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The Protection of Digital Broadcast Reception

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The Protection of Digital Broadcast Reception

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Abstract

Emissions standards were originally developed to protect contemporary radio services, including AM radio broadcasting, and, later, TV and FM radio. The measurement methods (detector type and bandwidth) were designed to model the effect on radio reception of interferers whose emissions occurred intermittently in time (e.g. electric motors in appliances) or only affected a single frequency (e.g. internal oscillators). Limit values were chosen reflecting the probability of interference resulting.

Digital broadcasting is affected by interference in different ways from analogue reception; meanwhile new interference types have arisen. How should standards evolve to reflect this and continue to protect reception?

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[†] Note that the opportunity has been taken to make some minor corrections.

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The Protection of Digital Broadcast Reception

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1. Introduction

Living as we do in an imperfect world, radio systems have always been subject to potential interference from various causes, and no doubt always will be! The challenge is to contain the prevalence of interference within certain bounds — ideally those within which radio systems can work without the users being aware of any shortcomings in reliability or perceived quality. Indeed this is enjoined upon us by both the International Radio Regulations and the European EMC Directive.

One type of problem is interference between radio systems, in other words the interfering signal is one which is intentionally emitted — it is someone else's wanted radio signal. In the case of broadcasting, the obvious source is another broadcaster operating in the same or a nearby channel within the same broadcasting band. The mechanisms are well understood, can be quantified in an agreed way and are generally taken care of in the planning process, whether in the formation of a large-scale plan at an international conference or in the application of an agreed procedure to modify a plan. The planning process includes the use of Protection Ratios[1] (PR), which are specific to the types of signal in question, both wanted and interfering. Note that in a period of transition, wanted and interfering radio signals may well be of different types.

That's well and good, but there is a whole other set of interference sources which also have the capability to disturb radio reception: those which give rise to radio-frequency emissions as a by-product of their operation. In earlier times, the dominant examples would arise from the use or switching of electrical power, e.g. power tools, domestic appliances with motors, light-switches, thermostats, (conventional) ignition for petrol engines…

Nowadays we also have to cope with apparatus using in-built electronics that may radiate as a by-product (e.g. switched-mode power supplies, clock-oscillator harmonics, digital processing…) as well as wire-line communications systems. In the latter, a signal is quite deliberately generated and injected into some kind of cable in order to communicate from point to point; some of this signal will also be radiated and have the potential to interfere with radio reception. So, in this case, the signal is intentional but its radiation is not.

2. Interference in a changing world

We now face a situation in which the possible interference scenarios are proliferating, while the process of interference regulation has to catch up — and quickly — or risk becoming irrelevant and ineffective.

Restricting ourselves to broadcasting as the 'victim' radio service, we have two broad classes:

- analogue broadcasting
- digital broadcasting.

In the UK[2], analogue broadcasting takes place in LF, MF and HF bands (AM radio), in VHF Band II (FM radio) and in the UHF Bands IV and V (analogue PAL TV). Digital terrestrial broadcasting

[1] The Protection Ratio is the ratio S/I of wanted-signal power to interfering-signal power that must be exceeded if reception is to be satisfactory.

[2] Europe as a whole is generally similar except that: some use is made of Bands I and III for television; some countries chose SECAM instead of the PAL standard for analogue TV; and some eastern European countries historically adopted a different band for FM radio from that used in W Europe.

is well established in Band III (DAB[3] radio) and Bands IV and V (digital TV to the DVB-T[4] standard), and is in the process of introduction in the LF/MF/HF bands (Digital Radio Mondiale). Various flavours of digital TV to handheld receivers (especially mobile phones) are undergoing trial (DMB-T, DVB-H…).

We also have various classes of interferers, old and new.

The traditional motors/switches/car-ignition category is still around, although regulation has achieved some success here. The author's personal experience is that this type of interference seems to be somewhat less common nowadays; such problems as arise often appear related to faults arising as the appliance etc ages.

Interferers of this traditional type have been dealt with in regulations under the assumption that their usage is transitory in nature, so that the probability of suffering interference in a particular place at a particular time (and on a particular frequency) can be held small enough by the application of an emissions template that is otherwise insufficient on its own to prevent interference.

