Siepel

Michael Faraday's Heritage

HYFRAL

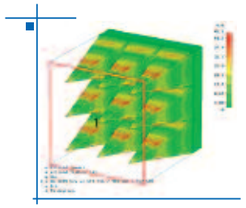
ELECTROMAGNETIC ABSORBERS

HYFRAL

电磁吸波材料

Since the middle of the 20th century, the variety of applications requiring electromagnetic absorbers has been increasing rapidly. Therefore, new materials had to be developed, each targeting a specific application and meeting specific properties.

With a manufacturing plant on over 5000 m², Siepel has been manufacturing electromagnetic absorbers under the trademark Hyfral since 1994. The growing demand for quality products led us to increase our manufacturing capabilities by 30% in 2005, to keep on producing top class, state-of-the art absorbers and offer, for every application, the best products targeting your needs:

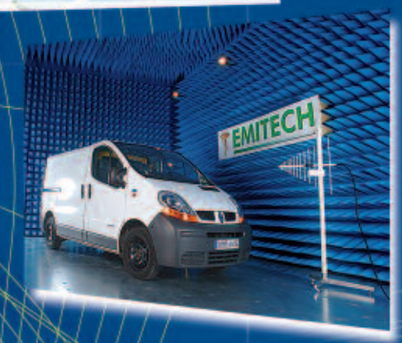


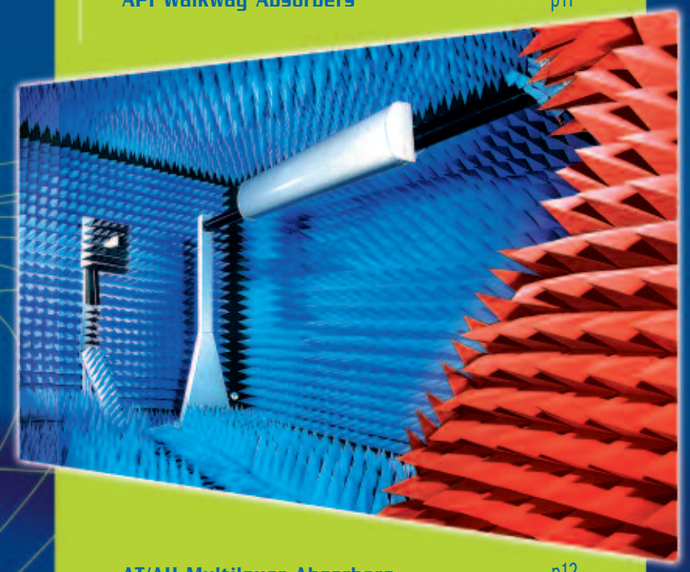
Ferrite
Pyramidal foam absorbers,
Outdoor weatherproof absorbers,
Silicone, epoxy, multi-layer absorbers,
High-power absorbers,
Narrowband/Broadband, ...

Focused on innovation, process optimization, quality control and improvement of performances, we have developed an in-house test laboratory, inclusive of RF/microwave test benches and a fire test lab, as well as an R&D department working with state-of-the art tools and software (CST microwave studio, FEKO, Micro-stripes...), dedicated to the development of new products and quality control of the absorbers characteristics:

Physical strength
Low weight
Weatherproof capabilities
High resistance
Good flexibility
Optimized geometry
Broadband behaviour
High performances
High power withstanding
Low cost
Best quality-to-price ratio on the market

Our commitment to your performances

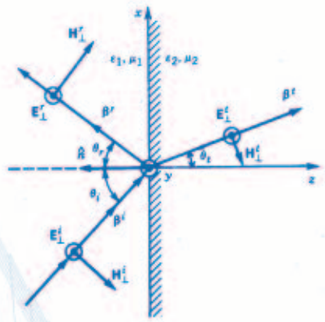


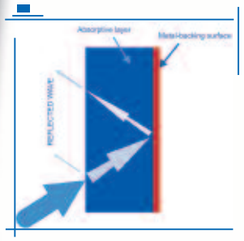


ELECTROMAGNETIC ABSORBERS: CRITERION OF CHOICE

Electromagnetic absorbers consist in a matrix and an electric or magnetic load. Their behaviour relies on their intrinsic parameters, as well as on the range of frequency they are efficient on. Absorbers' efficiency and performances are not determined by the quantity of energy absorbed, but by the level of forward energy which is reflected. This parameter is called **reflectivity**, expressed in **dB**.

Depending on the frequency of operation, absorbers can be classified in two main categories : narrowband and broadband.





