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HF Interference from a TV: a case study

This first part describes an interference problem and the steps taken towards its identification and cure. This has been achieved without the use of expensive test equipment and is offered as a model for others to copy. By adopting a very methodical approach it has been possible to learn a great deal about the anatomy of interference. How this information has been used is the subject of the second part, to be published next month.

INTRODUCTION. RSGB members experience significant problems of interference from TV receivers. These are usually solved by replacing the offending TV - which is then out of reach of technical study. Alternatively the inter-personal relationship between the culprit's owner and the victim becomes too strained to allow technical investigation. However, M0DIV recently approached the RSGB EMC Committee with an interference problem that appeared after he moved house – and the Panasonic TX-28DT4 TV in his lounge was too old to be returned to the shop.

His problem was a complete wipe-out of reception from 3 to 30MHz when the TV was operating, with interference being strongest in the 7MHz band. The installation layout is shown in **Figure 1**.

The amateur equipment is some 13m from the TV. M0DIV has two antennas; a loaded vertical for 40m and a horizontal loop for the other HF bands. The vertical is shown in Figure 1. It is in the best possible place for EMC - as far as it could be from any habitation. The loop was less satisfactory, since it ran around the top of the garden fence and across the flat roof of the kitchen. This is vulnerable to pickup from the mains.

Another concern was the mains power feed to the shack. This is drawn from a 13A socket in the bungalow roof space and routed along the top of the garden fence. There was an earthing stake next to the shack, and some complexity in the earth interconnect that needed to be checked against the rules for protective multiple earth **[1]**, but it did seem that pickup on this elevated mains cable could be effectively in series with the ground connection of the vertical and so introducing interference to the receiver at that point.

It was decided to concentrate on the worst problem – the interference from the TV when the vertical is being used on 40m.

G3SBA had a hunch that since the TV antenna cable was 10m long the interference peak at 7MHz might result from the antenna and its coaxial cable acting in common-mode as an quarter wave antenna, end-fed above ground, in the mode shown here in **Figure 2**.

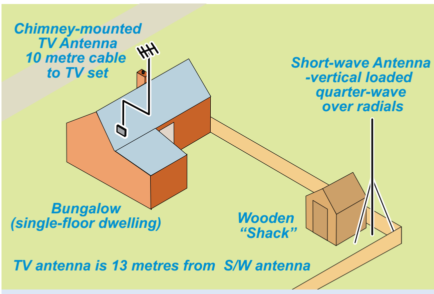

FIGURE 1: TV Interference scenario.

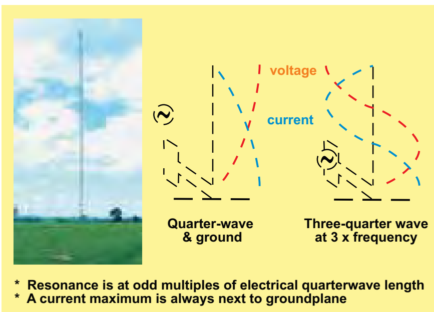

FIGURE 2: Aerials with one free end.

By *common mode* current we mean *the net current flowing in the same direction* in all the conductors of a cable. Such current makes its return path via earth or via the conductors of another cable, or by capacitive coupling or radiation and is responsible for most EMC problems. In the case of a coaxial cable of reasonable quality, the common-mode current is that which flows along the *outside* of the cable screen.

A vertical antenna driven relative to a low-impedance ground is a classic design shown in Figure 2 as a medium wave transmitting aerial. The current and voltage distribution at resonance is as shown in the middle drawing. The feed is impedance next to the ground plane is about 35Ω.

Note also the right-hand drawing which shows the resonance at three times the frequency. Later we will find both resonances in a common mode emission current plot for the TV antenna.

BASIC MEASUREMENTS. M0DIV lives in Hayle, Cornwall, and the writer in Hertfordshire. Therefore, the investigation could only use M0DIV's FT-100 receiver and simple low cost additional items that could go through the post. Since we wanted quality of data, not quantity, we concentrated on measurements at 7MHz.

