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Potential Changes to Electromagnetic Environment - Outdoor Environment (copy 1 of 1)

Deliverable 2, Part 2 of 4

for

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York Electromagnetics

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1 OUTDOOR ENVIRONMENT

1.1 About this document

This report is one of a series of four documenting the investigation and analysis of potential changes to the electromagnetic environment implied by the findings of research funded by the Radiocommunications Agency. This report is concerned with the effects that specific "outdoor" technologies will have on the electromagnetic environment in a typical domestic or commercial setting. It is intended that the data presented in the report will be used by Quotient Associates Ltd for further analysis. Consequently no conclusions or recommendations are given by this report.

1.2 Introduction

Unlike the indoor environment [1], the analysis of the outdoor environment will be concerned with sources of interference in the outdoors. This section of the study considers scenarios in which the threat system is external, but the victim services are indoors. The victim services may have an indoor or outdoor antenna.

Due to the larger distances typically found between threat and victim systems, the study will focus on sources generating high levels of radiated noise, and/or victim systems sensitive to low levels of interference. Again, victim services include: broadcast radio throughout the frequency bands from LW to DAB; terrestrial and satellite television; and mobile telephony.

Sources of significant interference include electrically powered vehicles (cars, trains, trams), industrial uses of RF energy including microwave ovens and RF welding equipment, and radiation from telecommunication cabling and power lines, increasingly being used to carry high-bit rate communications signals (including xDSL).

Due to the levels of deployment possible, there is greatest concern over the increase in electrically powered vehicles, both on road and rail. These threats have been investigated in research funded by the Radiocommunications Agency in previous projects [2, 3, 4], and have the potential to affect the operation of radio systems for some distance from the threat source.

Blanchard and Whitehead [2] recommends extending the range of frequencies covered to include a series of spot frequencies above 1 GHz, Konefal *et al* [3] notes that the EN 50121 series of standards do not provide the same level of protection as CISPR 11 (EN 55011) and recommends that new measurement techniques be investigated and limits be reduced; and

Ruddle [4] recommends changes to the measurement technique to reflect the changes in powertrain technology.

The aim of this section of the study is to quantify the potential degradation in the electro-magnetic environment which will occur by placing electrically powered trains/trams (meeting an 'inadequate' standard) in close proximity to a residential, commercial or light industrial (RCLI) building. Without the previous RA-funded research, the lack of protection may not have been highlighted. Effectively, data are presented to enable the cost of not reducing the limits to be calculated, rather than the benefit of reducing them (as in the Indoor Environment study).

Two scenarios of particular concern have been selected for further analysis: a domestic or office environment close to an urban street which could 'see' an increase in electrically-powered vehicles in the near vicinity; and a domestic or office environment next to a mainline railway track.

1.3 Scenario Description

1.3.1 Home and Office Scenario 1 - Urban Railway

Objective: For a domestic or office victim environment, to generate data showing how:

- Radio and television broadcast services, and mobile services could be affected by a 750V DC train/tram passing by outside the house/office;

In all cases, the anticipated impact levels on the victim services will be determined using:

- the existing standards relevant to a domestic environment (note that CISPR 22 is the appropriate generic emissions standard for the RCLI environment, which has stricter emissions limits than CISPR 11 mentioned earlier),
- the current standards to which new trains/trams would be built.

Konefal *et al* [3] have already identified inadequacies in EN 50121. An ongoing project [5] is investigating improved test methods to enable separate limits to be specified for continuous, repetitive and transient emissions.

The *change* to be modelled is, for a given location, the change in reception going from one known state (the domestic environment, as protected by current standards) to a second known state (the environment *x* metres from either: a train/tram meeting EN 50121 or an electric vehicle[1]). Duty cycles for each EMI source will be estimated based on existing and proposed tram schemes[2].

1.3.2 Home and Office Scenario 2 - Mainline Train Track

Objective: For a domestic or office victim environment, generate data showing how:

- Radio broadcast services and mobile telecommunications services could be affected by the location of the home/office next to a mainline (25 kV) rail system.

