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Close-field Probing to reduce EMC design risks Part 1

Helping you solve your EMC problems

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Using close-field probes to reduce design risks early in a project

— *Part 1* —

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Contents

1 Introduction to Part 1

This article, and the ones that will follow it, are about dealing with EMC issues during design and other project stages, to save time and money; reduce project/financial risks, and to help ensure that if we take products to a 'proper' EMC test lab for compliance testing, they will pass on the first test.

(It is important to note that for CE marking for legal sales in the European Union, there is no legal requirement under the EMC Directive to have ever done any EMC testing, which is a big help to start-up companies. Many established companies use EMC laboratory testing to help demonstrate that their products comply, but it is important to note that a product can pass all of the relevant EMC test standards and yet cause or suffer EMI in real-life and so fail to comply with the Essential Requirements of the EMC Directive. Discussing these issues goes beyond the remit of this article, but I have often written about them in the past.)

Close-field EMC probing (often called near-field probing) is difficult to do accurately, but it is an excellent *qualitative* technique that can be used to compare the EM characteristics of one thing, with those of another.

For this reason, although – like computer simulation – close-field probing cannot (generally, yet) be used to prove that a particular EMC laboratory test would be passed, it is of huge benefit in helping us discover and fix EMC problems.

These EMC problems can arise in all stages in the life of a module, product, equipment, system or installation (which I'll call an 'item' in the rest of this article) – from its initial proof-of-concept, through design, development, regulatory approval, Quality Assurance in serial manufacture, installation, etc. all the way to upgrades, repairs and refurbishments.

I think we all realise that the best time to deal with a risky design issue is as close to the start of a project as possible, when design changes cost little and there is plenty of design freedom. But many companies still guess at EMC design issues, leaving the discovery of EMC problems until near the end of a project when any changes are very costly and there is little design freedom.

It is a common joke that if you ask two EMC consultants the same question you will get three different answers – but one thing that all of the EMC consultants I have ever met agree on, is that time and cost will be saved overall by dealing with EMC design issues earlier in a project, compared with leaving them until the end.

The choice of materials for the construction of an item, and its mechanical design, is often done a long time before the electronic hardware is ready to be fitted into it, and this is often some time before its software is ready and all of its functions can be tested.

When EMC problems are discovered at this late stage in a project, it is often the case that a different choice of mechanical materials and/or a different mechanical design would easily solve the problem – unfortunately these are issues that are pretty much 'set in stone' and difficult, costly and time-consuming to change.

2 Making and/or buying close-field probes

Close-field EMC probing is low-cost and very useful, and for decades I (and many others) have been using them to detect the 'leakages' from electronic items to discover and fix the 'weak spots' that are probably causing the EMC test failures. For examples of this, see [1] [2] and [3].

These techniques can help to reduce the delays in time-to-market caused by the shortcomings in the EMC design, sometimes dramatically so. For example, it is not very unusual to find a problem and its solution in a few minutes, by using a close-field probe, when engineers working without the benefit of close-field probing have already spent several weeks and got nowhere. Once people learn to use close-field probes as described in these references, they wonder how they ever managed without them!

However, there are ways of using close-field probes to de-risk a range of EMC design issues very early in a project – long before the hardware or software are designed – when the mechanical design is being started and the constructional materials chosen.

I have read about these techniques from time to time, and promised myself I would investigate them, but you know how time flies......

Anyway, I was recently asked to present a full-day seminar on close-field probing techniques that save time and cost, and so I thought it was time that I finally got to grips with the kinds of techniques described by Scott Roleson [4] [5] [6], Doug Smith [7], Dr. Arturo Mediano [8], Ken Wyatt [9], by Tim Williams in the EMC Training Programmes held at EMC-UK events over recent years [10], and anecdotally by many others.

The material that I have gathered as a result will take more than one article in the EMC Journal to describe, so this article is mostly an introduction.

We can easily make close-field probes, even from a paper clip, see Figures 1, 2, 3 and 4. The largest probe dimension (i.e. the diagonal or major diameter of a loop) should be less than 1/6th of the wavelength at the highest frequency to be measured (e.g. for < 1GHz: < 50mm diameter) so that – even when placed close to a large lump of dielectric such as a PCB – they are still 'electrically small' and well below their frequency of first resonance.

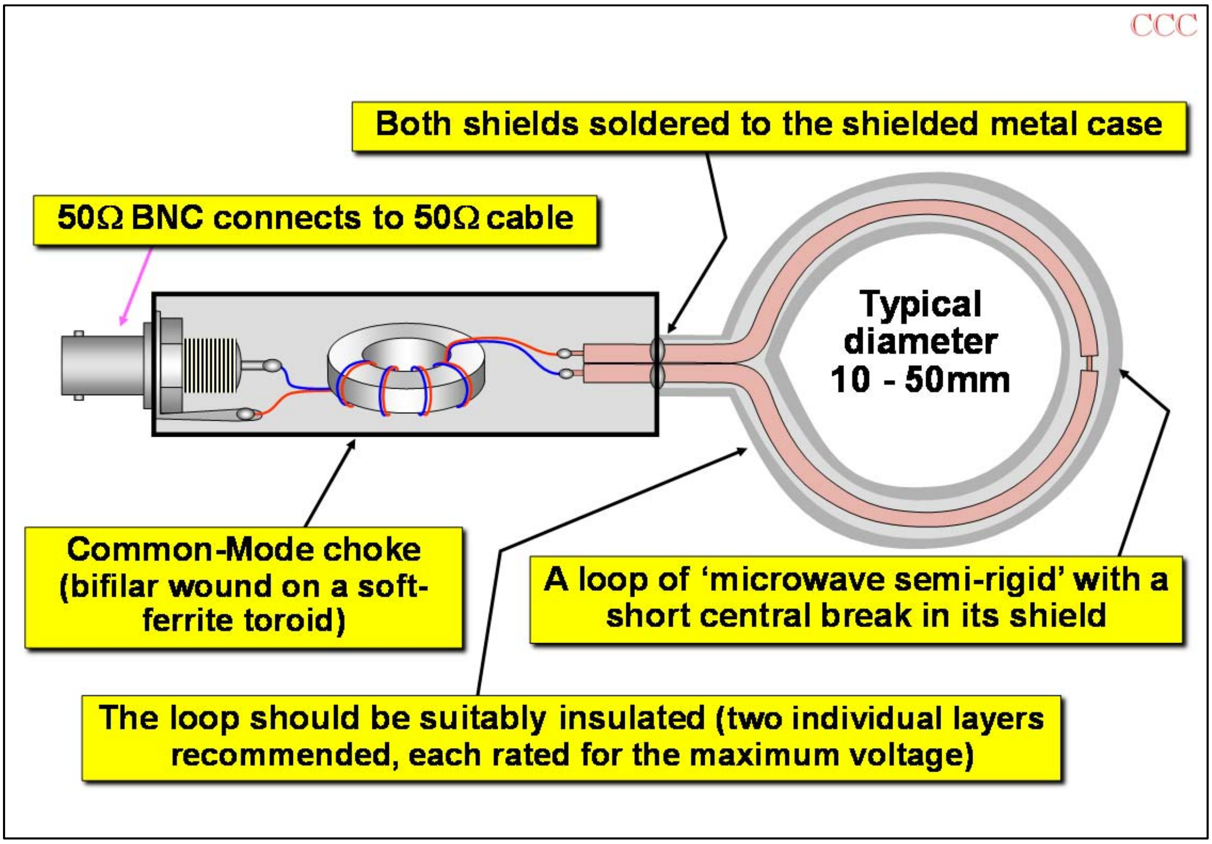

Figure 1 The construction of a good-quality close-field magnetic probe

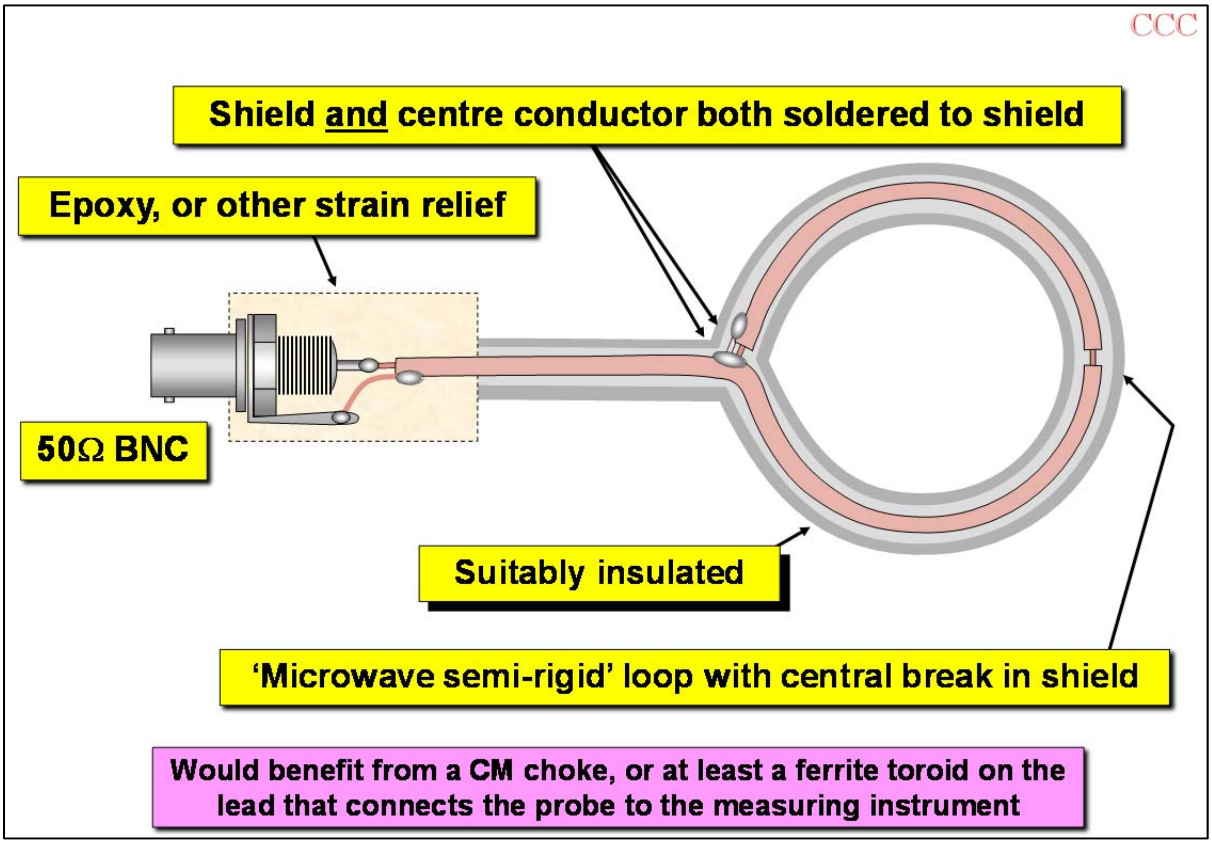

Figure 2 An easier magnetic field close-field probe design (but not so good)

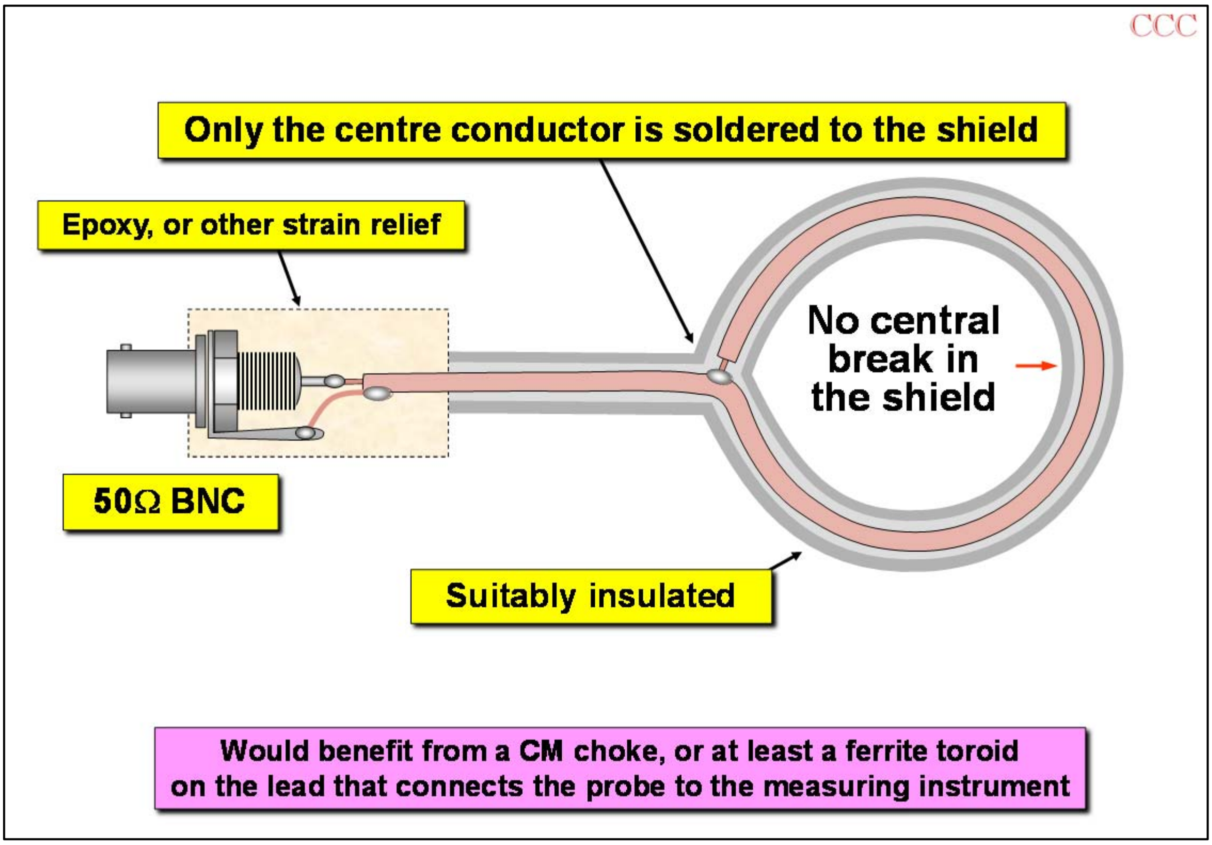

Figure 3 The simplest magnetic close-field probe design (but even less good)

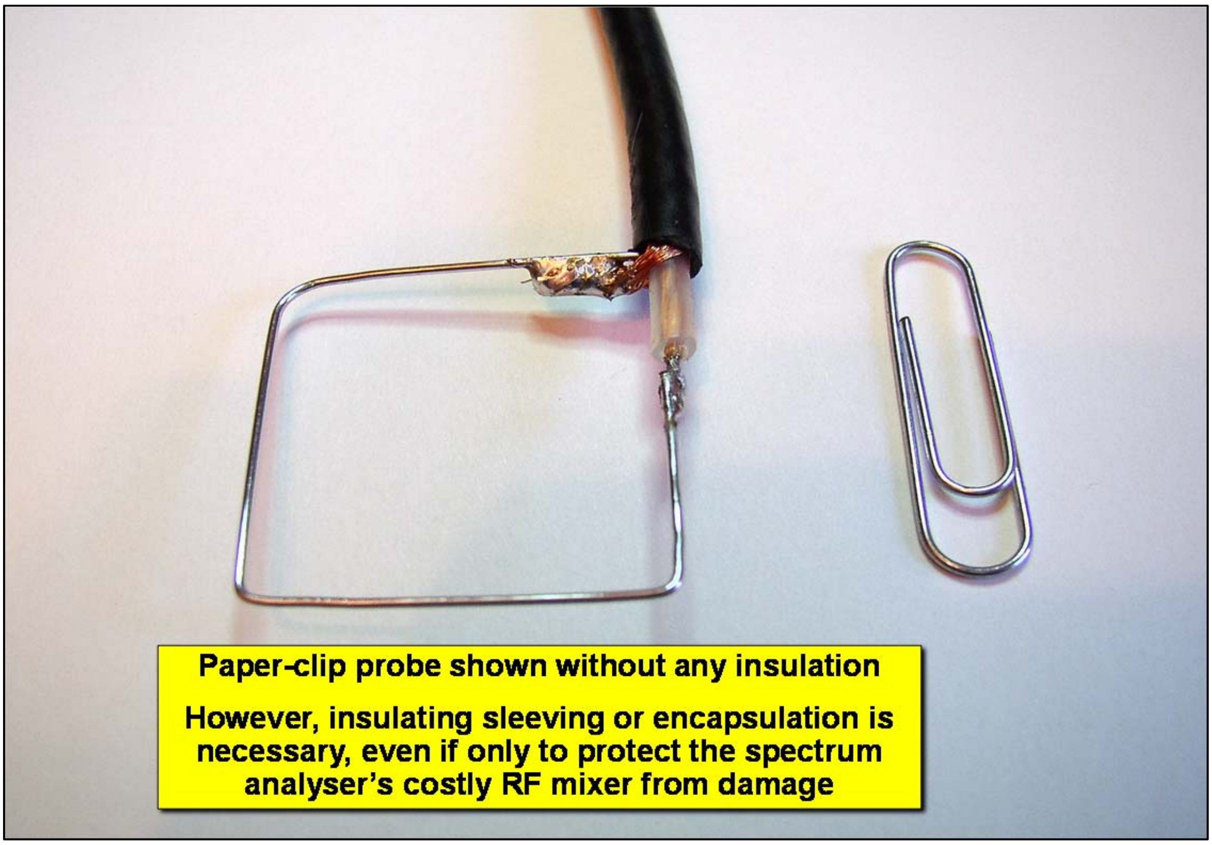

Figure 4 Using a paper clip to make an unshielded close-field probe

Close-field probes are often hand-made from 'microwave semi-rigid' cable, e.g. RG402 (approx. 3mm outside diameter) or RG405 (approx. 2mm outside diameter) because the stiffness of this type of cable helps the probes to retain their shape and so give more repeatable results, and also because their solid copper shields are very effective indeed.