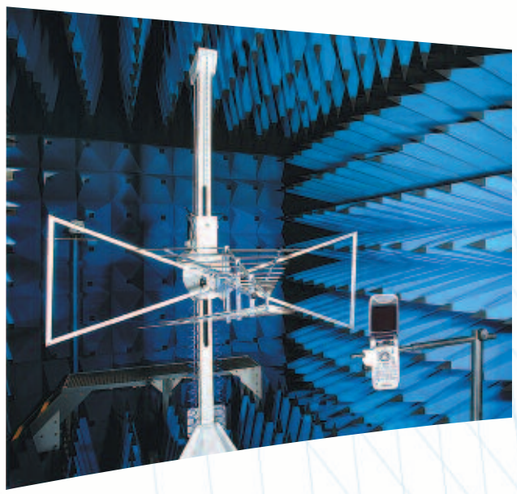
NARROWBAND ABSORBERS

They are resonant absorbers, determined by their center frequency (f_0) and the range of frequencies they are efficient on ($f_0 \pm \Delta f$). Resonant absorbers can be made of an absorptive layer (e.g. Ni/Zn ferrite tiles) backed with a metal plate; the main reflection is cancelled by the one on the metallic plane, as well as from absorption in the absorbing layer.

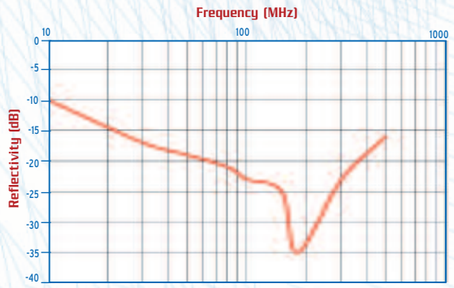
The efficiency of the absorbers is linked to the thickness of the absorptive layer, which is equal to a quarter of a wavelength of the resonant frequency ($(2n+1)\frac{\lambda}{4}$), and to the complex permeability μ. Therefore, a wave entering the material and reflected on the metallic backing plane reduces the reflected wave on the surface of the absorber.
A single-layer absorber with metal backing presents a reflectivity determined by the following parameters:

$$R_{dB} = 20\log 10 \left(\frac{i\sqrt{\frac{\mu}{\varepsilon}} \tan\left(\frac{2\pi f}{c}\sqrt{\mu\varepsilon}\, d\right) - 1}{i\sqrt{\frac{\mu}{\varepsilon}} \tan\left(\frac{2\pi f}{c}\sqrt{\mu\varepsilon}\, d\right) + 1} \right)$$

Where
μ = complex permeability = μ'- jμ''
ϵ = complex permittivity = ϵ' - jϵ''
d = thickness of the layer
c = speed of light in vacuum
f = frequency of operation



The choice of the material is of outmost importance, since appropriate values of μ'' and ϵ'' will lead to higher magnetic and electric losses (respectively), thus more dissipation of the energy into heat inside the material.



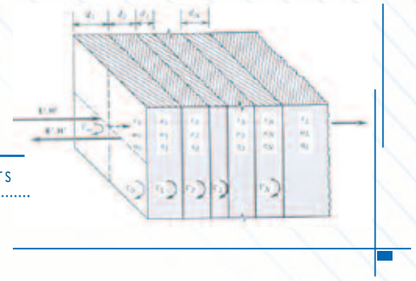
BROADBAND ABSORBERS

Unlike narrowband absorbers whose strength relies in the back reflection, broadband absorbers provide sufficient absorption inside the matrix. Therefore, a certain thickness of the material is needed (several wavelengths). The absorption is obtained by losses, created by the impedance of the material: Z_m
A forward wave propagated in free space (Z_0= 120 π Ω) enters the absorber, with an impedance mismatch which will determine the front-face reflection coefficient Γ: $\Gamma = \frac{Z_m - Z_0}{Z_m + Z_0}$

The aim of the absorber is to obtain a reflection Γ= 0, therefore Z_m must be as close as possible to Z_0

Two main techniques are used to read this:
- Load-gradient absorbers
- Progressive geometrically-shaped absorbers

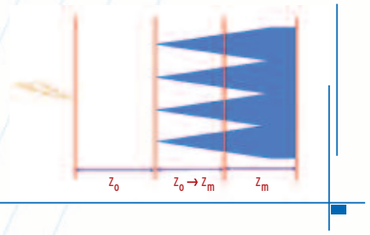
Load gradient absorbers



They consist in multiple layers of flat absorbers (multilayer technique), whose load is gradually increasing from the top (first contact to the forward wave) to the bottom. Each layer has a specific load, i.e a specific permittivity and a specific impedance, providing a progressive impedance matching to the electromagnetic waves.

- The first layer has a low carbon load (ϵ_1): $Z_1 \approx Z_0$
  Minimum reflection between free space and the first layer
- The second layer has a low carbon load (ϵ_2): $Z_2 \approx Z_1$
  Minimum reflection between the first and second layer
- This operation is repeated with as many layers as possible to reach the targeted reflectivity level

Geometrically-shaped absorbers



Such absorbers achieve the impedance gradient by the geometrical shaping of a matrix with constant impedance. They offer a better transition from free space to the dissipative medium. A forward wave entering the medium encounters a smoothly changing ratio of medium to the adjacent free space. The transitions can take the shape of pyramids, cones, circumvolutions...