The anticipated impact levels on the victim services will be determined using:

- the existing standards relevant to a (RCLI) environment,
- the current standards to which new trains/trams would be built.

1.3.3 Variables and Output

In both scenarios, the calculation of the received signal strength and interference powers will proceed in a similar way as for the indoor case.

Scenario Variables:

- Distance from environment to rails / street
- Distance from environment to broadcast transmitter / base station
- Radiated interference power P_n (dependent on standards)
- Number of noise sources N.

---

[1] Blanchard and Whitehead finds current standards for electric vehicles adequate.

[2] www.nottinghamexpresstransit.com states 4 to 20 trains per hour on each line (2 to 10 each way); www.gmpte.com states 8 to 20 trains per hour (4 to 10 each way).

Output: S/N ratio as a function of the above variables for each victim service.

- For broadcast services: percentage of the building within which the minimum protection ratio is not achieved.
- For mobile services: mean rise in wanted signal necessary to maintain the same level of signal quality in the home or office (for each of the home and office scenarios). This may vary according to the received signal level, but in practice we are only concerned with levels at the limit of coverage.

Tasks:

- List the services affected by each EMI source (these are the services that will be modelled).
- Describe and justify the emission levels assumed for each device with and without modification of standards resulting from research. Addressing the following questions:
  - What practical measures will manufacturers be required to take?
  - What is the approximate cost of these?
- Determine the minimum separation distances between each EMI source and victim receiver. Calculate impact on coverage in each home and office environment.

1.4 Specification

1.4.1 Victim Services

Table 1 presents key technical parameters for the radio services under consideration.

Service	Frequency	Minimum field strength (dBµV/m)	Co-channel protection ratio (dB)	Noise bandwidth
FM radio [6, 7]	87.5-108 MHz	60	45	100 kHz
DAB radio [8]	217.5-230 MHz	37	6.5	1.5 MHz
Analogue TV [7, 9]	470-590 MHz (Band IV) 598-854 MHz (Band V)	65 (Band IV) 70 (Band V)	50	5.5 MHz
DVB-T [7]	470-590 MHz (Band IV) 598-854 MHz (Band V)	56 (Band IV) 60 (Band V)	4	8 MHz
Mobile [7, 10]	880-915 MHz, 925-960 MHz (GSM-900)	34.3	9	200 kHz

Table 1 - Parameters of key broadcast and telecommunications services.

The protection ratios in Table 1 are for co-channel interference, ie the protection of one signal (eg an FM broadcast) from another signal of the same type (another, weaker, FM broadcast). Where signal/noise ratios are available, these have been used instead. Pearce *et al* [11] finds that DVB-T is very susceptible to wideband noise - a protection ratio of 20dB may be appropriate.

The generic emissions standard for Residential, Commercial and Light Industrial (RCLI) environments is EN 61000-6-3 [12] (formerly EN 50081-1). For radiated emissions between 30 MHz and 1 GHz, this specifies that products must meet the Class B limits of CISPR 22 (EN 55022) [13], the standard for Information Technology Equipment. Thus CISPR 22 is the standard which protects all of the services in Table 1 within the home and office environments.

The signal strength received at an antenna depends on the power of the transmitter and on the distance of the antenna from the transmitter - moving closer to a transmitter will generally increase the received signal strength.

