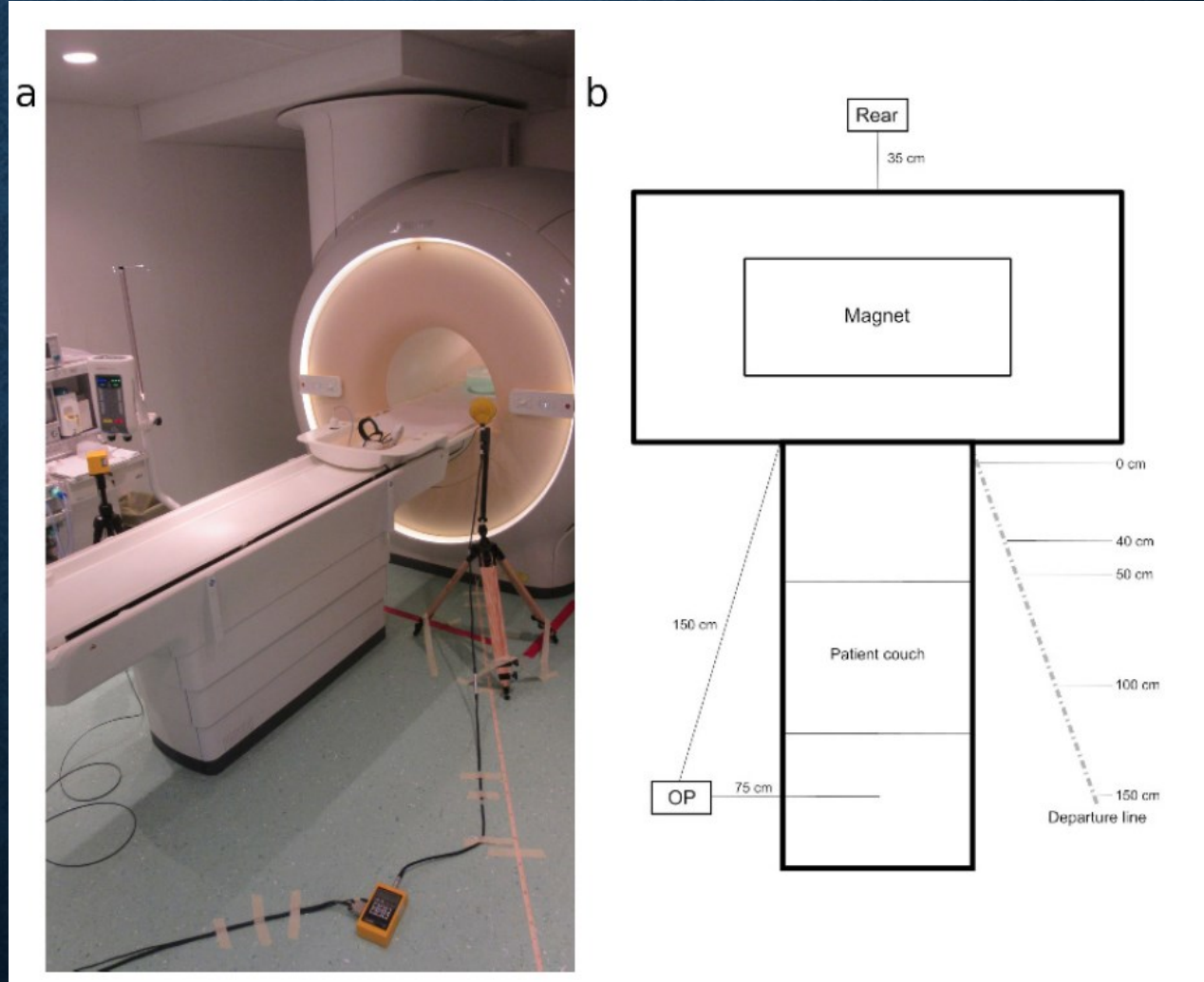
Data output: spectrum in continuous/discrete format





A CASE STUDY: ASSESSMENT OF THE EXPOSURE TO GRADIENT MAGNETIC FIELDS GENERATED BY MRI TOMOGRAPHS

Tests carried out on different tomographs (1 and 1.5 T)

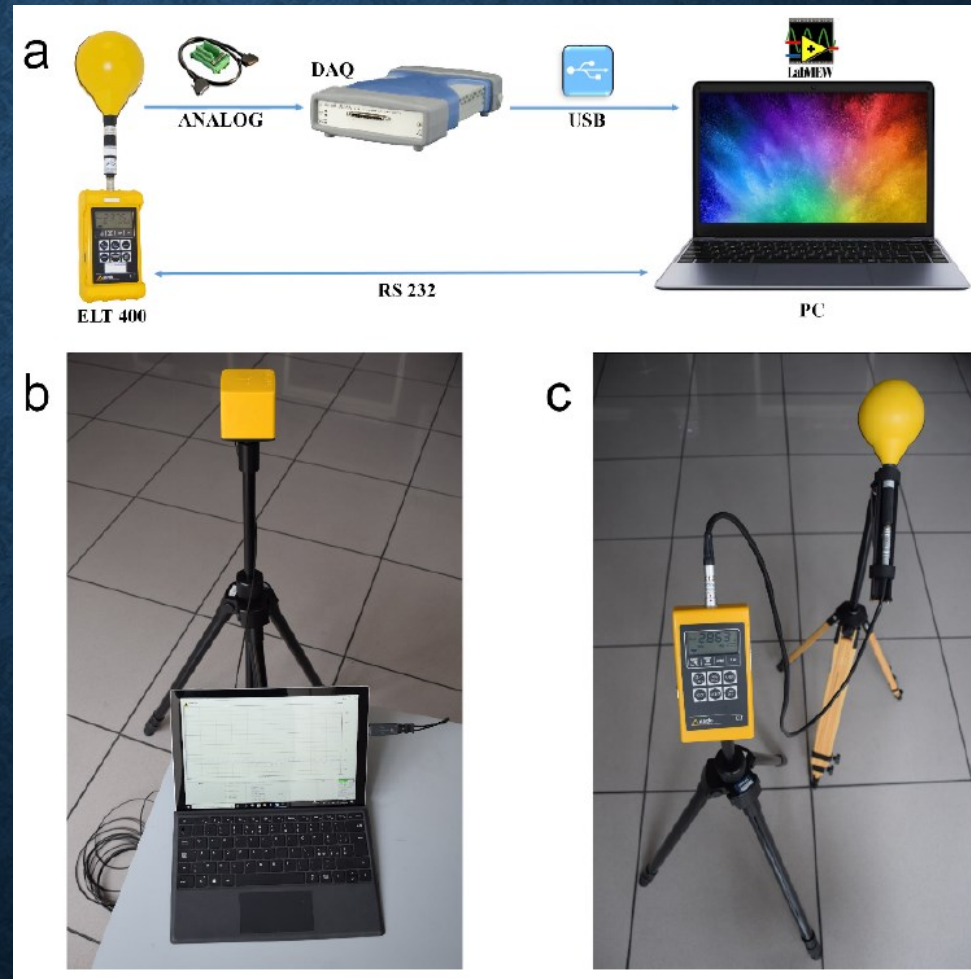




A CASE STUDY: ASSESSMENT OF THE EXPOSURE TO GRADIENT MAGNETIC FIELDS GENERATED BY MRI TOMOGRAPHS

Different instrumental chains:

- Narda ELT-400 probe, data acquired via Agilent ADC
- Narda ELT-400, stand alone setup
- Narda EHP-50F

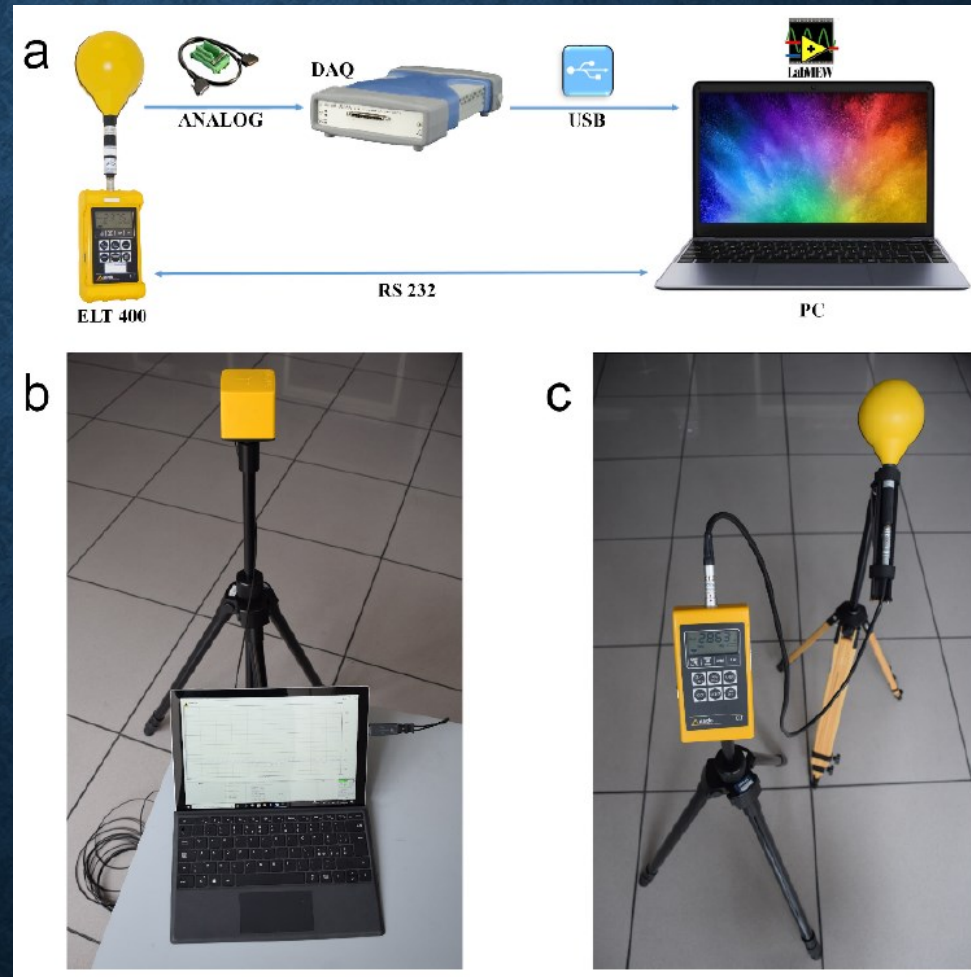




A CASE STUDY: ASSESSMENT OF THE EXPOSURE TO GRADIENT MAGNETIC FIELDS GENERATED BY MRI TOMOGRAPHS

Different instrumental chains:

- Narda ELT-400 probe, data acquired via Agilent ADC: provides raw data (analog output), skilled personnel required for data analysis
- Narda EHP-50F: Provides indexes, but no further analysis is possible





A CASE STUDY: ASSESSMENT OF THE EXPOSURE TO GRADIENT MAGNETIC FIELDS GENERATED BY MRI TOMOGRAPHS

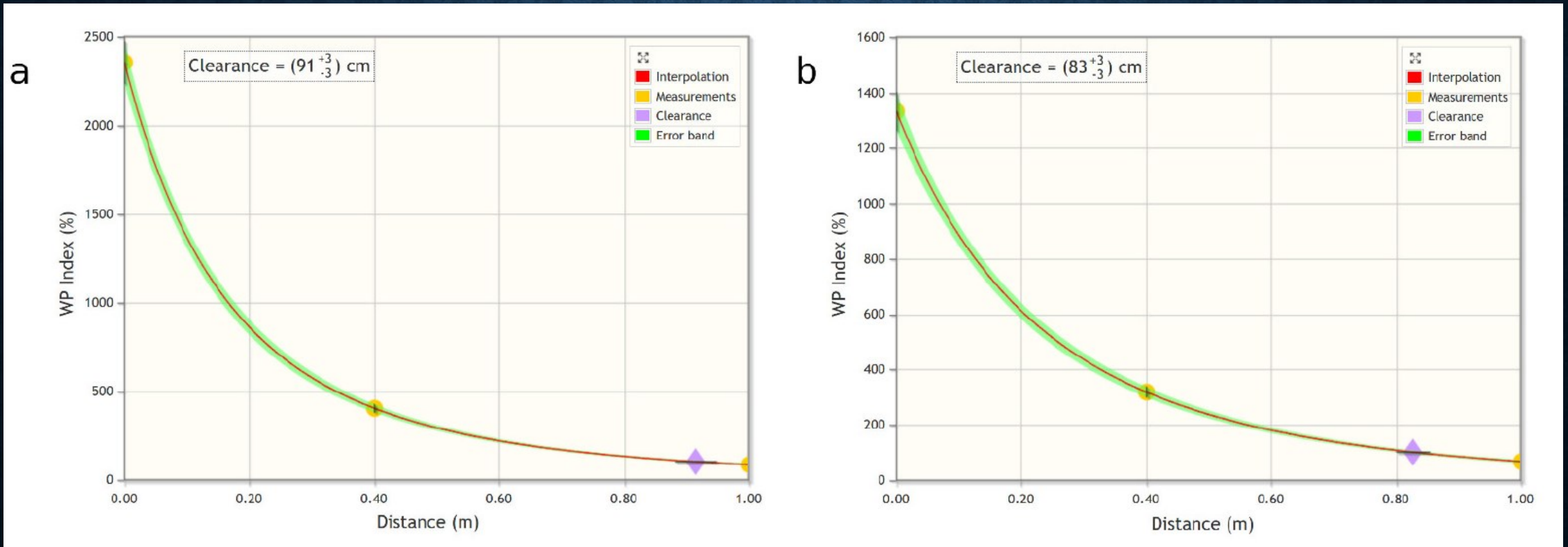
IWP are calculated at different distances from the gantry

Sequence	Distance (cm)	Height (cm)	RLs 1999/519/EC	Low ALs 2013/35/EU	High ALs 2013/35/EU
B1	0	100	1389%	45.0%	45.6%
	OP		22.5%	0.70%	0.60%
B2	0	100	2356%	76.0%	72.5%
	40		401%	13.0%	12.0%
	100		83%	2.50%	2.10%
	OP		51%	1.57%	1.25%
	0	160	1332%	40.1%	40.8%
	40		317%	9.70%	9.17%
	100		66%	2.00%	1.65%



A CASE STUDY: ASSESSMENT OF THE EXPOSURE TO GRADIENT MAGNETIC FIELDS GENERATED BY MRI TOMOGRAPHS

Interpolation of indices is performed to get a compliance area





MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic flux density generated by a system of various kinds of conductors, whose geometries can be defined as combination of several basic models.