To keep things simple we removed the VCR from circuit and just explored the TV receiver on its own. Test 1a – the TV on standby – gave only S0 to S3 at the shack, but turning the TV on (test 1b) raised this to S9, showing that the problem was not due to the TV's standby power circuit (as it sometimes is) and establishing a benchmark noise level against which to measure progress. **Figure 3** records these and the following steps.

The dBμV figures here are translated from the receiver S-meter readings using calibration data for the FT-100 published in *RadCom* **[2]**. Subsequent comparison with a Rhode & Schwarz measuring receiver suggests that they are correct to within 3dB.

The very encouraging considerable improvement shown for test 1f was achieved by the addition of a common mode antenna filter, type rcma. This device, which used a low-capacitance winding of RG179/BU coaxial cable on a pair of carefully chosen ferrite toroids, is shown in **Photo 1**. Measurements on a similar filter showed that it had an impedance of 3,000Ω at 7MHz and behaved as a very lossy inductor with a phase angle of 22°. This measurement and others associated with this work were made with a homemade N5EG vector network analyser **[3]**.

The mains filter rcmm used for test 1e comprised a similar toroidal common mode filter in series with a differential-mode filter, and so had slightly higher impedance.

We did, of course, try the two filters together, and found the further improvement set out in **Figure 3** tests 1c and 1d. However, substitution of the RSGB antenna filter HPFS (whose common mode impedance was a higher value – but capacitive) for test 1g showed worse performance.

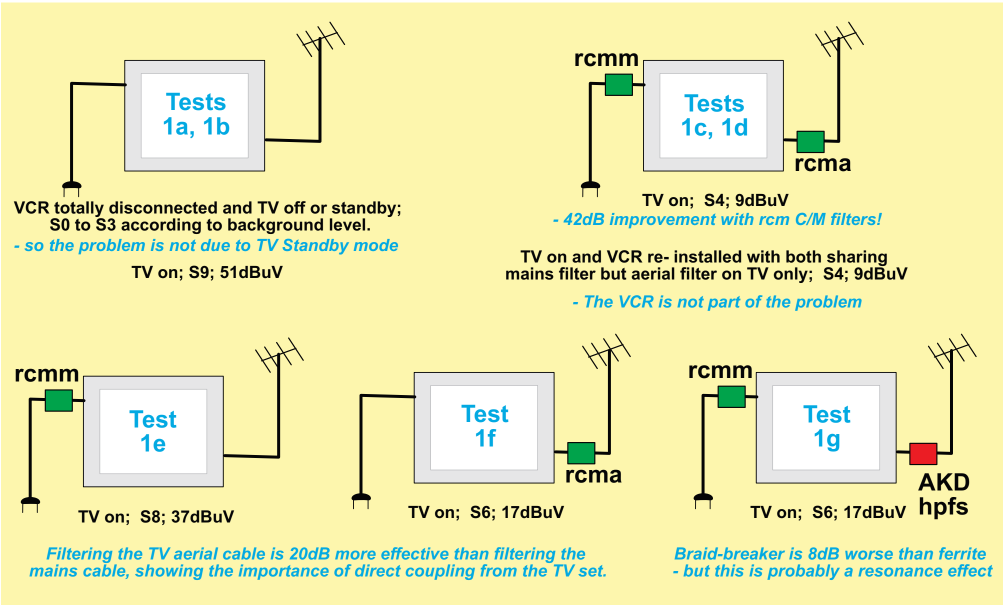

FIGURE 3: Experiments with common-mode filters.

This really interesting result confirmed that the antenna cable was operating near resonance, as was expected from the postulated quarter-wave vertical antenna operation mode, and that the reactance of the filter contributed to the tuning – detuning it in the inductive case and bringing it closer to a matched resonance in the capacitive case. It follows, however, that the HPFS would out-perform the toroid at some other frequencies. This tuning effect has serious implications for the design of common-mode filters: For effective general-purpose use over a wide frequency range they need to have substantially *resistive* impedance – not too capacitive or too inductive.

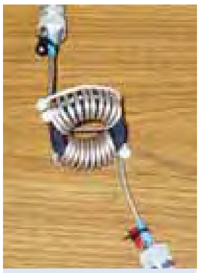

PHOTO 1: Filter rcma.