1.4.2 Sources of EMI

The sources of EMI under consideration are trains and trams. The series of standards EN 50121:2000 [14] describe the ‘EMC of Railway Applications’. This series has been adopted by CENELEC but its number has not been published in the OJEC and thus is not a harmonised standard. EN 50121-2 places limits on the emissions which should be seen at the railway boundary. The limits "benchmark" what is currently attained by the railway infrastructure and rolling stock, based on actual levels measured at railway locations across Europe, but including a margin for measurement uncertainty and statistical variation of sites. There is concern that the emission levels and measurement techniques do not adequately protect radio services since the standards do not distinguish between continuous, repetitive and transient emissions. The limit levels themselves are much higher than those specified in CISPR 11 (for Industrial, Scientific and Medical equipment), even allowing for the difference in measurement technique (see below). Figure 1 presents a comparison of the limits:

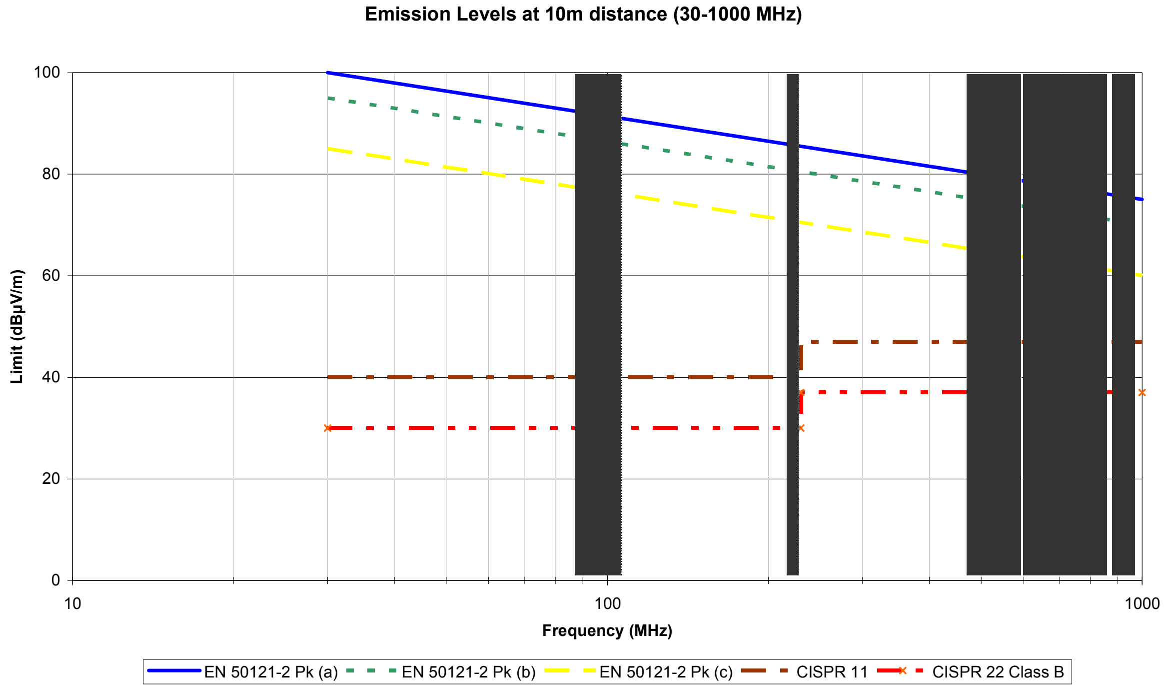

Figure 1 - A comparison of the emission limits between 30 and 1000 MHz set in EN 50121-2 for (a) 25kV AC rail systems, (b) 15kV AC and 3kV DC rail systems and (c) 750V DC rail systems, with CISPR 11 (Industrial environment) and CISPR 22 Class B (RCLI environment). Shaded bands indicate victim service frequencies.

The EN 50121-2 limits are specified for peak measurements and not the more usual quasi-peak measurement specified in CISPR 11 and CISPR 22. A quasi-peak measurement is time-averaged to correct for the interfering signal's occupancy of the measurement band, providing an assessment of the "annoyance" factor caused to a radio listener. However, quasi-peak measurements take too long to complete when measuring fast-moving trains - hence the specification of peak measurements. In the comparison of limits, Konefal *et al* notes the complexity in converting from peak to quasi-peak levels - a margin of 20 dB is noted as “generous” and this margin will be used in this report as a conversion. However, there is nothing in EN 50121-2 to prevent a train from emitting continuous emissions at the peak level.

