Image courtesy of TÜV SÜD, New Brighton, MN

White Paper

The Challenges of Delivering Large Anechoic Chambers for Testing Large EUTs

MVG
Microwave Vision Group

Introduction

Whenever starting a discussion about an EMC or antenna chamber design, very often it begins with a series of questions to aid in understanding the requirements. For example, in terms of an EMC chamber:

- What standards are you testing to?
- What performance requirements do you have for the NSA, the sVSWR, Field Uniformity, or is it for automotive or MIL-STD?
- Is the chamber to be pre-compliance or does it need to be fully compliant?

The same (or very similar) requirements must be discussed and understood when looking at antenna chamber design. While in this case there may not be standards to work to, there will still be performance requirements which need to be met. When looking at large chambers, there are also other issues which need to be considered as part of the design, many of which potentially have a civil engineering and/or building services implication.

This whitepaper will focus primarily on large chambers and large EUTs, considering some of the challenges which are faced when trying to design and implement such a chamber. It will not discuss the standards or test methods, instead focusing on the engineering aspects of designing and installing large chambers. The issues presented here are general, and equally applicable to EMC and/or antenna measurement chambers. Likewise, while the focus will be on large chambers, much of the information contained within is just as applicable for smaller chambers.

Why Use a Chamber?

The answer as to why we use a chamber for testing, be that for EMC or antenna measurements, should be relatively familiar, but let's recap.

Typically, the standards (especially in EMC) refer to the use of an open area test site (OATS), such as in *Image 1* below. These open area sites are the reference sites that we are looking to replicate when using a chamber.

Image 1 – Liberty Labs in Kimballton, Iowa; An example of an EMC open area test site

The image on the previous page shows an OATS with spacious open area around it, the weather is clear, with no wind or rain. However, this is not always the case.

Depending on geographic location and season, there may be wind, rain, snow, or other problematic weather conditions which can cause issues in the use of the site. In addition, there may be external signals which can interfere with the measurements, or cause other problems while trying to carry out a measurement program. So, while open area sites work well in theory, there are a set of challenges associated with them.

Using a chamber, on the other hand, provides many advantages:

- Reduces external influences – the ambient signals in the environment will not be seen inside the chamber
- Reduces reflections and scattering from nearby objects (the absorber in the chamber 'hides' the metallic walls and ceiling)
- Compact environment allowing for measurements in a much smaller space than would be possible with an open area site
- Replicates an open area environment, around and above the ground plane
- Weather proof!

Initial Host Building Considerations

When looking to integrate a chamber into a building, whether that is an existing building or a new host building, there are several challenges and issues that is necessary to consider.

Firstly: how much space is available for the chamber? In some cases, an existing host building might not be big enough. If however it is a new building, it may be necessary to design the building around the requirements of the chamber. Further, there may be additional special considerations to take into account:

- Are pits required in the floor of the chamber, and therefore in the host building floor, such as for the installation of a turntable?
- Where are the columns and ceiling beams located in the host building?
  - As these are not moveable, they may restrict the size of the chamber or where it can be placed.
  - Special measures may need to be taken to work around these.
- What is the access to the installation location like, are there any restrictions due to the location?
  - When installing chambers, all the materials (some of which might be large and/or heavy) need to get to the location, and after completion, customers must be able to get their EUTs into the chamber location.
  - If the EUT is for example a vehicle, then there must be a clear path to get it to the chamber door.

Floor Requirements

As the chamber is going to sit on the floor of the host building, understanding the requirements for the floor is an important early consideration. Typically, this requires us to understand the loads which will be imposed by the chamber onto the host building floor, as well as the distribution of those loads.

If the chamber is on the ground floor, typically it's going to be installed directly on the host building concrete slab, and generally this will be fine as it is. However, when on the first or a higher floor, is it possible that the chamber will be installed on top of a raised (false) floor, and these typically have a relatively low maximum load rating. It might be possible to install directly on the concrete slab of an upper floor, but again, these typically have a lower load rating than a ground floor slab would have.

In either case, it might be that the chamber will present a higher load than the slab or raised floor can take. As such, understanding chamber loads is extremely important.

An important aspect to understand here, and early on in the process, is that the chamber loads will not be evenly distributed across the floor area. It is not unusual to be asked what the distributed floor loading of the chamber will be, but this is not usually the highest load presented by the chamber. Rather, the base of the supporting columns used for the steelwork, as well as the edges of the chamber, tend to have the highest loads associated with them. The distributed floor load, excluding the load presented by the EUT, is generally much lower.