The application interface is divided into several sections:

- Sorgenti e grigliato di calcolo**:
 - Definizione delle sorgenti**:
 - Numero di strutture: 12
 - Forma del segnale: Continua
 - Tipo di struttura: Bobina circolare 3D
 - Corrente di picco: 190 A
 - Fase: 0
 - Geometria della struttura n. 1**:
 - X_{centro}: 126.25 mm
 - Y_{centro}: 0 mm
 - Z_{centro}: 0 mm
 - Raggio interno: 157 mm
 - Raggio esterno: 356 mm
 - Spessore: 115.5 mm
 - θ: 0°
 - ψ: 90°
 - φ: 0°
 - Numero di spire: 192
 - Verso corrente: Orario
 - Numero di segmenti: 0
 - Replica alla struttura n. >>
- Grigliato di calcolo**:
 - SRID: Sistema di riferimento locale
 - Y_{ini}: 0 mm
 - Z_{ini}: 0 mm
 - Passo: mm
 - Passi lungo X: 350
 - Passi lungo Y: 0
 - Passi lungo Z: 0
 - Unità di output: μT
- Impegni geometrici**:
 - Tipo di geometria: Seleziona...

- Buttons**: Calcola, Reset, JSON, Crea GPKG, Da grigliato.

Red arrows point from various diagrams to the application interface:

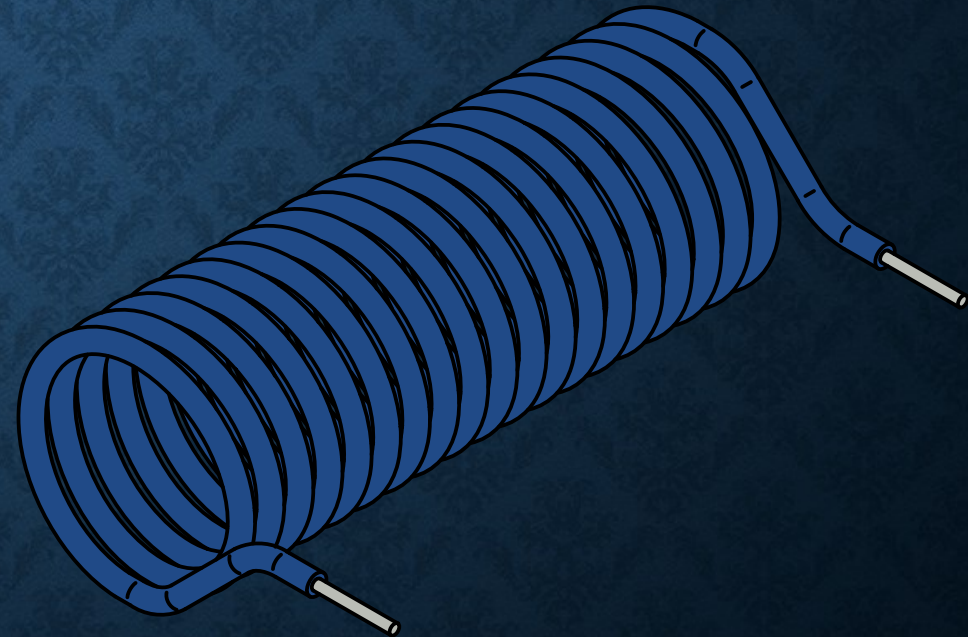
- A 3D model of a solenoid coil points to the "Numero di strutture" and "Tipo di struttura" fields.
- A 2D diagram of a triangular conductor points to the "Forma del segnale" field.
- A 3D model of a rectangular conductor points to the "Raggio interno" and "Raggio esterno" fields.
- A 3D model of a toroidal core points to the "Raggio interno" and "Raggio esterno" fields.
- A 2D diagram of a circular conductor points to the "Raggio interno" and "Raggio esterno" fields.
- A 3D model of a rectangular core points to the "Raggio interno" and "Raggio esterno" fields.



MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

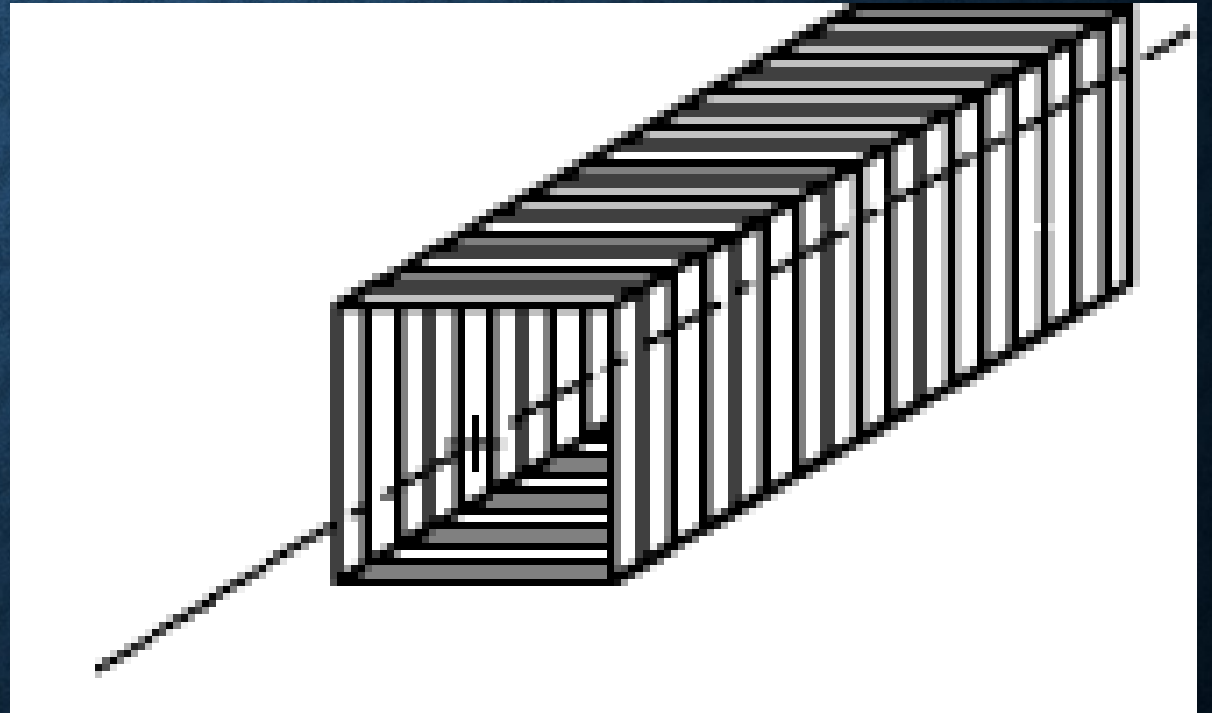




MAGNETIC FLUX DENSITY CALCULATION

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- Circular section solenoid
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- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

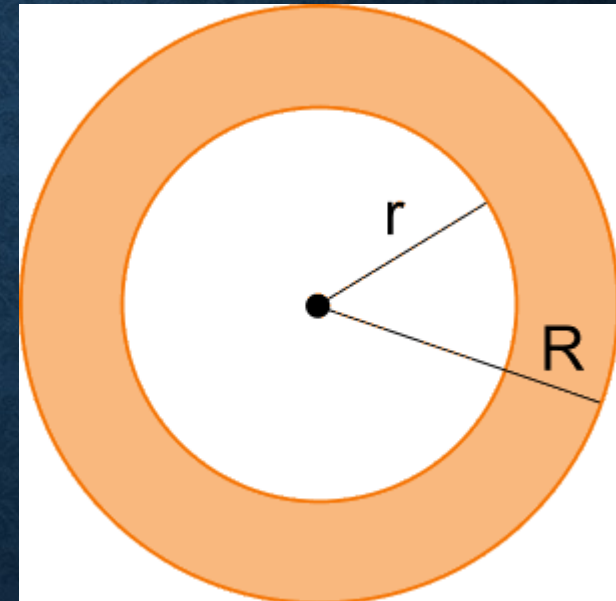




MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

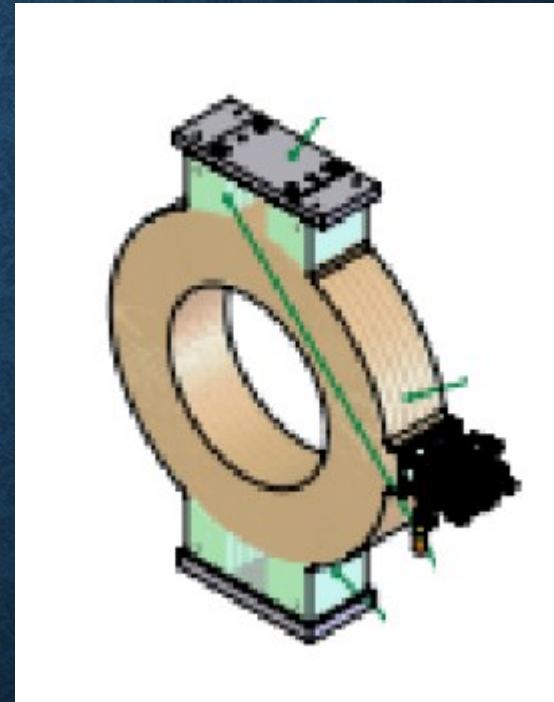




MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

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MAGNETIC FLUX DENSITY CALCULATION

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- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