An additional benefit is that the dielectric material in these semi-rigid cable types is solid Teflon, and so is unaffected by soldering at any normal temperatures. SMA connectors (male and female types) are readily available for soldering directly to these same cable types, helping to make robust and reliable probe assemblies.

Magnetic-field close-field probes are often called 'loop' probes, but there is no good reason for making them in a circular shape. In fact, rectangular probes have some advantages when used on flat surfaces, as is often the case in practice. And, I have recently discovered that making them rectangular is much easier and quicker than trying to bend semi-rigid cable into a neat circle!

I don't plan to discuss electric-field close-field probes in this article, because as yet I have no real experience with them. But I often use unshielded loop probes (like the paper clip probe in Figure 4) when searching for 'leakages' and 'weak spots', because they pick up electric (E) fields as well as magnetic (H) fields. When we don't know the nature of a possible leakage (i.e. whether it leaks E or H fields) using an unshielded loop probe can help save time in locating it.

Figure 5 shows four probes that are simply made of enamelled copper wire soldered to SMA PCB-mount connectors: unshielded loop probes that I really ought to insulate better (so I never let anyone else use them).

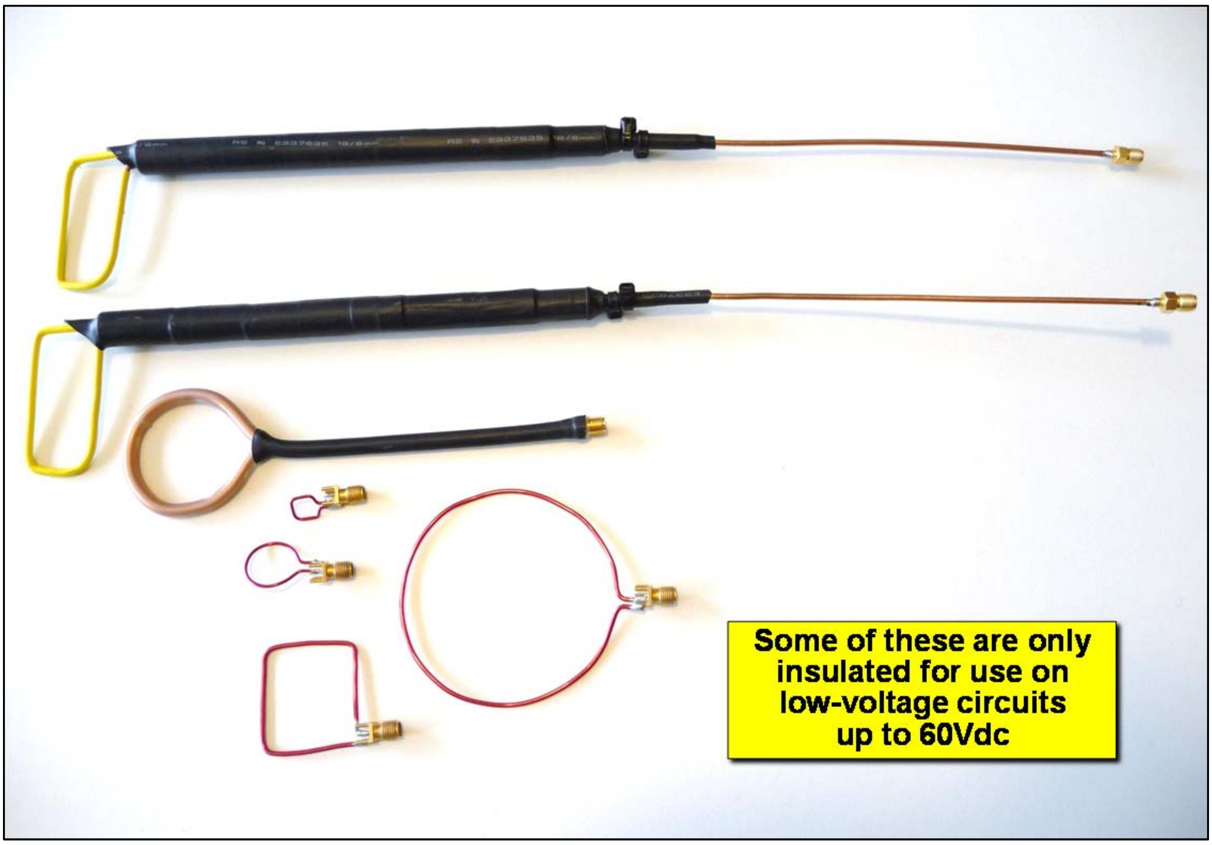

Figure 5 The range of close-field probes that I use (at the time of writing)

When we don't feel like spending the time making our own close-field probes, or when a professional appearance matters, we can purchase close-field probes from numerous suppliers of EMC test equipment, for example those in Figures 6, 7, 8 and 9.

Figure 6 Examples of close-field probes from Aariona, Laplace Instruments and ETS-Lindgren

Figure 7 Some of the many close-field probe kits from Langer EMV-Technik

Figure 8 **Hewlett-Packard's venerable close-field probes, and currently available ones from Agilent (soon to be renamed Keysight Technologies) and Teseq (which used to be Chase EMC)**

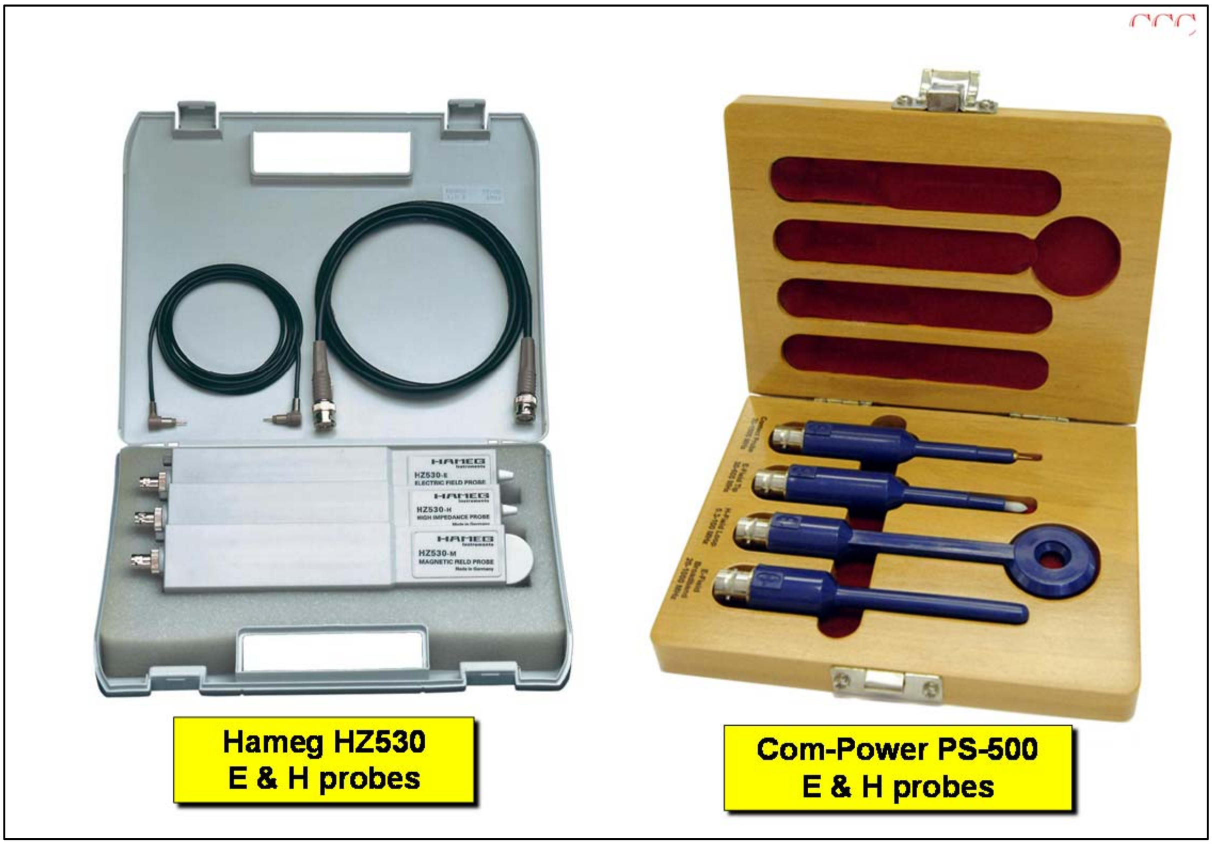

Figure 9 **Examples of close-field probes from Hameg and Com-Power**

Close-field probes can be used to great effect with spectrum analysers costing as little as £800, such as those in Figures 10 and 11. These are all portable instruments, but some require mains power whilst others can run on their built-in batteries – very handy for discovering problems in the field.

Figure 10 Examples of portable spectrum analysers, including some very low-cost ones

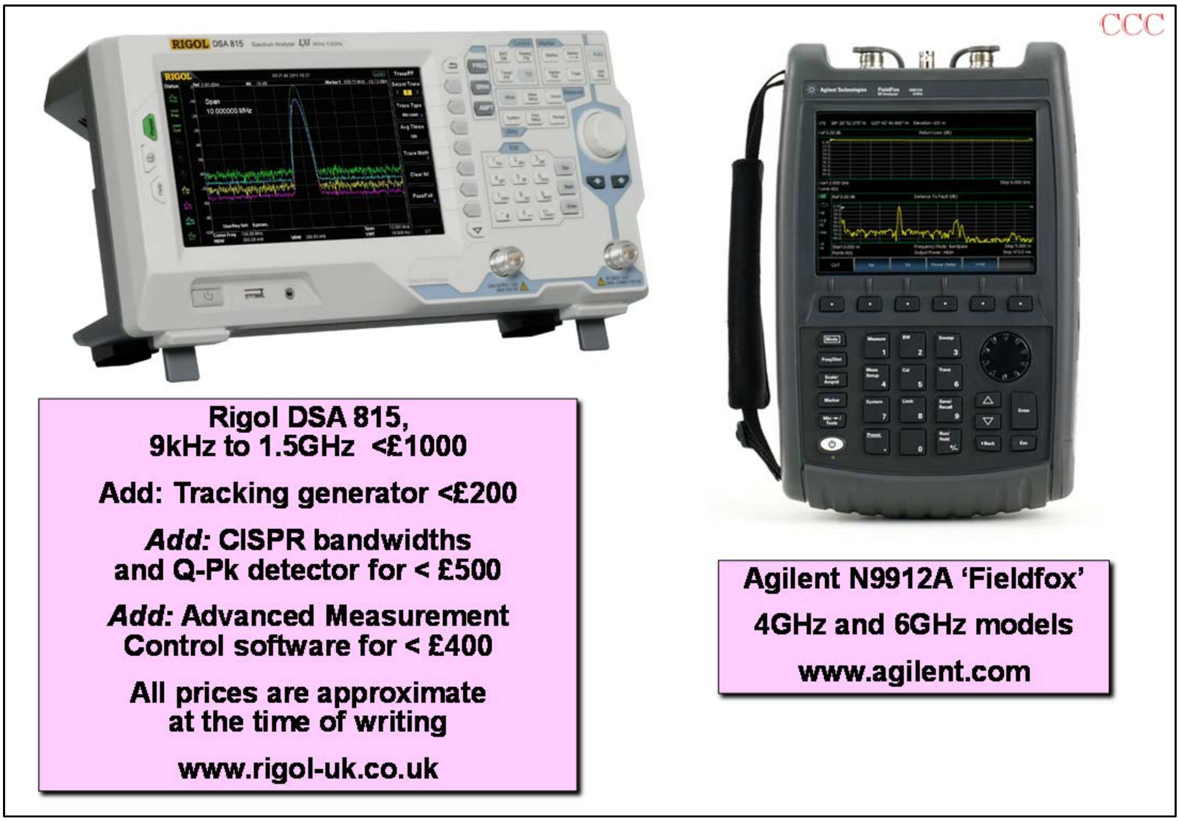

Figure 11 Some more examples of portable and low-cost spectrum analysers

It is also possible to use close-field probes with oscilloscopes that we probably already have, although we would have to learn to view and understand the resulting waveforms instead of spectra. Some oscilloscopes have FFT capabilities, but I have rarely found the spectra they produce to compare with the same probe measuring the same thing using a spectrum analyser. However, I recently learned that Tektronix are now offering oscilloscopes with built-in 'time domain' spectrum analysers that are compliant (or nearly so) with CISPR 16 requirements and of course are much faster than the traditional swept-narrowband filter type of spectrum analyser.

To repeat the excellent work of Roleson, Smith, Mediano, Wyatt and Williams and use close-field probing to discover and solve EMC design issues before there is any hardware that can be operated to check for leakages, requires either a broad-band noise source or a spectrum analyser with a tracking generator.

A wide-range of broad-band noise sources are available from various suppliers, with useable upper frequencies from 1GHz to 40GHz. They may be called Comparison Noise Emitters (CNEs); Reference Noise Generators (RNGs); Emissions Reference Sources (ERSs); Comb Generators, etc., and there is even a rather lovely Universal Spherical Dipole Source (USDS).

Having searched on and off for an affordable spectrum analyser with a tracking generator for over a decade (my preference running to second-hand Agilent E7400s from eBay) I finally purchased a Rigol DSA 815 for a little over £1000. This is a Chinese brand, with a very high quality presentation and a user interface that – up to a point – is almost identical to the E7400 series (and even its predecessor, the HP8591E series – the 'green screen' portable workhorse of the EMC industry for many years).

Ken Wyatt had reviewed the very same model in 2012, [11], and been very impressed with its price/performance ratio. He also used it in [9].

Trying to repeat the work described in references [4] through [9], I found that my usual quick-to-make low-cost H-field probe construction method (Figure 3) gave very variable results in some sensitive types of measurements. I think it must be that because they were not very well balanced, they were very susceptible to hand-capacitance and even just the proximity of metal and dielectric objects (or bodies).

By trial and error I found that adding about 200mm of ferrite tubes gave much better, more repeatable performance, allowing me to use my quick and easy-to-make close-field probes. Figure 12 shows two such probes under construction, with their strings of ferrite tubes exposed.

Because EMI-suppressing ferrite materials are conductive to some degree, I wanted to prevent variations in contact resistance from occurring between the tubes and the copper shield. I also wanted to reduce hand-capacitance effects as much as I could. So before feeding the tubes onto the probes, I first covered the copper semi-rigid cables' shields with heat-shrink insulating sleeve (just visible (yellow) at either end of the strings of ferrites in Figure 12).

I don't know if this precaution was worthwhile, but it seemed like a good thing to do.

Then I ransacked the various ferrite sample kits I had been given over the last 24 years to find ferrite tubes that had inner diameters just large enough to slip over the heat-shrink sleeving. As Figure 12 shows, they were mainly from Wurth, Kitagawa and Steward (which is now owned by Laird Technologies). I don't think the type of ferrites used matters a great deal, as long as they have their highest impedances generally around the middle of the frequency range of interest for close-field probing – in my case between 50 and 1000MHz.

To get a good fit to the heat-shrunk semi-rigid cable, the SMA connector should only be soldered to the semi-rigid ***after*** the ferrites have been assembled onto the probe.