Considering this, an early initial requirement is often to develop the supporting steelwork arrangement, taking into account all the loads which are known at the time. This typically include factors such as the anechoic lining and any services which might be attached to the chamber. For example, a lining of ferrite tiles and hybrid absorber (as typical for EMC) is going to be heavier than if just broadband absorber (such as for antenna measurements) is used. Further, if there will be services running across the ceiling of the chamber (eg HVAC) these need to be taken into account as well.

Supporting Steelwork Design

The supporting steel work design therefore depends on many factors:

- **Chamber dimensions:** the length, width and particularly the height will have a big impact on the supporting steelwork.
- **Anechoic lining:** as previously mentioned, ferrite and hybrid solutions for EMC are typically a lot heavier than broadband solutions for antenna measurements.
- **Services fixed to the walls and/or ceiling**

Other factors to take into account include the size and location of the chamber doors, especially if they are sliding doors (even though the final location for these might change during the chamber design process) and also the EUT load if this is to be significant (and if it will be supported from a crane).

Images 2a-2b below show some typical preliminary steelwork designs for different chambers.

It can be observed in these images that there are differences in the steelwork design depending on the size of the chamber, and the requirements of the chamber. The design in *2a* has double height associated with it, as in this case a single steelwork structure is being used to support two different chambers. In *2b*, there is a top hat arrangement above the chamber to accommodate a crane.

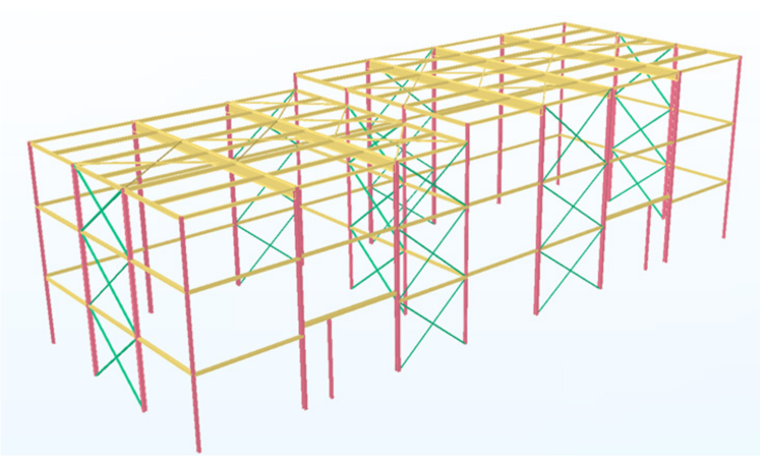

Image 2a

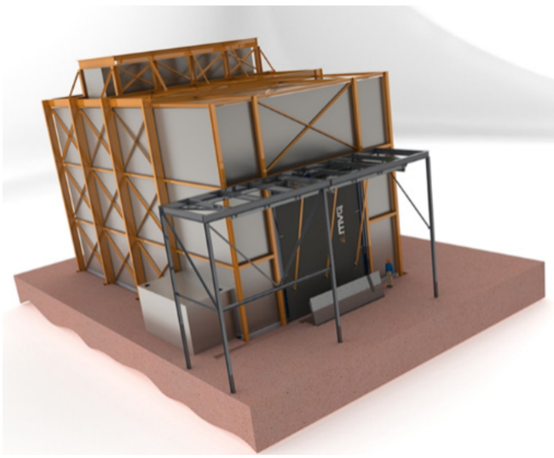

Image 2b

Another very important aspect of the supporting steelwork design is to ensure that it's designed and manufactured to meet the requirements of applicable local and national regulations. Different parts of the world, and sometimes even different parts of the same country, might have different requirements.

In Europe, for example, there are the Construction Products Regulations and these include requirements on the structural steelwork. The applicable standard, EN1090 (to which the chamber division of MVG are accredited), relates to the structural steelwork design and management, as well as the construction / installation of the steelwork. In some parts of the world, there may also be seismic requirements which need to be taken into account. These are all requirements which the chamber provider will be able to incorporate into the overall steelwork design.

Floor Requirements, Cont.'d

With a large and therefore typically heavy EUT, a welded floor will often be considered for the chamber to ensure that it can withstand the loads which will be presented. In terms of the host building, this will typically require that a pit is prepared in the host building floor to facilitate the installation of the chamber floor. Additionally, further pits might be required if turntables and/or dynos are to be integrated. The chamber designer will usually be able to provide the host building contractor with the required concrete levels for the host building floor.

In terms of installing a welded floor, initially a grillage (steelwork frame) will be placed down which will then be infilled with concrete. Floor panels will then be placed on top of this, before welding them together as well as to the grillage structure. This results in a very strong, and stable, floor surface for heavy EUTs. Indeed, floor surfaces constructed this way are typically able to withstand many tens of tons of EUT load on top of them, 50-70 tons (or more).