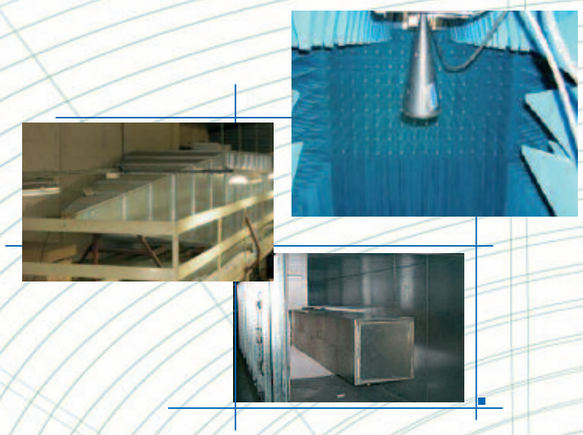
Combination of both techniques

It is possible to use combination both techniques (load gradient + special shape), in order to obtain absorptive materials with specific properties and reflectivity performances: hybrid absorbers, pyramidal multilayer absorbers..

SPECIAL & UNIQUE FEATURES

Absorbers Characterization

HYFRAL absorbers are tested in-factory during the various manufacturing processes, to ensure the best quality is delivered to our customers. Their reflectivity performances are tested in our in-house laboratories :
- 30 MHz – 2 GHz: Coaxial line for S11 measurement in the time domain
- 2 GHz – 40 GHz: Full Anechoic Chamber for S21 measurement in the time domain.

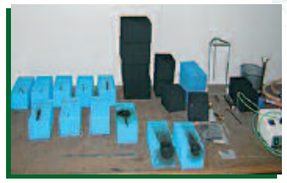


Fire Retardant Properties

Our absorbers are compliant with the main international standards regarding fire retardant properties:

NF P 92 501
NRL 8093 tests 1, 2 & 3
DIN 4102 class B2
ISO 11925-2 Euroclass E
UL94 HBF
ISO 4589-2

Tests are led during absorbers manufacturing, as well as during R&D processes in order to optimize the quality of our products.



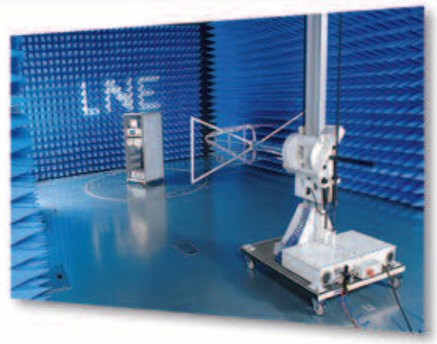
Unique Plastic Paint

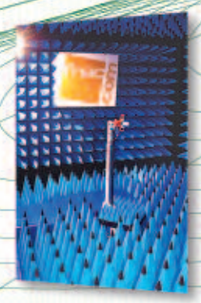
Siepel has developped a specific plastic paint, unique worldwide, which combines the advantage of keeping the absorbers performances, and enhancing the usual feature for easier everyday use :

- Several colours available:
  Possibility to design a custom logo
- Better mechanical resistance
- Better maintain of the carbon inside the absorber (no carbon dust)
- Longer lifetime:
  Performances guaranteed up to 20 years
- Improved brightness for more comfortable working environments.

Which Absorber For my Application ?

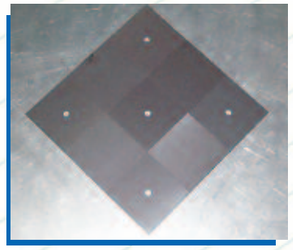
REF	TYPE	FREQUENCY	REFLECTIVITY (dB)	APPLICATION	FEATURES
FE	Ferrite	10 MHz – 2 GHz	-3 -> -26	EMC	T=6.7 mm
HY	Hybrid	10 MHz – 40 GHz	-11 -> -23	EMC	Ferrite + matched pyramid
APM	Pyramidal	80 MHz - 200 GHz	-6 -> -52	EMC, antenna, RCS, Radio	Broadband
APX	Truncated	80 MHz - 26 GHz	-6 -> -42	EMC	EMC only!
ADM	Wedge	200 MHz - 200 GHz	-10 -> -42	RCS, compact ranges	Incidence angles >50°
APC	Convoluted	1 GHz - 200 GHz	-17 -> -52	Antenna	High frequencies
API	Walkway	200 MHz - 40 GHz	-10 -> -35	Antenna, RCS, Radio	200 kg/m²
AT / AH	Multilayer	300 MHz – 40 GHz	-20	Antenna	Positionners
CR / PR	Reticulated	2 - 26 GHz	-8 -> -18	Antenna	Easily cutable
AHP	High power	1 GHz - 18 GHz	-9 -> -50	Compact range, PIM	2 W/cm²
AI	Weatherproof	200 MHz – 18 GHz	-15 -> -30	Antenna, RCS, radio	Outdoor use
ASI / APU	Resonant	1 – 26 GHz	-20	Outdoor, Shielded boxes	Narrowband
MI	Multilayer	30 MHz – 200 GHz	-11 -> -52	EMC, radio, antenna, RCS	Multi-purpose