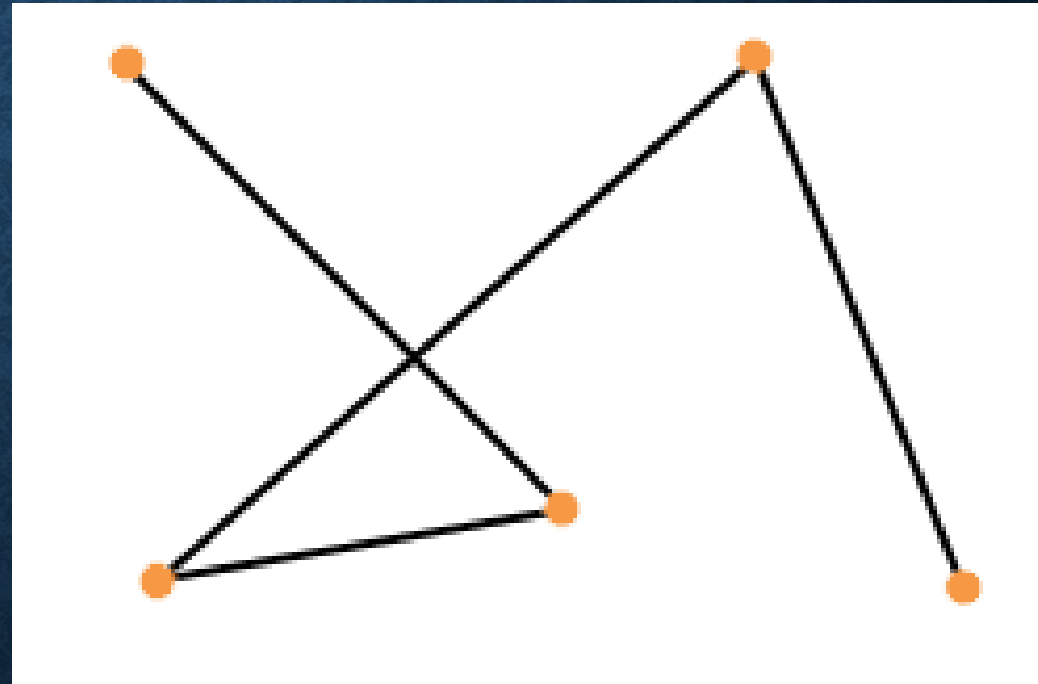




MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

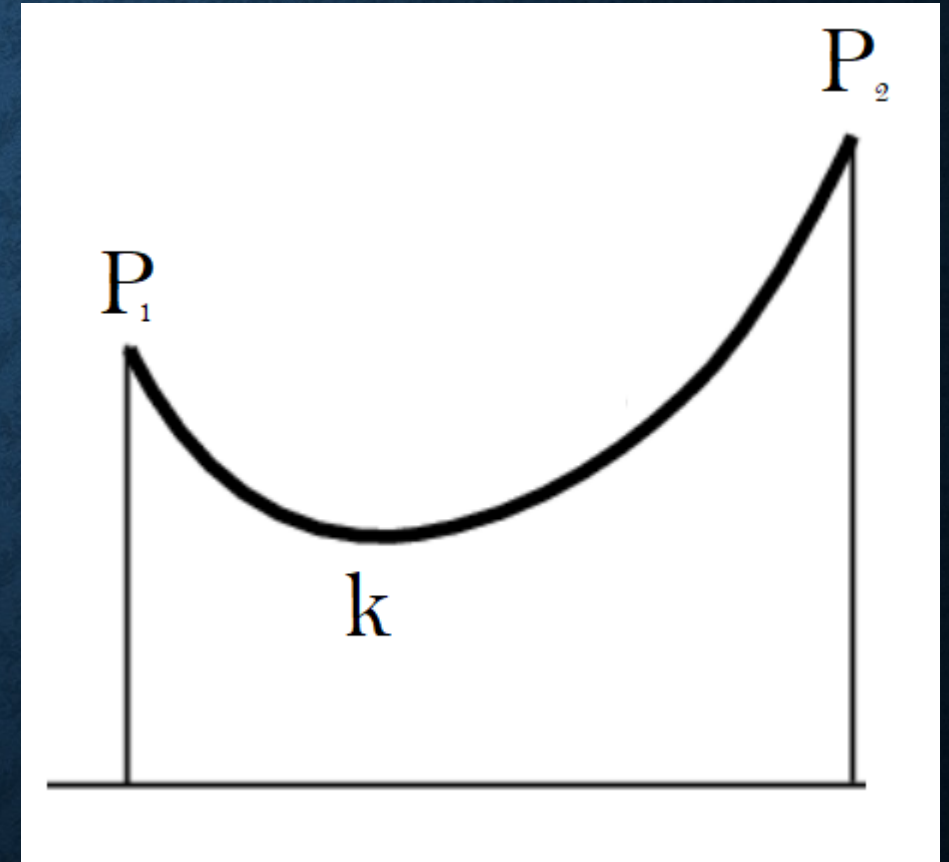




MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files

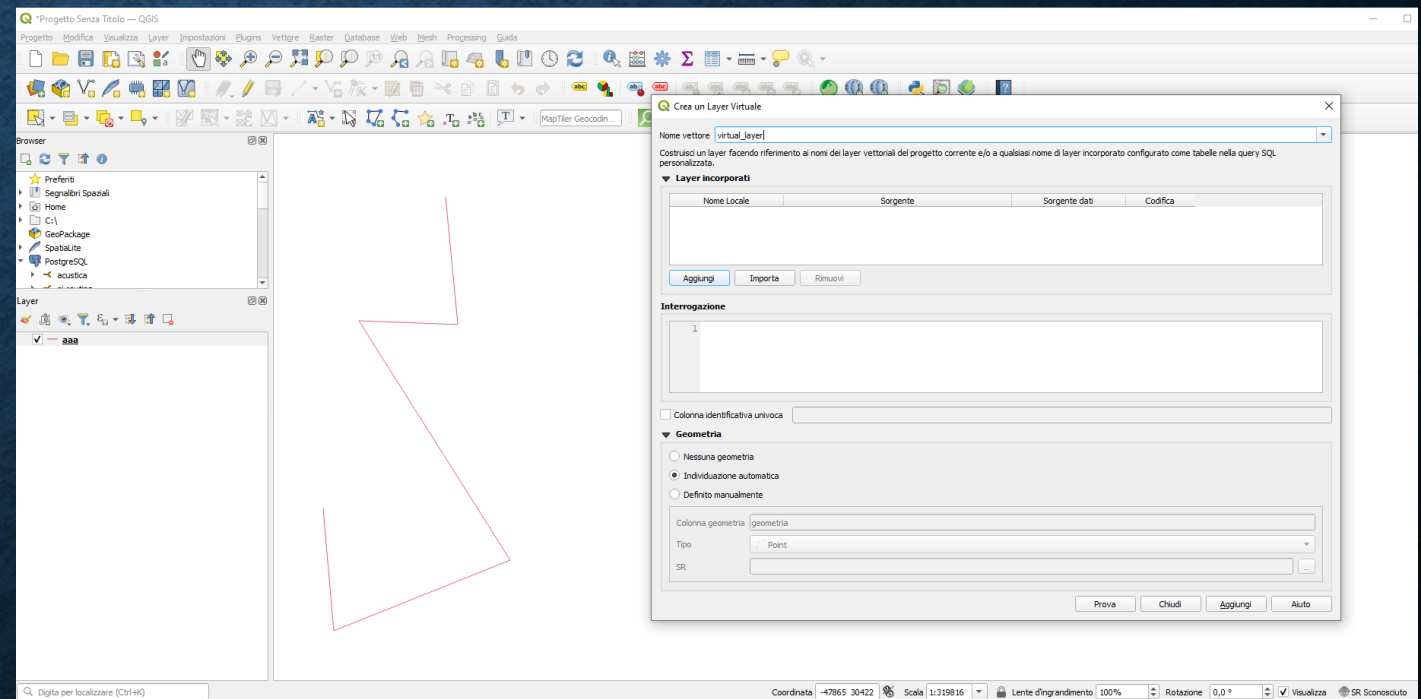




MAGNETIC FLUX DENSITY CALCULATION

An application calculates the magnetic induction generated by a set of conductors of type:

- Circular section solenoid
- Rectangular section solenoid
- Corona coil
- 3D circular coil
- 3D rectangular coil
- Broken line
- Catenary
- Geometry imported from GIS files





MAGNETIC FLUX DENSITY CALCULATION

In the various types of sources, the simplest constituent element can be:

- a segment (as in the case of the catenary, which is approximated by a broken line)
- a circular loop

The contribution of the field at each point of the calculation grid is determined for each elementary source (segment or circular loop) and the results are then added.



MAGNETIC FLUX DENSITY CALCULATION

The user can:

- specify up to 12 configurations of conductors of these types
- define their geometric and electrical characteristics
- calculate the value of magnetic induction in a regular grid



MAGNETIC FLUX DENSITY CALCULATION

- Geometries can be positioned and oriented appropriately in space
- Any set of conductors that can be represented as a combination of simple configurations can be described.

Sorgenti e grigliato di calcolo Risultati del calcolo Presentazione ed istruzioni Un caso studio

Definizione delle sorgenti

Numero di strutture 12

Forma del segnale Continua

1 2 3 4 5 6 7 8 9 10 11 12

Tipo di struttura Bobina circolare 3D

Corrente di picco 190 A

Fase 0°

Geometria della struttura n. 1

Xcentro 126.25 mm

Ycentro 0 mm

Zcentro 0 mm

Raggio interno 157 mm

Raggio esterno 356 mm

Spessore 115.5 mm

θ 0°

ψ 90°

φ 0°

Numero di spire 192

Verso corrente Orario

Numero di segmenti 0

Replica alla struttura n. ...

Grigliato di calcolo

SRID Sistema di riferimento locale

Xini 0 mm

Yini 0 mm

Zini 0 mm

Passo 10 mm

Passi lungo X 350

Passi lungo Y 0

Passi lungo Z 0

Unità di output μT

Impegni geometrici

Tipo di geometria Seleziona...

Da grigliato Crea GPKG

Calcola Reset JSON



MAGNETIC FLUX DENSITY CALCULATION

- The calculation is performed in free space
- The presence of ferromagnetic elements inside the coils is not considered
- Nor other objects in the surrounding space

Sorgenti e grigliato di calcolo Risultati del calcolo Presentazione ed istruzioni Un caso studio

Definizione delle sorgenti

Numero di strutture 12

Forma del segnale Continua

1 2 3 4 5 6 7 8 9 10 11 12

Tipo di struttura Bobina circolare 3D

Corrente di picco 190 A

Fase 0°

Geometria della struttura n. 1

X_{centro} 126.25 mm

Y_{centro} 0 mm

Z_{centro} 0 mm

Raggio interno 157 mm

Raggio esterno 356 mm

Spessore 115.5 mm

θ 0°

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Numero di spire 192

Verso corrente Orario

Numero di segmenti 0

Replica alla struttura n. ... >>

Grigliato di calcolo

SRID Sistema di riferimento locale

X_{ini} 0 mm

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Passo 10 mm

Passi lungo X 350

Passi lungo Y 0

Passi lungo Z 0

Unità di output μ T

Impegni geometrici

Tipo di geometria Seleziona...

Da grigliato

Crea GPKG

Calcola

Reset

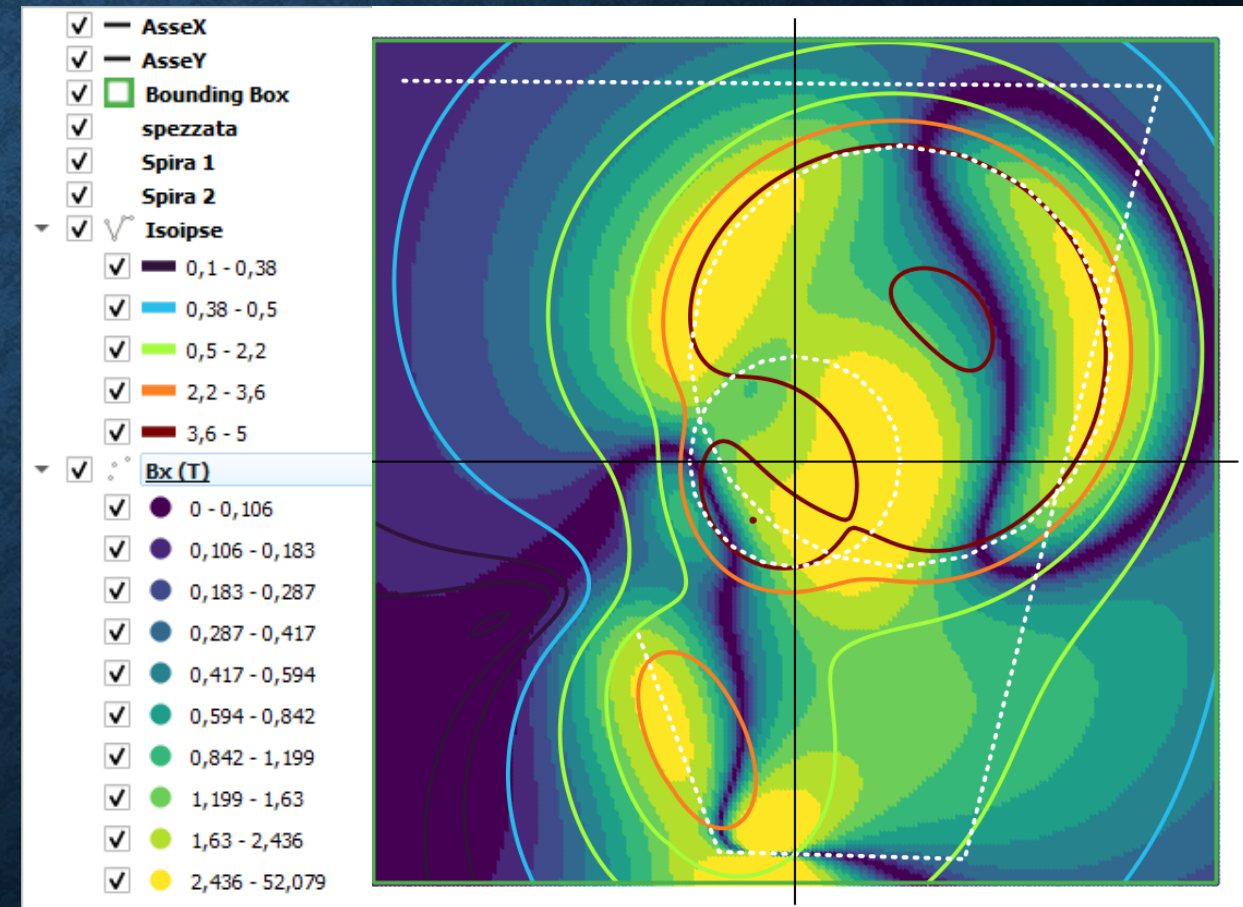
JSON



MAGNETIC FLUX DENSITY CALCULATION

Example of expected output:

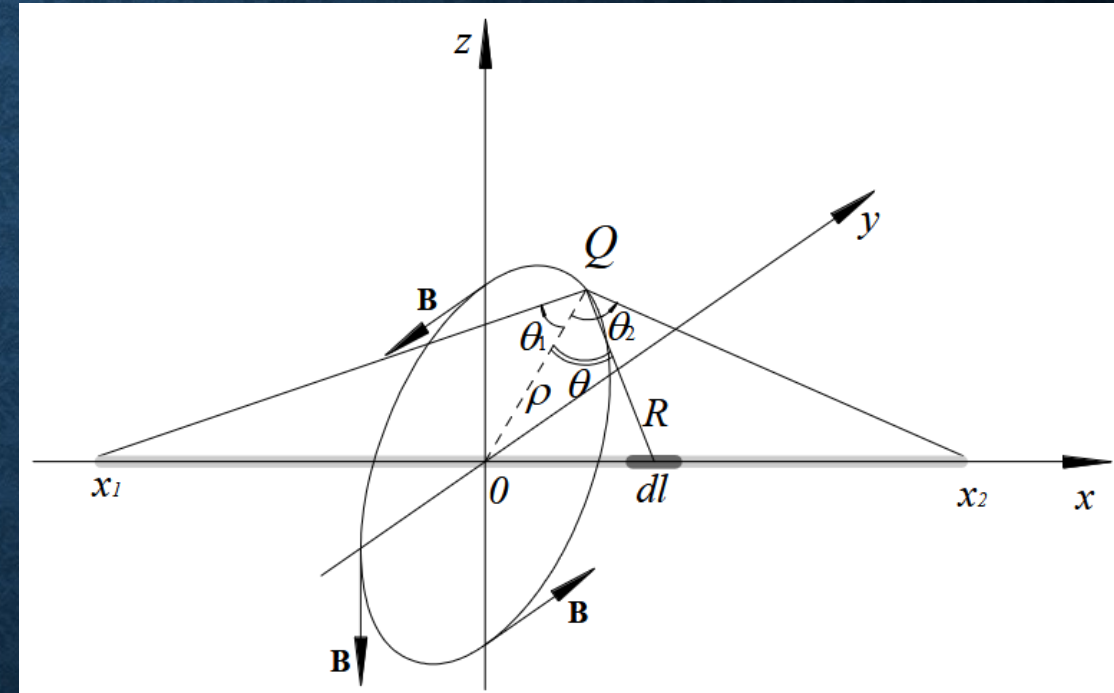
- 3 simple sources (one broken line, 2 circular loops)
- Field map in QGIS
- Isohyps
- Overlap with sources and bounding boxes (of the calculation grid)





MAGNETIC FLUX DENSITY CALCULATION

The solution to the field calculation of a segment carrying current is quite simple.