Thinking further on the supporting steelwork arrangement, and as briefly discussed earlier, when the initial design for the steelwork is produced, the chamber designers can perform a load calculation (*Figure 1*). This will show the host building designer how the chamber loads are distributed between the columns, wall edges, and across the floor area.

Typically, the EUT load is excluded from this calculation, but if required it can also be included. As mentioned earlier, this is mainly going to impact the distributed floor loading rather than the column or the wall edge loading. Unless, that is, the EUT is suspended from a crane!

It's very important for the host building designers to understand these loads to ensure that the concrete slab is designed with the right thickness and strength, and also that any strengthening if required is placed into the slab at the correct locations.

[redacted] [redacted]

Provisional Foundation Loadings

MVG | EMC

Column Static Dead Actions Vertical: kN

Grid Lines	A	B	C	D	E
5	31	94	94	88	30
4	60				37
3					96
2	60				37
1	32	94	94	88	30

Column Live Actions Vertical (Temp inc Crane): kN

Grid Lines	A	B	C	D	E
5	73	185	164	175	51
4	109				89
3					96
2	109				89
1	34	185	164	175	51

Column Static Dead Actions Horizontal kN

Grid Lines	A	B	C	D	E
5	10	20	20	20	10
4	10				10
3					10
2	10				10
1	10	20	20	20	10

Column Live Actions Horizontal kN

Grid Lines	A	B	C	D	E
5	20	30	30	30	20
4	45				30
3					30
2	45				30
1	20	30	30	30	20

Chamber Wall Static Dead Vertical line Action		20.8 kN/m
Chamber Wall Static Live Vertical line Action		2 kN/m
Chamber Floor Static Dead Vertical Action (excludes concrete infil)		2 kN/m2
Chamber Floor Live Vertical Action EUT		50 kN/m2
Chamber Floor Live Vertical Action EUT	tba	kN
Chamber Floor Construction Live Vertical Action		40 kN

All Actions are unfactored

Fig. 1 – A loading calculation sheet

Chamber Access

Fig. 3a – Single Leaf Swing Door

Fig. 3b – Double Leaf Swing Door

Fig. 4a & 4b – Sliding Door with Associated Supporting Steelwork

The next step to think about is how to get the EUT into the chamber – obviously, this is an important consideration! The main factors to consider here are the size of the EUT, its weight, and how it moves. For example; is it on wheels, does it need to be forklifted, will it be on a crane?

Once this is established, the next consideration is what type of door will be required. In many cases, a swing door is suitable but, should this be a single leaf door (*3a*) or a double leaf door (*3b*)? Or, if a sliding door is required (*Image 4a, 4b*), what size does it need to be? Typically as the door size increases, a sliding door becomes a more practical solution. It should however be noted that with a sliding door, as you can see in images *4a* and *4b*, there is additional supporting steelwork, and this would need to feed into the supporting steelwork design and loading calculation as previously discussed.

Once the type of door is decided, we need to consider how we will transition from the outside to inside the chamber, and the size / weight of the EUT will have a bearing on this. RF shielded doors, such as used on EMC chambers, usually have a door threshold associated with them, this is to ensure the RF shielding of the chamber is maintained when the door is shut. The physical door leaf itself is larger than the open area space which is revealed once the door is opened.

As such, consideration must be given to ways of overcoming the door threshold. This will in part be driven by the EUT's size and weight, and how it is going to be moved. Does it, for example, need to have flush access into the chamber, or can the threshold be stepped over in some way?

There are different ways of achieving flush access into a chamber, lift tables, flaps, or ramps can and are often incorporated. If the door is higher up, such as shown in *Image 5* where the chamber could not be constructed in a pit, it is possible to use ramps and semi-auto ramps. In this case, the top section of the ramp raises once the door is opened, ensuring ease of access for wheeled EUTs.