We also made a number of tests using specially made 3-wire 13 amp toroidal filters at each end of the fence-top mains cable. These are not reported in detail here since they showed that the coupling route from culprit to victim was not conduction to the shack via the mains wiring. The situation might have been very different had we used MODIV's horizontal loop.

The observation from Figure 3 that a filter in series with the antenna is 20dB more effective than a similar filter in the mains lead was very clear evidence that the interference current in the antenna cable was greater than that in the mains cable – which invalidates the CISPR13 measuring method used by manufacturers. This was reported to the TV's makers and to the CISPR/I/WG2 Multimedia Emission Standard committee, which resulted in the professional measurements and standards activity that will be discussed next month.

PHOTO 2: The TV antenna cable shield experimentally connected to the radiator. The grey ring in the upper view is the current transformer used for the measurements to be described in Part 2.

INSTALLATION EARTH. The TV was powered from a 'Protected Multiple Earth' TN-C-S mains distribution system. It was located directly in front of a central heating radiator, and measurement showed that cross-connecting the radiator to the antenna cable outer (**Photo 3**) considerably affected the interference current flow in the antenna cable – increasing it at some frequencies and decreasing it at others. From this it was clear that the resonance effects already noted were of the TV antenna and mains cables *in combination*. A mains 'ground' connection is a very uncertain thing at radio frequencies. However it must be best in principle to minimise the complexity of the RF situation by connecting all possible metalwork together to form the lowest-impedance earth that is possible without compromising electrical safety.

Having understood the situation with just the TV operating it was time to restore the SCART cable to its normal interconnection to a VCR, and route the TV antenna connection via the VCR. We then explored the effect of these extra connections by measuring the common-mode interference current flowing in each of these cables. No additional filters of any sort were present during these tests.

The dBμA figures in **Table 1** were obtained with the shielded clip-on 1:5 ratio current transformer in **Photo 3**. This was used with the same FT100 receiver as before – but that was now brought into the lounge and battery powered.

Readings were taken from the receiver S-meter and converted into dBμV as before and thence to dBμA using the current transformer calibration. Accuracy should be similar to the ±3dB established for the FT100. The fluctuations noted are variations with TV picture content.

These current measurements show that:

- The antenna cable current shows strong maxima at 7MHz and 24 to 28MHz. These maxima appear to correspond to the common mode low-impedance resonance of the TV antenna cable in its quarter-wave and three-quarter wave modes as discussed above. Once again

TABLE 1: Common-mode current flow on the SCART and other cables. The units are dBμA.

MHz	Antenna Cable	Mains Cable	SCART Cable
1.8	–3 to +10	< –10	10
3.5	22	10	10
7.0	37	22	37
10.0	2 to 10	10	10
14.0	10 to 22	–6	10
18.0	–9	< –10	10
21.0	–3 to +10	< –10	22
24.0	37	22	22
28.0	37	10	10
50.0	< –10	< –10	< –10

we are reminded that for a comparison of real-life emission with standard test parameters the possibility of low-impedance resonance of external cabling must be considered.

- In almost every case the interference current on the mains cable is less than that on either the antenna cable or the SCART cable. *We may conclude that the EMC filtering within the TV is only effective for the mains lead.*

PHOTO 3: G3SBA's wide-band current transformer, shown disassembled. This view shows how the 5-turn secondary winding on the lower half-core is shielded with copper foil and PCB laminate. Once assembled round the cable-on-test the two halves are held tightly together by the elastic bands.

- The current flowing between the TV and the VCR is relatively large. If we take an installation-sized view this suggests that if a TV set is used with a VCR, then it is a waste of time putting a common-mode choke at the TV set's antenna connection, since interference current would simply flow from the TV via the SCART cable to the VCR and thence onto the actual antenna cable. This teaches that from the Standards point of view it is equally important to limit the emission from the TV's SCART port since this becomes an antenna port upon connection to the VCR. However, for an existing installation such as that at MODIV the antenna filter should just be moved to the point where the antenna plugs into the VCR.

When this was done MODIV's problems were largely fixed.

We had identified a number of interesting issues to take to TV manufacturers and to the International Standards community. These will be the subject of next month's article.