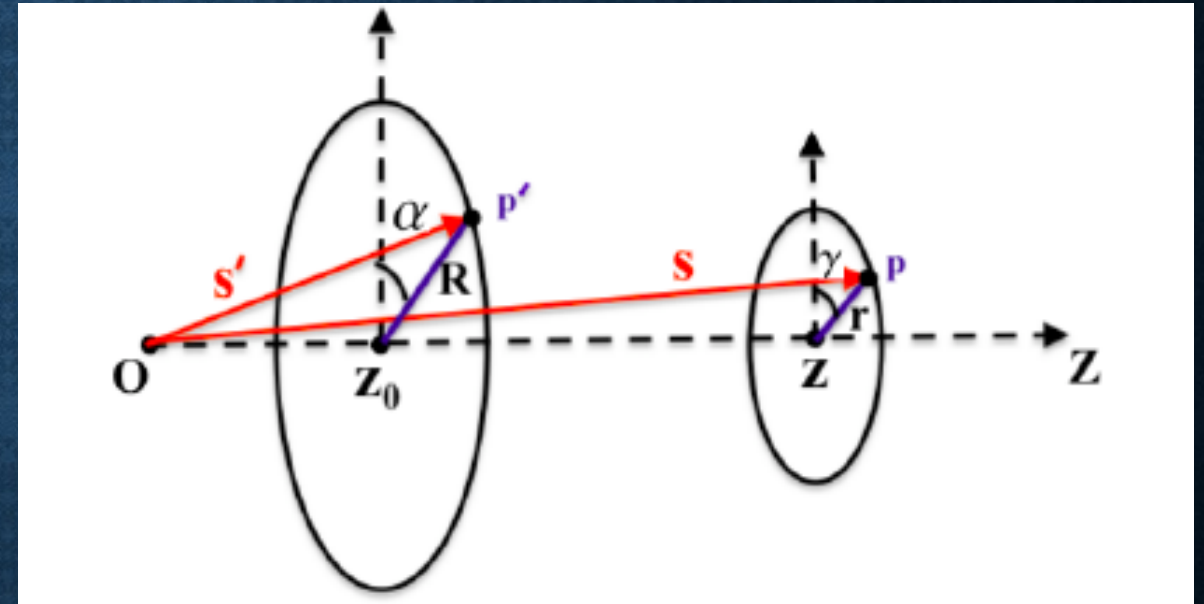


$$\mathbf{B} = \frac{\mu_0 I}{4\pi\rho} (\sin \theta_2 - \sin \theta_1) \hat{\mathbf{e}}$$



MAGNETIC FLUX DENSITY CALCULATION

- The solution in all space in the case of a circular loop requires more complex mathematical considerations
- It starts from the determination of the vector potential.





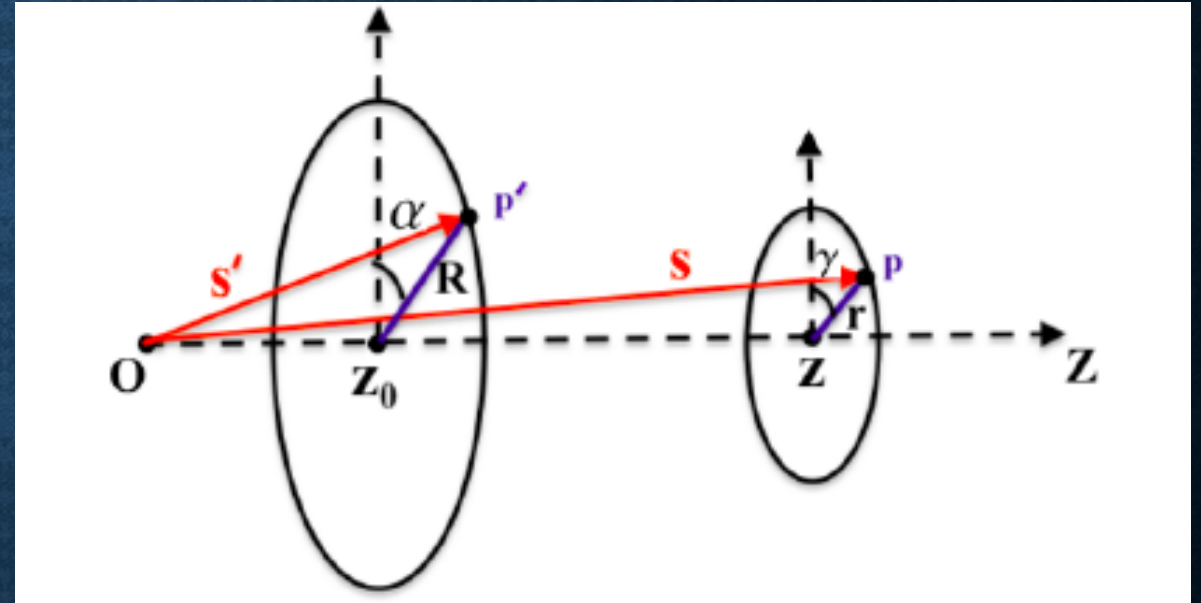
MAGNETIC FLUX DENSITY CALCULATION

Magnetic flux is a zero-divergence field, it can be expressed as a curl of a potential field:

$$\vec{B} = \vec{\nabla} \times \vec{A}$$

and by choosing the Coulomb gauge we get the solution :

$$\vec{A} = \frac{\mu_0 I}{4\pi} \oint_C \frac{\vec{dl}}{s}$$





MAGNETIC FLUX DENSITY CALCULATION

The longitudinal and radial components for the magnetic flux density are obtained :

$$B_z = \frac{\mu_0 I}{2\pi \sqrt{z^2 + (R + r)^2}} \left(\frac{R^2 - z^2 - r^2}{z^2 + (r - R)^2} E(k) + K(k) \right)$$
$$B_r = \frac{\mu_0 z I}{2\pi r \sqrt{z^2 + (R + r)^2}} \left(\frac{R^2 + z^2 + r^2}{z^2 + (R - r)^2} E(k) - K(k) \right)$$

E, K : complete elliptic integrals of I and II species

$$k = 2 \sqrt{\frac{rR}{z^2 + (R + r)^2}}$$
$$E_1(k) = \int_0^{2\pi} \frac{d\theta}{\sqrt{1 - k^2(\sin \theta)^2}}$$
$$E_2(k) = \int_0^{2\pi} \sqrt{1 - k^2(\sin \theta)^2} d\theta$$



MAGNETIC FLUX DENSITY CALCULATION

An alternative procedure, proposed by INFN, leads to :

$$B_r = \frac{\mu_0 I M_z}{2R} \left[\frac{\xi}{2\eta(1+\xi)} \right]^{\frac{3}{2}} \left[{}_2F_1 \left(\frac{3}{2}, \frac{3}{2}; 2; \frac{2\xi}{1+\xi} \right) - {}_2F_1 \left(\frac{1}{2}, \frac{3}{2}; 1; \frac{2\xi}{1+\xi} \right) \right]$$

$$B_z = \frac{\mu_0 I}{2R} \left[\frac{\xi}{2\eta(1+\xi)} \right]^{\frac{3}{2}} \left[(\eta + 1) {}_2F_1 \left(\frac{1}{2}, \frac{3}{2}; 1; \frac{2\xi}{1+\xi} \right) - \eta {}_2F_1 \left(\frac{3}{2}, \frac{3}{2}; 2; \frac{2\xi}{1+\xi} \right) \right]$$

${}_2F_1$: hypergeometric function

$$\xi = \frac{2rR}{r^2 + R^2 + (z - z_0)^2}$$

$$\eta = \frac{r}{R}$$

$$M_z = \frac{z}{R}$$



MAGNETIC FLUX DENSITY CALCULATION

The mathematical equivalence of the two methods is demonstrated using the relations:

$$E\left(\frac{2\xi}{\xi+1}\right) = \frac{\pi}{2} \frac{1-\xi}{1+\xi} {}_2F_1\left(\frac{1}{2}, \frac{3}{2}; 1; \frac{2\xi}{1+\xi}\right)$$

$${}_2F_1\left(\frac{3}{2}, \frac{3}{2}; 2; \frac{2\xi}{1+\xi}\right) = \frac{4E\left(\frac{2\xi}{\xi+1}\right) + \left(\frac{\xi-1}{\xi+1}\right) K\left(\frac{2\xi}{\xi+1}\right)}{\frac{2\pi\xi(1-\xi)}{(\xi+1)^2}}$$



VALIDATION OF THE PROCEDURE

An internal validation of the software results was performed by comparing:

- the exact formulation that uses elliptic integrals
- the exact formulation that uses the hypergeometric function
- the approximate calculation in which the loop is approximated with a broken line, progressively increasing the number of segments constituting the single loop (tests were performed by approximating the loop with 20, 200, and 2000 segments)



VALIDATION OF THE PROCEDURE

Validation result:

- The result obtained in the first 2 cases is coincident up to the 13th digit, the 2 formulations are equivalent, and the discrepancies are due to the implicit approximations in the libraries used. In particular, the language used to perform the calculations is Python 3.9 and the SciPy.special library is used to calculate elliptic integrals and hypergeometric functions.
- The comparison of these results with those obtained from the approximation with a broken line showed a progressive convergence in the number of identical digits as the number of segments with which the loop is approximated increases.
- **Warning:** very different calculation times (10x with a loop approximated by 20 segments)



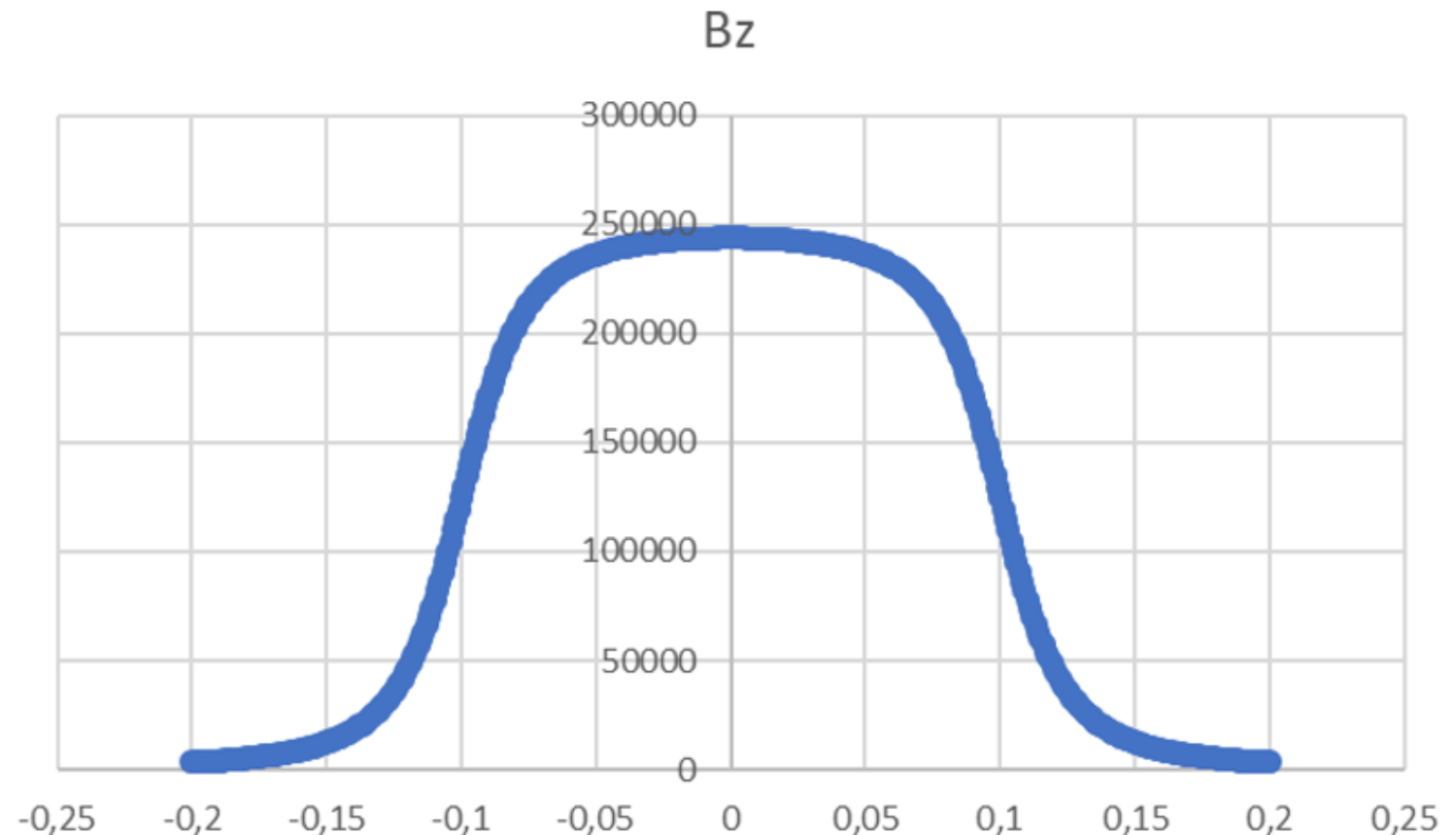
VALIDATION OF THE PROCEDURE

Finally, the expected result at the center of a solenoid:

- 200 coils
- radius: 25 mm
- distance between coils: 1 mm
- current intensity: 200 A

coincides with that expected from the theory for the infinite solenoid:

$$B = \frac{\mu_0 NI}{l}$$





THE RESULTS OF THE CALCULATION

At the end of the calculation:

- some summary values of interest are displayed (calculation time, minimum and maximum values of the induction module)
- it is possible to download the text file containing the results:

X	Y	Z	B	Bx	By	Bz
0.0	0.0	0.0	628.3185307179	0.0	0.0	628.3185307179
0.0	1.0	0.0	0.317730752302	0.0	0.0	0.317730752302
0.0	2.0	0.0	0.039380643144	0.0	0.0	0.039380643144
0.0	3.0	0.0	0.011650089610	0.0	0.0	0.011650089610
0.0	4.0	0.0	0.004912192226	0.0	0.0	0.004912192226
0.0	5.0	0.0	0.002514405568	0.0	0.0	0.002514405568
0.0	6.0	0.0	0.001454895688	0.0	0.0	0.001454895688
0.0	7.0	0.0	0.000916126557	0.0	0.0	0.000916126557
0.0	8.0	0.0	0.000613700191	0.0	0.0	0.000613700191
0.0	9.0	0.0	0.000431005356	0.0	0.0	0.000431005356
...						
100.0	98.0	0.0	0.000000114455	0.0	0.0	0.000000114455
100.0	99.0	0.0	0.000000112751	0.0	0.0	0.000000112751
100.0	100.0	0.0	0.000000111072	0.0	0.0	0.000000111072

Ready to be imported
in Excel, QGIS...