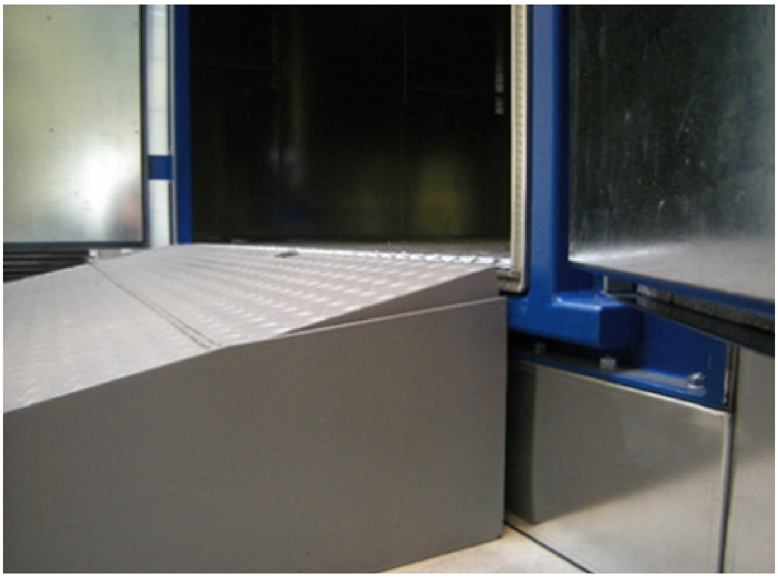

Image 5 – Flush access with a higher door, using a semi-automatic ramp.

The solution which is used will be driven by how the EUT is going to be moved into the chamber, and also any particular restrictions which may exist in the host building.

Moving the EUT when in the Chamber

Once the EUT is in the chamber, we then have to consider how it will be moved around the chamber.

Many larger EUTs will have wheels, such as cars or trucks, and other vehicles. But sometimes, especially when the EUT is an antenna system which is typically not on wheels, it might need lifting once inside the chamber.

This often requires that a crane is integrated into the chamber, and it is necessary to consider how that crane will move, which will depend on the type and size of EUT, and where it needs to be moved to. For example;

- Is it a simple, up-down movement with the crane fixed in a single position?
- Does the crane need to move, for example, across the width of the chamber?
- Where will the EUT be picked up, and where does it need to be placed down (eg from the door to a measurement position)?
- Does it require a full XY movement inside the chamber in order to cover the whole floor area?

Also it is important to think about the load which the crane will be carrying. Again, depending on what that load is, different crane solutions might be preferable over others.

Does the crane need to be hidden (so that it does not influence the measurements) and, if so, how can that be achieved? Keeping the crane hidden may be especially necessary if using a large crane to lift a large load, where exposure of the crane will be detrimental to the measurements which are being conducted.

Below are several examples of different cranes inside chambers. *Image 6* shows an XY gantry crane running the whole length of a shielded chamber. This type of crane solution allows for the entire floor area of the chamber to be covered. In this case, as it is a shielded chamber (no RF absorber), hiding the crane was not required.

Image 6

An alternative solution, such as in *Image 7*, shows a single axis crane in a top hat arrangement. Here the crane will run across the width of the chamber, most likely to move an EUT from the door to a measurement position.

The mechanics of the crane are hidden within the top hat, meaning they are not exposed during any measurement programs.

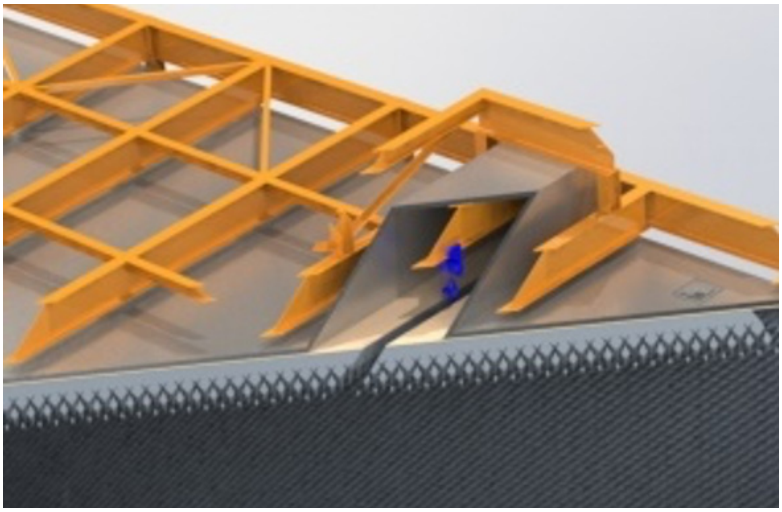

Image 7

In this third example, *Image 8*, we see another method for hiding a crane within the absorbers. Shown here is a jib crane, which can be swung out to pick up the EUT, then swung back again once the EUT has been placed into position. As it is covered in absorber, once it is parked against the wall, it is not exposed and will not impact the measurements which are being done in the chamber.

Another way of moving an EUT when it's in the chamber is to include a turntable. This is very typical for EMC chambers, though less common for antenna measurement chambers (though there might be other positioners, such as AZ/EL, which are akin to a turntable). However, depending on the overall requirement, it might be that there is a turntable.