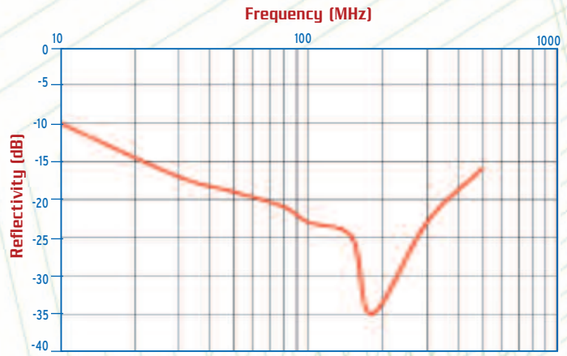


HYFRAL ABSORBERS SPECIFICATIONS

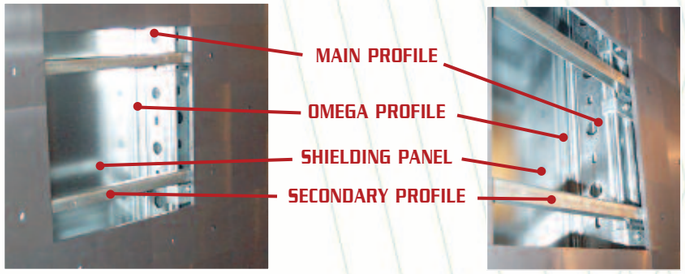
FE Ferrite Absorbers



Ferrites are resonant absorbers made of ceramic material with metallic oxides (Ni/Zn), available in multiple thicknesses, from 4 to 7 mm. Optimal performances are usually obtained with 6.7 mm tiles: down to -35 dB on the central frequency (180 MHz).
Their good performances on the frequency range [30 MHz; 1 GHz] (see table below) make them perfectly suitable for most EMC applications, in which the use of ferrite tiles makes it possible to optimize the size of the installations and design compact chambers.



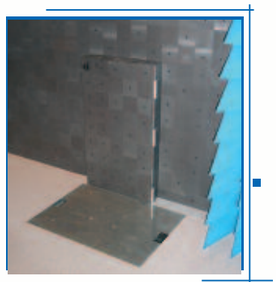
Ferrites usually come as 100 x 100 mm tiles, mounted by set of 9 units on 300 x 300 mm metal-backed panels. The completely innovative panel installation system, SIEPEL-patented, allows an easy dismounting of the installation and a total flexibility of the systems.



Each 300 x 300 mm panel can be either screwed on wooden boards in existing enclosures, or used on a unique flexible and innovative rails system when installed in SIEPEL high performances shielded rooms.

Minimum reflectivity of Ferrites in dB *

Type	Thickness (mm)	30 MHz	50 MHz	80 MHz	100 MHz	150 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	6 GHz
FE 10 N	6	-10	-14	-18	-20	-26	-22	-16	-8	-7	-4	-3
FE 10 Z FE 30 Z	6,7 8 to 19	-17	-19	-21	-23	-25	-23	-16	-10	-7	-4	-3

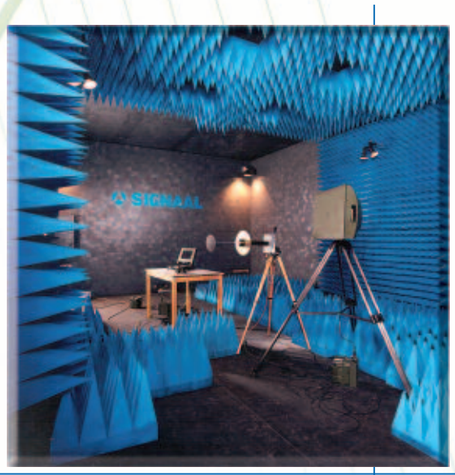


Anechoic chambers lined with ferrite tiles can meet the performances requested by the most common international EMC standards from 26 MHz up to 1 or 2 GHz, depending on the size of the chamber.

In order to extend the performances up to 18 GHz or more, hybrid foam absorbers must be added on the top of the ferrite panels.

HY Hybrid Absorbers

Combination of ferrite tiles and special matched pyramidal absorbers, hybrid absorbers have broadband performances, perfectly suitable for EMC applications. The average reflectivity values are below -15 dB on a wide range of frequencies (from 30 MHz to 40 GHz). Therefore, they are mostly aimed at equipping chambers for EMC compliance.