With at least a 200mm length of ferrite tubes slid onto the 'handle' of the probe, I then heat-shrunk over the top of them all, to stop them from moving around and possibly affecting performance. Also, the shrink sleeving might help to reduce hand-capacitance effects, and will certainly help to protect the ferrites from damage – they are very brittle and can easily become cracked by rough handling or accidents.

Figure 12 A view of my new probes during assembly

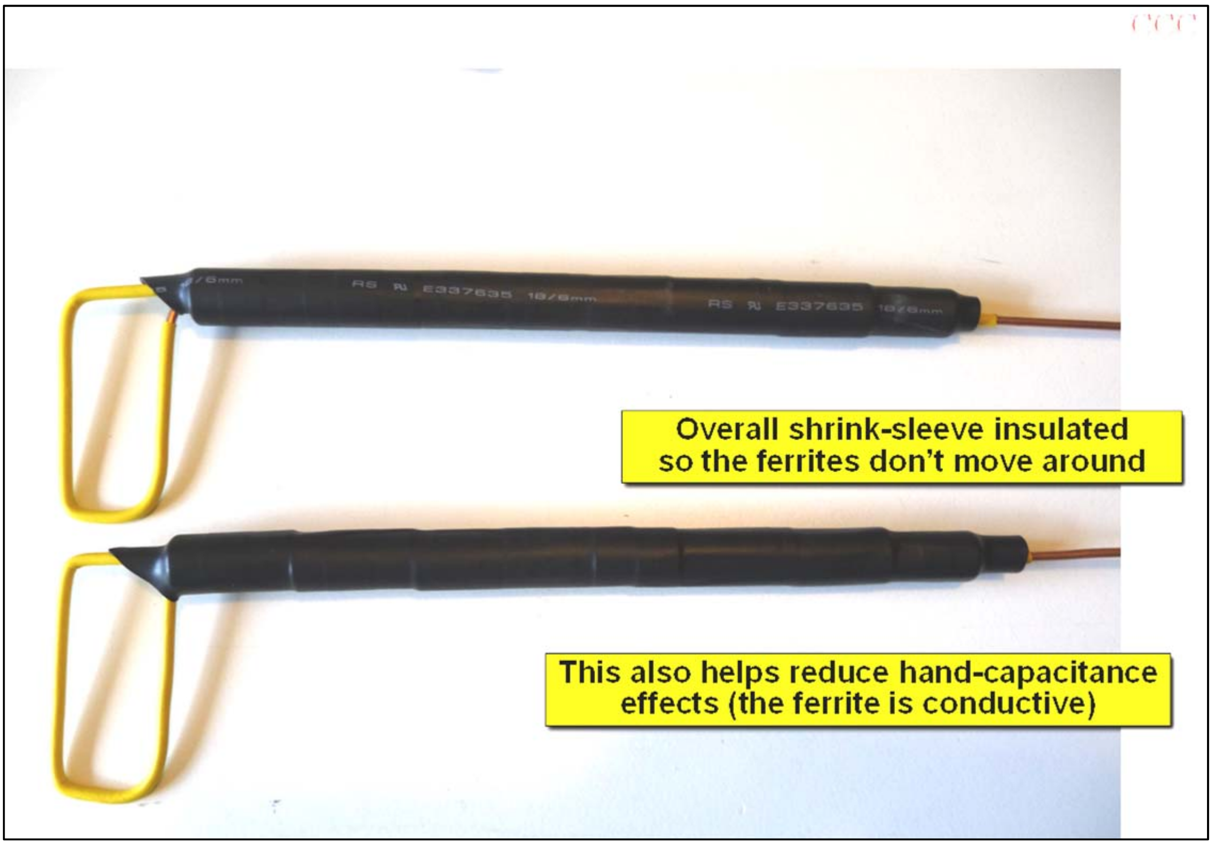

Figure 13 My new RG405 probes when finally assembled

I made two sets of two probes with long ferrite 'handles' – four in all. One pair used RG402 ('3mm') semi-rigid, and the other pair used RG405 ('2mm'). (The RG402-based probes I bent into a special shape to use with a clamping arrangement for measuring sheet materials – about which I plan to write in a future article.)

3 The 2-probe method of finding flaws in shielding

The first close-field probing technique I want to describe uses two probes, one energised by the spectrum analyser's RF output from its tracking generator, the other connected to its RF input, as shown in Figure 14.

The metal box being used is my 'famous demo box' – created over a weekend using hand tools (and it shows) for a bit of entertainment during a break in an EMC conference in 1992. It – and much prettier, professionally-made versions of it – have since been used to give hundreds of EMC demonstrations worldwide.

(My demo box is intentionally unpainted and free from other surface treatments, because its aluminium-zinc casting alloy maintains a low contact resistance (unlike plain aluminium) which is important for making good connections to conductive gaskets and also for various things that I use it to demonstrate. It looks rather ugly, but my professionally-made versions had nice shiny mirror surfaces, achieved by a technique similar to French-polishing.)

My demo box is based on having a noisy circuit inside, plus connectors for power and data cables, to be close-field probed in the traditional way of looking for leakages, as a means of demonstrating good practices in enclosure shielding, cable shielding, and filtering.

But here I am using it without any power to its internal circuits, to see how much of what I know about its EMC design issues can be discovered by using a spectrum analyser (SA) with a tracking generator (TG) and two close-field (CF) probes. To see if such EMC design flaws could be reliably detected during the early stages of an item's mechanical design, when design freedom is high and design changes cost little.

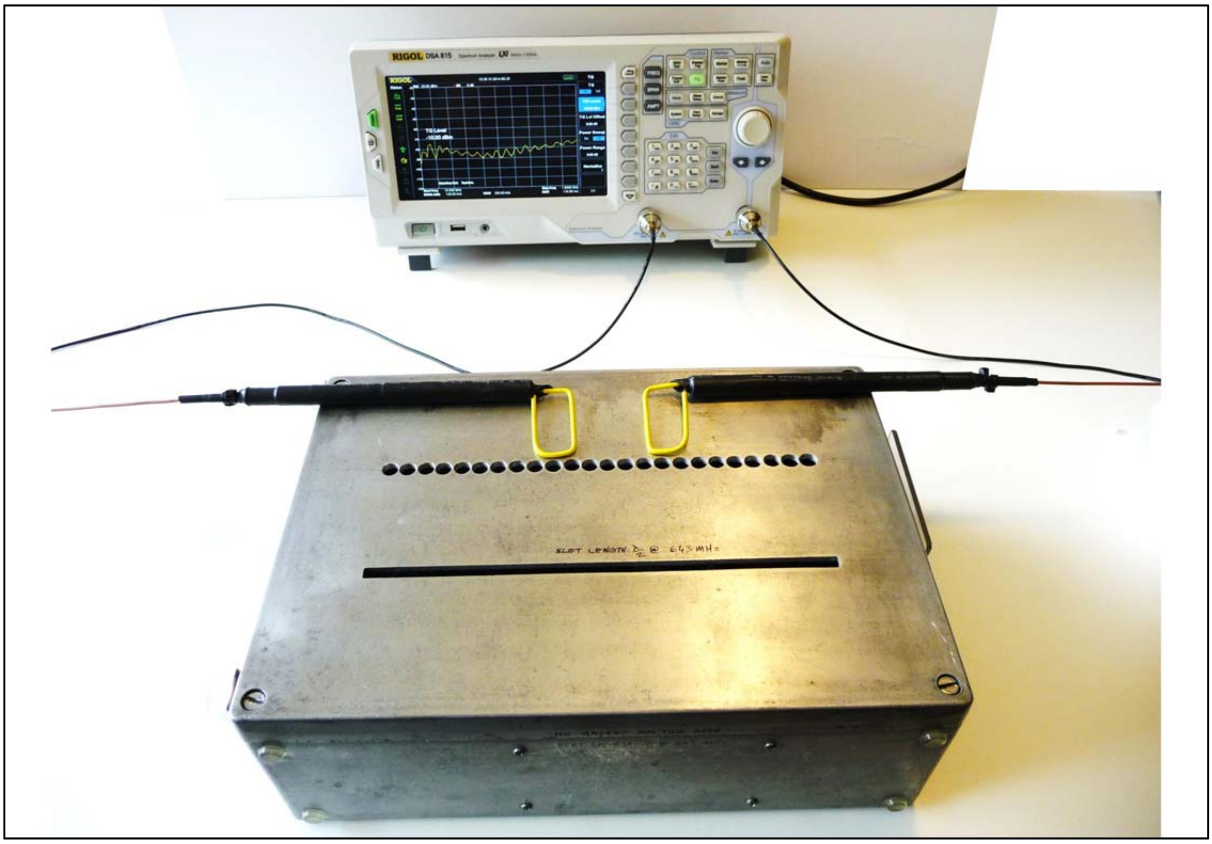

Figure 14 Looking for shield imperfections with two CF probes – the set-up (1)

In Figure 14 I am holding the two CF probes – one connected to the TG's RF Output, the other to the SA's RF input – close against the solid metal of the demo box's lid. Figure 15 shows the result on the SA's screen: the measure of the RF energy that couples between the two probes.

Figure 15's amplitude is scaled at 10dB/decade, the internal pre-amplifier is switched on to reduce the noise floor, the RF attenuator is set (manually) to 0dB and the top of the amplitude scale is -20dBm (although the units don't matter, only the dBs, because we are making comparisons: relative measurements, not absolute ones).

The horizontal axis displays the frequency range from 10MHz to 1GHz, on a linear scale. The resolution bandwidth (RBW) is 120kHz, the video bandwidth (VBW) is 300kHz, and the TG's output level is set to -10dBm so as not to overload the RF input when we get to Figures 20 and 21.

(I suppose I could have set the RF attenuator to -10dB and the TG to 0dBm, but I am used to setting the RF attenuator to 0dB to maximise sensitivity when using CF probes to measure leakages with low-cost SAs, so it has become a habit.)

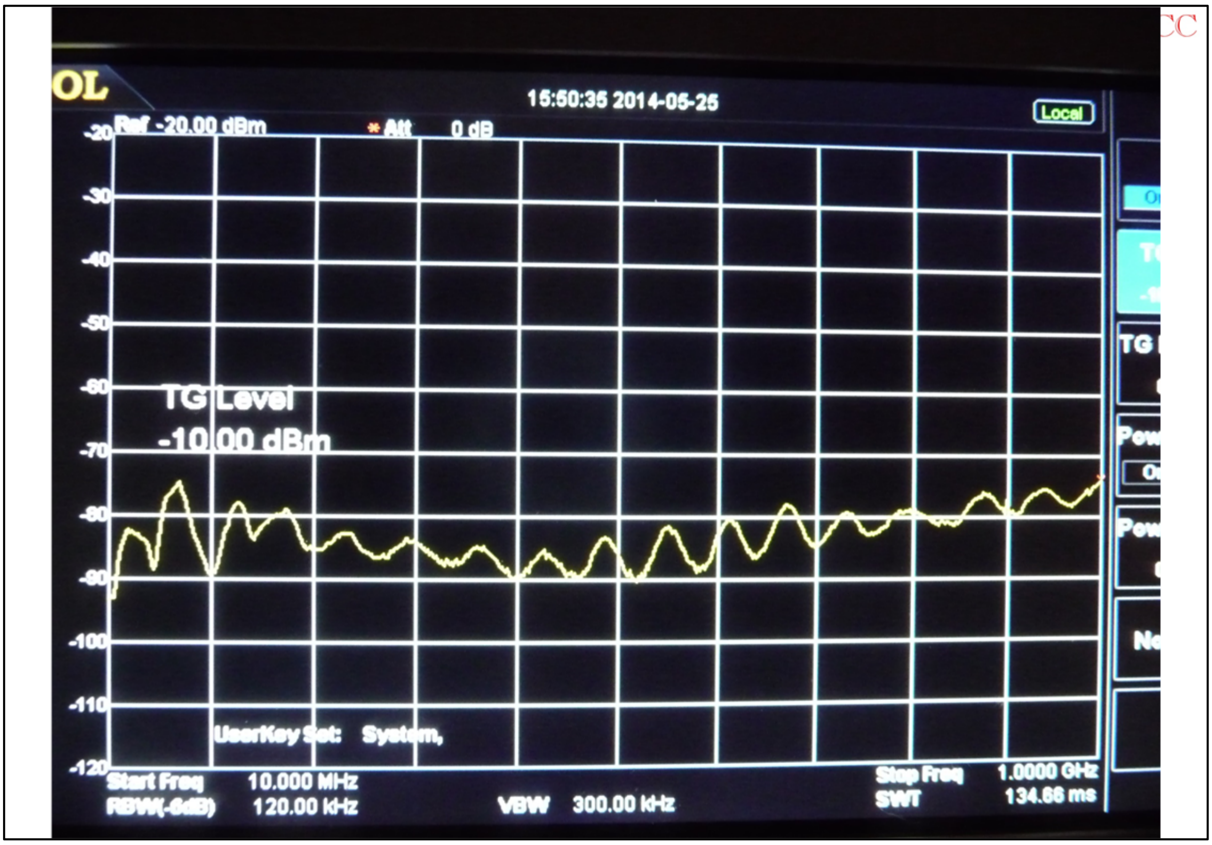

Figure 15 Looking for shield imperfections with two CF probes – the display (1)

Figure 15 shows that the coupling between the two probes is about -80 to -90dBm between 10MHz and 700MHz (i.e. an attenuation of -60 to -70 dB, given that the Reference Level is -20dBm), with a slight rise to -75dBm to -80dBm (i.e. -55 to -60dB) around 1GHz.

The ripples that can be seen on the display are most probably due to the reflections caused by the impedance mismatches inherent in my probe design – which puts a short-circuit at the end of a coaxial 50Ω transmission line. The ripples are not important for this kind of measurement, so I don't mind them.

Figure 16 shows the two probes in the same physical relationship to each other and the lid of the metal box, but now slid forward to lie over the row of small holes, which has the same open area for ventilation as the larger slot we will come to in Figures 20 and 21.

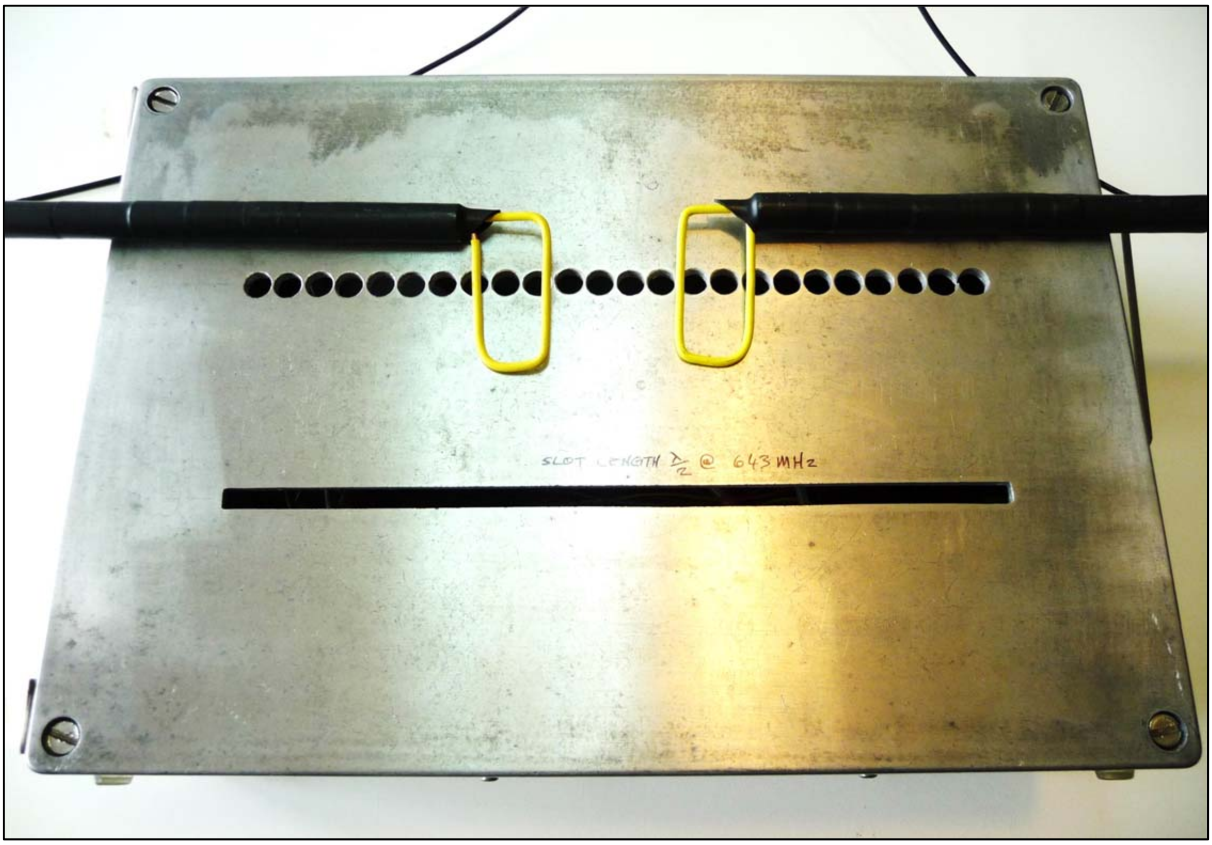

Figure 16 Looking for shield imperfections with two CF probes – the set-up (2)

Figure 17 shows almost exactly the same poor coupling between the probes as for set-up (1) in Figure 15.