Let us consider some examples. If a DIY power tool emits interference at a level that disturbs reception in the same household while it is being used, that is unwelcome but not in itself disastrous. Being practical for a moment, you probably can't hear the radio above the noise of the tool's motor etc, and you certainly shouldn't be looking at the TV while handling power tools yourself! Any remaining disputes are within the scope of negotiation within the household.

If the tool also interferes with your neighbour's reception, that is less satisfactory — but under the assumption that you only use this tool very occasionally for a few minutes at a time, it too may just be acceptable. It would not, however, be acceptable for emissions from such a device to be so great as to be able to affect say 100 neighbours; now the probability that *someone, somewhere* in this group is using a DIY tool at any given time is multiplied up to the extent that the probability of reception being disturbed in this neighbourhood would be excessive. Considering other appliances that are used more frequently and for longer periods — examples in increasing order of potential use could be a washing machine, a light fitting or indeed a television itself — it will clear that they ought to be treated more strictly, in proportion to their greater probability of being in use.

A whole new class of interferers has arisen as the result of building digital circuitry[5] into apparatus. Even if this has no (intended) connections to the outside world, the operation of this circuitry has the potential to radiate. The spectrum of the radiation way well have peaks related to the clock frequency or frequencies, but can also have a substantial element which is more or less broadband in character[6]. If the operation is for extended periods, and apparatus of this type becomes commonplace then there is a clear risk that a spectrum template imposed under the assumption of intermittent, discrete-frequency emissions will no longer be adequate.

Perhaps the most extreme extension of this trend is wire-line communications systems [1, 2], where signals are impressed on a cable for the purposes of communications. There is a range of potential problems here too:

- the cables[7] may be more or less 'leaky' — varying the potential for emissions

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[3] Digital Audio Broadcasting according to the Eureka 147 standard.

[4] Digital Video Broadcasting — Terrestrial.

[5] I suppose I can include switched-mode power supplies as being in the 'digital' category, for the purpose of this explanation.

[6] Only with relatively simple repetitive processing will there be a purely line spectrum of clock harmonics.

[7] Note that the way they are fed and terminated also influences the radiation, even with a 'perfect' cable.

- the cables may be more or less effective in transmission, varying the necessary injection level

  — the two above will together determine the level of emissions
- the cables may be more or less extensive, increasing the sphere of affected locations
- the cable communications may be intermittent, but many are continuous in nature
- the emissions are likely to be broad enough in spectrum to affect at least several channels in a given broadcasting band, but the overall breadth may also be so great as to affect a plurality of bands

So not only are the *broadcasts* changing from analogue to digital — in many respects the the *interferers* may be said to be doing the same thing.

Interferers have changed in one further way: many devices now have a *standby mode*, either for user convenience (e.g. when you have finished viewing, you can put your TV into standby using a remote control, without having to leave your chair) or because the device needs the ability to turn on again autonomously to do its job (e.g. a VCR or PVR). Emissions regulations have commonly been so drafted as to apply only when the device is operating 'normally', which is interpreted as excluding standby conditions. Because of this exclusion, little attention may be paid to what happens in standby mode — with the consequence that some devices, once placed extensively on the market, have been found to cause significant interference in standby. Note that there is a conundrum here in applying assumptions about usage-probability factors: the more that emissions in normal usage are excused, on the basis that a particular device will not be used for a significant % time, the more emissions from the same device in standby mode cannot be so excused, since the standby use must therefore approach 100%.

3. Reception properties of digital broadcast standards

3.1. They aren't analogue...

Paradoxically, digital radio and TV can be said, in some ways, to be both better and worse (compared with analogue) in relation to interference effects.

Take the example of AM (either LF/MF/HF radio or UHF TV). The signal-to-*noise* ratio (SNR) required at RF is closely related to that achieved in the audio or video signal. The ear and eye are both fairly sensitive to noise, so the presence of noise can be discerned at quite a low level, leading to high SNRs being required if reception is to be truly unimpaired. The effects of interference are similar, in that the signal-to-interference ratio (SIR) also should be high if there is to be no audible or visible impairment. It is also the case that when interference is perceptible it will have a particular aural or visual character that means even non-experts know that interference is occurring. However, it remains possible to extract some 'intelligence' from even a badly-impaired signal, albeit with the listener or viewer becoming more or less annoyed. Analogue reception is thus often described as exhibiting *graceful degradation* in the presence of noise and interference.