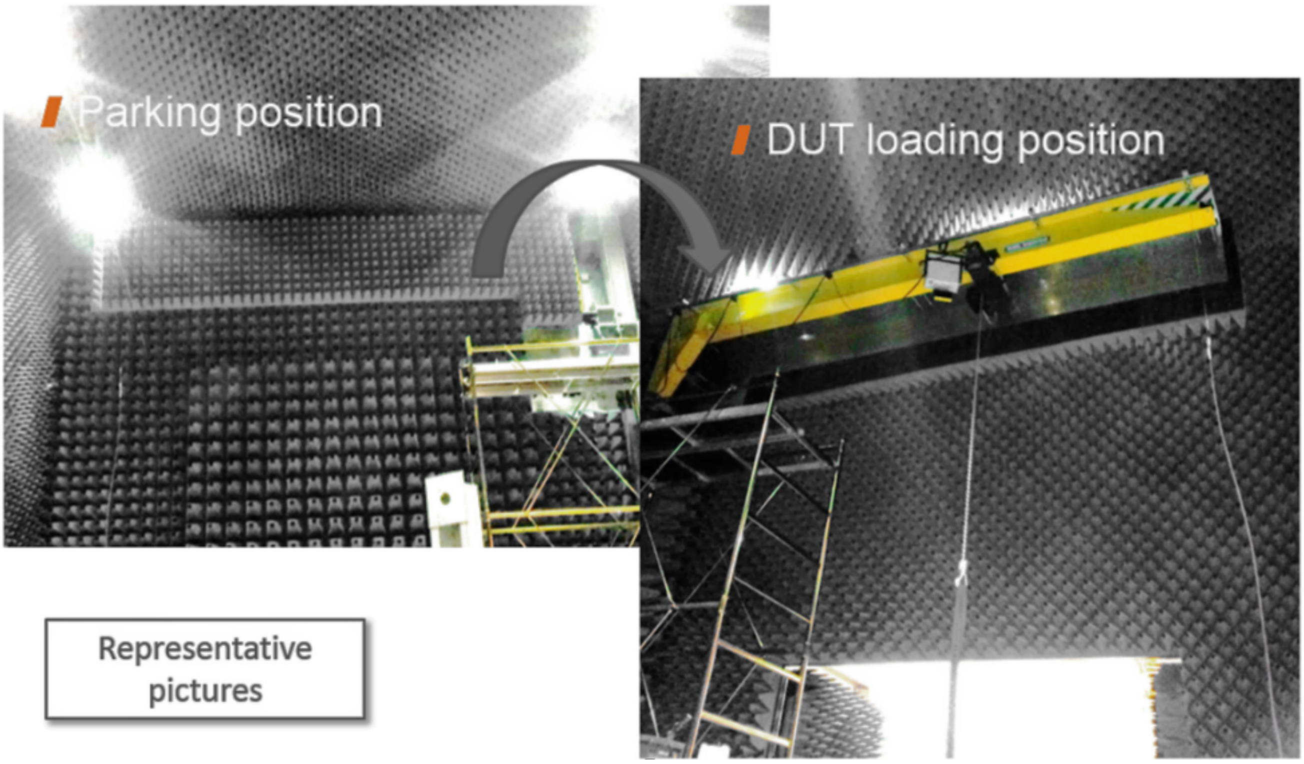

Image 8

Depending on the size of the turntable, this might require that there is a pit in the host building floor in which the turntable will be housed. The size and complexity of the turntable will vary based on the project requirements, and therefore the size and complexity of the pit and the structure around it will also vary based on the project requirements.

In the example below (*Image 9*), we can see the shielded pit for a turntable. The turntable in this example was 11m in diameter, with an integrated dyno. As such, the pit was very large, and due to the design of the turntable / dyno, required that there was a concrete plinth to support the structure.