Scenario 1 involves an urban tram/light railway system. Table 2 presents the emission levels allowed at 10m for various frequencies.

Frequency	EN 50121-2 (750VDC) peak limit	CISPR 22 Class B quasi-peak limit
100 MHz (FM)	76.4 (75.9 - 77.3)	30
220 MHz (DAB)	70.8 (70.5 - 70.9)	30
530 MHz (Band IV)	64.5 (63.8 - 65.4)	37
730 MHz (Band V)	62.2 (61.1 - 63.7)	37
920 MHz (GSM 900)	60.6 (60.3 - 60.6, 60.6 - 60.9)	37

Table 2 - Emission level limits at various spot frequencies (figures in brackets are limits at the edges of the listed victim service frequency bands).

Scenario 2 involves a mainline 25 kV AC railway. Table 3 presents the emission levels allowed at 10m for various frequencies.

Frequency	EN 50121-2 (25kVAC) peak limit	CISPR 22 Class B quasi-peak limit
100 MHz (FM)	91.4 (90.9 - 92.3)	30
220 MHz (DAB)	85.8 (85.5 - 85.9)	30
530 MHz (Band IV)	79.5 (78.8 - 80.4)	37
730 MHz (Band V)	77.2 (76.1 - 78.7)	37
920 MHz (GSM 900)	75.6 (75.3 - 75.6, 75.6 - 75.9)	37

Table 3 - Emission level limits at various spot frequencies (figures in brackets are limits at the edges of the listed victim service frequency bands).

EN50121-2 states conversion values for measurements made at non-standard distances which are frequency-dependent. The frequency dependency indicates that noise from the train will be attenuated more at lower frequencies compared to free-space propagation. The propagation loss increases to 24 dB/decade below 110 MHz; to 33 dB/decade below 1.6 MHz and to 36 dB/decade from 400 kHz down to 150 kHz. These values will be used in the analysis.

Above 1 GHz, in common with most current EMC standards, no limits are specified. Currently, however, the traction package (the main noise source) is unlikely to produce significant interference above several hundred MHz, although traction package frequencies may increase in the future. While digital electronic hardware capable of emitting significant EMI above 1 GHz may be introduced onto a train, it is probable that such equipment will be similar to hardware available for a generic Industrial environment. Apparatus intended for use onboard rolling stock is covered by EN 50121-3-2 which, for radiated emissions, refers to EN 55011 (CISPR 11). These industrial emission limits are relaxed by 10 dB compared to the generic RCLI limits of CISPR 22. The increased distance between train and house/office and the attenuation provided by the train body and building wall are enough in this instance to reduce the emissions seen inside the house/office to below the levels produced by equipment inside the building meeting RCLI limits. Therefore the presence of a rail system in close proximity to domestic and commercial buildings is unlikely to further degrade the internal EM environment above 1 GHz.

1.4.3 Typical Environments

Modern tram systems are increasingly being routed in close proximity to domestic and commercial dwellings - as close as 5m from the exterior walls of houses, and down to 3m from shop fronts in city centres. Figure 2 shows a tramline in Nottingham.

Figure 2 - An urban tramline running close to houses. © Nottingham Express Transit [15]

Although the trams can travel quickly when off-road (up to 50 mph / 22 m/s) they travel much more slowly when on streets or in pedestrianised areas - the average speed of a Nottingham Express Transit (NET) tram is 14.3 mph (6.4 m/s) [16]. Physical tram dimensions are around 30-40m long, 2-3m wide and 3-4m high (NET trams are 33m long, 2.5m wide and 3.35m high).

Analysis within the house will take place at various tramline-house distances (variable *d* in Figure 3 and Figure 4). For ease of modelling, both floors are laid out identically, including the siting of three devices per floor within each frequency band which just meet CISPR 22 Class B limits. These devices are placed 0.7m above floor level and the contour plots presented are at this height. Note that the noise from these devices does not perturb the external antennas due to the increased distances and the attenuation of external walls.