Digital systems do away with this nearly linear relationship between noise or interference and their visible or audible impact, and so graceful degradation is replaced by the so-called *digital cliff*. If the combined noise and interference is below a certain critical level, then reception is unimpaired; the effect of any interference is imperceptible. However, if the noise or interference increases further beyond that critical point then the impact on the sound or picture swiftly passes through fairly gross impairments to the point where reception simply fails: the loudspeaker goes quiet, the screen goes blank.

So the very great merit of digital systems for broadcasting is that the irreducible low-level interference that causes continuing annoyance with analogue systems (e.g. MF ‘monkey chatter’[8], patterning or ghosting in television) simply has no impact on the listener or viewer. Reception is ‘cleaner’.

However, when the interference becomes a flood, the digital dam bursts and reception fails altogether.

3.2. What they have in common

The DAB, DVB-T and DRM standards all share a common basis, in that they all use Coded Orthogonal Frequency-Division (COFDM) as their modulation system. They do use different parameters, as appropriate to their different applications, and have other fine-detail differences.

However, the common principle is that the source-coded video or audio data to be transmitted is then encoded with a forward-error-correcting code (increasing their redundancy) and distributed over a substantial number of closely-spread carriers for transmissions. If selective fading occurs as a result of the reception path (e.g. from the effects of multipath) then the various carriers will be individually received more or less well. Thus some of the data, on some of the carriers, may be corrupted or destroyed but the error corrector in the receiver can cope with this, aided by information that tells it whether particular data has travelled via a ‘good’ or ‘bad’ carrier. See [3] for a fuller explanation.

The required signal-to-noise ratio varies depending on the settings of the various parameters such as code rate, and, within DRM and DVB-T, on the choice of modulation constellation. These ‘knobs’ and others are made available to broadcasters so that they may tailor the system to their particular requirements. The SNR required also depends on the reception path, being least for a Gaussian channel (flat frequency response with simply white noise added). As the channel becomes more selective, so more of the error-corrector ‘power’ is in effect eaten up with coping with the multipath having concentrated errors on ‘bad’ carriers. Thus there is then less correction power in hand to deal with noise.

If interference takes the form of essentially white Gaussian noise then its effect is easy to predict: it contributes to a ‘lifting of the thermal noise floor’ and simply eats up some of the noise margin. Clearly, the SIR must exceed the nominal SNR needed for the mode in use, and the ‘real’ noise would have to be negligible if the SIR equals the nominal SNR required. The permissible SIR in reality will thus in practice be greater than the nominal SNR so as to leave some headroom for the inescapable ‘real’ noise.

However, interference often has another character and in this case only experiment with the actual combination of interferer and receiver can reveal what levels of interference are acceptable. There may be crucial dependence on some parameter setting, so we must be very careful of generalising.

3.3. Time-interleaving, impulsive interference

Both DRM and DAB include an element of time-interleaving, whereby the order of transmission of data is somewhat reshuffled. This means that adjacent data presented to the error corrector in the receiver comes from non-adjacent parts of the transmitted waveform. This has the effect of reducing the impact of transmission-path ill-effects that are concentrated in time (somewhat similarly to the simple explanation just presented concerning selective fading). Both DRM and DAB need this since time-varying channels are expected for both: DAB is intended to cover the case of mobile reception, while in DRM the dominant cause of time variation tends to be the movement of ion concentrations in the ionosphere rather than movement of the receiver.

[8] A descriptive term for the effects of adjacent-channel interference in AM systems!

DVB-T was originally designed for fixed reception; this, taken together with the costs of time-interleaver memory[9] at the time of defining the standard, meant that no specific time-interleaving was included. However, even if reception takes place at fixed locations, that does not mean there are no time-varying effects. There are various sources of impulsive interference in and around the home and their propensity to cause difficulties in reception of digital television varies in quite complicated ways with the chosen DVB-T system parameters. This has received detailed study under the auspices of the Digital Television Group (DTG) and more information can be found in Ref. [4].

The key point to note is that interference which has a time-varying character, such as impulsive interference, requires very detailed consideration before its impact on any given digital broadcasting system can be predicted[10]. Furthermore, the chosen parameters of the broadcasting system, where it offers options to the broadcaster, may vary the susceptibility to a given interferer quite dramatically.