Minimum Reflectivity Performance (dB) of Hybrid Absorbers *

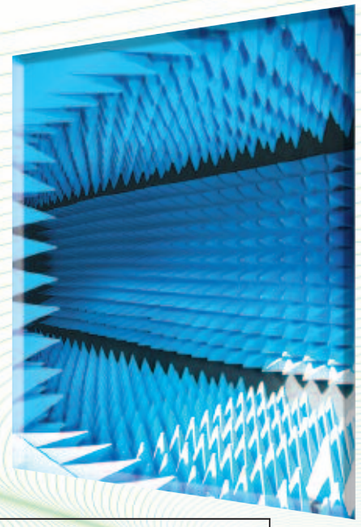
Type	Height (mm)	30 MHz	50 MHz	80 MHz	100 MHz	150 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz	40 GHz
HY 5	58	-14	-15	-15	-15	-14	-12	-10	-12	-8	-6	-3	-3	-3	-3
HY 10	108	-14	-15	-15	-15	-14	-12	-10	-20	-10	-6	-6	-7	-7	-7
HY 20	218	-16	-19	-21	-23	-16	-17	-16	-11	-10	-10	-10	-11	-15	-15
HY 30	313	-18	-20	-20	-20	-18	-15	-13	-14	-11	-11	-15	-17	-20	-20
HY 45	463	-18	-20	-19	-18	-18	-16	-15	-15	-14	-17	-20	-23	-20	-20

Ferrite tiles are efficient from 30 MHz up to 1 GHz, whereas hybrid pyramids provide sufficient reflectivity levels above 1 GHz.
Hybrids are not a simple combination of ferrite and standard pyramidal APM absorbers, as HY are characterized by a lower carbon load than APM. They are "transparent" enough to electromagnetic waves below 1 GHz, so that ferrite tiles can be efficient at lower frequencies.
The combination ferrite and matched pyramidal absorber is highly performing over the whole frequency range 30 MHz - 40 GHz.

Hybrids are designed for use in EMC anechoic chambers, to meet the specifications of the commercial EMI standards (such as EN 50147-2, EN 55022, ANSI C63.4, CISPR 16...) and EMS standards (EN / IEC 61000-4-3), as well as MIL-STD or specific applications.

* For incidence angles close to the normal

APM Regular Pyramidal foam Absorbers



Pyramidal absorbers of the APM series are made of a polyurethane foam matrix with 90% open cells, for optimal impregnation of carbon and excellent material homogeneity.
They can be fitted on-demand with the specific and unique plastic paint developed by SIEPEL for improved resistance to time and mechanical constraints.

Available in different heights, to each its different load and range of frequencies, APM have excellent reflectivity performances (up to -55 dB at high frequencies), from 80 MHz to 100 GHz and more.

Minimum reflectivity of HYFRAL APM in dB *												
Type	Height (mm)	80 MHz	200 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz	40 GHz
APM 3	28							-12	-13	-13	-14	-16
APM 5	55						-20	-25	-30	-35	-40	-35
APM 9	89					-15	-21	-33	-40	-43	-45	-50
APM 12	115					-18	-30	-35	-43	-50	-50	-52
APM 20	210				-16	-30	-36	-45	-50	-52	-52	-52
APM 30	305				-24	-34	-37	-47	-52	-52	-52	-52
APM 45	455				-29	-40	-41	-50	-52	-52	-52	-52
APM 55	550			-25	-33	-43	-46	-50	-52	-52	-52	-52
APM 66	660	-6	-21	-27	-38	-45	-47	-52	-52	-52	-52	-52
APM 80	800	-10	-22	-28	-41	-48	-52	-52	-52	-52	-52	-52
APM 85	850	-10	-23	-28	-42	-49	-52	-52	-52	-52	-52	-52
APM 100	1000	-13	-26	-33	-43	-52	-52	-52	-52	-52	-52	-52
APM 110	1100	-15	-28	-38	-43	-52	-52	-52	-52	-52	-52	-52
APM 120	1200	-19	-28	-38	-43	-52	-52	-52	-52	-52	-52	-52

Standard dimensions of APM absorbers are 610 x 610 mm (L x W), with specific heights according to the range of frequency.

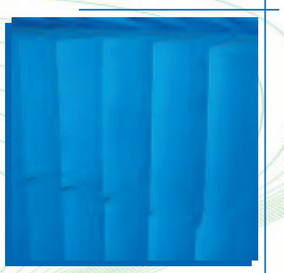
Most common applications of APM are :
Antenna radiation pattern - Radio measurements - RCS chambers - EMC (MIL-STD-461...)

APX Truncated Pyramidal Absorbers

With performances similar to APM, APX are pyramidal absorbers with truncated top and reduced height, designed to provide efficient space saving in anechoic chambers. The reflections on the flat surface do not have any significant impact at low frequencies when APX are installed on non-critical areas.