WEBSEARCH

[1] www.rsgb.org/emc/pdfs/leaflets/emc7protectivemultipleearthingmembers.pdf

[2] Yaesu FT-100 Transceiver review by Peter Hart, *RadCom*, June 1999, pp29-32

[3] A Low-Cost 100 MHz Vector Network Analyzer with USB Interface, Tom McDermott, N5EG, and Karl Ireland, *QEX* July/August2004, pp3-14

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HF Interference from a TV part 2: Design Quality and International Standards

The first part of this article described the analysis of the interference problem at M0DIV and the steps taken to fix it. Along the way much was learnt about the route for such interference. In this second part, the ways in which TV designers may prevent such interference are analysed by G3SBA. He then describes the present status of the relevant International Standards, the work that is in hand for future improvement and how the opportunity was seized to make an input to it. He also discusses the wider implications for cable-borne emission and sets out the case for tighter limits for the common-mode interference introduced into antenna cables.

PHOTO 4: M0DIV's TV being tested by CISPR/I/WG2 members in the test laboratory

THEORETICAL ANALYSIS. For product EMC standards it is accepted that conducted emission and immunity is the prime concern at low radio frequencies, and that radiated effects predominate at high frequencies. This distinction is based upon the (rather over-simplified) fact that for equipment to be an efficient antenna its largest dimension must be a significant part of a wavelength. If its dimension is less than that then most radiation will come from the associated cables. Accordingly the crossover point is based on equipment size, and is generally set at 30MHz, where a tenth-wavelength is 1 metre. This choice of frequency is almost certainly too high for a large-screen TV whose screen diagonal may nowadays be considerably larger than 1 metre.

Cable emission is the result of common-mode current flow and so it is necessary to understand the sources and relative magnitudes of common mode current flow in the various cables connected to an electronic product.

Consider the common-mode equivalent circuit of the product shown in **Figure 4**. A TV receiver is shown but the approach would equally applicable to any other equipment or system. For simplicity we start by considering a product with just a mains supply cable and an antenna cable.

The TV can be visualised as having three connection routes or 'ports', as shown here. Each has the possibility in principle of having an associated emission source and current flow. (Magnetic emission is a possible complication that is not considered here). The measurements reported in Part 1 showed that there must be substantial interference current flow through the capacitance Ce in the case of a 28" CRT-type TV receiver. Therefore we should come up with an estimate for the value of Ce.

Figure 5 shows the situation simplified to two concentric spheres. The inner one represents the TV and the outer represents earth. We can now use Gauss's formula to determine the capacitance between the spheres.

It can be seen that the capacitance is approximately proportional to the TV size and not too sensitive to the proximity of its surroundings. Whilst the earthed surroundings of a real TV do not form a concentric sphere this approximation leads to a relatively small error as may be seen from a comparison between the last two lines of the table.

The reactive impedance figures in the right-hand column, by comparison with the typical 150Ω transmission line impedance of a cable in common mode with an earth return, show that the impedance to ground should not be neglected in any of the tabled scenarios. Of course, since the enclosure port is capacitive, its impedance is inversely proportional to frequency and so in most cases below 1MHz it will not provide an important route for interference current.

The enclosure port certainly has a more serious effect for larger EUTs such as large-screen TVs that have become more commonplace in the last 15 years.

SOURCES OF EMISSION FROM A TV. Is it possible for the three common-mode voltage generators Va, Vm and Ve to exist in practical TV and other multimedia equipment? All three will result from circuit features within today's electronics, aggravated in some cases with poor shielding and poor arrangement of the internal ground connections.

Specific causes are as follows:

- Vm will certainly result from differential-mode to common-mode conversion within the main and standby switched-mode power supplies.
- Ve will result from the operation of TV display screens as well as from any of the conductors internal to the EUT that carry high potential high frequency voltages, such as switched mode power supplies, line scan circuits and video drive circuits. Plasma displays operate with a 200kHz, ±200V switching supply applied to a large number of transmission lines across the display tube face. This has a trapezoidal waveform whose harmonic content may easily be emitted. For TVs with CRTs the line scan and video drive waveforms will have components in the HF bands. LCD TVs have a high voltage, high frequency backlight supply – typically 1kV RMS at 50kHz. The possibility of external interference is limited since it must be a good sine wave to avoid interference to the rest of the receiver's electronics!
- A voltage Va driving the antenna in common mode might result from coupling to the intermediate frequency (IF) or local oscillator frequency (LO) circuitry due to finite impedance of equipment conductors between the tuner and the remainder of the receiver. This is probably the least likely source of emission in present-day equipment – but Vm and Ve will still drive the antenna cable.