This sets challenges to the regulators. If these detailed interactions are not properly accounted for, then it is likely that:

- some scenarios that are otherwise attractive to broadcasters will not be adequately protected
- manufacturers of appliances are nevertheless driven to expend effort to pass a test even though the protection that results is inadequate.

It is even possible that regulation can make things worse than they would have been!

4. How regulation can make things worse

Existing regulations concerning interference emissions are very much rooted in the analogue beginnings of radio. The measuring-receiver detector and bandwidth are chosen to model well the impact of more-or-less impulsive noise on an analogue receiver. Interference is implicitly regarded as more or less annoying so that some flexibility can be entertained. The assumption is also made that the interference is from sources that are localised (not widespread) and intermittent in nature, with a certain limited rate[11] of use. The limits set are not low enough to guarantee that emissions at that level cause no impairment when they occur; they simply assure a reasonably low probability of occurrence, as already discussed. Where emissions are more continuous (e.g. emissions from internal oscillators) it is assumed that they only interfere with a single reception channel, compared with the widespread number of possible ones, and this is taken as a ‘probability’ factor taking the place of the one for intermittency that is no longer applicable.

Let us now consider how this well-meaning regulation can actually inspire behaviour on the part of manufacturers that makes real-world problems worse for digital reception. Because some of the old assumptions are no longer valid, the standards are indeed counter-productive.

Consider a product containing a microprocessor or other digital processing (which, today, is almost any product!). The manufacturer finds that emissions of some internal clock harmonic exceed the spectral template laid down in a standard. Remember, the levels are defined in terms of a measurement receiver with a specified more-or less narrow bandwidth[12]. One way for the manufacturer to bring this into compliance would be to add some deliberate jitter to the clock so that its spectral lines are spread out — becoming sufficiently broader than the specified bandwidth of the measuring

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[9] More significant for a high-bit-rate system such as DVB-T than for DAB.

[10] Note once again the contrast with analogue reception, in particular analogue TV. If a single burst of interference (say from the switching of a poorly-suppressed thermostat) obliterates 10 or 20 lines in a single TV field the disturbance is minimal, whereas the impact on digital TV reception, once it occurs, is very much greater.

[11] ‘Frequency’ would be a better English word here, except that it has another connotation in this context!

[12] The measurement bandwidth depends on the frequency band in question, e.g. it is 9 kHz for LF/MF/HF.

receiver — and thus it appears that its potential to cause interference has been reduced. At least the emissions *as measured*, with the specified test procedure, appear to be reduced, and the limit template is now respected. However, suppose the radio service potentially affected is one of our trio of digital broadcasting services that uses COFDM as its modulation system. With this system, a narrow-band interferer, even of relatively high level[13], causes little problem — it prevents reception of one carrier, but the error corrector in the receiver can cope with the resulting erasures[14]. However, the same interfering power spread over several carriers (an outcome encouraged by the present-day standards) will cause reception to fail.

So we have the scenario where the measurement method interprets the product (in its original form, with a pure-tone emission) as exceeding the emission limit of the standard, when actually it would have caused no problem to the reception of the digital broadcast service. Because of this the manufacturer is encouraged to make a design change — solely for the purpose of passing the test, since adding jitter is of no benefit to the operation of the product, while making the change causes the manufacturer both expense and delay to market. As a result of the design change, the product now measures as being below the limit, but the effect of interference is increased, perhaps even to the point where reception is now impossible. And remember, with a digital receiver, "impossible" means exactly what it says. Reception isn't impaired, it stops. Silence. Blank screen.

Clearly, it is very important in setting regulations to beware of **unintended outcomes**.

5. The regulatory challenge

The regulatory challenge is considerable. The switchover from analogue to digital means of broadcasting (and indeed in other types of radio service) has started. In some cases, it is well under way and a clear timetable to completion is established (digital TV in the UK is a good example). In others it will take a much longer time to complete.

So for some time there will remain some analogue services to continue protecting, yet there is an urgent need to protect new digital services right from the start of their introduction, lest that introduction should fail just from the very existence of interference issues.

At the same time we have both the 'traditional' interferers and constantly evolving new ones.

We need regulation that correctly deals with all four classes of interference scenario:

- traditional interferer ➙ traditional analogue broadcast service
- traditional interferer ➙ new digital broadcast service
- new interferer ➙ traditional analogue broadcast service
- new interferer ➙ new digital broadcast service.