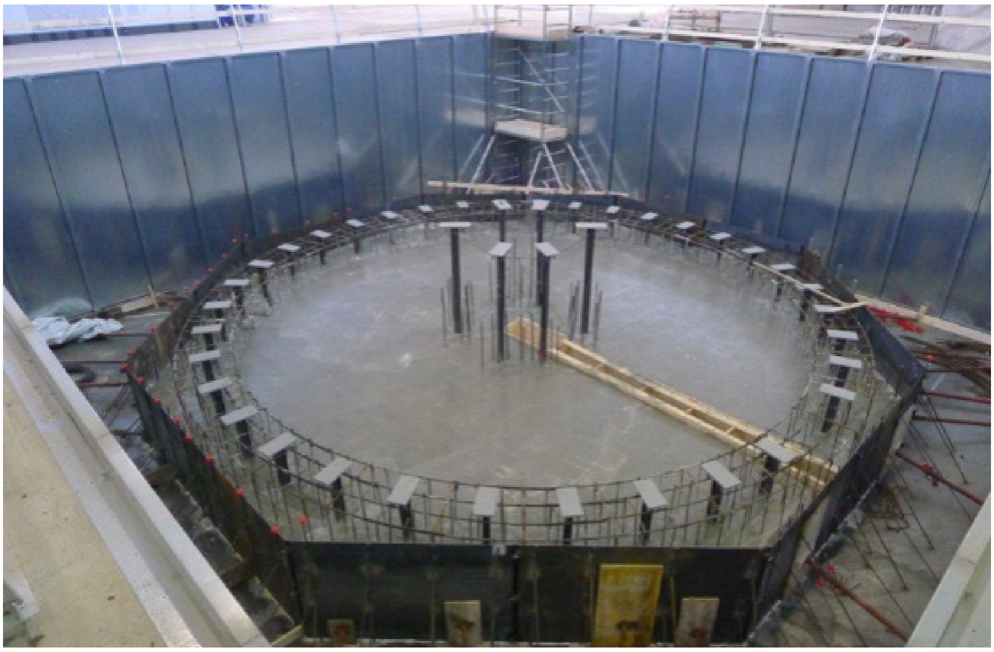

Image 9

It should be noted that getting elements such as this integrated into a chamber is not a straightforward process. It requires diligent interaction and cooperation between the chamber designers, turntable / dyno supplier, end customer, and the host building contractors to ensure that the different aspects of the installation are done in the right order, and that everything is prepared ready for the delivery and installation of the turntable.

Building Services Integration

The integration of the building services covers many different issues such as electrical services, mechanical services, HVAC, and also fire detection and suppression. Each of these have different requirements and challenges which need to be addressed. Not all of them will apply to every single chamber solution, but the general aspects here are very common to many different chambers.

Building Services Integration – Electrical

The main item to consider with regard to the electrical integration are the power line filters which will be required for the chamber. These are primarily for providing power for the EUT, but also for any supporting equipment, as well as general power, and any additional shielded rooms such as control and amplifier rooms.

When defining the filters, it is essential to understand the power requirements for the EUT, does it require single-phase, three-phase, or DC, or a combination of? What voltage and current is needed, not only for the EUT, but also for any auxiliary equipment which might be in the chamber, and also for general chamber power (eg lights)? There might also be other equipment in the chamber which needs power, such as turntables and cranes, and these typically will be on a different supply to that used for the EUT.

While defining the filters, it should also be kept in mind that power has to be supplied to them. The provision of these supplies is a host building requirement, and early discussion with the customer is advised to ensure that suitable supplies exist.

For most applications, the filters are standard sizes (both physically and also in terms of voltage / current), but for some applications they can be physically very large and very heavy, and also require high voltage / current supplies. As an example, for the filter arrangement shown in *Image 10* below, this was about 2m wide, 3m high, and weighing about 2,000kg.

Image 10

A further example of electrical services which need to be integrated within the chamber include communication systems, allowing personnel who are inside the chamber to communicate with those outside, for example in a control room. Further, in most cases it is necessary to have a data connection between the EUT and other systems inside the chamber, and auxiliary equipment outside. Likewise, there are typically a series of control signals for the EUT, or for the measurement system, inside the chamber.

Many of these connections also require filters, but in some cases they can be managed by means of fiber optic converters. From an RF point of view, fiber optics are a great way of getting signals in and out of the chamber, and allow many connections for which copper cabling and filters are not suitable or applicable. Further, because there is no copper cabling being carried in and out of the chamber, it is a good way of maintaining the overall shielding integrity of the chamber.

Building Services Integration – Mechanical
For the mechanical services, we have to manage the waveguide interfaces which will be needed. Such services might come into the chamber via penetration panels in the walls of the chamber, or floor boxes within the floor of the chamber (typically used when there is a raised floor in the chamber). Examples of such services might include: gas(es), compressed air, coolants, and water.

The services which are required for a chamber will very much depend on those which are required by the EUT, and supporting the operation of the EUT. Fibre optics, such as were discussed earlier, also need to be brought into the chamber and this is typically achieved by means of a waveguide interface. Two other areas to consider when thinking about mechanical services are fire detection and suppression, and HVAC. Both of these need waveguides for where they access the chamber, and we will look at both of them in following sections.