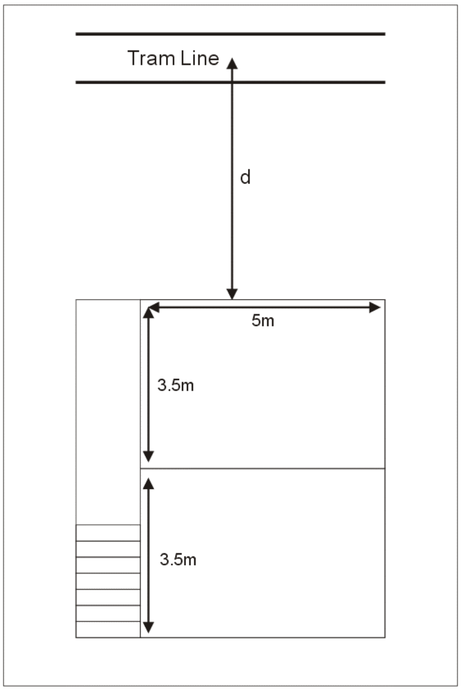

Figure 3 - Plan view of the Scenario 1 model. The hallway is not used in calculating the volume of the house affected.

The effect on a roof mounted antenna, 10m above ground level, will also be analysed.

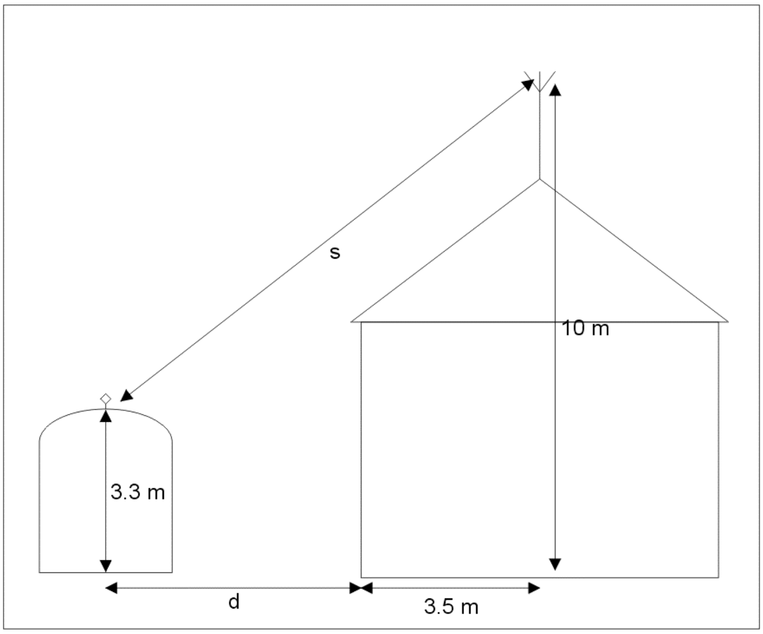

Figure 4 - Side view of the Scenario 1 model, including distances relating to the tram and antenna.

The second scenario concerns the siting of domestic or commercial property close to a mainline railway system. Increasingly, residential and commercial properties are being sited on land in close proximity to railways. The average speed of an Intercity train is 64.5 mph (28.7 m/s) [17]. The length is estimated as 150m (given a typical railcar length of 18-20m and typical train length of 7-9 cars).

The model of an office building is shown in Figure 5 and Figure 6; it is a single floor building and also has a roof mounted antenna 10m above ground level. Four devices within each frequency band which just meet CISPR 22 Class B are placed in this larger model. Again, the devices are sited 0.7m above floor level and the contour plots presented are at this height. The noise from these devices does not perturb the external antennas due to the increased distances and the attenuation of external walls.