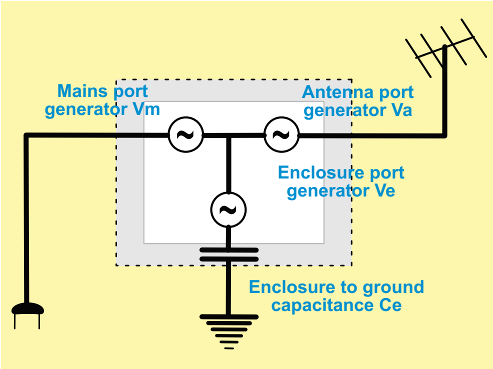
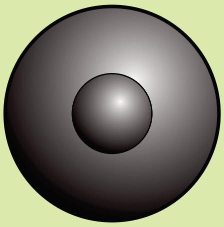


FIGURE 4: A basic multimedia equivalent circuit



C (pF) = 4 x π x e_0 / (1/a - 1/b)

where π = 3.142, eo=8.845, and a and b are the diameters of the inner and outer spheres respectively in metres.

	EUT radius	Surround radius	Capacitance	Impedance @ 30MHz
Portable 12" TV	0.15m	0.90m	20pF	265Ω
Domestic 24" TV	0.30m	0.90m	50pF	106Ω
Large 36" TV	0.50m	0.90m	125pF	42Ω
Well-spaced 36" TV	0.50m	3.00m	67pF	80Ω

FIGURE 5: Concentric spheres are used as the basis for calculating the equivalent capacitance for Ce in Figure 4.

The best and cheapest way for the manufacturer to deal with these interference sources is as part of the product design of the circuitry concerned. Local shielding, minimising stray capacitance (particularly in transformers) and control of voltage rise times are all important. If the problem is left until later then much more expensive filtering may be required.

The integration of computing and TV technologies has resulted in products which each have many different cabled connections – both analogue and digital. To filter these separately is clumsy and expensive. The ultimate example of this is the common-mode choke. At HF it is a large, costly component that (as discussed in Part 1) cannot be guaranteed to work in all situations. Careful product design can reduce the emission on all connections at the same time at much lower cost.

DID MODIV'S TV MEET THE EMISSION STANDARD? Working through fellow members of the British Standards Institution's Product EMC committee, G3SBA submitted a paper [4] covering the above matters to the relevant International Standard Committee. Contacts then arranged for the TV to be checked by its manufacturer.

The manufacturer's in-situ plots of peak common-mode (common mode) current against frequency shown in **Figure 6** cover both the antenna cable and the mains cable.

Note that the antenna current is typically 8dB higher than the mains current. This confirmed directly what we had already concluded from the results of inserting filter chokes. We return to this topic in the next section.

Note also the broad maximum at 7.5MHz, which is still enhancing emission at 7MHz – confirming the initial theory that the TV antenna acts as a resonant HF vertical. The three-quarter-wave resonance is also evident at around 25MHz.

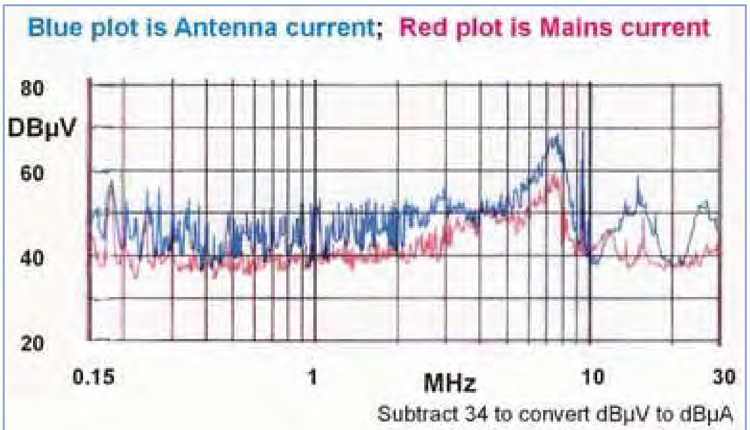


FIGURE 6: The conducted emission spectra measured at Hayle.