Figure 17 Looking for shield imperfections with two CF probes – the display (2)

Figure 18 shows the probes, still held in the physical relationship to each other and the lid of the metal box, but now slid even further forward to lie over the solid metal inbetween the row of small holes and the larger slot. Figure 19 shows almost exactly the same poor coupling between the probes as for set-up (1) in Figure 15 and set-up (2) in Figure 17.

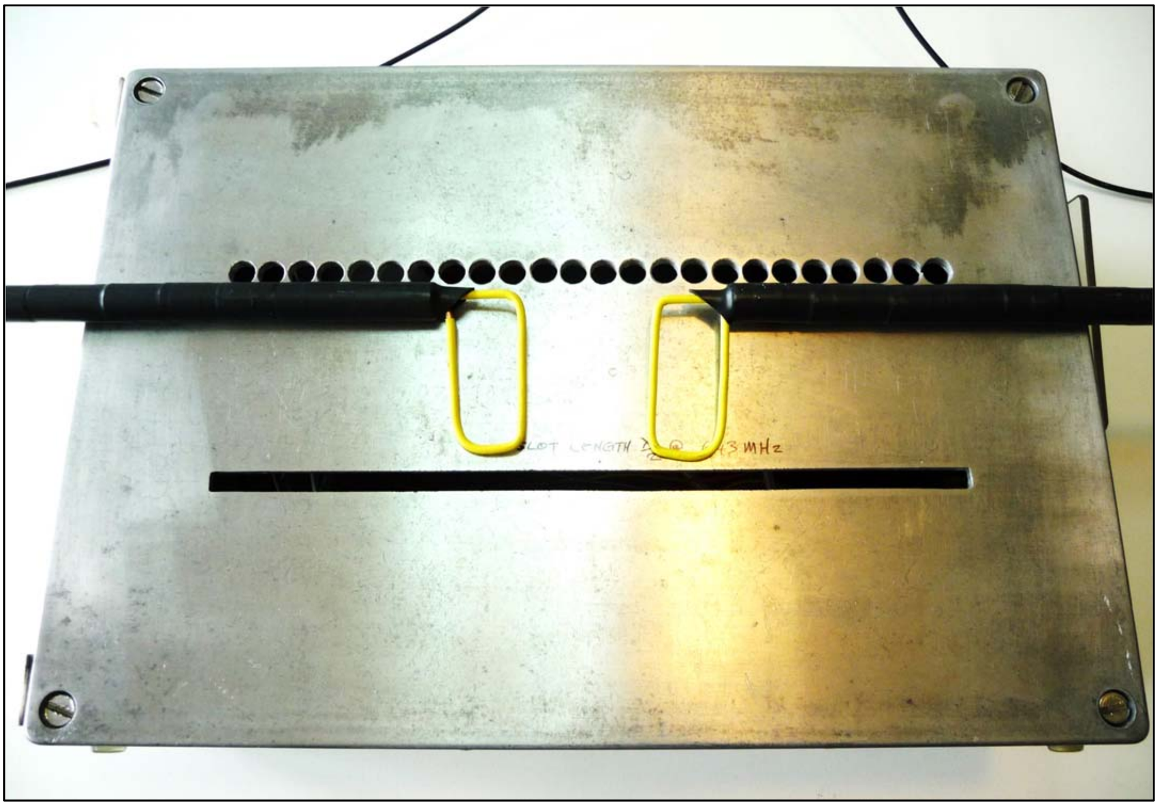

Figure 18 Looking for shield imperfections with two CF probes – the set-up (3)

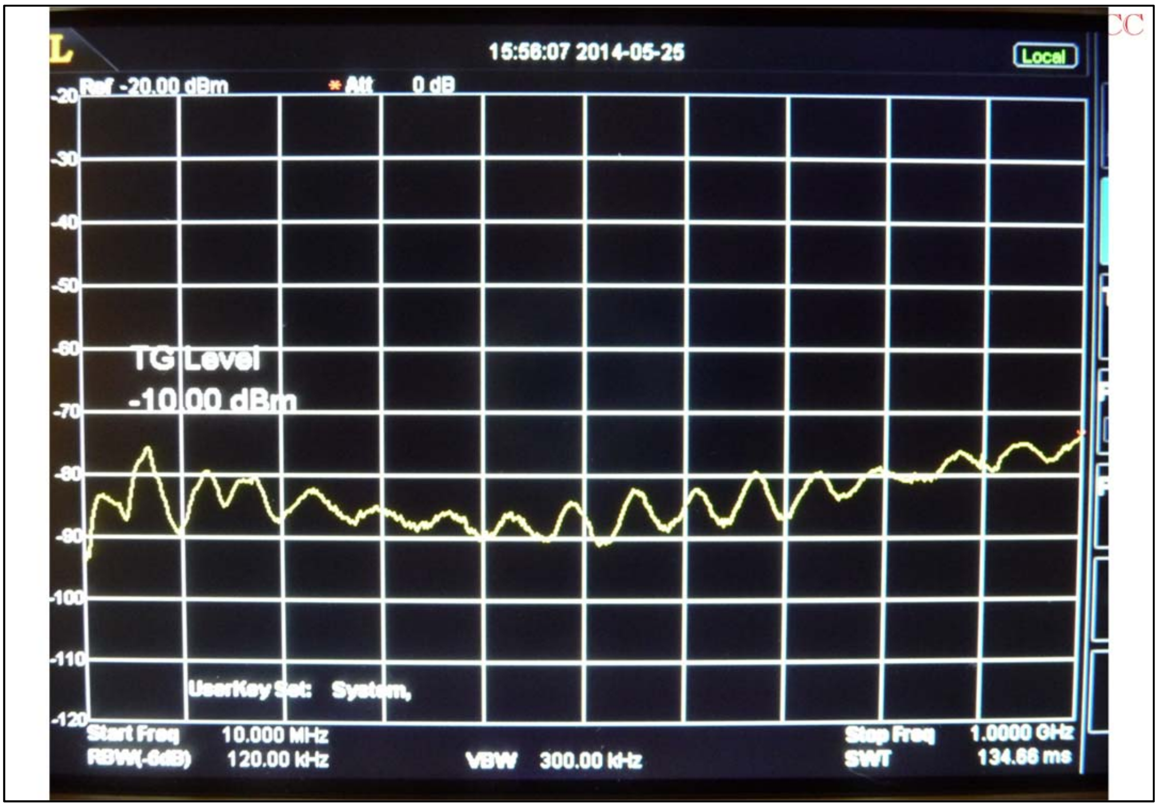

Figure 19 Looking for shield imperfections with two CF probes – the display (3)

Figure 20 shows the probes, as previously in the same physical relationship to each other and the lid of the metal box, but now slid further forward to lie over the large slot. Figure 21 shows markedly higher coupling between the probes than we saw with set-ups (1), (2) or (3) (Figures 15, 17 or 19 respectively).

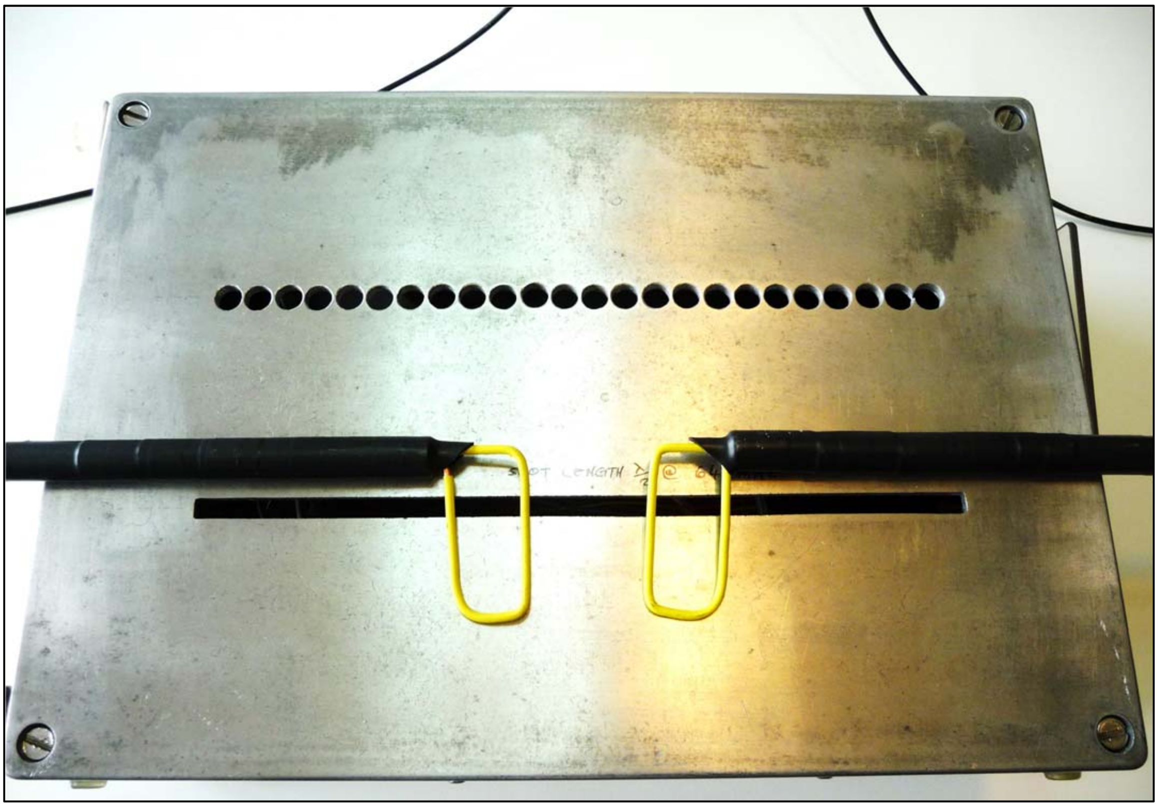

Figure 20 Looking for shield imperfections with two CF probes – the set-up (4)

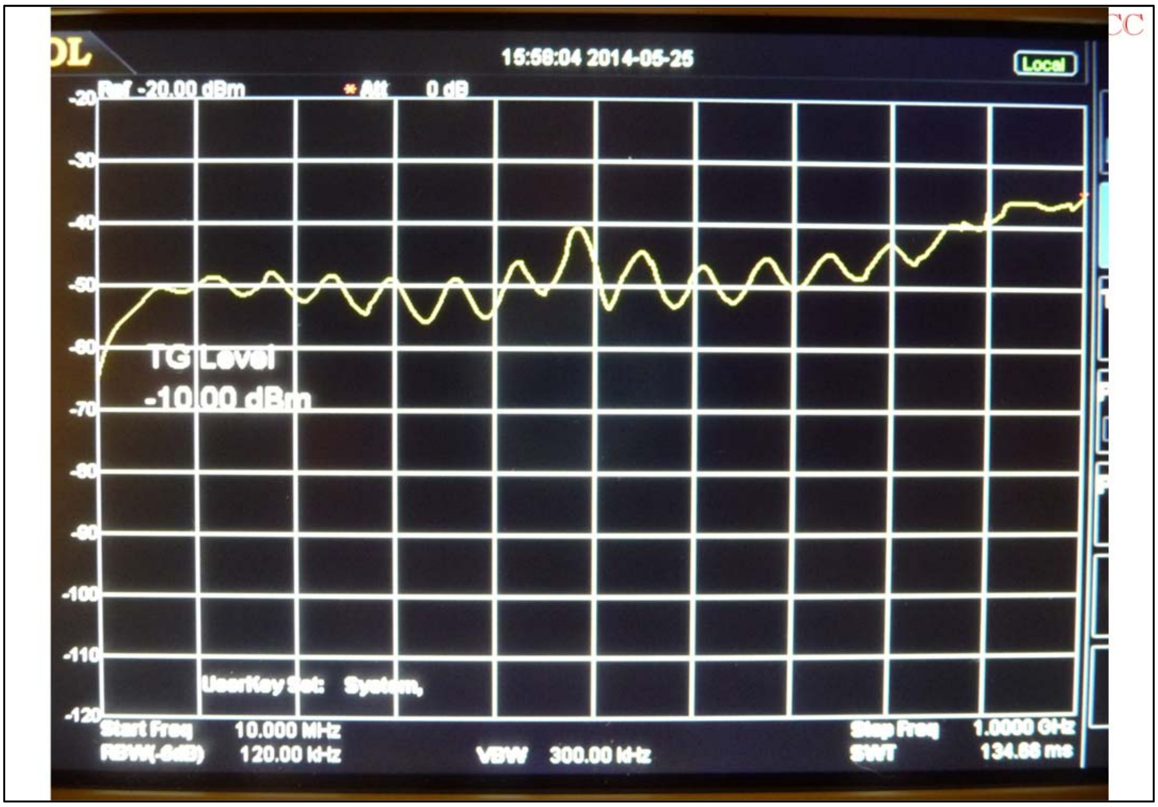

Figure 21 Looking for shield imperfections with two CF probes – the display (4)

Figure 21 shows that over most of the frequency range, the receive probe is now picking up around -45 to -55 dBm (i.e. an attenuation of -25 to -35dB), rising above about 700MHz to around -35dBm (i.e. -15dB attenuation) at 1GHz. To see if this roughly 35dB increase in coupling (decrease in attenuation) between the two CF probes is caused by the slot rather than the close proximity of the edge of the box lid, set-up (5) is shown in Figure 22 and its results in Figure 23.

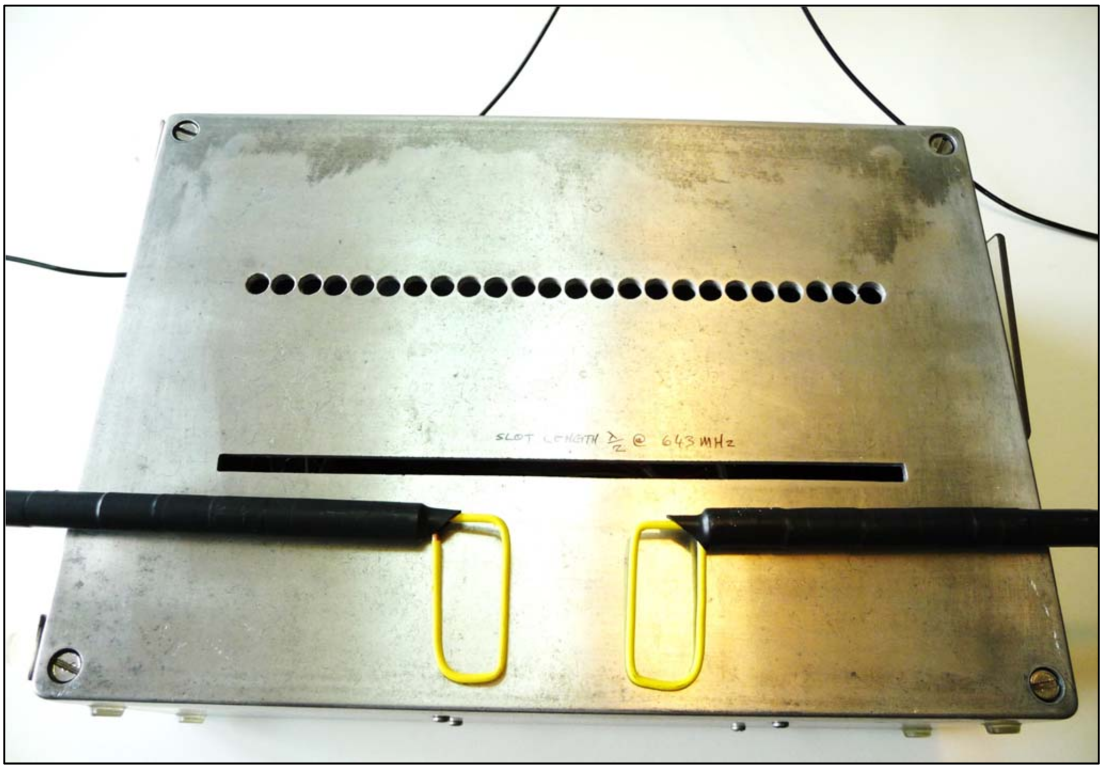

Figure 22 Looking for shield imperfections with two CF probes – the set-up (5)