Note, however, that only the first of these can be said to be covered by present regulations, and that only to the extent that the assumptions made when they were set have not been overtaken by events.

The protection of digital services presents a major challenge simply because the 'digital cliff' makes the consequences of inadequate protection rather severe: the digital service stops working altogether. This would not, by any interpretation, match the EMC Directive wording of allowing it to "operate as intended"! So there is little room for error or complacency.

Some sympathy must therefore be extended to regulators. Precise knowledge of the parameters of both the 'victim' radio service and the interfering signal are needed in order to determine the level

[13] Within obvious limits of front-end overloading, converter linearity…

[14] In much the same way as the receiver handles selective fading, as already described.

of interference that can be tolerated. Yet radio services and interferers are meanwhile both changing at an ever-increasing rate. Drafting new regulations or reviewing existing ones in such a way that the necessary protection is given to radio services — without being unduly restrictive and driving up manufacturing costs — is going to require both determination and imagination.

6. Conclusions

Radio services, including broadcasting, are entitled to operate as intended without interference — a principle outlined in the International Radio Regulations. EMC regulations should help to achieve this, and in many ways have been successful in containing the interference from 'conventional' interferers to 'conventional' radio services.

However, things are changing rapidly, exposing various new problems. Radio services are adopting digital techniques at the very same time as the range of products that may cause interference is growing, while these products themselves also incorporate digital circuitry that causes emissions of a new character. The old probability-factor assumptions are losing validity. Indeed examples can be found where taking action to bring a product into compliance with existing EMC standards actually increases the interference problems the product causes.

Such unwanted consequences should be very carefully guarded against when reviewing EMC standards or drafting new ones.

7. References

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Protection of Digital Broadcast Reception

New services — and new interferers!

Jonathan Stott

Contents

- What is interference?
- Broadcast systems
- Original basis of EMC regulation
  - it worked
- The digital difference
- Changing interferers
  - need to reassess methods
- When regulation goes wrong
- Conclusions

Protection — from what?

- Radio systems require and are entitled to protection from **interference**

> "*interference:* The effect of unwanted energy due to one or a combination of *emissions*, *radiations*, or inductions upon reception in a *radiocommunication* system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy"
>
> ITU-R Radio Regulations, S1.116

— and two interferer types

- Other radio systems
  - carefully regulated through ITU-R procedures
    - Radio Regulations S15.1-11
    - frequency bands allocated to particular services
    - planning with protection ratios, often single-service issue
- Non-radio interference — *focus of this talk*
  - incidental result of use of other apparatus
  - ITU Radio Regulations require that it "does not cause harmful interference to a radiocommunication service"
    - Radio Regulations S15.12 & S15.13

Broadcasts to be protected

analogue digital

- Both old and new forms of broadcasting to protect
  - digital will eventually supplant analogue
    - TV switchover in UK has defined timetable, starts very soon
- Analogue
  - AM radio, FM radio, PAL TV
- Digital
  - DAB radio, DVB-T TV, DRM radio
  - these are all based on COFDM
    - Coded Orthogonal Frequency-Division Multiplexing

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It used to be simple (I)

- Interference regulation began in simpler times
  - analogue radio services (probably AM)
  - most interference from electrical appliances
    - by-product of using or switching electrical power
    - commutators, switches, thermostats
  - and from simple car ignition
    - before suppressors!
- and had some success

It used to be simple (2)

- Measurement method matched source & victim
  - bandwidth same as AM receiver bandwidth
  - quasi-peak detector modelled impact of impulsive noise
- Emission levels chosen took benefit of:
  - **graceful degradation** of analogue
  - reasonable **probability factors**

It used to be simple (3)

- Graceful degradation — *for analogue*
  - even a very low level of interference can be perceptible
  - impact worsens as level is increased
    - over a range of 10's of dB
    - eventually reception is impossible
  - implies have to allow *some* degree of disturbance
    - and regrettable, but not disaster, if get level some dB's wrong
- So permissible level depends on duration and frequency of occurrence → *probability factors*