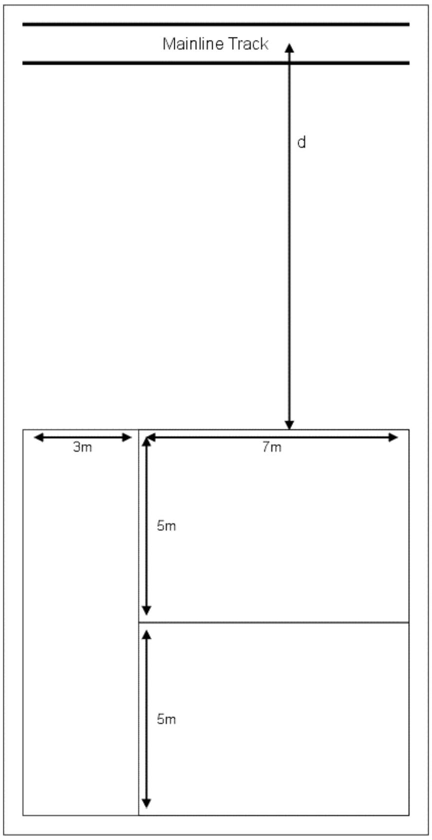

Figure 5 - Plan view of the Scenario 2 model.

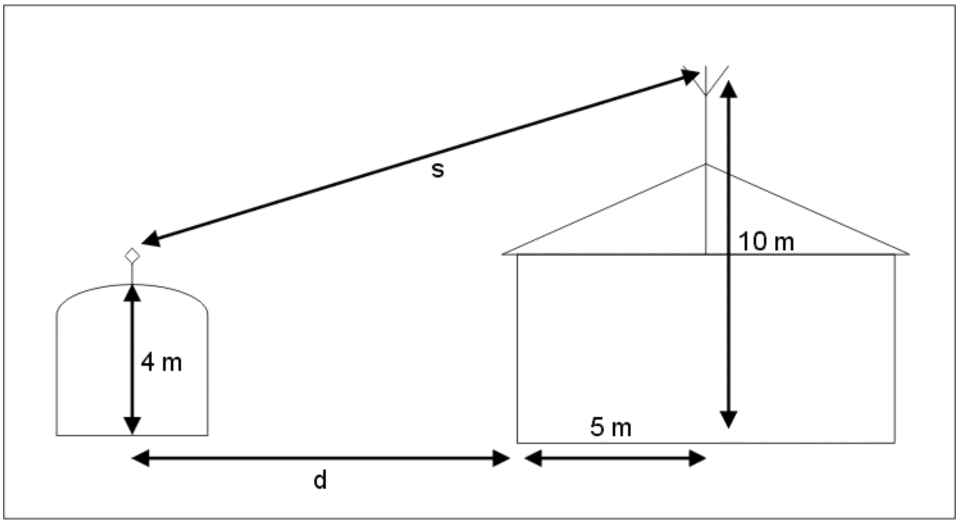

Figure 6 - Side view of the Scenario 2 model, including distances relating to the train and antenna.

Although the buildings are labelled as a ‘house’ and ‘office’, respectively, their layout is quite generic and results from either scenario are applicable to either residential or commercial buildings.

1.5 Modelling

1.5.1 Assumptions

Firstly it is assumed that the victims are in the far-field with respect to the noise sources. As an EM wave propagates from its source, energy is exchanged between the E and H fields until the far-field ratio (E/H = 377 Ω) is reached; this takes a few wavelengths to happen. As the radiating mechanism for the noise sources is not known (ie whether they emit predominantly E fields from antenna-like structures or H fields from current loops) the E/H ratio in the near-field is also not known; this is a larger problem for lower frequencies. EMC standards allow measurements to be taken 3m from a device under test at frequencies down to 30 MHz, which are assumed to be far-field measurements. Given the increased source-to-victim distances in this model (compared to the Indoor models), the assumption that the victims are in the far-field therefore has a high degree of validity.