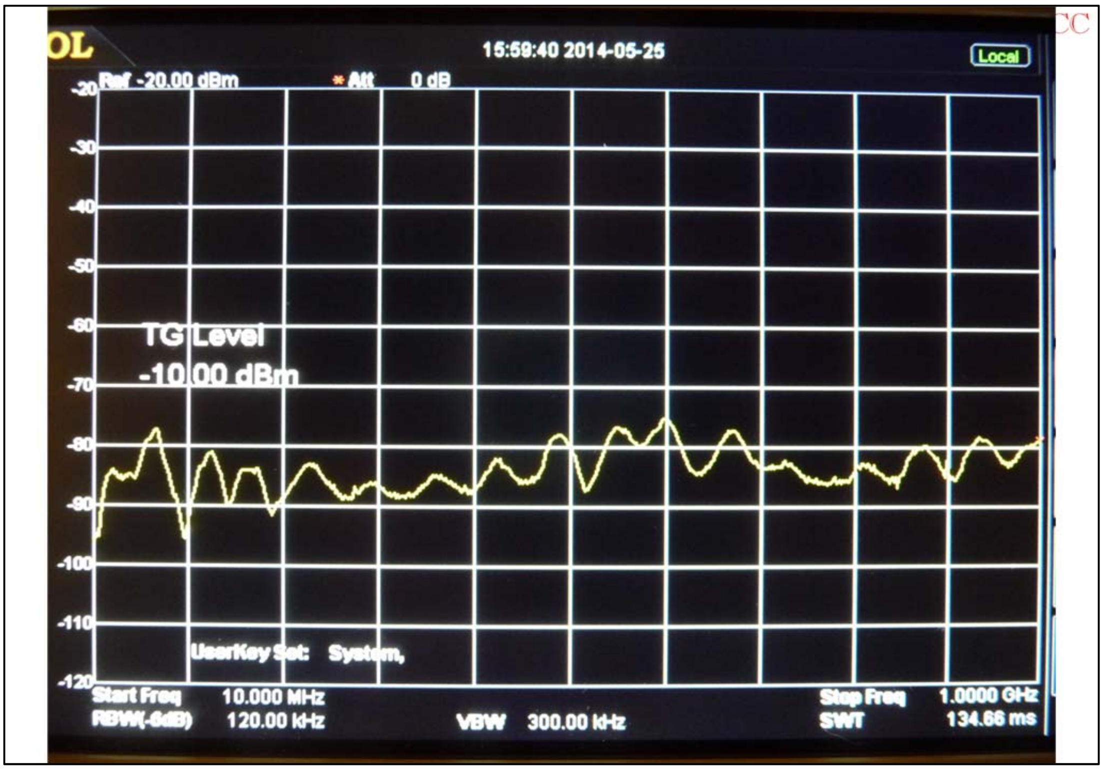

Figure 23 Looking for shield imperfections with two CF probes – the display (5)

Figure 23 shows that the coupling between the CF probes is once again as low as it was for set-ups (1), (2) and (3).

Clearly, the large slot allows RF energy in the range 50MHz to over 1GHz to couple much more strongly between the two CF probes, than the other structures on the lid of the box. We might expect this to indicate that we should expect much less shielding effectiveness from the slot, than from the row of holes having the same ventilation aperture, and indeed this is what we see when probing the powered-up box for its RF leakages in its traditional 'demo' role.

So there we have it – a mechanical EMC design flaw revealed very early in a project well before there was any hardware or software that could make it possible to test the item in a laboratory to any of the relevant published standards for EMC compliance, such as CISPR 22 or 24 (EN 55022 or EN 55024).

And I haven't mentioned it so far, but a very important and useful feature of most CF probing techniques is that they can be done almost anywhere, anytime, on our desks or assembly/test benches, and certainly don't need a shielded room!

If our neighbour happens to be operating a very noisy prototype in close proximity, we may need to wait until he or she stops, or move a metre or two to quieter location, and it may also prove necessary in some situations to load all the mains or other cables to our desk or test bench (not just the power cable to the SA, but all of them) with clip-on ferrite tubes. But in many cases such measures are not needed.

Those who need high-performance shielding, and/or to shield frequencies much higher than 1GHz, will of course find that the row of holes in set-up (2) (Figure 16) has too little shielding effectiveness (although not anything like as bad as the large slot).

If high-performance shielding is required, there are a number of improvements to this two-probe method that should help (although I haven't tried them myself yet):

- Increase the TG's output level.
  Use an external RF power amplifier if necessary, but in this case feed its RF output to the energised probe through a 50Ω 6dB attenuator of the same or higher power rating as the amplifier, so as not to provide the amplifier with so much of an impedance mismatch that it could be damaged.
- Vary the physical relationships between the two probes, and between the probes and the metal surface, to see if greater sensitivity can be achieved.
- Try using probes with larger loop areas.
- Use a more expensive SA with a larger dynamic range (i.e. a lower noise floor).
- Use a narrower RBW to improve the dynamic range.
- Use trace averaging to help improve the dynamic range (only useful when the noise floor, when the two probes are both over solid metal, looks like random noise).
- Use high-performance double-screened RF coaxial cables from the SA to the probes, load the cables with clip-on ferrites, keep the RF Output cable far away from the RF Input cable.

Alternatively, the 'internal RF excitation' method shown in Figures 35 through 40 in this article might prove to be more suitable.

Continuing with the 2-probe method of detecting flaws in shielding, the lid of my 'famous' demo box is fitted to its base with a conductive gasket clamped between them – except where part of the gasket is missing along one long edge.

Figure 24 shows the 2-probe method applied to a lid-to-base joint where we know the conductive gasket is present (it is written on the box!). Let's call this set-up (6). Figure 25 once again shows poor coupling between the two probes (just as we had for set-ups (1), (2), (3) and (5) above).

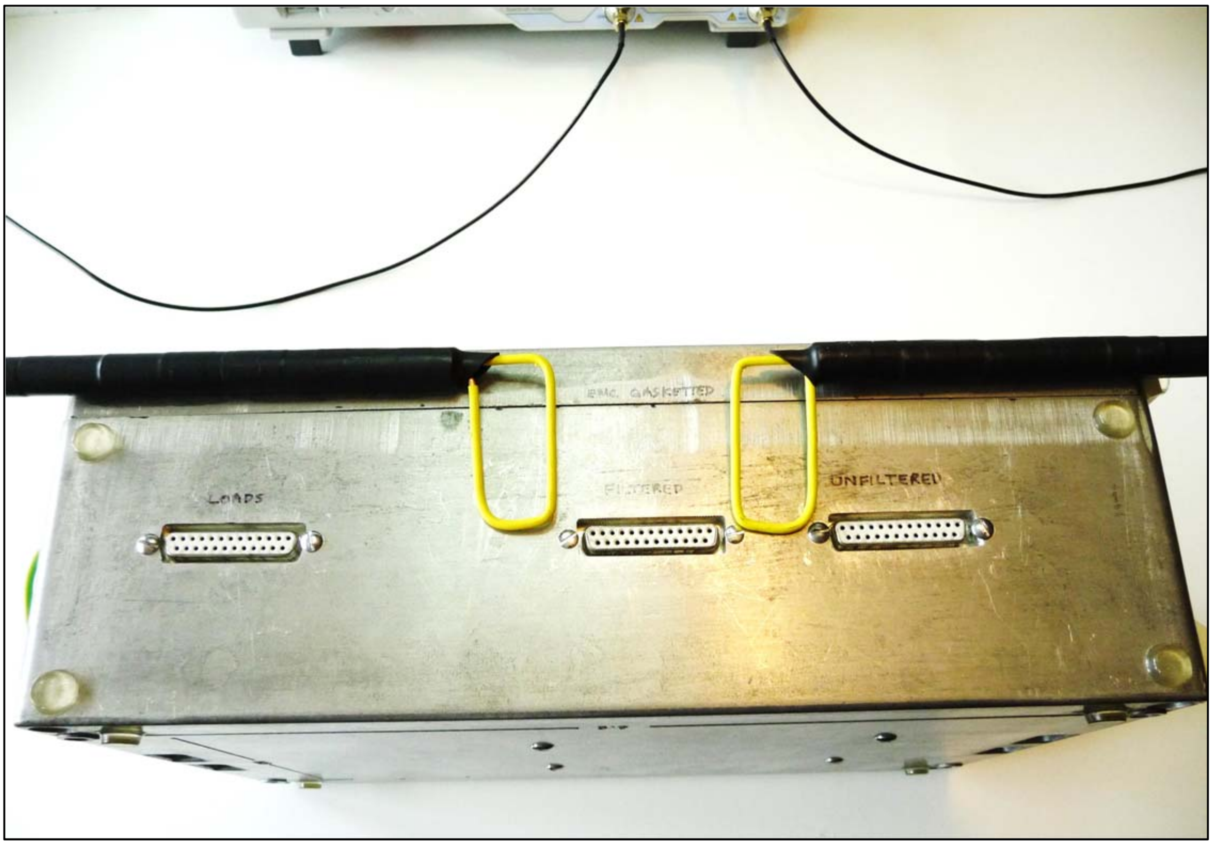

Figure 24 Looking for gasketting imperfections with two CF probes – the set-up (6)

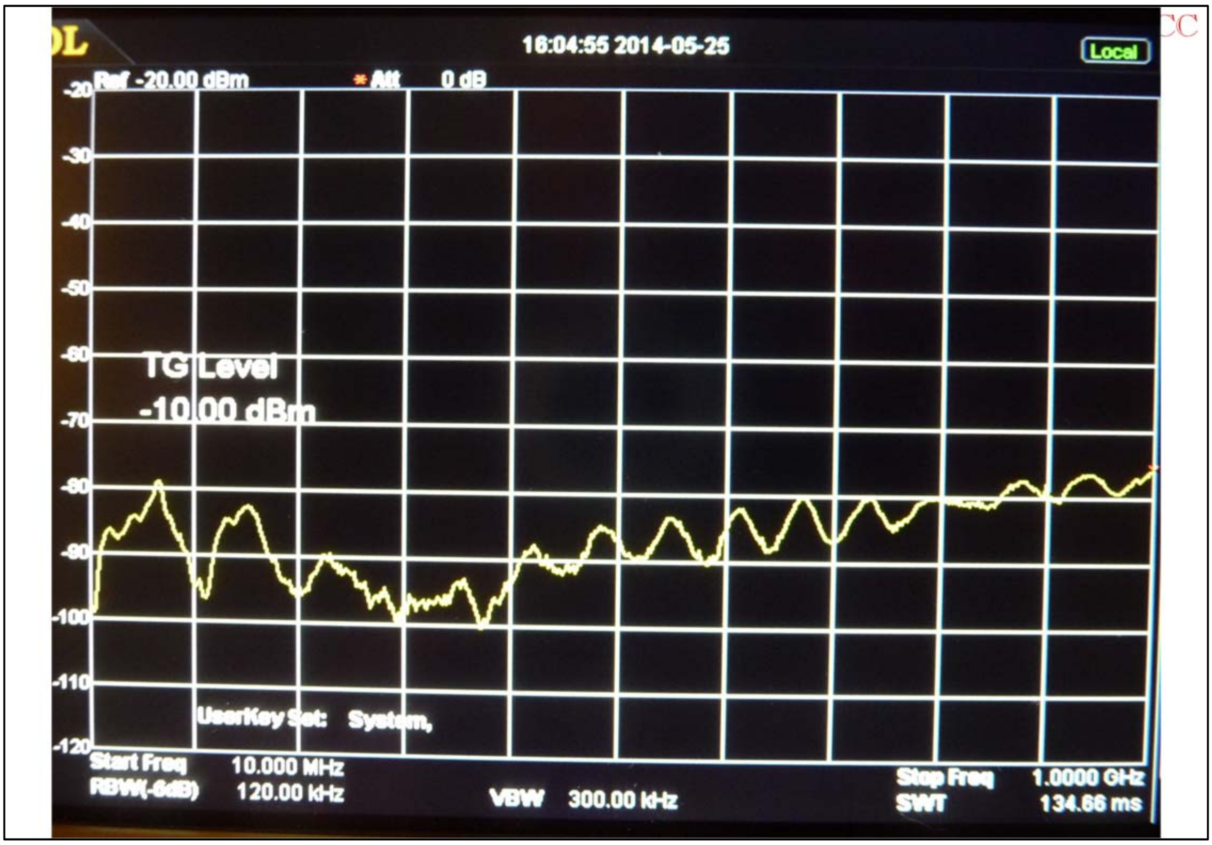

Figure 25 Looking for gasketting imperfections with two CF probes – the display (6)

But when the probes are applied to the side with the missing gasket, as shown in Figures 26 and 27, we quickly see that the coupling between them has increased by 20 to 30dB.

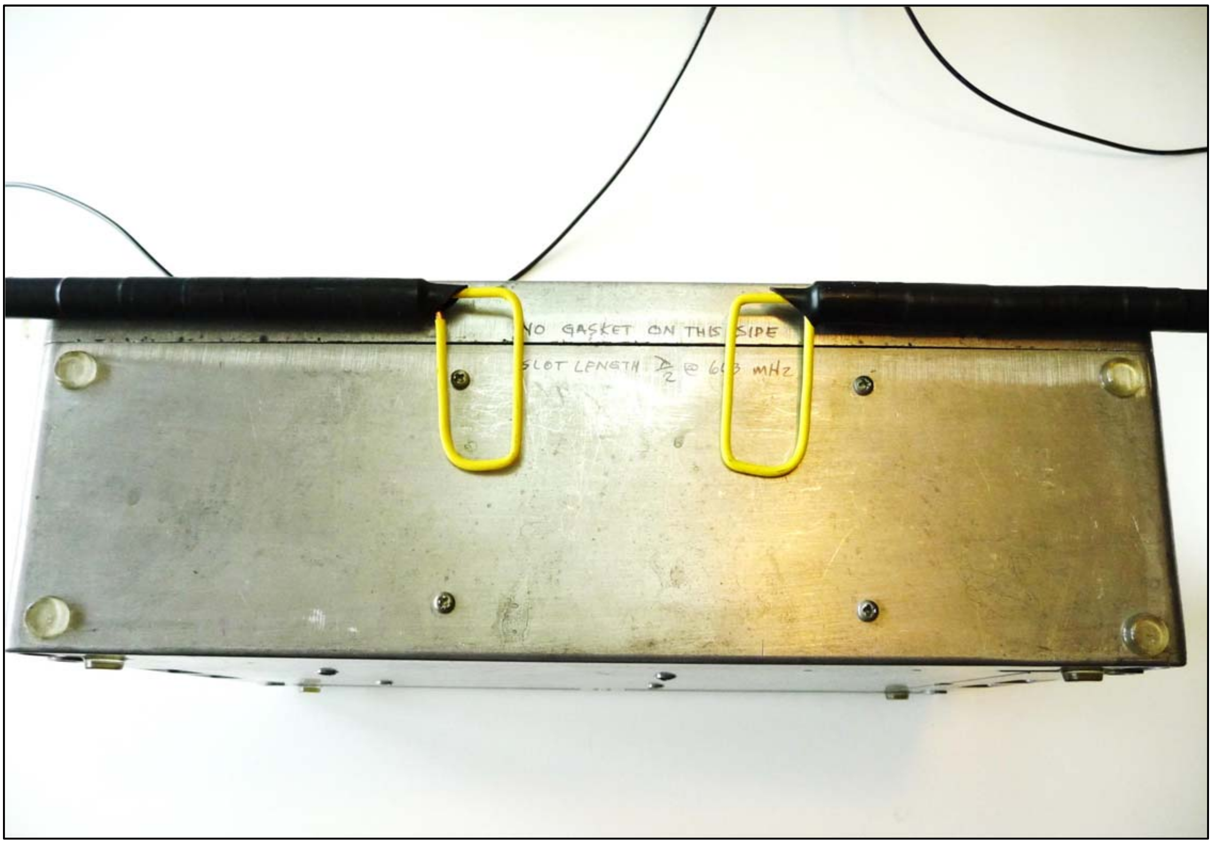

Figure 26 Looking for gasketting imperfections with two CF probes – the set-up (7)