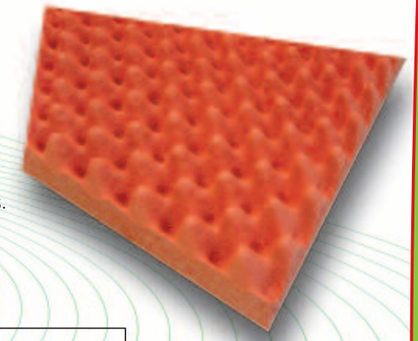
Minimum reflectivity of HYFRAL APX in dB *														
Type	Height (mm)	50 MHz	80 MHz	100 MHz	200 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz	26 GHz
APX 30	305				-7	-14	-24	-29	-30	-33	-37	-38	-40	-40
APX 40	400		-1	-3	-12	-20	-27	-29	-30	-33	-37	-38	-40	-40
APX 50	500		-6	-7	-20	-26	-30	-32	-32	-35	-39	-41	-42	-42
APX 60	600	-1	-6	-7	-20	-26	-30	-33	-35	-36	-40	-41	-42	-42

ADM Wedge Absorbers



With similar performances as APM, the wedged shape of ADM absorbers makes them efficient for incidence angles > 50°, for which they drive the waves and significantly reduce reflections. They are mainly used for high performances chambers used for microwave measurements (such as near-field, antenna patterns or RCS measurements).

APC Convoluted Absorbers

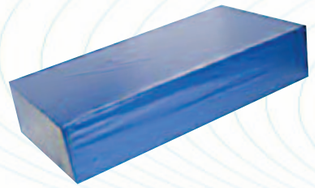


Convoluted absorbers are historically the first absorbers using geometrical transition principles. Their excellent performances and characteristics above 10 GHz, for minimized dimensions, make them ideal for most applications in this range of frequencies.

Minimum reflectivity of HYFRAL APC in dB *								
Type	Height (mm)	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz	26 GHz
APC 8	80	-17	-22	-27	-33	-39	-42	-45
APC 10	100	-19	-23	-30	-34	-45	-50	-50
APC 15	150	-27	-34	-39	-45	-50	-50	-52

API Walkway Absorbers

These absorbers are designed to provide access to antennas and EUT in fully anechoic chambers. They can withstand up to 200 kg/m² loads, with standard base dimensions 1220 x 610 mm. Their performances reach -30 dB, as they consist in pyramidal absorbers tied together and sealed in a plastic envelope. Their heat dissipation is 0.13 W/cm² max continuous, with vinyl coating M2.
They can withstand up to 290 V/m max CW.



Minimum reflectivity of HYFRAL API in dB *									
Type	Thickness (mm)	200 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 to 8 GHz	8 to 12 GHz	12 to 18 GHz
API 21	210				-20	-24	-21	-19	-18
API 31	310			-10	-24	-24	-21	-19	-18
API 40	400			-20	-25	-28	-27	-22	-20
API 55	550		-10	-22	-32	-32	-31	-26	-23
API 78	780	-10	-15	-25	-35	-35	-35	-30	-26

* For incidence angles close to the normal

AT/AH Multilayer Absorbers

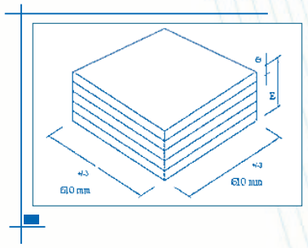
AT and AH are a range of flat absorbers consisting of 3 (AT) or 5 (AH) layers of polyether polyurethane foam with 90% open cells impregnated by a dielectric carbon solution, a binder and a fire retardant. Used to cover all metal surfaces, masts and antenna bases, they can also help reduce coupling effects between antennas. High absorption characteristics can be obtained with small thicknesses.

Available for standard dimensions 610 x 610mm, the height of the absorbers depends on the thickness of every layer.
The number of layers determines the frequency range of operation of multilayer absorbers: the more layers, the wider the frequency range.

Minimum reflectivity of HYFRAL AT in dB *

Type	Thickness (mm)	100 MHz	150 MHz	200 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz	26 GHz	40 GHz
AT60	60				- 6	- 11	-20	- 20	- 20	- 20	- 20	- 20	- 20	- 20
AT350	350	- 8	- 12	- 15	- 16	- 17	- 20	- 22	- 23	- 23	- 23	- 23	- 23	- 23

The main advantages of such absorbers are :
- Reflectivity values obtained are better than - 20 dB.
- Flexibility: Can be easily cut
- Light weight: Targeted applications are RCS reduction, Antenna measurements...

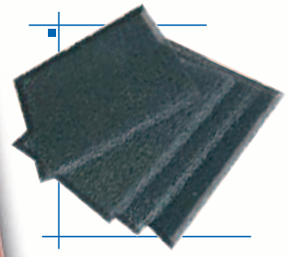


HYFRAL AH specifications AT

Type	Thickness of a layer	Total thickness	Frequency (GHz)	Weight (Kg)
AH 25	5 mm	25 mm	9 to 100	0.56
AH 30	6 mm	30 mm	5 to 100	0.67
AH 40	8 mm	40 mm	2.4 to 100	0.89
AH 75	15 mm	75 mm	0.95 to 100	1.65
AH100	20 mm	100 mm	0.8 to 100	2.22
AH 125	25 mm	125 mm	0.6 to 100	2.78
AH 250	50 mm	250 mm	0.3 to 100	5.55

Minimum reflectivity: - 20 dB, for specified frequencies.