The narrow spikes are currents induced from strong broadcast transmitters – note the peaks in the medium-wave band (0.5 to 1.5MHz) and in the 31m band (9MHz).

We found that the 7.5MHz TV noise maximum moved to 6MHz when the ground connection to the TV was supplemented by connection to the radiator as in Photo 2 last month. This confirmed that the resonant frequencies were dependent on the antenna

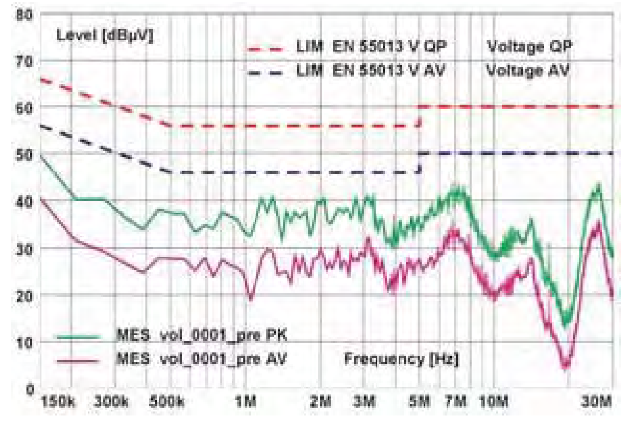


FIGURE 7: The mains cable noise measured with a Line Impedance Stabilization Network.

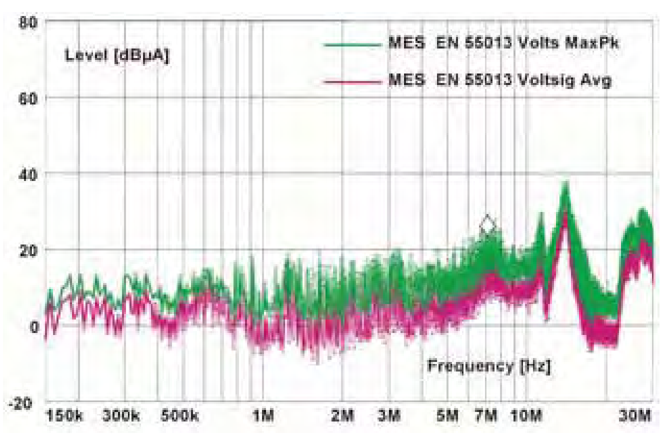


FIGURE 8: The antenna cable noise measured with a current clamp.

and earth system as well as on the TV itself.

Note the antenna current peak at 7.5MHz of 68dBμV that is equivalent to 34dBμA. From this it is possible to estimate the actual radiated power. Assuming that the TV antenna is acting as a quarter-wave monopole over ground with 37.5Ω input impedance it may be calculated that the power input from the TV is 93nW. Assuming 0dB antenna gain (the theoretical gain is 2dB) the field at 10 metres – the conceptual "protection distance" within a domestic environment – is 44.5dBμV/m.

Whilst under CCIR rules the "Amateur Service" is not entitled to any protection, this interference level is above the 40dBμV/m CCIR service area field strength for AM broadcast transmitters. Since reception of such transmitters requires a signal/noise ratio of 30 to 40dB the common-mode current launched onto the antenna by the TV is some 35 to 45dB too high even for short-wave broadcast reception to be of the quality intended. Broadcast reception will be degraded over a considerable area around the TV.

PROFESSIONAL TESTING. The TV was then moved to an EMC test house. First it was tested to EN55013 (=CISPR13). At the present time this is the product standard for "Sound and television receivers and associated equipment". It requires no direct test on the antenna connection, but seeks to infer the antenna current from measurements on the mains lead carried out with the antenna terminals first isolated and then grounded. Since the plot with the antenna floating was almost identical at high frequencies and only a few dB lower below 10MHz, only the plot with the antenna grounded is shown here in **Figure 7**.