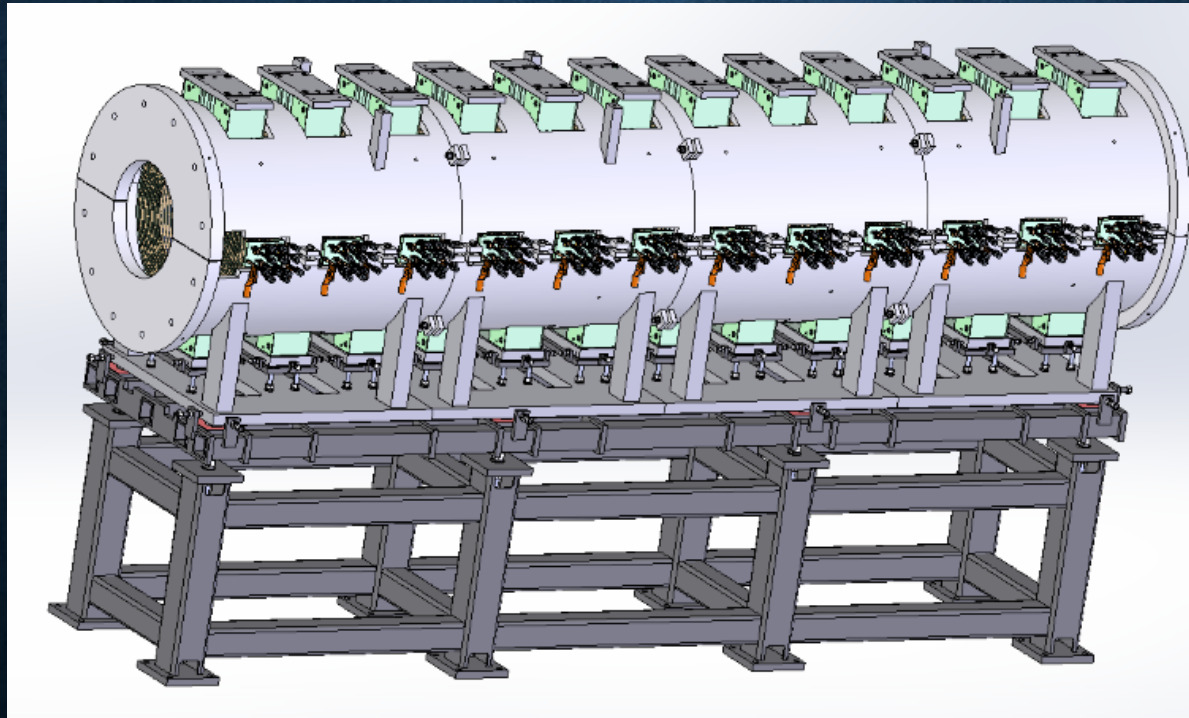
THE RESULTS OF THE CALCULATION

At the end of the calculation :

- ...
- it is possible to download a zip file containing the source geometries in GeoPackage format
- it is possible to set 2 values (for 2 Cartesian axes) among those for which the calculation was performed in the grid and display the trend of the field (modulus and components) along the third coordinate in the graph.

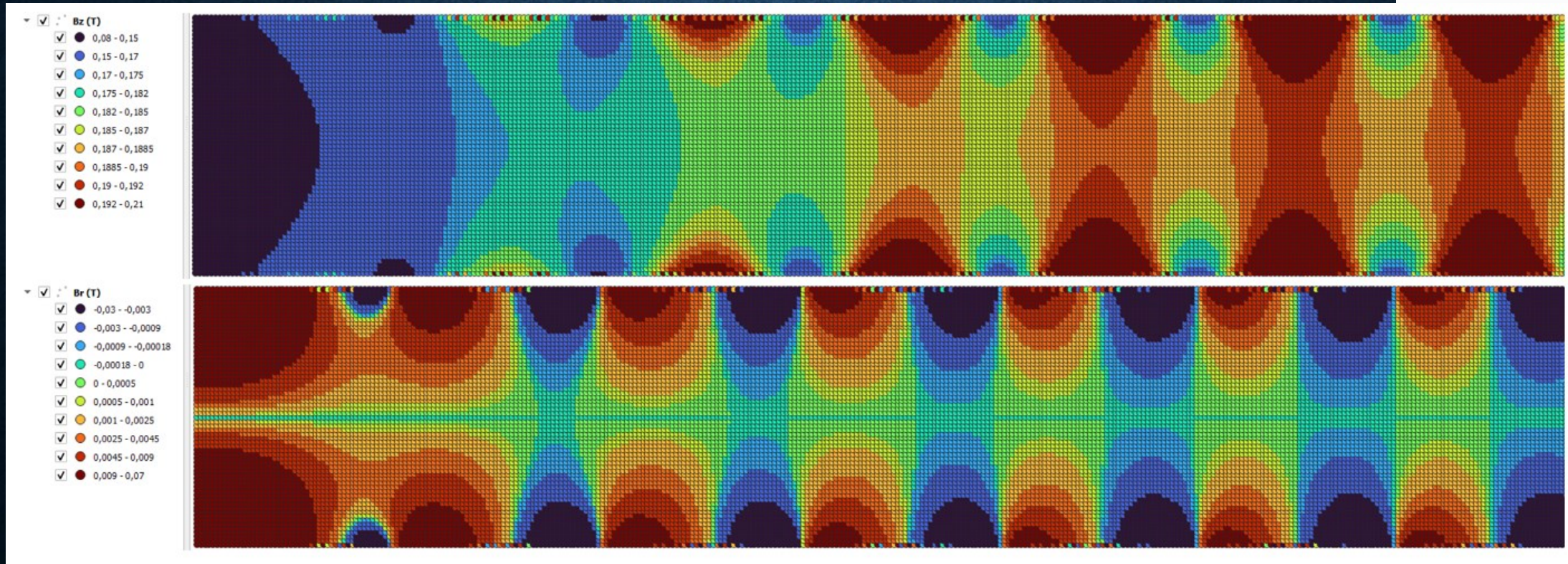
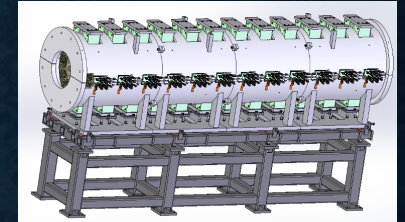
PRACTICAL APPLICATIONS

In the accelerator field, there are several relevant applications of focusing systems for charged particle beams using magnetic lenses.



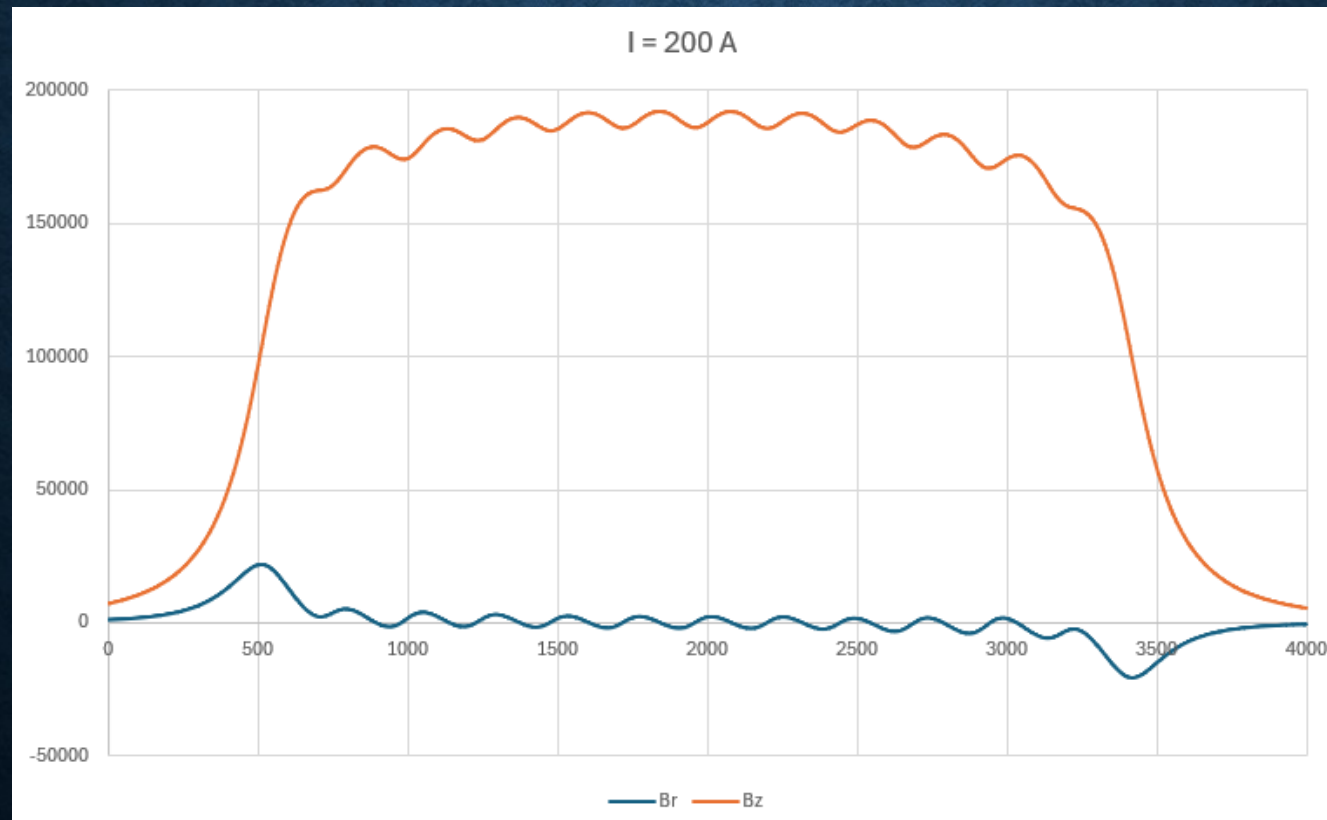
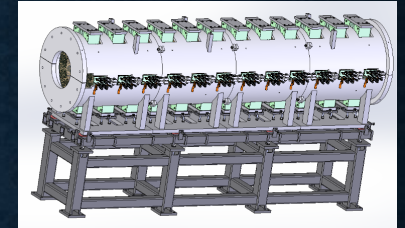
PRACTICAL APPLICATIONS

Maps with the axial (above) and radial (below) field components.



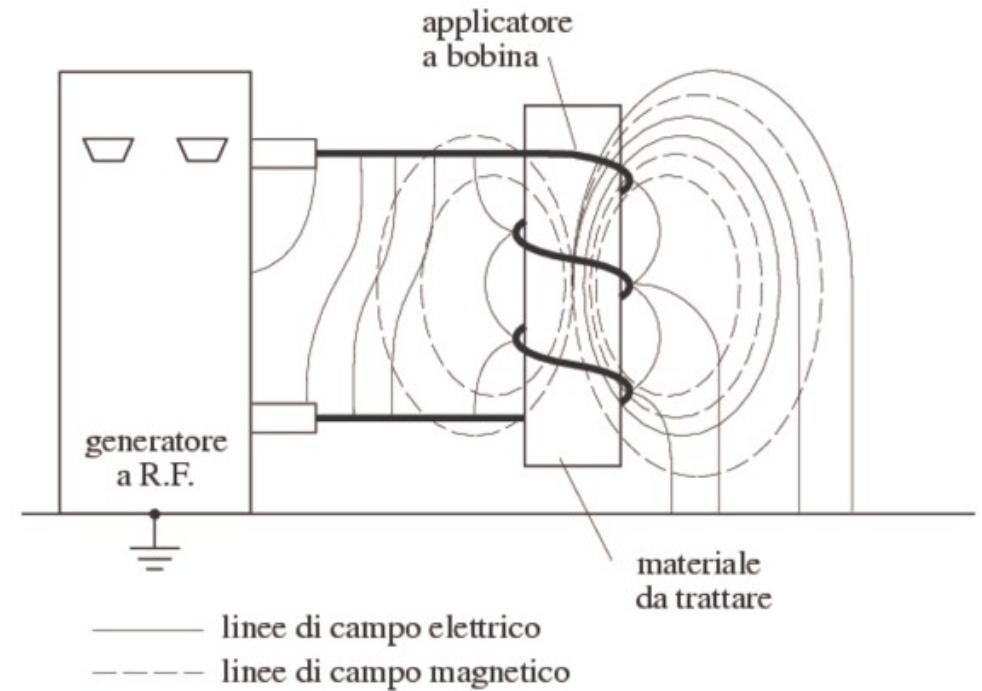
PRACTICAL APPLICATIONS

Trend of the radial (in blue) and axial (in orange) components of the induction along a trajectory parallel to the central axis of the structure.