CR/PR Reticulad Absorbers

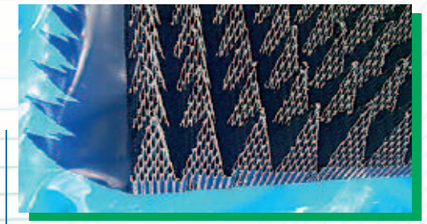


CR/PR is a range of low cost absorbers consisting of reticulated foam impregnated with a carbon dielectric solution and a binder, which can easily be cut, and are designed for use in antenna manufacturing, antenna pattern improvement, front-to-back ratio enhancement and side lobe level reduction.

Minimum reflectivity of HYFRAL PR in dB *

Type	Height (mm)	3 GHz	4 GHz	8 GHz	12 GHz	26 GHz
PR 10	10			- 10	- 12	-13
PR 15	15		- 8	- 13	-15	-18
PR 20	20		- 12	-18	-18	-18
PR 50	50	- 15	-16	-18	-18	-18

AHP High-Power Absorbers

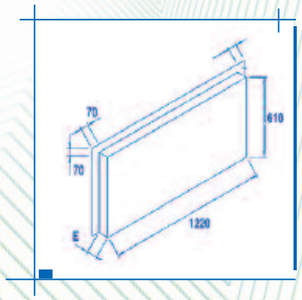


The open honeycomb structure of the AHP allows using forced ventilation from the back, ensuring a better dissipation of the energy.
When regular absorbers can withstand power densities up to 0,2 W/cm², AHP capabilities raise this value up to 2 W/cm² and even more with forced ventilation. AHP should be lined up in critical areas, where energy focus is maximum. they are designed for the lining areas of anechoic or semi-anechoic chambers subject to very high power density.

Minimum reflectivity of HYFRAL AHP in dB *

Type	Height (mm)	1 GHz	2 GHz	4 GHz	8 GHz	12 GHz	18 GHz
AHP 9	89	-9	-25	-30	-33	-40	-40
AHP 12	115	-10	-26	-31	-34	-40	-40
AHP 20	210	-23	-28	-33	-42	-42	-43
AHP 30	305	-25	-31	-43	-48	-43	-46
AHP 45	455	-27	-34	-47	-50	-45	-47
AHP 55	550	-29	-35	-48	-50	-45	-47
AHP 66	660	-31	-36	-50	-50	-45	-47

AI Weatherproof Absorbers



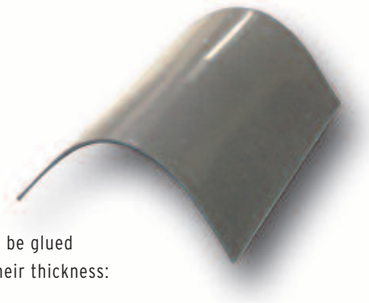
Weatherproof absorbers consist in a foam absorber, sealed in plastic envelope, with standard base dimensions 1220 x 610 mm.
They are designed mostly for outdoor use (RCS reduction, antenna towers concealing...)

Minimum reflectivity of HYFRAL AI in dB *

Type	Thickness (mm)	200 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 to 18 GHz
AI 5	95					-15	-20
AI 9	130				-16	-21	-27
AI 12	155				-23	-28	-30
AI 20	250			-15	-28	-30	-30
AI 30	345			-22	-30	-30	-30
AI 45	495			-28	-30	-30	-30
AI 55	590		-20	-30	-30	-30	-30
AI 66	700	-15	-25	-30	-30	-30	-30