The purple plot is of the average current in 9kHz bandwidth and is to be compared with the blue limit line. The green plot is of the corresponding peak value. This is to be compared with the red limit line, though if it is too close a time-consuming but lower quasi-peak measurement may be substituted.

It can be seen that the TV receiver meets the requirements comfortably – even though it had produced serious interference. One calls to mind the broad obligation in the EC EMC Directive to "not cause undue interference".

Note the peaks at 7, 14 and 28MHz that were close in frequency to those observed in the on-site test. There is an unfortunate co-incidence of the TV's inherent 7MHz emission peak with the user's TV antenna resonance.

Conformance to CISPR13 is quite inadequate to allow short-wave reception nearby.

THE IMPLICATIONS FOR THE PROPOSED "MULTIMEDIA" EMISSION STANDARD. In view of the convergence between Radio/TV equipment and computers there are plans to replace the different standards for these by a single CISPR32 standard that will cover both. This new standard provides an opportunity to make significant changes to the requirements. G3SBA's contacts were able to convene a meeting of some interested members of the international multimedia emissions working group to witness the above laboratory tests and to make further tests.

First we compared the common-mode RF currents in the mains and antenna cables under laboratory conditions. To do this a current transformer was first applied to the mains cable, with the antenna cable grounded. This translated the curve of the previous plot to the changed measuring method. The general shape was as before and the maximum current peaks at 7 and 24MHz were at about 21dBμA peak in 9kHz bandwidth – that is 11μA.

Using the same method we measured the antenna cable current as shown in **Figure 8**. From 500kHz to 30MHz this current is larger than the mains noise current. The increase is about +5dB from 500kHz to 5MHz, rising to +10dB at 10MHz and peaking to +20dB at 14MHz. This is the third piece of evidence that brings into question the assumption of equal mains and antenna currents that underlies the existing standard.

The peaks at 7, 21 and 28MHz are reminiscent of those observed at Hayle but the magnitudes are rather different. In the laboratory the 7MHz peak is smaller – presumably because the circuit impedance is higher. The 14MHz peak is much larger – at this frequency MODIV's TV antenna would have been half-wave resonant and exhibited a very high impedance which would have minimised the current flow. So we may note that the interference current experienced in practice will vary widely with installation conditions.

In view of the "convergence" objective of the new standard it was of great interest to know if the subject TV set would have passed or failed the emission limit that is applied to telecommunications cables in office equipment. **Figure 9** shows that it would pass – but only just. This issue was of some concern to the TV manufacturers present, since a natural form of construction is to mount all the external connectors onto a metal plate and there is no natural place to mount a common-mode choke such as that used in the tests described in Part 1. Accordingly the team found another TV to test – a larger and more up-to-date 32" LCD model. It was tested to the telecommunications cable limit. **Figure 10** shows that it passed with a comfortable margin, showing that this LCD receiver emitted less than the CRT model.

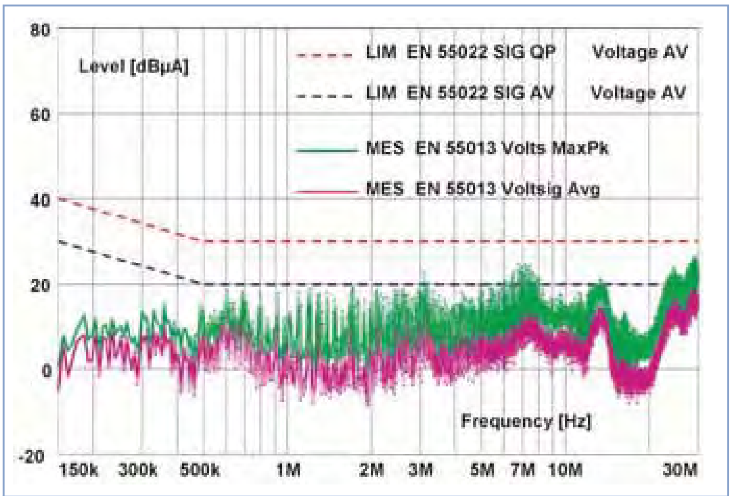


FIGURE 9: The antenna cable of a 28" CRT TV tested as a data cable.