Probability factors

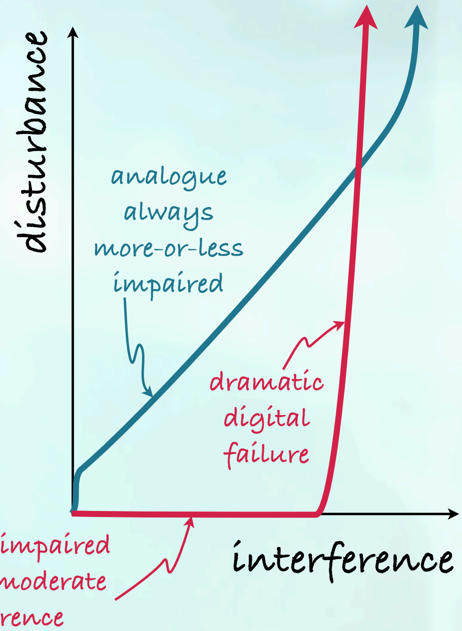
- Suppose a particular, potentially-interfering device
  - is only to be used intermittently
  - is unlikely to be widespread in use
  - is subject to production spread of its emission levels
  - has narrowband emissions, centred on random frequency
- then these probability factors can be taken into account in setting emissions limits
- A reasonable idea?
  - ***only while assumptions remain valid***

"the world only needs 5 computers..."

BBC

The digital difference (I)

- Analogue degrades gracefully
  - important part of the probability-factor approach
- Digital systems are different!
  - immune to interference
    - below a certain threshold level
  - then degrades rapidly
    - within few dB
  - finally fails completely
    - no sound or picture



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The digital difference (2)

- Impact of interference on digital reception depends on fine details, not just the interference level
  - continuous or intermittent interference
  - length & spacing of interference bursts
    - compared with interleaver lengths, frame structure
  - spectral character of interferer
    - broadband or narrowband in comparison with wanted signal
- A continuous interferer may be worse than an intermittent one of higher level

Interferers have changed too

- Not just electromechanical appliances…
- …now sophisticated electronics in 'everything'
  - internal clock oscillators
  - 'hash' from digital circuits
  - switched-mode power supplies
  - signal *intentionally* sent along wires
    - may also radiate
    - local connections: printers, USB, Ethernet …
    - distant connections: DSL, PLT…
  - widespread use
  - 24h/7d usage not unusual

How valid are the old assumptions now?

5 computers per ~~planet~~

Interferers have changed too

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How valid are the old assumptions now?

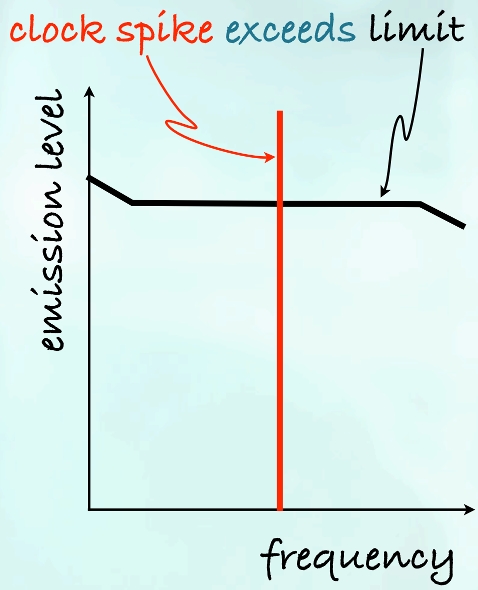
5 computers per home!

When regulation goes wrong

- Regulation can have unpleasant, unintended result
  - beyond failing to protect …
  - … it can actively make things worse!
- Arises when the method of measurement does not closely model the damage the interferer causes
  - diversity of radio-system types now too great
  - simple "one-size-fits-all" approach no longer adequate

Where we fail — example (I)

- Appliance has internal clock
  - emission likely to exceed limit



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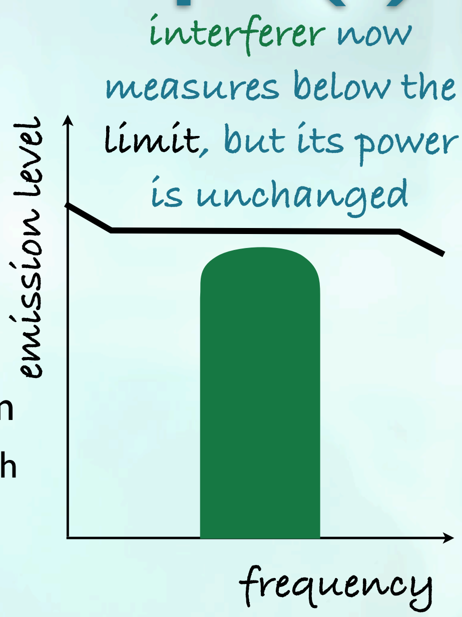
Where we fail — example (I)