* For incidence angles close to the normal

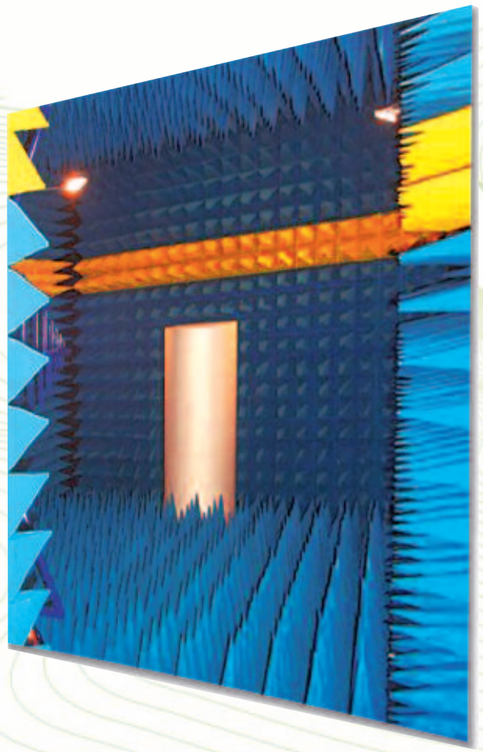
ASI Silicone & APU Urethane Absorbers

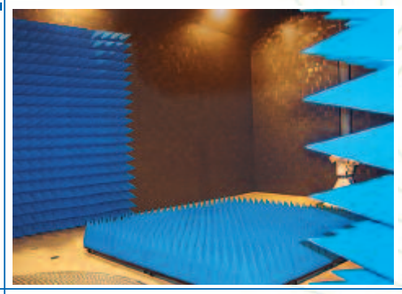


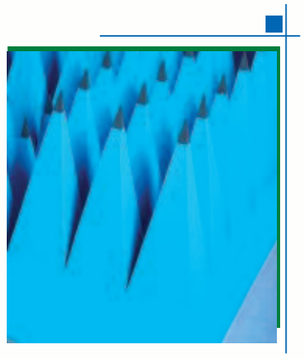
ASI are flexible absorbers made of elastomer resin and a magnetic load,
especially designed for outdoor environments, available as 300 x 300 mm tiles to be glued
over metal plates. Silicones are resonant at working frequencies, depending on their thickness:
from 1 mm to 6 mm, for resonant frequencies between 1 GHz and 26 GHz.
Their reflectivity performances can reach up to -30 dB @ f_0 , with approximately -20 dB
on a bandwidth as wide as 15% of the central frequency.

APU type absorbers have the same physical characteristics as the absorbers based on silicone matrix,
but as they are based on polyurethane and they can be painted.
For example, they can be used in small anechoic cabinets for radio testing on narrow band devices, e.g. Bluetooth, WLAN, Tx / Rx, etc.

Material	Resonance Frequency	Thickness
ASI 1.5	1.5 GHz	4.3 mm
ASI 2	2 GHz	3.7 mm
ASI 2.5	2.5 GHz	3.2 mm
ASI 3	3 GHz	3.2 mm
ASI 4	4 GHz	2.5 mm
ASI 5	5 GHz	2 mm
ASI 6	6 GHz	2 mm
ASI 8	8 GHz	2 mm
ASI 10	10 GHz	1.9 mm
ASI 15	15 GHz	1.4 mm
ASI 18	18 GHz	1.2 mm







MI Multilayer Pyramidal Absorbers

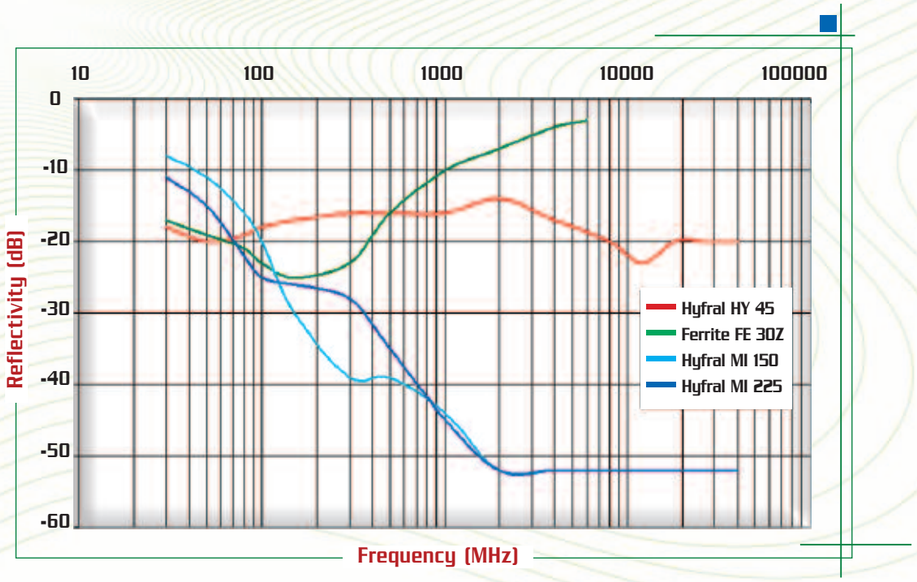
MI absorbers combine the properties of a gradient load with geometrical impedance matching. They consist in a pyramidal absorber with low load, creating an impedance matching and absorption of low frequency electromagnetic waves, while the multilayer base of the absorbers provides a progressive carbon load and absorption of high frequency waves.

Therefore, MI absorbers have incomparable broadband performances, from as low a 30 MHz up to 200 GHz.

Minimum Reflectivity of HYFRAL MI in dB *

Type	Height (mm)	30 MHz	50 MHz	80 MHz	100 MHz	150 MHz	300 MHz	500 MHz	1 GHz	2 GHz	4 GHz	8 GHz and +
MI 76	760	-1	-3	-8	-11	-18	-25	-30	-41	-42	-50	-52
MI 100	1000	-4	-9	-15	-19	-23	-35	-36	-42	-50	-52	-52
MI 120	1200	-7	-10	-15	-19	-28	-37	-38	-43	-50	-52	-52
MI 150	1500	-8	-11	-16	-20	-30	-39	-39	-44	-52	-52	-52
MI 225	2250	-11	-15	-22	-25	-26	-28	-35	-45	-52	-52	-52

The total overall height of the MI ranges from 760 mm (MI 76) up to 2,25m (MI 225), with flat layers installed first, surmounted by the pyramids. Their excellent performances meet the requirements of both EMC (civil, military and aeronautics) and ETSI standard.



* For incidence angles close to the normal

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