PRACTICAL APPLICATIONS

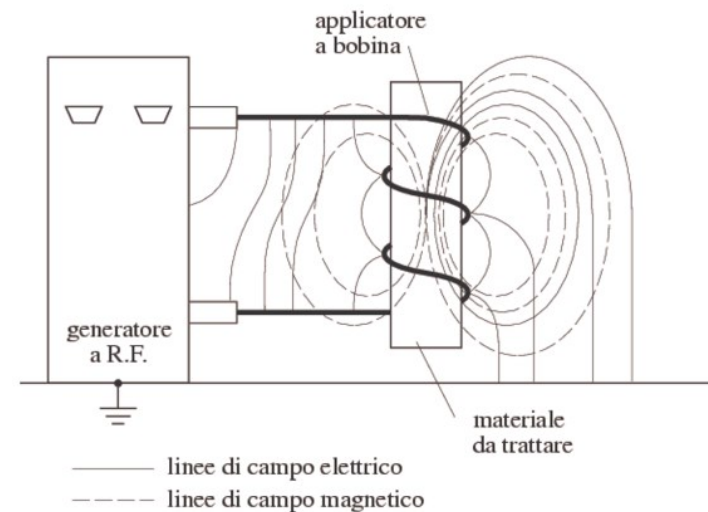
In the field of radiation protection, a case study is that of exposure to the magnetic field generated by an induction furnace used in the goldsmith industry.





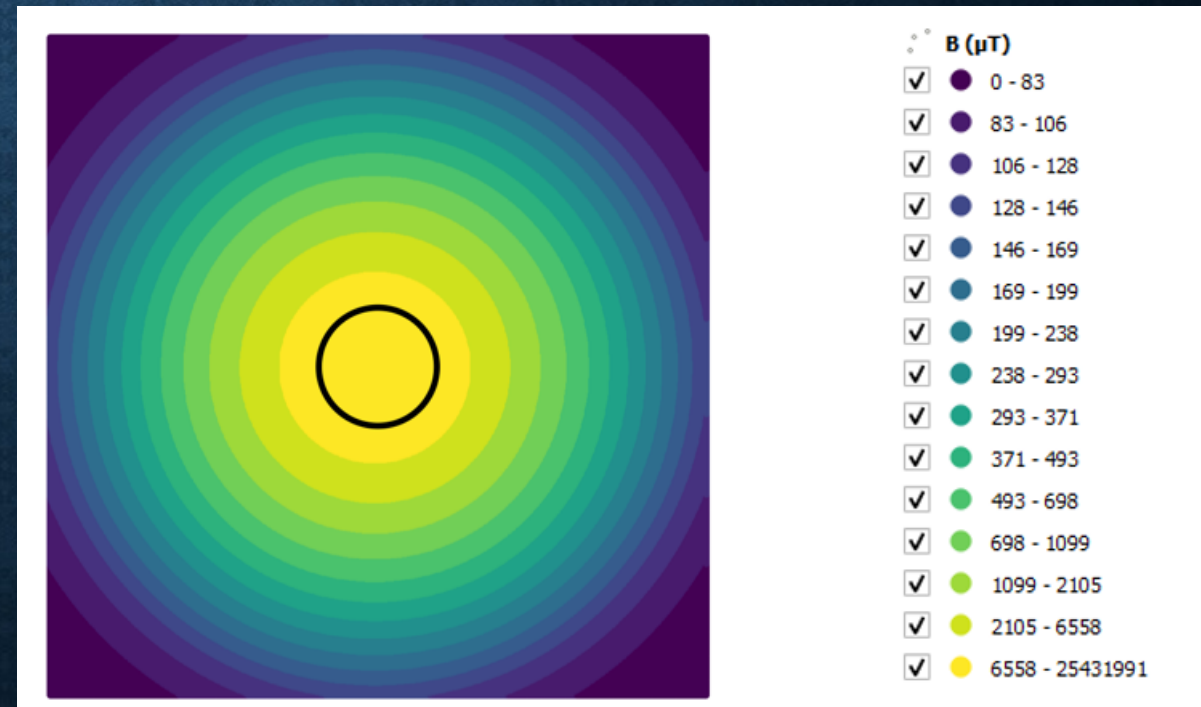
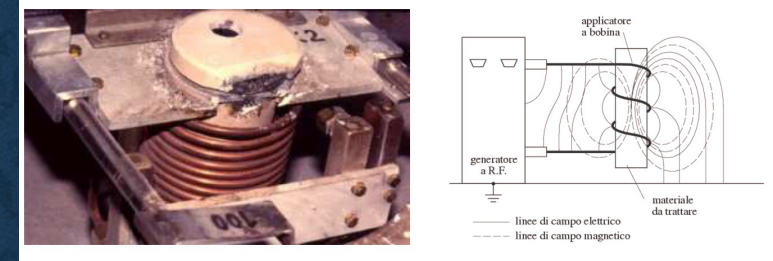
PRACTICAL APPLICATIONS

- It is a solenoid wrapped around a cylindrical crucible, connected to a radio frequency generator.
- It uses strong magnetic fields to induce eddy currents in the metals to be worked, heating them until they melt.
- Typical working frequencies range from a few kHz to a few tens of kHz.



PRACTICAL APPLICATIONS

- The results of the calculation are reported, displayed in QGIS, and superimposed on the source geometry (in the horizontal plane), automatically exported by the calculation program in geoPackage format.
- The results are consistent with the simulations performed when the device was analyzed.





AIMD

2 specific tools dedicated to AIMD available on WebNIR platform:

- Estimation of the voltage induced at the input of a pacemaker
- Operational indications for risk assessment in workers with AIMD

Documents about *Source recognition and characterization*:

- RFID
- UMTS and LTE
- Wi-Fi and Bluetooth



ESTIMATION OF THE VOLTAGE INDUCED AT THE INPUT OF A PACEMAKER

The tool allows to calculate the voltage induced at the input terminals of a pacemaker, according to its exposure conditions (the values of electric field intensity and/or magnetic field), through the implementation of the formulas reported in the appendix of the standard CEI EN 50527-2-1 ed. 2 (2016).



ESTIMATION OF THE VOLTAGE INDUCED AT THE INPUT OF A PACEMAKER

Estimation of the induced voltage (green symbol in the graph) across a pacemaker as a function of the electric and magnetic field – worst case conditions on a loop of area = 225 cm².

$V_{pp}^{ind,max}$: maximum induced voltage in open circuit, expressed as a peak-to-peak value (V)

$E(t)$: instantaneous value of the measured electric field (V/m)

$B(t)$: instantaneous value of the measured magnetic field (A/m)

Frequency range	$V_{pp}^{ind,max}$ ⓘ		Paragraph Standard 50527-2-1
[16.6 Hz; 60 Hz]	Unipolar	$\max(3,6 \cdot 10^{-7} \cdot \mathbf{H}(t) + 4,4 \cdot 10^{-9} \cdot \mathbf{E}(t)) \cdot f$	E.3.5.1
	Bipolar	$\max(1,8 \cdot 10^{-8} \cdot \mathbf{H}(t) + 2,3 \cdot 10^{-10} \cdot \mathbf{E}(t)) \cdot f$	
[60 Hz; 150 kHz] ⓘ	Unipolar	$3,6 \cdot 10^{-7} \cdot \mathbf{H}_p \cdot f$	E.3.3
	Bipolar	$1,8 \cdot 10^{-8} \cdot \mathbf{H}_p \cdot f$	
[150 kHz; 5 MHz]	$3,6 \cdot 10^{-10} \cdot \sqrt{10^6 \cdot \mathbf{H}_p^2 + \mathbf{E}_p^2} \cdot f$		E.3.6
[5 MHz; 30 MHz]	$\max \left\{ \begin{array}{l} 6 \quad 55 \cdot 10^{-10} \cdot \mathbf{H}_p \cdot f^{1,4} \\ 3 \quad 6 \cdot 10^{-10} \cdot \sqrt{10^6 \cdot \mathbf{H}_p^2 + \mathbf{E}_p^2} \cdot f \\ 3 \quad 17 \cdot 10^{-16} \cdot \mathbf{E}_p \cdot f^{1,9} \end{array} \right\}$		E.3.7
[30 MHz; 200 MHz]	$5,1 \cdot 10^{-2} \cdot \max \left\{ \begin{array}{l} 377 \cdot \mathbf{H}_p \\ \mathbf{E}_p \end{array} \right\}$		E.3.8
[200 MHz; 400 MHz]	$4,1 \cdot 10^{23} \cdot \max \left\{ \begin{array}{l} 377 \cdot \mathbf{H}_p \\ \mathbf{E}_p \end{array} \right\} \cdot f^{-3}$		
[400 MHz; 450 MHz]	$6,37 \cdot 10^{-3} \cdot \max \left\{ \begin{array}{l} 377 \cdot \mathbf{H}_p \\ \mathbf{E}_p \end{array} \right\}$		



ESTIMATION OF THE VOLTAGE INDUCED AT THE INPUT OF A PACEMAKER

The induced voltage value obtained can be compared with the immunity levels that pacemakers must satisfy, at various frequencies (16.6 Hz - 60 Hz, and 150 kHz – 450 MHz), to verify their compatibility under actual exposure conditions.

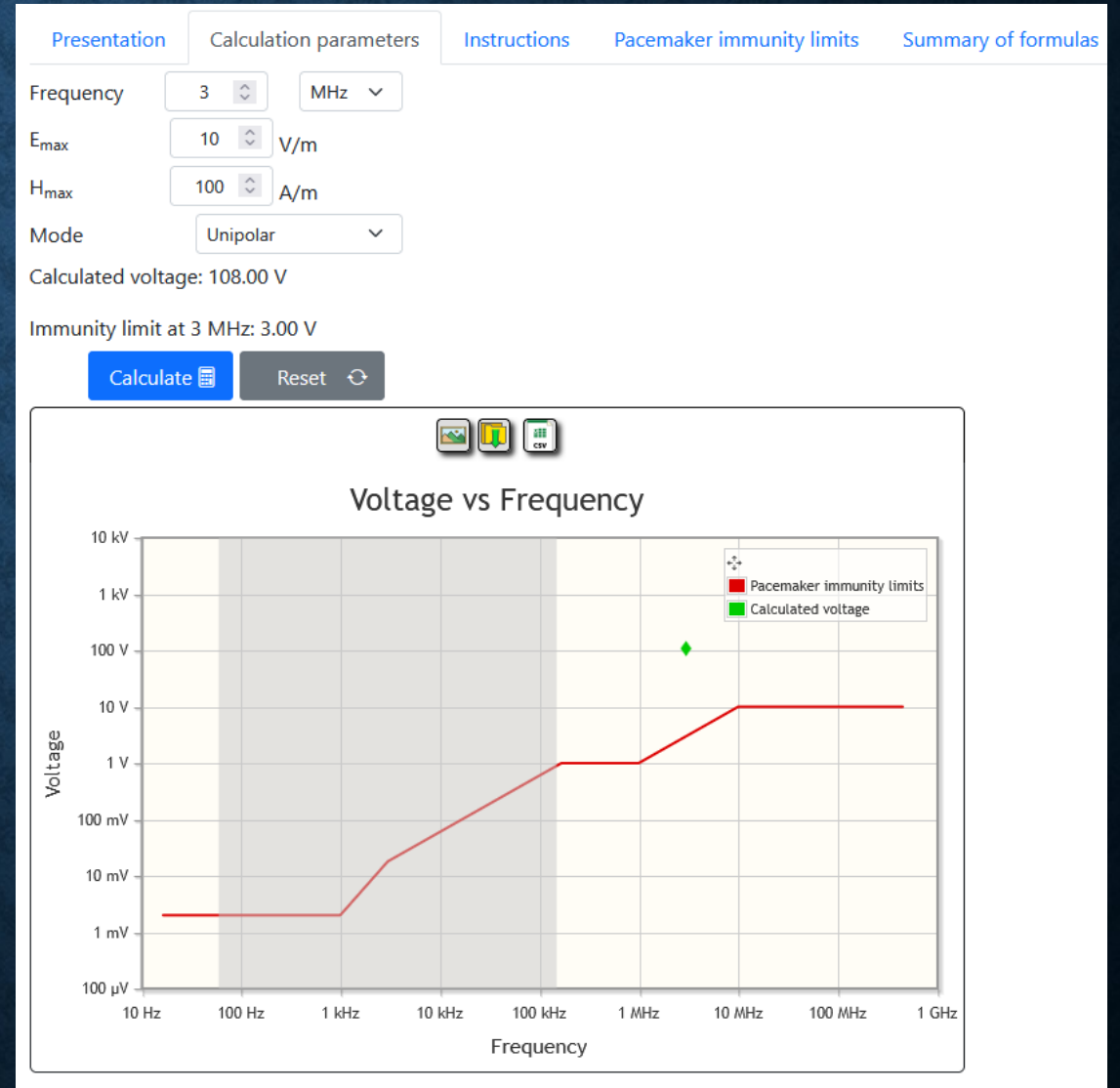
In the range between 60 Hz and 150 kHz there are no validated studies that allow the electric field to be correlated with the induced voltage on the pacemaker, therefore the instrument does not support this frequency range. The calculation is performed for a purely magnetic field.