Secondly, it is assumed that building walls attenuate EM energy by a factor which is constant over the frequencies considered; these factors are 10 dB for external walls (as suggested by EN 55011) and 5 dB for internal walls.

Thirdly, it is assumed that the permitted levels extend cocoon-like around each train; this allows for a simplification of geometry in the model to a quasi-1D problem which may appear to over-estimate the levels some distance away from the train. However, the coupling of EMI into the rails and *catenary* (overhead power line) is not accounted for and overall the net effect of the simplifications is likely to be neutral or slightly optimistic.

The decay of field strength with distance is assumed to be free-space above 110 MHz. Below 110 MHz the decay is assumed to follow the values presented in EN50121-2.

For Scenario 1, it is assumed that equal levels of noise affect both floors - the height of the train compared to the house allows this simplification to be valid. Although the centroid of the tram is further from the upper floor, the difference in values is negligible.

A small number of electrical devices (three in the Scenario 1 model, four in the larger Scenario 2 model) are assumed to be noisy (ie just meeting CISPR 22 Class B) in each frequency band; for ease of modelling the noisy devices are assumed to be sited at the same position for each frequency band.

FM and DAB antennas are assumed to be omni-directional. External and internal TV antennas are assumed to have a 10 dB rejection of off-axis EMI.

It is assumed that a 20 dB reduction to the peak values permitted by EN 50121-2 gives a more realistic profile of the potential for interference to the radio services under consideration. This estimation of quasi-peak levels will be compared with the required signal levels in Table 1 to gauge the impact of a railway on radio services in the surrounding environment.

1.5.2 Scenario 1 Results - Urban Tram/Light Railway

1.5.2.1 Interference to FM Radio

Figure 7 presents the EM noise contours permitted at 100 MHz by EN 50121-2 for a 750V DC rail system within a house sited 5m from the track. Figure 8 presents the EM noise contours permitted between 30 MHz and 230 MHz for three devices (positioned at the black circles) meeting CISPR 22 Class B.