Building Services Integration – HVAC
When considering HVAC for a chamber, there are different solutions to consider, and depending on which is selected, the method of integration will vary. The choice of HVAC solution will also depend on several factors:

- Is the chamber anechoic or just shielded?
- What are the heat loads in the chamber?
- What size HVAC system is needed to handle those heat loads?

For an anechoic chamber, typically a ducted HVAC system is preferable compared to other types of system. With a ducted system, all of the HVAC plant is external to the chamber, with the air being ducted in and out. To get the air through the shield, a series of attenuvents will be used, these are typically a honeycomb material and act as a waveguide beyond cut-off. It is important to ensure that the attenuvents are correctly sized for the HVAC system, taking into account the pressure drop through the vent, and that there are sufficient quantity of vents. The advantage of a ducted system, as previously mentioned, is that the whole HVAC system is outside of the chamber, so it will not impact any of the measurements.

For non-anechoic environments such as shielded rooms or control rooms, often a split system can be used. The air handling unit is inside the shielded room, and the condenser unit is outside the host building. In such systems it is necessary to pass power and control between the two units, and also the coolant, these penetrations being managed by filters and waveguides as required. Split systems are a very efficient way to manage air conditioning requirements in such environments. But again, it’s important to understand that the heat loads in the shielded chamber will have an impact on what type and size of system is required.

Related to the issue of HVAC, but from a different perspective, are exhaust extraction and vehicle cooling, such systems are typically required if engines will be running in the chamber.

Exhaust extraction systems can be installed in different ways depending on the requirements of the chamber, and how the chamber will be used:

- A standalone system whereby a non-conductive pipe is run across the floor of the chamber, this connects to an exhaust vent in the chamber wall, and then externally to the chamber there is an extraction fan which is used to draw the exhaust fumes out
- An integrated system where the exhaust extraction is typically integrated into a turntable and all the pipework runs under the floor of the chamber

Likewise, vehicle cooling systems can also either be standalone or integrated. Standalone mobile systems can be moved around the chamber to the required location as required, whereas for an integrated system the cooling fans are typically built into the turntable / dyno. A mobile system is blowing air which is already inside the chamber, the same could be the case for an integrated system, or it could have a fresh air supply. The best method will depend on the EUT and the specific cooling requirements.

Fire Detection and Suppression

The inclusion of fire detection and suppression in chamber design is becoming increasingly important. There is an increased awareness from customers, and especially their H&S and Fire officers that chambers need protection, as well of course as the protection of life. This can also lead to requiring additional egress paths out of the chamber in the event of a fire, or other emergency escapes paths being needed. When including fire detection and suppression systems with a chamber, these can either be standalone or, integrated with the host-building systems.

Incorporating a fire detection into a chamber is a relatively straightforward process. In most cases a gas aspirating system is preferable compared to a standard smoke detector, and the use of such systems is a very common solution. They are also easy to install and low cost (especially when compared to the chamber!)

One of major the advantages of a gas aspirating system, especially for use in anechoic chambers, is that there are no electronics inside the chamber. All of the monitoring, analysis and control for the fire detection system is outside of the chamber. The pipe work for the fire detection system typically runs externally to the chamber, up and down the walls, and across the roof. The only part which is in the chamber is a short length of plastic pipework. These enter the chamber via waveguide penetrations, and are required so that the air from within the chamber can be sampled.

Such fire detection systems are usually supplied as a standalone solution, but they can be very easily integrated into the host building management system, thereby allowing the chamber to be seen on the main building control panel. Whilst these are designed primarily for fire detection, they can also be extended to include for the detection of many other gases such as carbon monoxide, carbon dioxide, nitrogen dioxide, or methane. This is very important for many applications, particularly if vehicle engines will be running inside the chamber.

A fire suppression system is slightly more complicated to integrate into a chamber, and will require the involvement of a specialist 3rd party contractor to supply and install. When considering a fire suppression system, there are several questions that first need to be answered to understand what kind of suppression system is required:

- What are the potential ignition sources and fuels in the chamber?
- What is the right suppression agent (will depend on the ignition sources and fuels)?
- What is the volume of the chamber and any other areas which will need to be protected – including under the floor if the chamber has a raised / false floor?
- What are the prevailing local requirements and regulations with regard to fire suppression systems?

For many reasons, the use of a gas based suppression system, rather than a water based system, is preferable for shielded and anechoic facilities. However, it has to be borne in mind that with such systems space has to be found for storing the gas cylinders, and this will be outside of the chamber. Depending on the type of gas used, and the size of the chamber, the storage requirements could be quite large. Allocating space for this needs to be considered in the overall host building design, as well as taking into account how they will be integrated with the chamber, and the rest of the associated fire suppression system equipment.