ESTIMATION OF THE VOLTAGE INDUCED AT THE INPUT OF A PACEMAKER

The calculation is performed by entering the frequency of interest and the maximum peak values of the electric and magnetic fields measured.

The induced voltage value obtained is compared with the immunity levels that pacemakers must satisfy, at the various frequencies, in the conducted immunity tests provided for in the technical standard EN 45502-2-1:2003 (table in next slide).





ESTIMATION OF THE VOLTAGE INDUCED AT THE INPUT OF A PACEMAKER

Immunity limits of pacemakers (red line in the graph) for conducted disturbances in the frequency range [16 Hz; 450 MHz] according to the tests indicated in *Standard 45502-2-1: Active implantable medical devices*.

Frequency range	Test signal amplitude (peak-to-peak)	Paragraph Standard 45502-2-1
[16.6 Hz; 1 kHz]	$2mV$	27.5.1
[1 kHz; 3 kHz]	$2mV \cdot \left(\frac{f}{1kHz}\right)^2$	
[3 kHz; 167 kHz]	$6mV \cdot \left(\frac{f}{1kHz}\right)$	
[167 kHz; 1 MHz]	$1V$	27.5.2
[1 MHz; 10 MHz]	$1V \cdot \left(\frac{f}{1MHz}\right)$	
[10 MHz; 450 MHz]	$10V$	27.5.3

In the case of bipolar measurements, the test signal amplitudes are reduced by a factor of 10.



RISK ASSESSMENT FOR WORKERS WITH AIMD

In the EU, the EMC requirements for AIMDs are provided in the standards of the family EN45502. As for pacemaker and implantable cardioverter defibrillators, EMC requirements are provided in the ISO 14117:2019 - Active implantable medical devices — Electromagnetic compatibility — EMC test protocols for implantable cardiac pacemakers, implantable cardioverter defibrillators, and cardiac resynchronization devices.

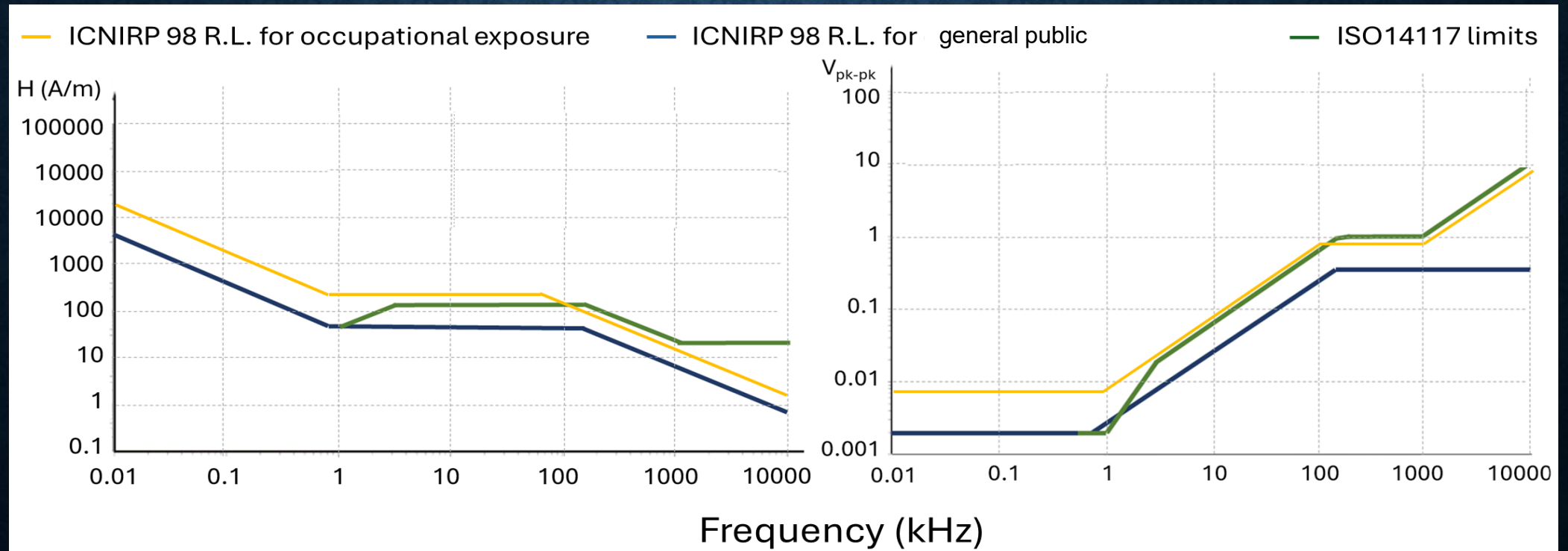
Standards' background: the immunity levels are determined to protect the AIMD from the foreseeable electromagnetic environment derived from the European Recommendation 1999/519/EC, which was based on the recommendations for the General Public of the ICNIRP Guidelines 1998.



RISK ASSESSMENT FOR WORKERS WITH AIMD

Comparison between the immunity test level adopted by ISO 14117 and ICNIRP 1998 reference level for the general public and occupational exposure (10 Hz to 10 MHz).

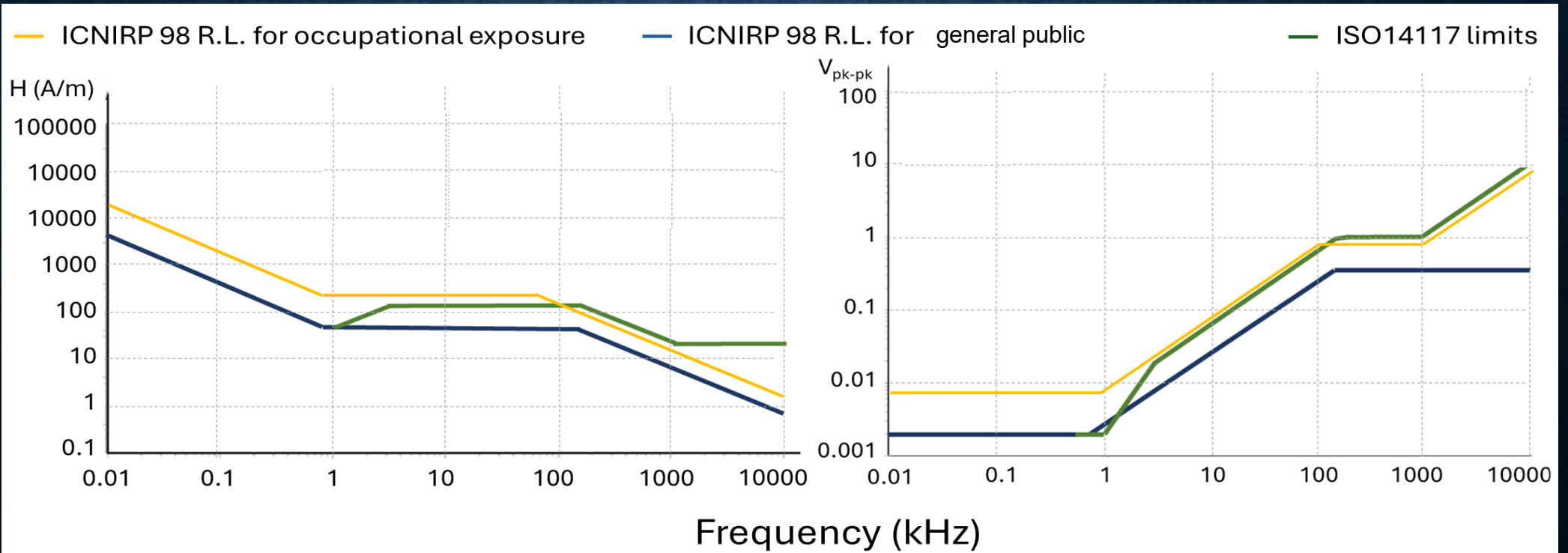
The risks for a worker who wears an AIMD could be considered acceptable if exposed to EMF levels below the ICNIRP reference levels for the General Public.





RISK ASSESSMENT FOR WORKERS WITH AIMD

In workplaces, powerful sources of EMF are likely to be encountered, and reference levels for the General Public can be exceeded. Thus, the safety of a worker who wears an AIMD is not guaranteed anymore. In addition, the aforementioned standards take into account only the EMF sources that can be encountered in common-life scenarios (e.g., LTE/4G cellular phones, Wi-Fi transmitters, etc.).





RISK ASSESSMENT FOR WORKERS WITH AIMD

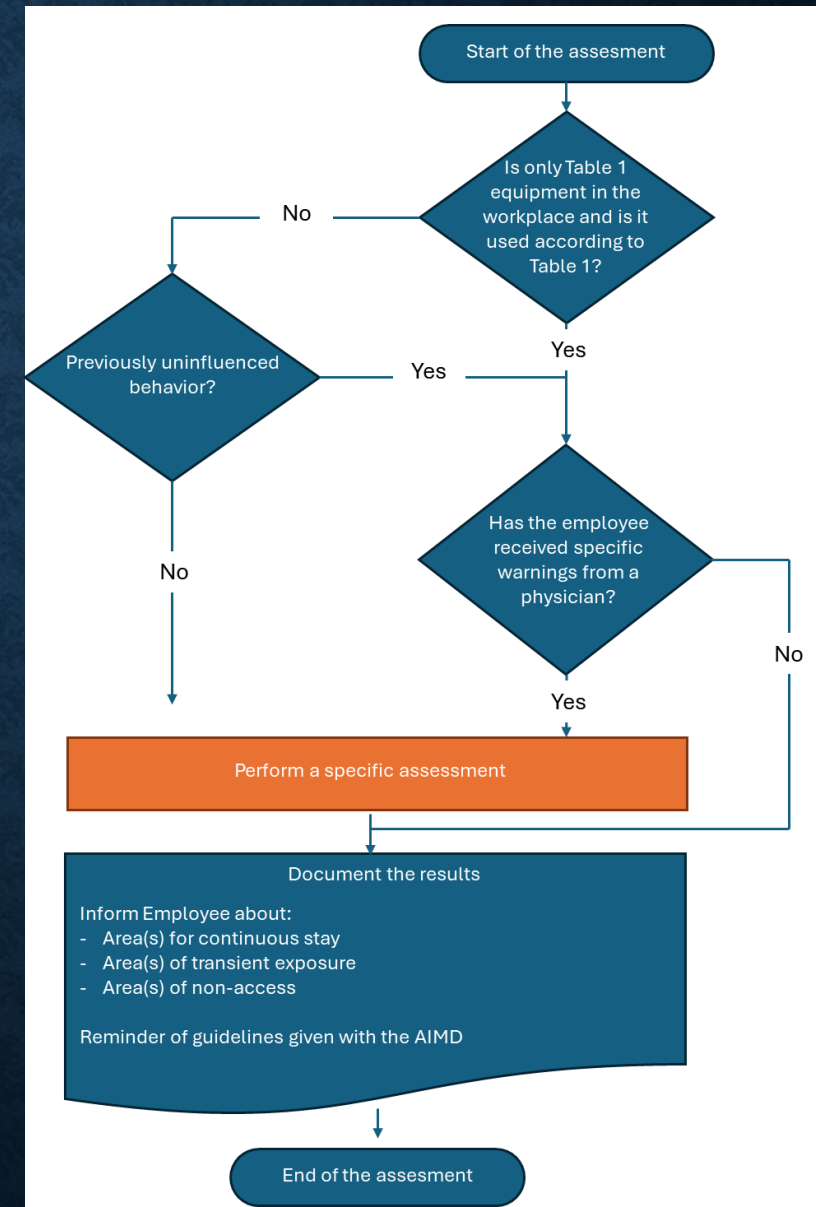
The EMF sources in a work environment can be very specific in terms of modulation, pulse repetition time, etc., and can pose a risk even at levels below the ICNIRP reference levels for the General Public.

Consequently, the existing standards reasonably protect the General Public wearing AIMDs but are not sufficient to protect workers wearing AIMDs. For these reasons, the EU has developed a series of technical standards to support the employers in the risk assessment of workers who wear AIMDs: the general standard EN50527-1 with the particular standards EN50527-2-X for the different AIMD classes.



RISK ASSESSMENT FOR WORKERS WITH AIMD

The EN EN50527 family standards provide a general procedure for the specific assessment required for workers with an AIMD: an initial simplified analysis is required, followed, when necessary, by a deeper specific risk assessment for the AIMD-employee.