- Appliance has internal clock
  - emission likely to exceed limit
- Manufacturer well-intentioned
  - wants to play by rules
  - adds jitter to spread the spectrum
    - wider than measurement bandwidth
    - now complies with limit



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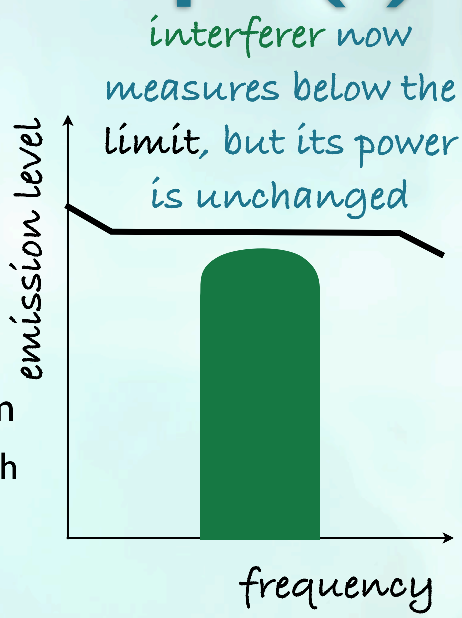
Where we fail — example (1)

- Appliance has internal clock
  - emission likely to exceed limit
- Manufacturer well-intentioned
  - wants to play by rules
  - adds jitter to spread the spectrum
    - wider than measurement bandwidth
    - now complies with limit
- So that's OK then?

Maybe not…



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Where we fail — example (2)

- **Measured value** of emission reduced
  - power unchanged
- Has impact on wanted radio service been reduced?
  - if radio service narrow-band, perhaps *yes*
  - if radio service wide-band, perhaps *no*
- Consider specific example of digital broadcast
  - DAB, DVB-T, DRM…
  - use **C**oded **O**rthogonal **F**requency-**D**ivision **M**ultiplexing

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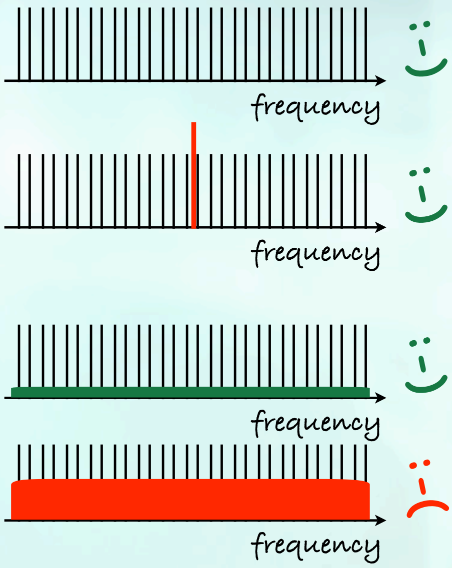
Where we fail — example (3)

- COFDM sends coded data distributed over many carriers
- Narrow-band interfererence
  - knocks out a carrier or two
  - little harm — errors correctable
- Wide-band interference
  - disturbs all carriers
  - much lower level tolerable



Where we fail — example (4)

- In our example (clock-related emissions)
  - 'spike' fell in band for digital broadcasting
  - 'spike' above limit, but negligibly harmed reception
  - manufacturer took steps to meet rules
    - **thereby causing much worse interference impact**
- Beware unintended consequences!
  - obeying the rules made result much worse
  - cost manufacturer trouble — **and no one benefited**

Conclusions (1)

- Radio systems require and are entitled to protection from interference
- Many types of broadcasting to protect
  - analogue/digital, narrow/wide band services
- 'Traditional' protection worked, but relied on
  - probability factors
  - graceful degradation of analogue
- Beware of solving wrong problem

Conclusions (2)

- New types of interferer and wanted radio signal
  - probability factors cannot be assumed unchanged
  - need to legislate for/measure real impact of interference
  - avoid nonsensical unintended consequences that
    - make interference impact worse
    - cost manufacturers effort to no benefit
- Need to ensure EMC legislation solves real problems
  - otherwise EMC activity is little more than a **Protection Racket!**

Thanks for listening!

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