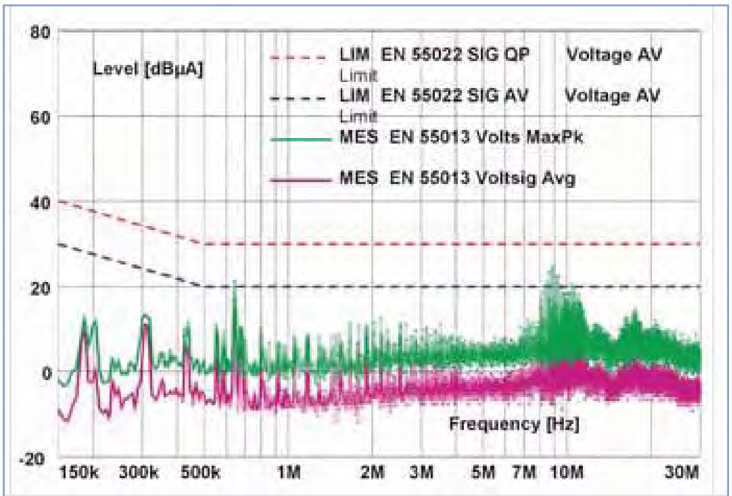


FIGURE 10: The antenna cable of a 32" LCD TV tested as a data cable.

At the wrap-up meeting G3SBA made the point that manufacturers should not design with common-mode chokes for the reasons set out earlier in this article (see 'Sources of emission from a TV'). He went on to say that the proper interpretation of the above work is that domestic TV aerials in common-mode may be particularly efficient emitters at their resonant frequencies, and that CISPR13 does not adequately address the emission from the antenna port of physically large TVs.

The group decided to propose a new test in the next draft of the Multimedia Standard [5]. This test specifies a common-mode impedance of 150Ω and sets voltage or current limits like those for telephone and data cables. This is a really positive step.

However 150Ω is much higher than the 25Ω that we have shown to be representative at the resonant frequencies of a TV antenna and its cable, and the work described above shows that an unacceptable signal-noise ratio even for broadcast reception at the 10m protection distance may result. The evidence of TV antenna resonance and the known theoretical feed impedance of a monopole above ground may result in the current flow in a real installation being much higher than that during qualification testing, and user problems are inevitable.

Our findings came at just the right time to attract the attention of the Standards Committee working on the Multimedia Emission Standard. As a result of their interest our early results and theoretical analysis have been confirmed, and taken into account for the next draft of the Standard. This has subsequently been circulated to the National Committees for comment.

However, to tighten the limits on this new test during the later stages of development of this new standard will require concerted action by the amateur and short-wave broadcast communities worldwide. The RSGB EMC Committee will be seeking the help of other IARU members to make this happen.

BROADER STANDARDS ISSUES. For interference to occur, a culprit, a victim and a path must all exist at the same time and at the same frequency, and the limited probabilities of each of these events are accounted for in the estimation of appropriate limits. However, our work has demonstrated that continuous wideband interference emitters such as TV video circuits – and by implication also PLT and ADSL data circuits – 'seek out' the frequencies of structural cable/antenna resonance at which they are well-matched so that the chance of interference is much increased. This is a relevant consideration for the Standards for wideband telecommunications services also. Accordingly descriptions of this work have been presented in professional media **[6, 7]**.

ACKNOWLEDGEMENTS. This work has been successful thanks to a huge degree of co-operation between many people. In particular, the author would like to thank Mike Dickinson and his wife, the members of CIS/I/WG2, the staff of Panasonic UK and of the UK TEC EMC Laboratory.

WEBSEARCH

[4] *"Rationale for conducted emission measurements on Multimedia Equipment"* by Richard Marshall. Committee contribution CIS/I/WG2 (Morsman-Marshall) 07-01.
[5] CISPR/I/224/CD Annex B Table B7.
[6] *"Interference emission from TV receivers in theory and practice"* by Richard Marshall. EMC-UK 2007 Conference, Newbury, UK 16th/17th October 2007.
[7] *"Measurements of Interference from TV receivers in relation to CISPR13 and CISPR32"* by Richard Marshall. NPL Electromagnetics Day, Teddington, UK 29th November 2007.