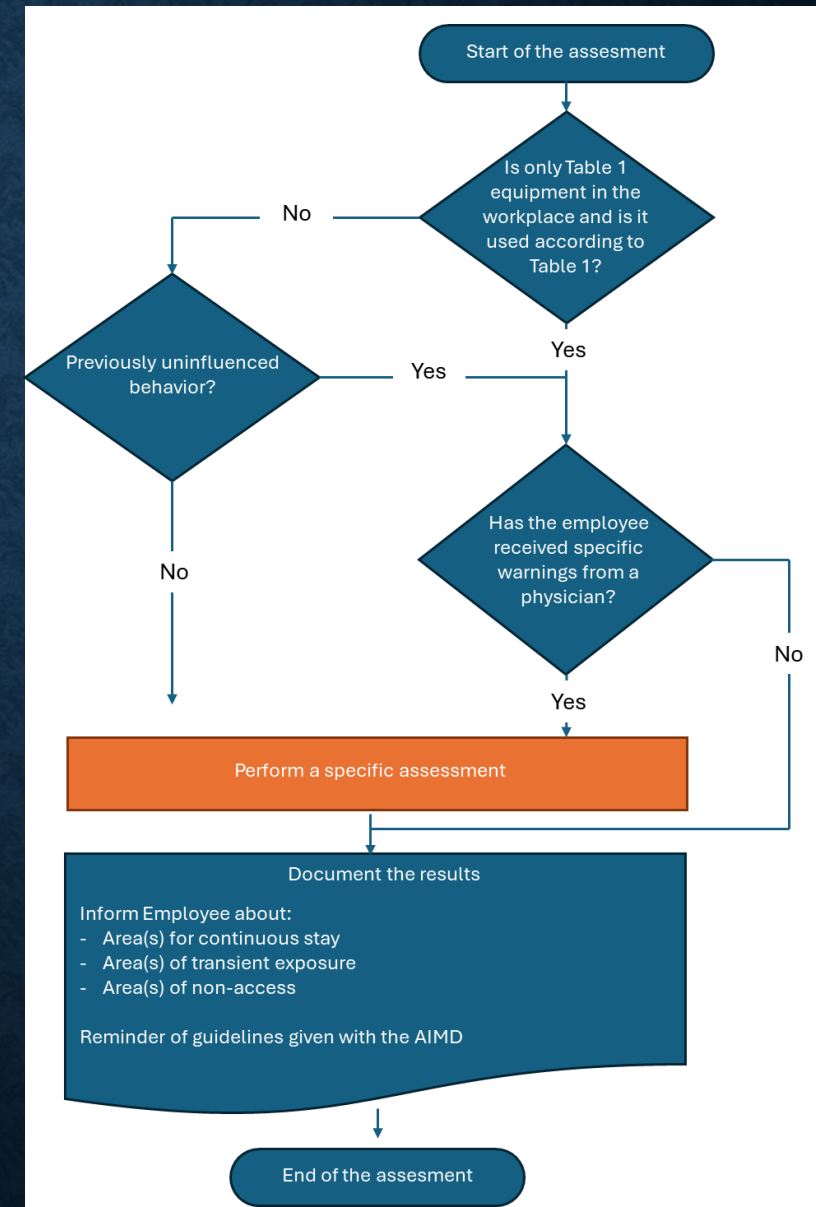


RISK ASSESSMENT FOR WORKERS WITH AIMD

The initial simplified analysis starts from the identification of all the EMF sources active in the workplace and their comparison with a list of equipment reported in a table, called whitelist.

The simplified analysis can be considered sufficient if:

- all the EMF sources are listed in the table;
- all the EMF sources are used in accordance with the indication reported in the “exceptions and remarks” column;
- the AIMD employee has not received specific warnings from the responsible physician that the AIMD may be susceptible to EMI from one of the present equipment.

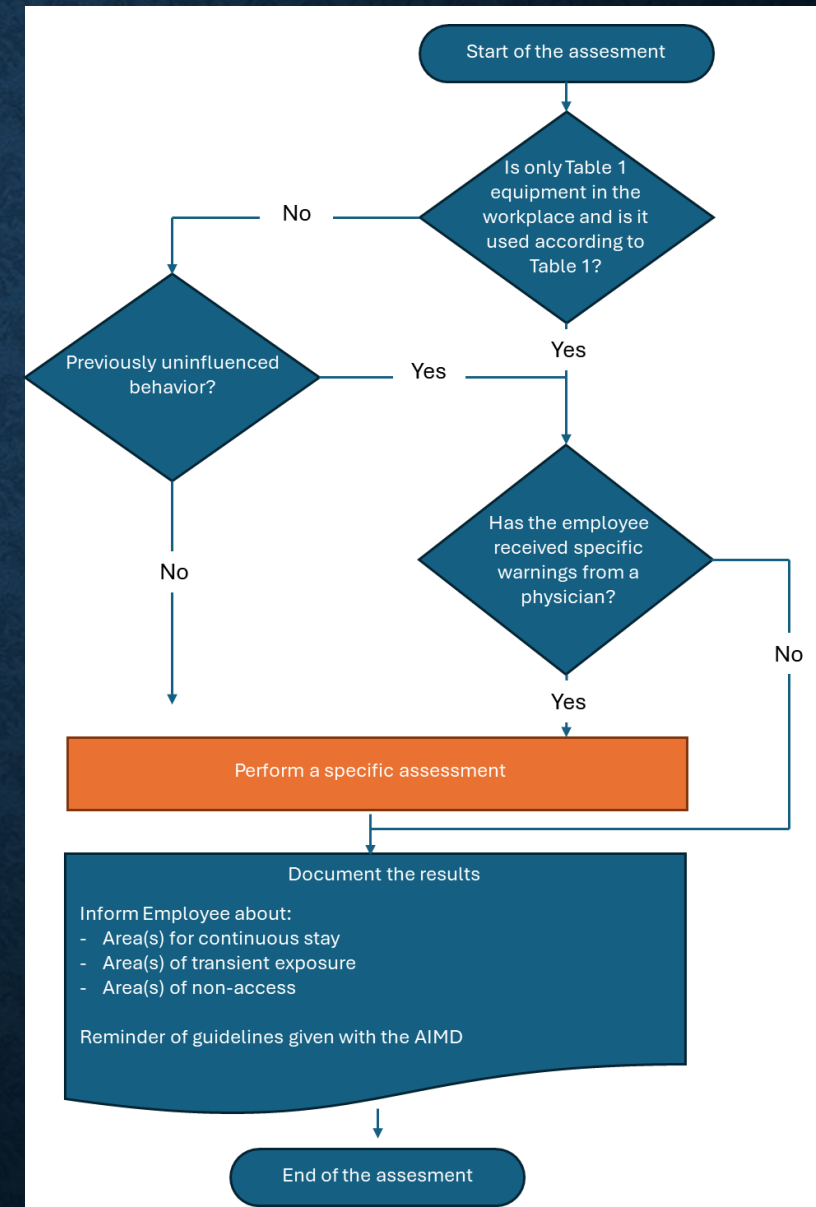




RISK ASSESSMENT FOR WORKERS WITH AIMD

If one of the previously mentioned conditions is not verified, a specific risk assessment shall be carried out, under the specifications provided in Annex A of the standards. The risk assessment should involve input from:

1. the employer and, if applicable, his/her occupational health and safety expert and/or occupational physician;
2. the AIMD employee and his/her responsible physician; and
3. experts (technical and medical), e.g., the manufacturer of the AIMD.



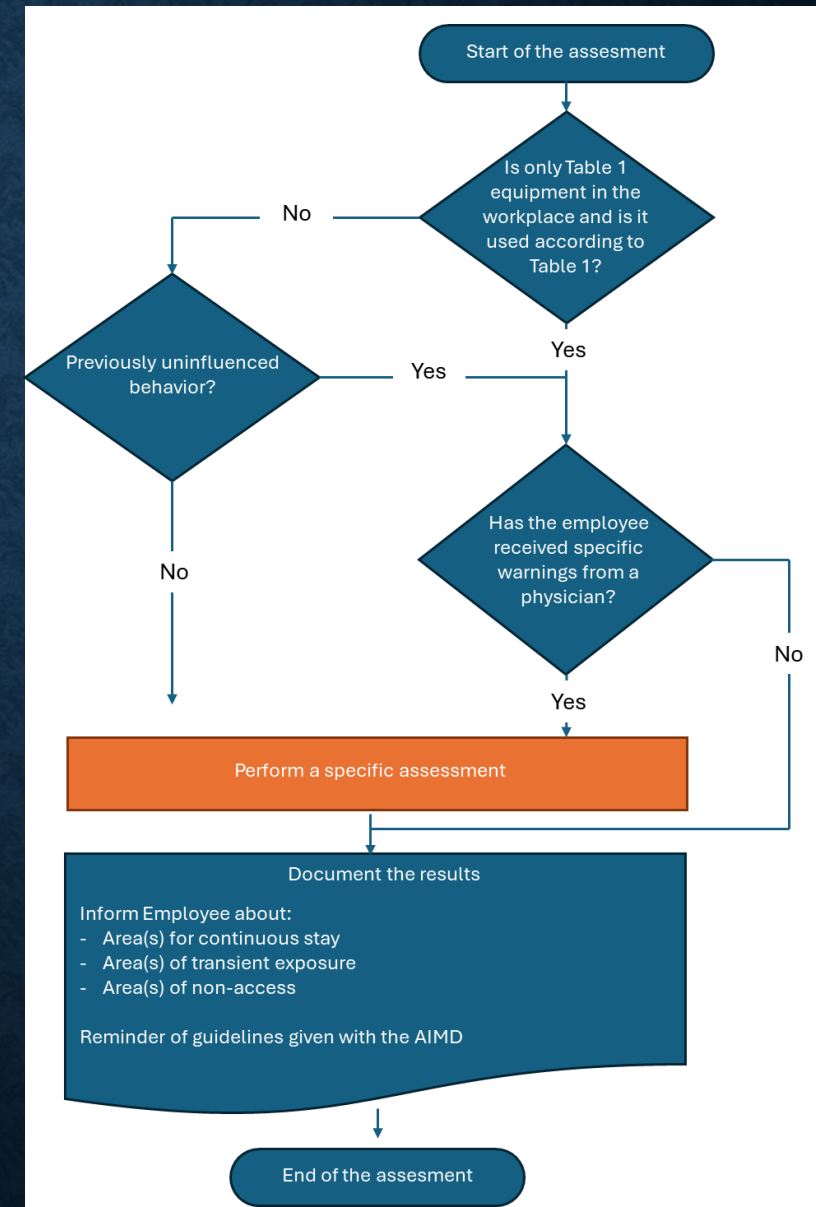


RISK ASSESSMENT FOR WORKERS WITH AIMD

Then, two alternative methods to perform the risk assessment are proposed: the “non-clinical approach” and the “clinical approach”.

The former bases risk assessment on measurement, calculation, and/or information provided by the manufacturer of the AIMD and does not involve the worker directly.

The latter needs the AIMD employee to be exposed under clinical supervision to the foreseeable exposure situations or in a laboratory simulating the workplace exposure situation.





THE AIMD SECTION OF WEBNIR

The guided procedure implemented on the WebNIR platform for risk assessment for workers with AIMDs follows the steps indicated in the technical standard 50527-1, as described previously.

As a first step, after having entered the details of the AIMDs present in the examined worker, the user must indicate whether, in the workplace, there are certain sources of electromagnetic fields, chosen from a pre-established list (the whitelist), indicating for each of these the compliance with the instructions provided in it.

Is the worker a carrier of AIMD?

YES
✓

NO
▼

Specify type, brand and model of AIMD

Type	Brand	Model	⊕ ⊖
Pacemaker	Boston	Model 1	

Continue
✓

LIST OF INSTRUMENTATION TABLE 1
As a first step in the risk assessment, a series of equipment that could be present in the workplace will be presented, for which the potential risk for workers with AIMD has already been assessed and it is therefore possible to carry out a simplified risk assessment. For each item reported in the source list, the user, in addition to indicating its presence by means of a check mark, must indicate whether it complies with specific indications on their method of use and operation, which will be shown on the screen from time to time.

Check whether the workplace contains equipment listed in [Table 1](#) of the CEI EN 50527-1 standard and whether the indications reported in the *Exceptions and Notes* column of the same Table are complied with.

Select the equipment of interest:

☐ Lighting fixtures ⓘ

☐ Computers and IT equipment ⓘ

☒ Computers, tablets, IT equipment including wireless communications ⓘ

☐ Comply / ☒ Does not comply with instructions

☒ Office equipment ⓘ

☒ Comply / ☐ Does not comply with instructions

☐ Smartphones, mobile phones and cordless phones ⓘ

☐ Two-way radios ⓘ



THE AIMD SECTION OF WEBNIR

For such sources, the potential risk for workers with AIMDs has already been assessed, and it is therefore possible to carry out a simplified risk assessment.

The user will then be asked to indicate the presence of other sources not listed in the table, and he will finally be presented with a series of questions relating to the work environment and the clinical history of the worker for whom the risk assessment has to be performed. The procedure will conclude with creating a report summarizing the outcome of the risk assessment procedure.

Is the worker a carrier of AIMD?

YES
✓

NO
▼

Specify type, brand and model of AIMD

Type	Brand	Model	⊕ ⊖
Pacemaker	Boston	Model 1	

Continue
✓

LIST OF INSTRUMENTATION TABLE 1

As a first step in the risk assessment, a series of equipment that could be present in the workplace will be presented, for which the potential risk for workers with AIMD has already been assessed and it is therefore possible to carry out a simplified risk assessment. For each item reported in the source list, the user, in addition to indicating its presence by means of a check mark, must indicate whether it complies with specific indications on their method of use and operation, which will be shown on the screen from time to time.

Check whether the workplace contains equipment listed in [Table 1](#) of the CEI EN 50527-1 standard and whether the indications reported in the *Exceptions and Notes* column of the same Table are complied with.

Select the equipment of interest:

☐ Lighting fixtures ⓘ

☐ Computers and IT equipment ⓘ

☒ Computers, tablets, IT equipment including wireless communications ⓘ
☐ Comply / ☒ Does not comply with instructions

☒ Office equipment ⓘ
☒ Comply / ☐ Does not comply with instructions

☐ Smartphones, mobile phones and cordless phones ⓘ

☐ Two-way radios ⓘ



THANKS