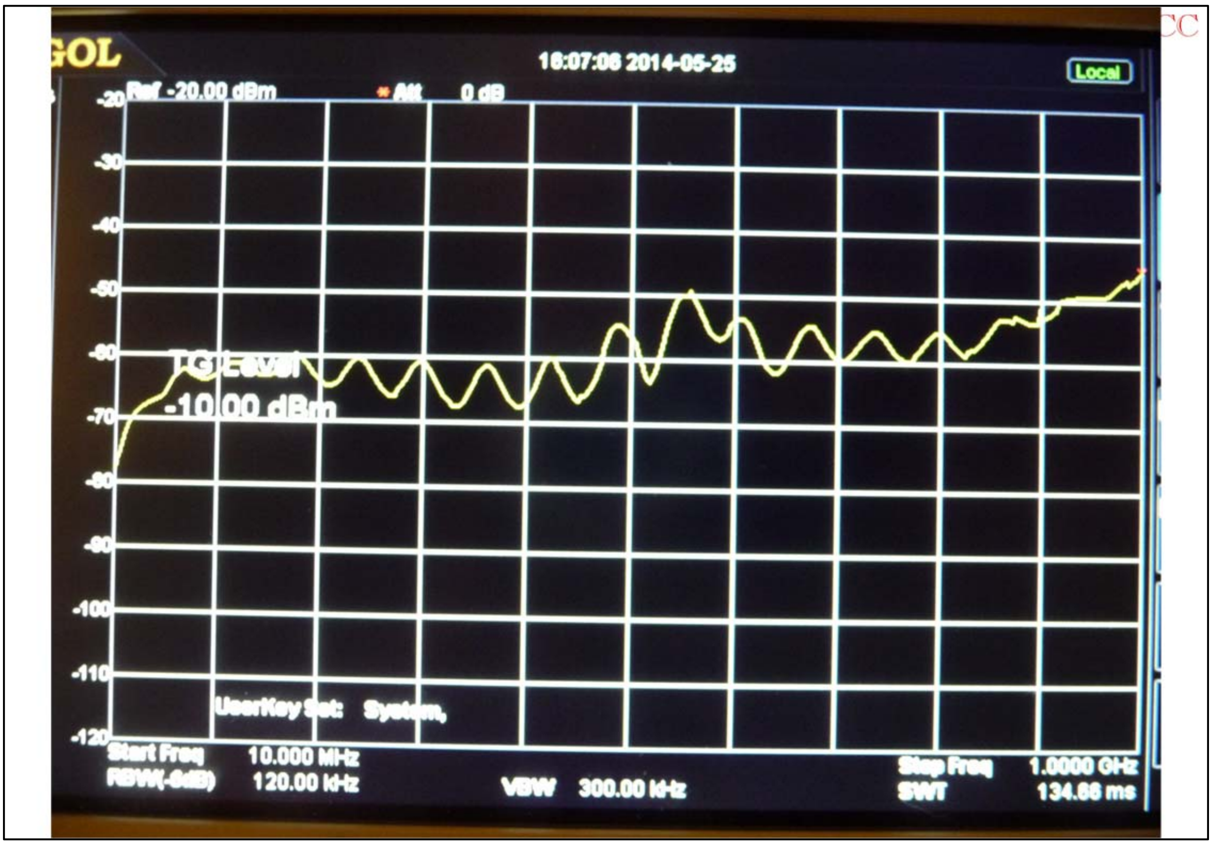

Figure 27 Looking for gasketting imperfections with two CF probes – the display (7)

As well as being able to be used for checking adequate gasket design at an early stage in a project, this technique could be used in serial manufacture to discover whether a gasket had been mis-assembled; and used when fault-finding in the field to discover if a gasket had become ineffective due to corrosion, in both cases being a quick diagnostic tool that does not require dismantling the item concerned to be able to look at the gasket (or where it should be).

4 The 1-probe 'reflectometer' method of finding flaws in shielding

Figures 28 and 29 show one of my new ferrite-handled probes being used with a directional coupler, in this case a Mini-Circuits' ZFDC-20-5+ with SMA connectors that match my CF probes and cables.

This little module cost me about £80, and is specified to have nominally -19.5dB of directional coupling from 100kHz to 2GHz. I am using it backwards as a reflectometer – as Figure 29 shows.

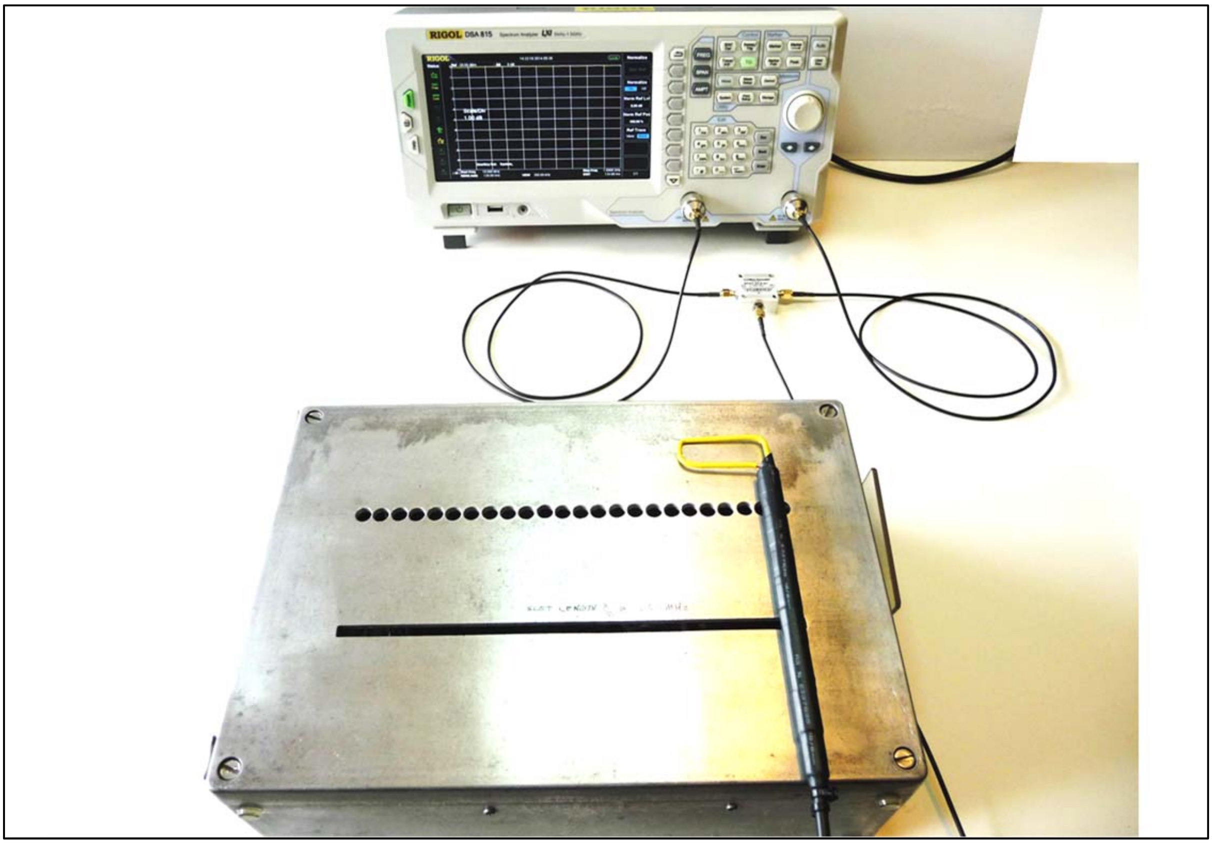

Figure 28 Looking for shielding imperfections with a reflectometer – normalising

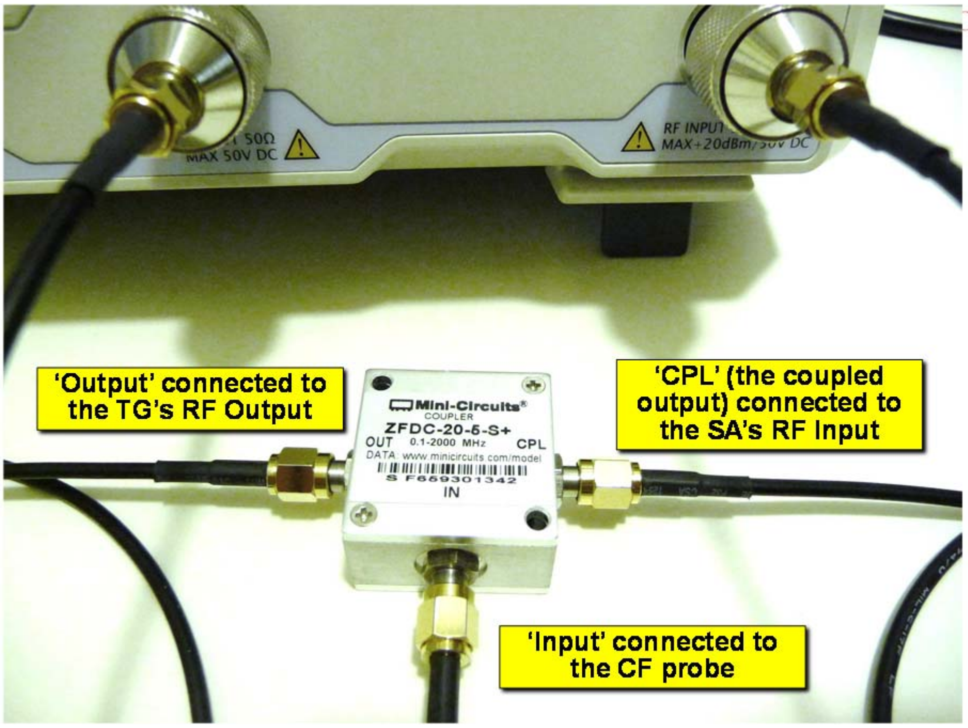

Figure 29 A closer view of the directional coupler in Figure 28

Used in this way, any RF that is not reflected at the impedance mismatch caused by the 'shorted-turn' CF probe will be revealed as a dip in the response, but – as Tim Williams of Elmac Services warned me – the 20dB or so loss in the directional coupler makes this a relatively insensitive method. So as can be seen in Figures 30 and 32, I have set the vertical axis to 1dB per division. All the other SA and TG settings are the same as for the two-probe method described earlier.

With this method, the first step is to 'normalise' the measurement with the probe held against a solid piece of metal, as shown in Figure 28. Figure 30 shows the resulting display – a straight line along the 0dB line at the top of the display.

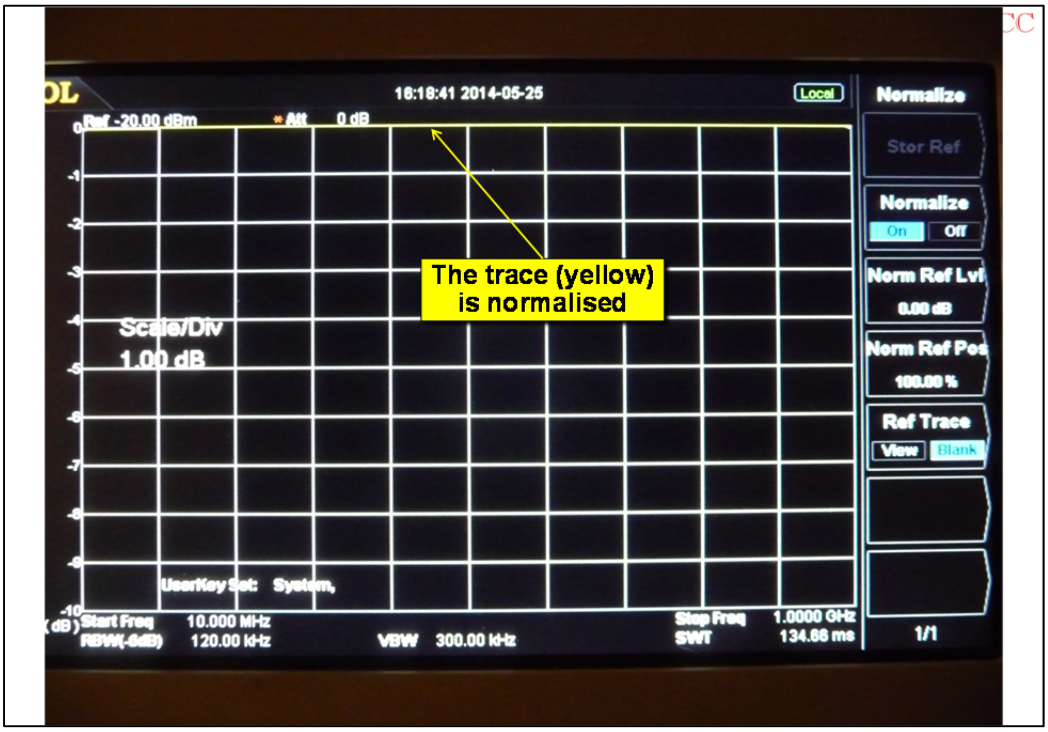

Figure 30 Looking for shielding imperfections with a reflectometer – the normalised display

Figure 31 shows set-up (8), with the normalised probe moved to the large slot on the top of the box, without changing its proximity to the box's metal surface (it is always held against it, touching the metal surface).

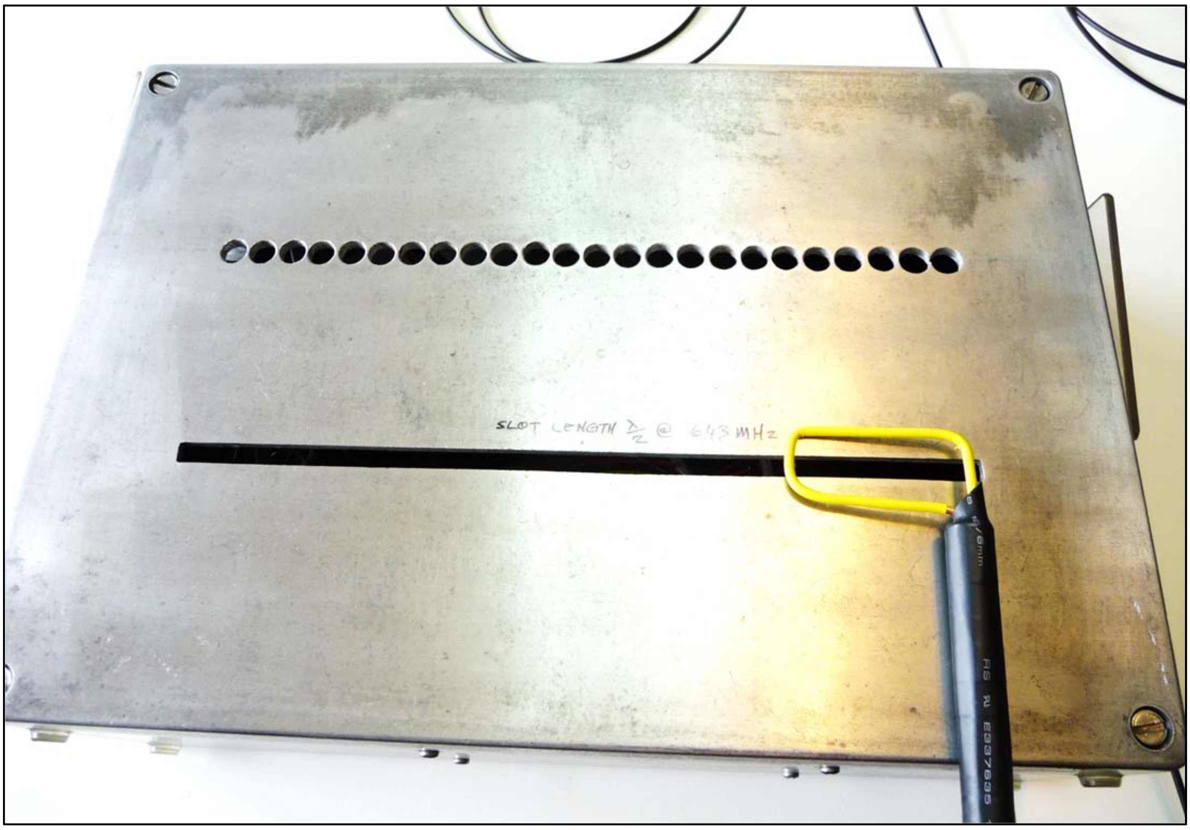

Figure 31 Looking for shielding imperfections with a reflectometer – set-up (8)