Anechoic Design

Typically for EMC applications, the anechoic (or absorber) design is driven by the standards which are being tested against. Within those standards, such as CISPR16, there are performance requirements (the NSA and sVSWR), and the absorber layout is designed to ensure that these are met. However in MIL STD 461, for example, there is no chamber performance specified but rather the absorber reflectivity, and the selected absorber must meet it.

The size of the chamber and the EUT has some impact on the absorber design, but not an overriding impact, the aim is to meet the applicable performance requirements in the standard. For example, in *Image 11* we see a compact chamber which is used for pre-compliance measurement, and therefore relatively small hybrid absorbers may be used. A 10 meter EMC chamber (*Image 12*), where the NSA and sVSWR have to be met, might call for a combination of, for example, 12”, 18”, and 30” hybrid absorbers. MIL STD 461 chambers, such as in *Image 13*, might use a 20” broadband absorber.

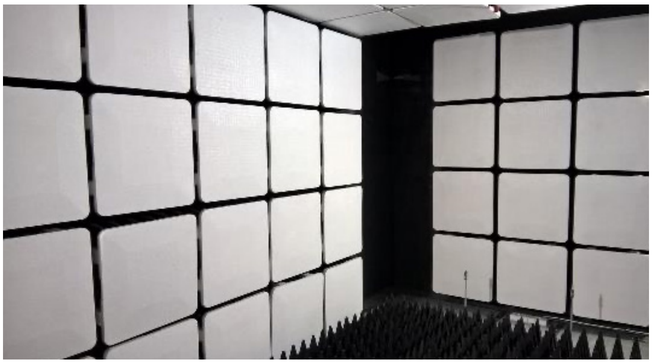

Image 11

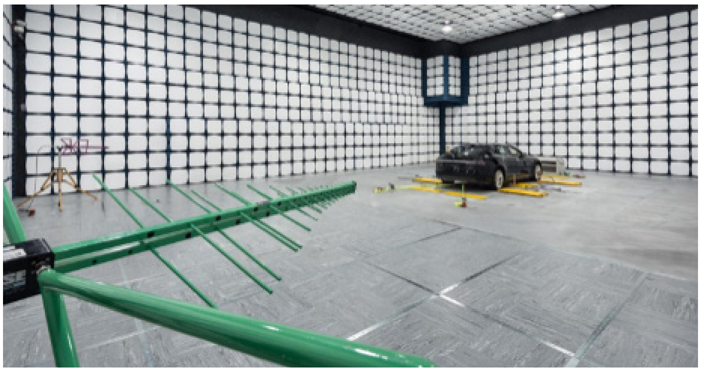

Image 12

Image 13

The absorber design will depend on the standard, more than on the EUT which is being tested. But, we need to take the absorber design into account early in the design process as, if larger and/or heavy absorbers are being used, this will have an influence on the steelwork and the supporting structure design for the chamber.

As an example, for an antenna chamber where the lowest frequency of interest might be 100MHz or lower, then typically some very large absorbers will be required, such as the MVG AEP-72 broadband pyramidal absorber shown below. Large absorbers like this are used in antenna chambers as a lower reflectivity is needed than for EMC, and as such large broadband pyramidal absorbers are preferable compared to a typical EMC lining of ferrite and a smaller hybrid. The MVG AEP-72 shown here, is 72 inches high (approx. 1.8m), and each piece weighs approximately 19kg. This means that the absorbers are presenting the best part of 60kg/m^2 of load to the chamber. So, the absorber design, especially if they are large and therefore heavy, not only feeds into the structural design as mentioned above, but also can have a significant impact on the chamber loads, which in turn feeds back into the host building floor requirement.

Image 14 – MVG AEP-72 pyramidal absorbers

Summary

To conclude, there are many advantages of using a chamber for EMC and antenna measurement programs. Primarily, this is because the chamber provides a controlled and repeatable test environment, and one which will not be impacted by bad weather.

Integration of a large chamber for EMC or antenna testing presents several challenges and issues which need to be considered. In all likelihood, a chamber supplier will have come across most if not all of them before, and will therefore be able to offer a solution. Of course, some projects present new challenges and issues, and if they don't have an immediate solution, then it is likely that they will be able to adapt one from a previous project.

Early engagement with the chamber supplier, especially when designing a new host building, can be very advantageous. The chamber supplier can provide a useful sounding board to ensure all important factors are being considered, and also to provide valuable input into the design process for the host building. It also allows them to highlight any areas of potential concern, or where the host building presents limitations to the chamber.

Thereby, helping to ensure that the final completed chamber will be as required, without compromise, and where all aspects have been considered early in the process.

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