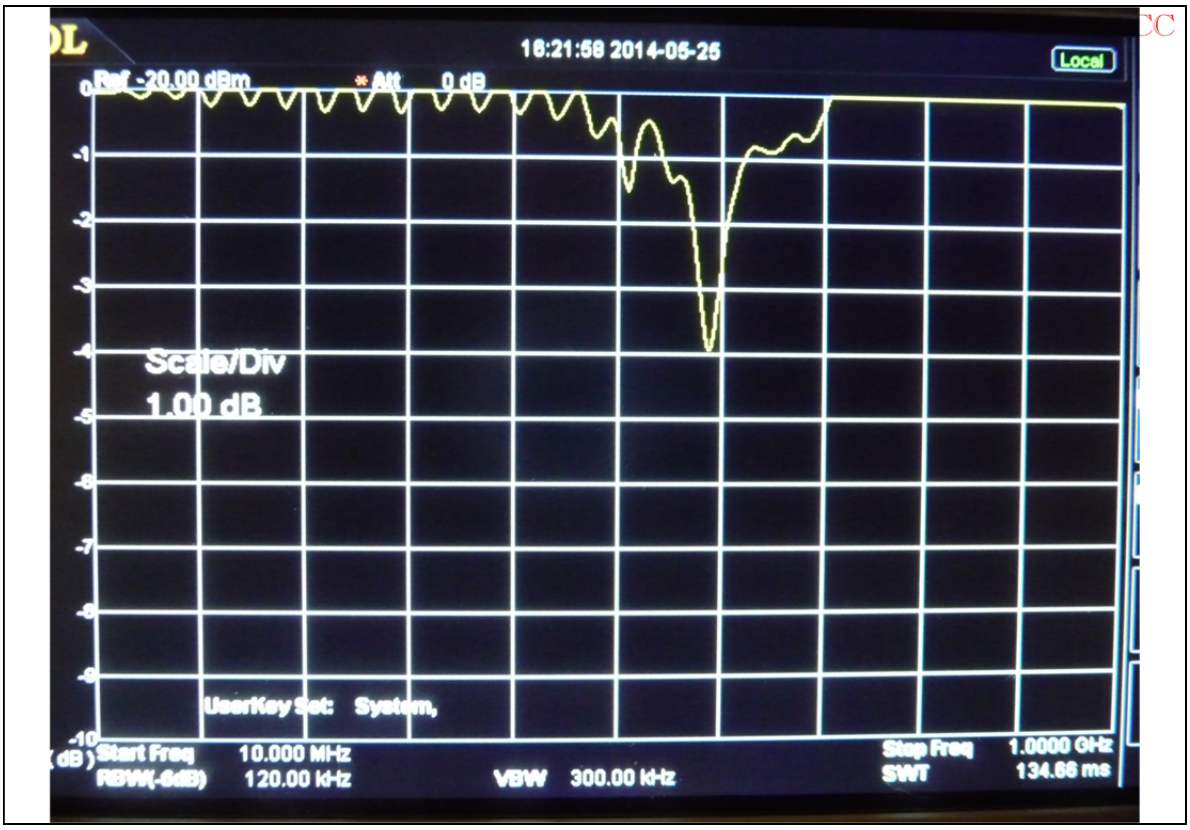

Figure 32 Looking for shielding imperfections with a reflectometer – the display (8)

Figure 32 shows the resulting display, when the CF probe has been moved around so as to maximise the depth of the dip, which is caused by energy being lost into the shield imperfection (instead of being 100% reflected back into the probe as perfect shielding would do).

The maximum dip depth is reached with the probe at one end of the slot, which is not unexpected because it is the location of the maximum magnetic field emissions from an ‘accidental slot antenna’ at resonance.

The dip frequency correlates well with the first resonance frequency at 643MHz (i.e. when the slot’s length equals half a cycle of the wavelength).

This is different from the two-probe method described earlier, which did not reveal anything about the slot’s resonant frequencies. I think this is because the two-probe method simply measures the coupling between the fairly localised eddy current patterns for the probes, which do not extend far enough to excite the whole length of the slot and cause it to resonate.

Quite probably, if when using the two-probe method, we located one probe at each end of the slot, the slot’s first resonance frequency would then show up.

Figure 33 shows the reflectometer method being used to identify the missing gasket on my demo box, with Figure 34 its displayed output.

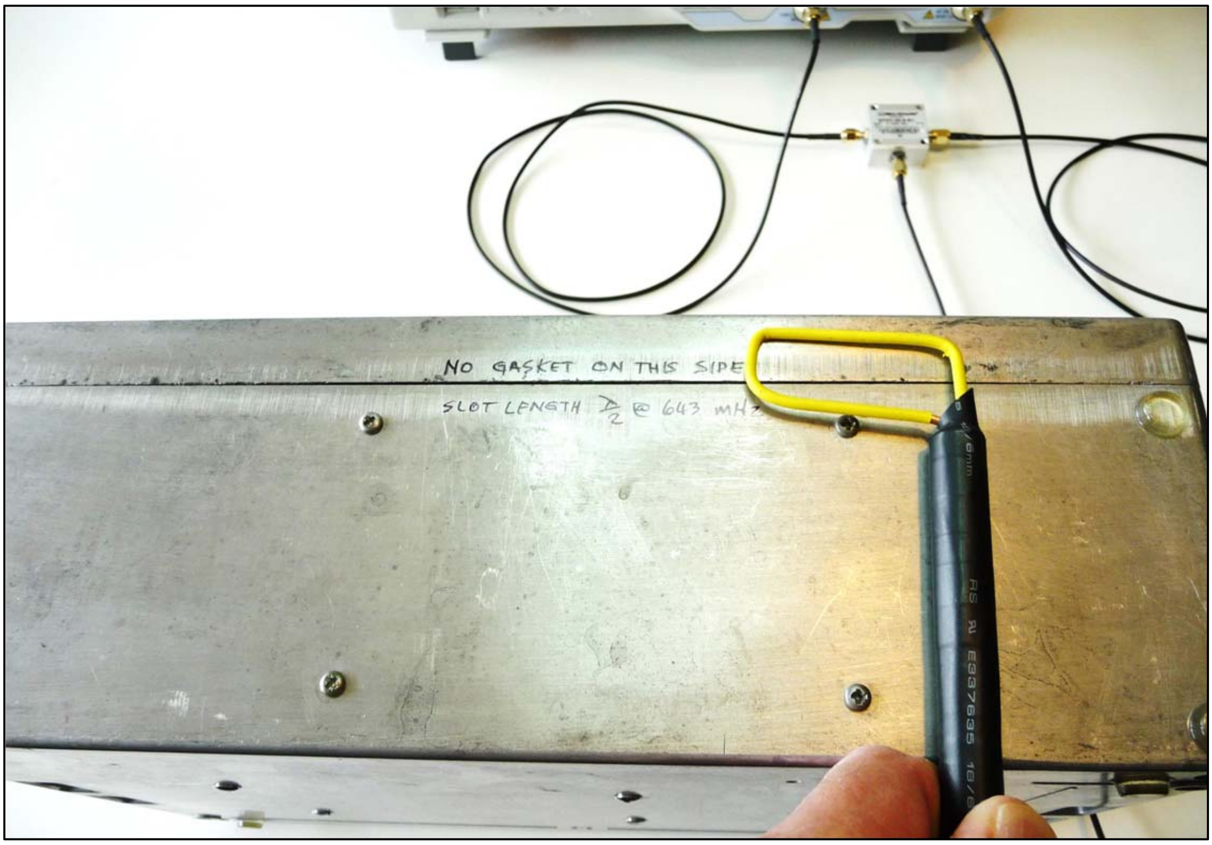

Figure 33 Looking for shielding imperfections with a reflectometer – set-up (9)

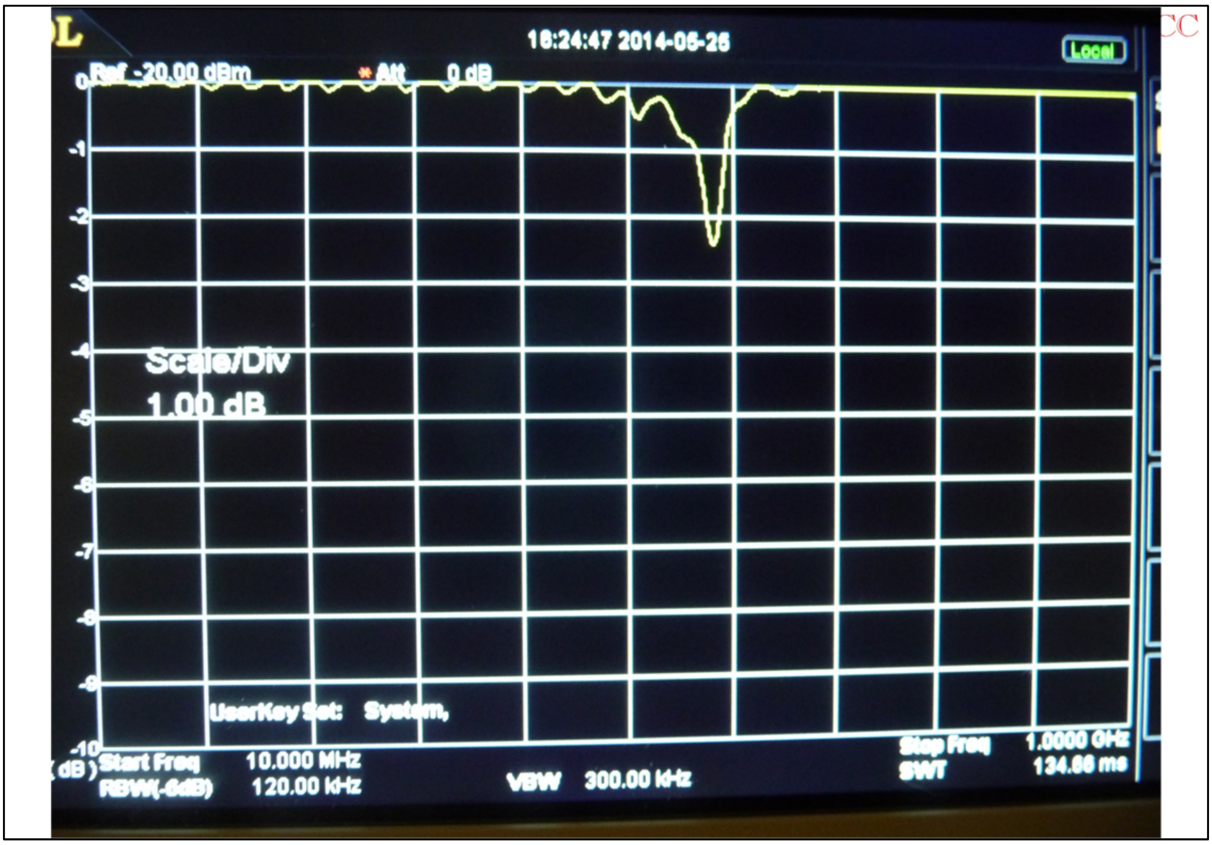

Figure 34 Looking for shielding imperfections with a reflectometer – the display (9)

The dip in Figure 34 is only about 2.5dB, but it is at exactly the same frequency as the dip measured for the large slot in set-up (8) – Figure 31. This was not unexpected, because the demo box's missing length of gasket is exactly the same as the length of the slot in its lid – so they will have the same first resonance frequency.

So not only does this method identify the fact that there is a missing (or badly degraded) gasket, it finds its ends and makes it possible to determine how much length is missing (again, without dismantling the item).

5 The 2-probe 'internal illumination' method

Figure 35 shows one of my more basic CF probes (no ferrites on its handle) probing the row of small holes on the lid of my demo box, while the TG's RF Output is fed directly to a CF probe that is *inside* the demo box.

Figure 36 shows the location of the CF probe, which is nothing more than a 95mm-long piece of (insulated) wire sticking into the box via a 'through-bulkhead-mounting' SMA connector. This is an E-field CF probe, being used here to 'illuminate' the inside of the box with RF energy from the TG.

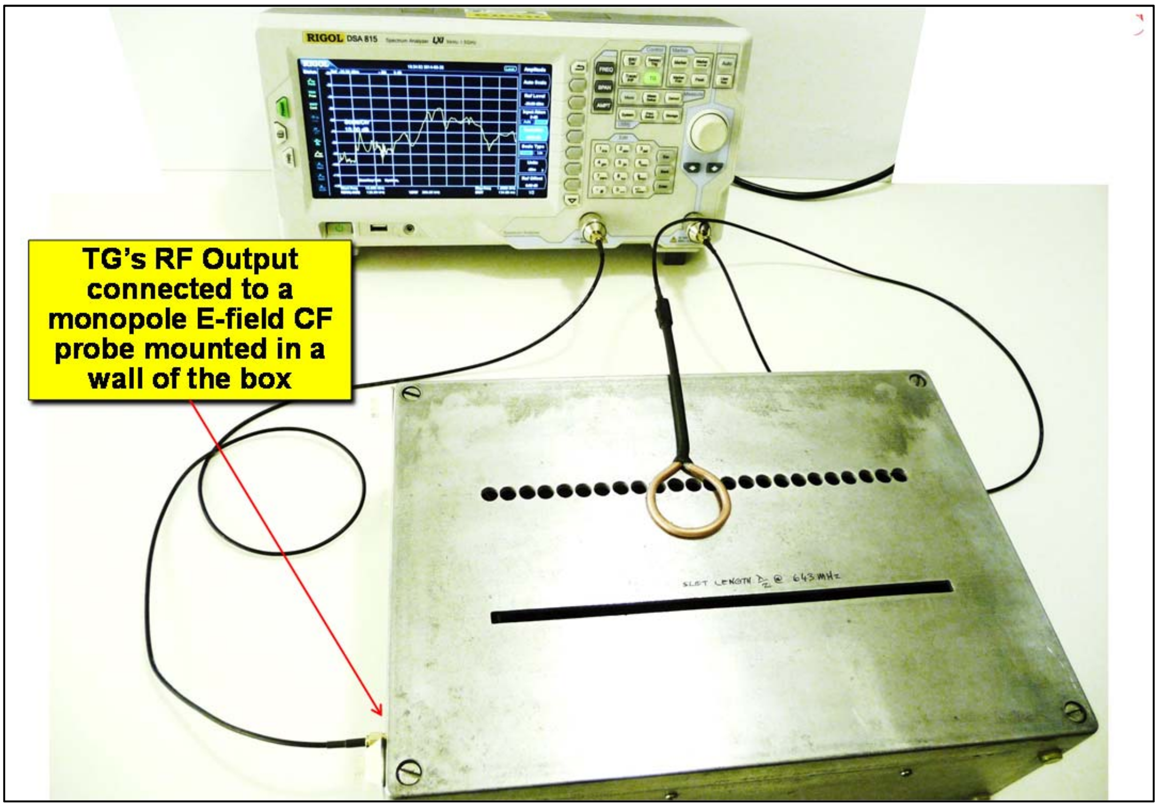

Figure 35 Looking for shielding imperfections with internal illumination – set-up (10)

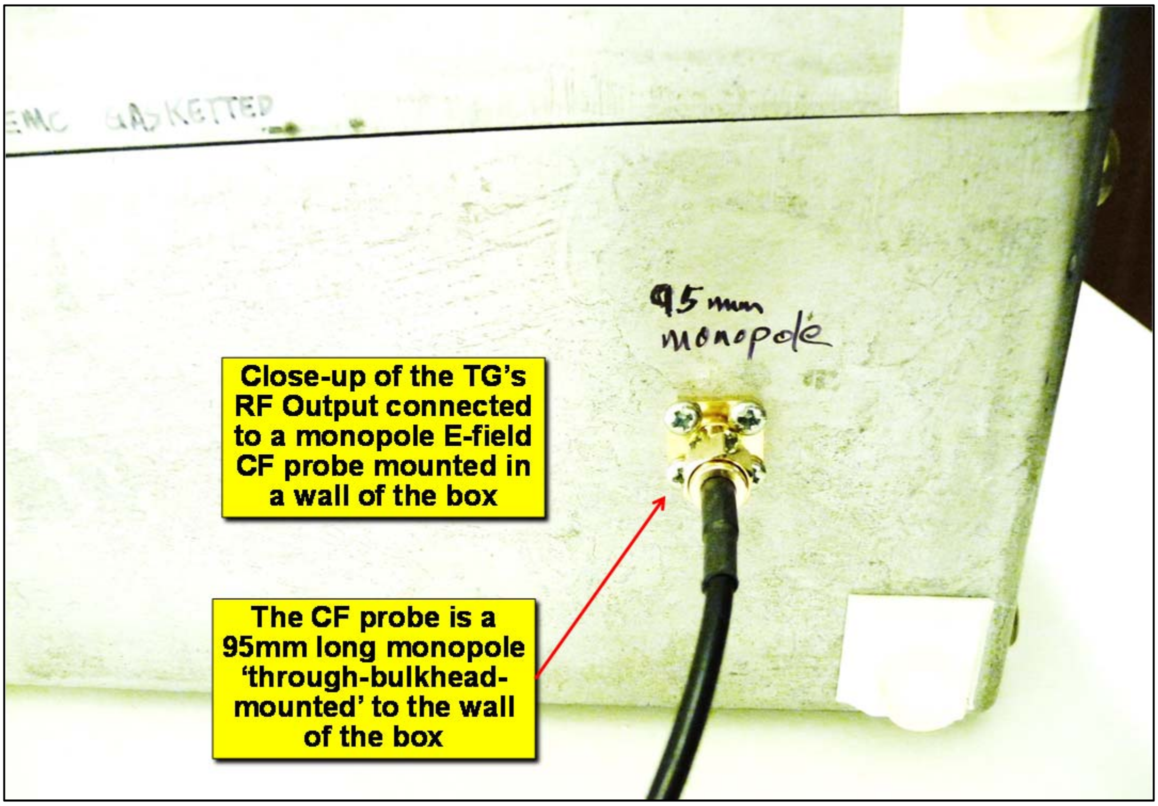

Figure 36 Looking for shielding imperfections with internal illumination – the internal CF probe

Figure 35 shows the capture of the yellow trace whilst the probe is held over the row of small holes, and Figure 37 the capture of the pink trace whilst the probe is held over the large slot (with the yellow trace 'frozen').

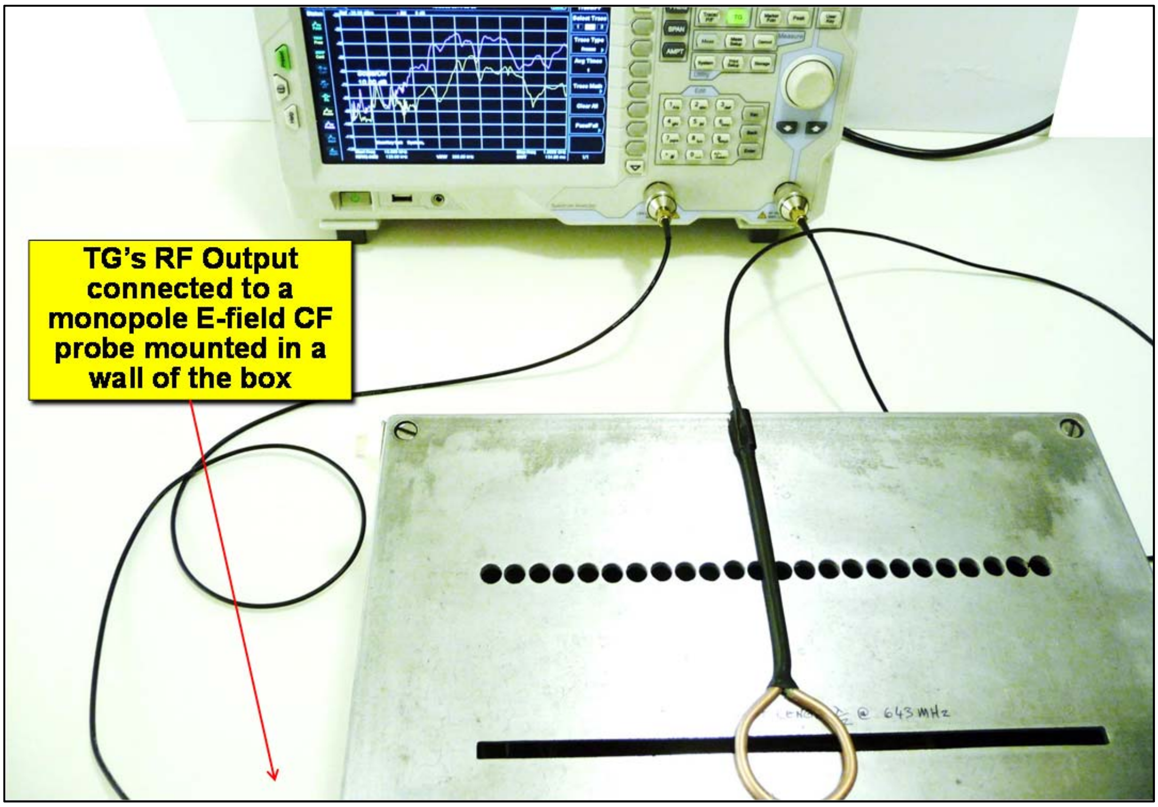

Figure 37 Looking for shielding imperfections with internal illumination – set-up (11)

Figure 38 shows the resulting display. The yellow trace is for the CF probe on the box lid away from the large slot, while the pink trace shows the probe held the same way moved to the middle of the large slot.

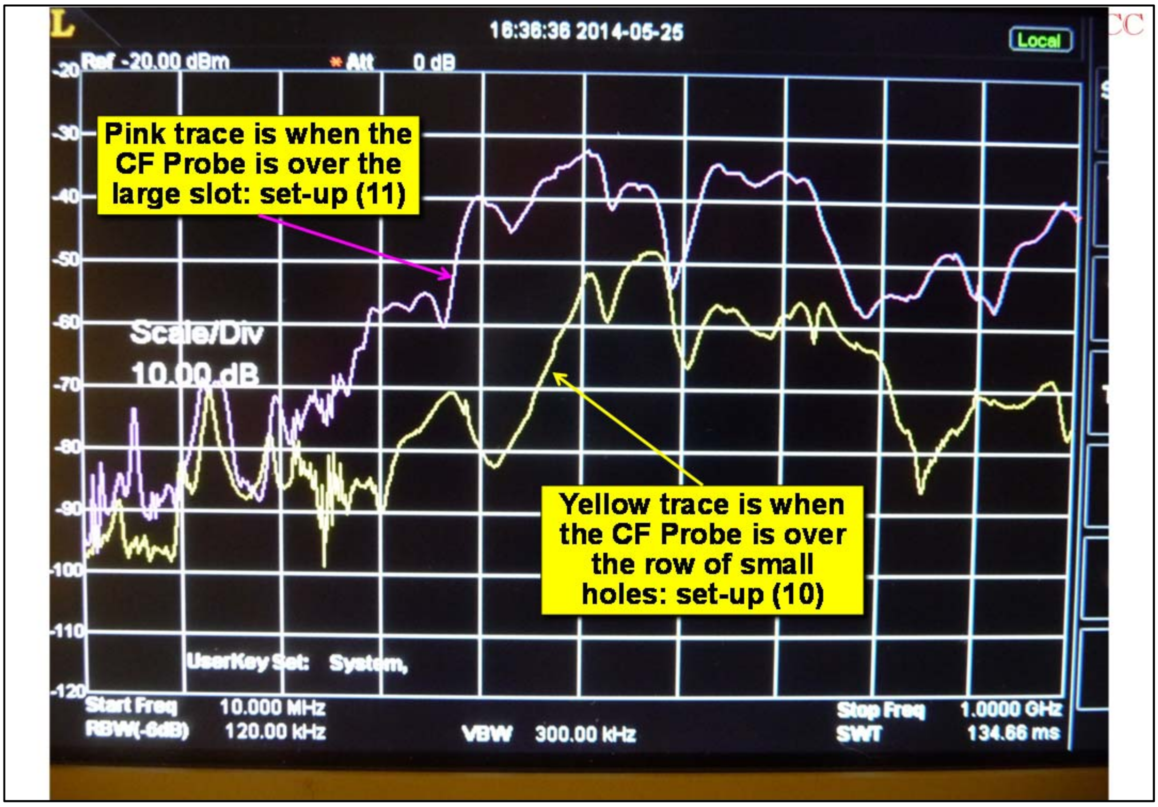

Figure 38 Looking for shielding imperfections with internal illumination – displaying both (10) and (11)

Clearly, the moveable CF probe was picking some emissions from the fixed E-field probe inside the box when it was not over the large slot, set-up (10), but also clearly it was picking up significantly more emissions when it was over the slot, set-up (11).

Figures 39 and 40 show exactly the same procedure using one of my newer 'ferrite handled' probes (although set-up (12) for the yellow trace was not photographed). These show that – for this kind of CF probe test at least – the ordinary probes do just as well as those with 200mm ferrite tubes.

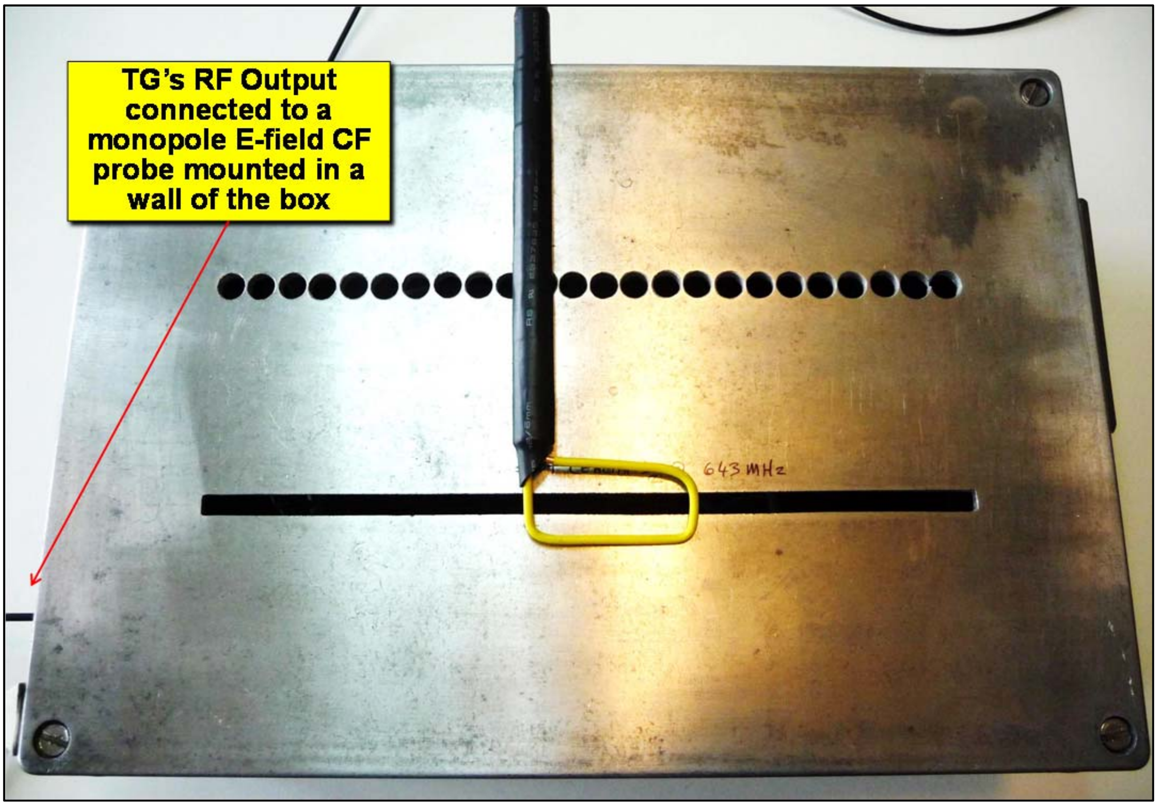

Figure 39 Looking for shielding imperfections with internal illumination – set-up (13)

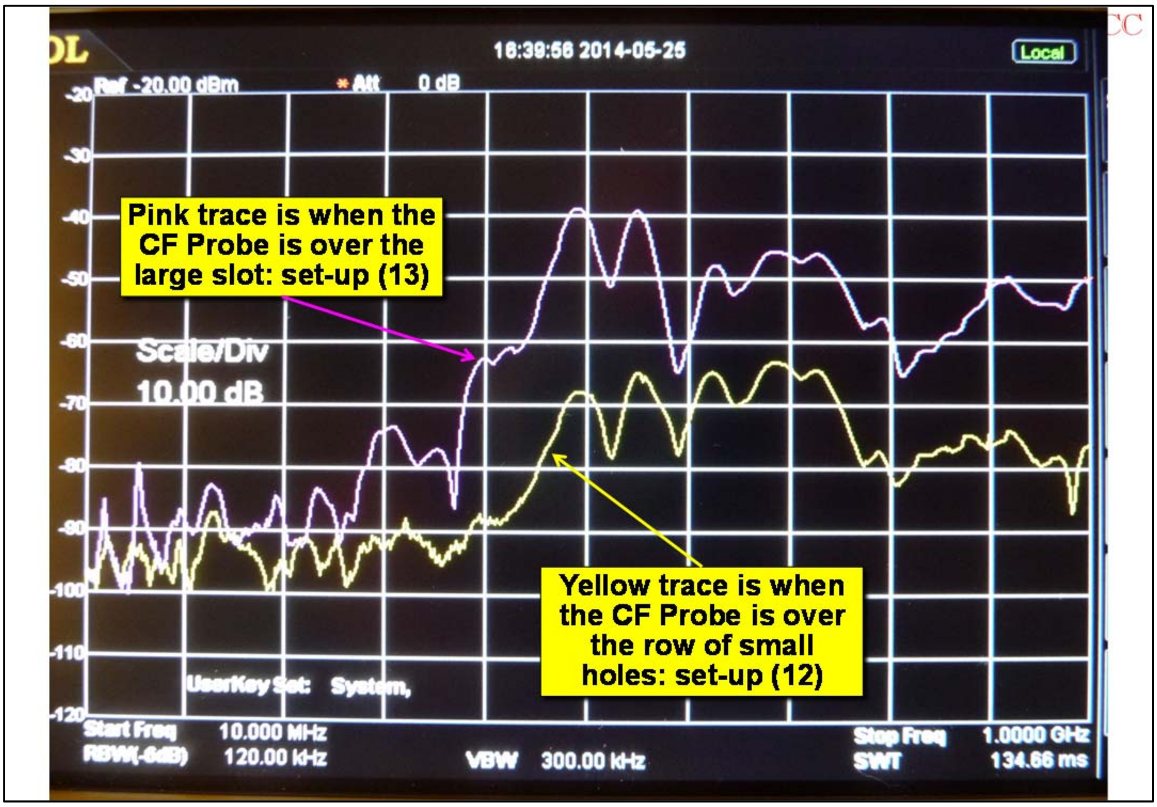

Figure 40 Looking for shielding imperfections with internal illumination — displaying both (12) and (13)

I have a lot more material on these sorts of CF tests, which can be done by (or for) mechanical designers early in a project to de-risk the choice of materials, assembly methods and overall design – but I have run out of room, so they will have to wait for future editions of the EMC Journal.

6 References for Part 1

[1] "EMC Testing", by Tim Williams and Keith Armstrong, EMC Compliance Journal, 2001-2002, available from www.cherryclough.com and www.theemcjournal.com. This is a series with 7 parts, and only Parts 1 and 2 are especially relevant to close-field probing.

[2] "Signal and Noise Measurement Techniques Using Magnetic Field Probes", by Doug Smith, IEEE 1999 International EMC Symposium, reprinted at http://emcesd.com/pdf/emc99-w.pdf.

[3] "Cost-effective use of close-field probing" webinars parts I and II, by Keith Armstrong, may be viewed at www.interferencetechnology.com/webinar-series (scroll down the webpage).

[4] "Evaluate EMI Reduction Schemes with Shielded-Loop Antennas", Roleson S, EDN, 29(10):203—207, 1984, which does not seem to be available via Google.

[5] "Benchtop EMC Testing Techniques for Medical Equipment (using close-field probes)", Scott Roleson, Medical Device & Diagnostic Industry Magazine, January 1998, available from www.mddionline.com/article/benchtop-emc-testing-techniques-medical-equipment.

[6] "Finding EMI Resonances in Structures", Roleson S, EMC Test Design, 3(1):25—28, 1992, which also does not seem to be available via Google.

[7] "Measuring Structural Resonances", by Doug Smith, 'Technical Tidbit, June 2006', available from www.emcesd.com/tt2006/tt060306.htm. There is a great deal more on close-field probing, other useful diagnostic techniques and much else on EMC and especially ESD at Doug's website: www.emcesd.com. A quote from a visitor to this site: "Every time I browse your site, I never get any work done. I spend hours on it and get in trouble." – so don't complain that you were not warned!

[8] "Near field probes: Useful tools for Electronic Engineers", Dr. Arturo Mediano, EMC-Europe 2013, Bruges, 2-6 Sept, Short Course 1.

[9] "Measuring Resonance in Cables", Ken Wyatt, EDN, October 29, 2013, www.edn.com/electronics-blogs/the-emc-blog/4423597/Measuring-resonance-in-cables.

[10] For example, EMC-UK 2014: www.emcuk.co.uk/conference, but please note that this year's EMC-UK training programme might not cover close-field probing techniques as it often has in previous years.

[11] "First impressions - Rigol DSA815TG spectrum analyser" by Kenneth Wyatt, in EDN, July 06, 2012, www.edn.com/electronics-blogs/the-emc-blog/4389791/First-Impressions--Rigol-DSA815TG-Spectrum-Analyzer.