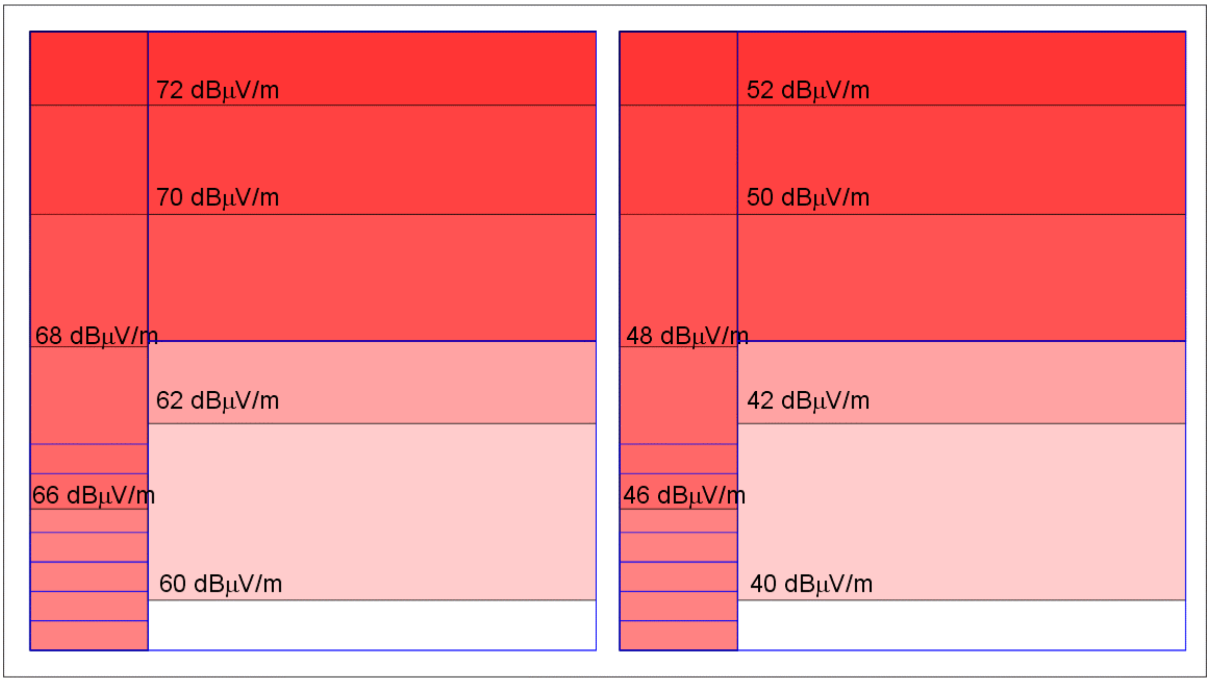

Figure 7 - Levels permitted at 100 MHz by EN 50121-2, rails 5m from the house. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

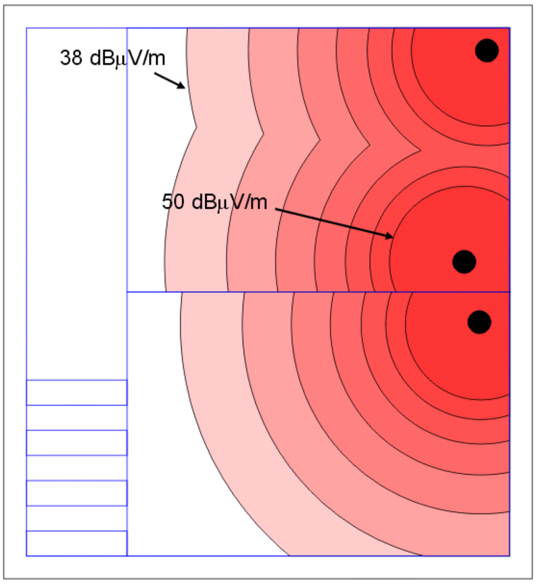

Figure 8 - Emission levels permitted between 30 and 230 MHz from three devices meeting CISPR 22 (EN 55022) Class B. The contours are 2 dB steps.

Table 4 presents the percentage of the house volume which is unable to receive FM broadcasts on a receiver with an indoor antenna for four tram-house separations (assuming a 20 dB correction to obtain quasi-peak levels as noted in section 1.4.2) and for noise emitted from the configuration of domestic devices in Figure 8, as a function of the FM signal strength present externally.

FM Signal Strength Present Externally (dBµV/m)	**Volume of house blocked (%)**				
	Tramline-house separation				**Interference from internally located devices**
	5m	**10m**	**15m**	**30m**	
60	100	100	100	100	100
…	…	…	…	…	…
82	100	100	100	100	100
83	100	100	100	50	100
84	100	100	100	50	100
85	100	100	100	50	100
86	100	100	100	0	100
87	100	100	100	0	100
88	100	100	100	0	100
89	100	100	76	0	100
90	100	100	50	0	97
91	100	97	50	0	92
92	100	75	50	0	85
93	100	55	50	0	80
94	100	50	50	0	71
95	92	50	50	0	61
96	77	50	26	0	52
97	63	50	0	0	45
98	51	50	0	0	36
99	50	37	0	0	30
100	50	20	0	0	24
101	50	6	0	0	19
102	50	0	0	0	14
103	50	0	0	0	10
104	40	0	0	0	8
105	30	0	0	0	6
106	20	0	0	0	4
107	12	0	0	0	3
108	4	0	0	0	1
109	0	0	0	0	<1

Table 4 - Volume of house unable to receive FM broadcasts due to a tram emitting 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 50% are due to the internal wall.

Table 5 presents the level of EMI seen at a roof mounted antenna for various tram-house separations and includes the straight-line tram-antenna separations *s* which arise from the geometry noted in Figure 4. Recall from section 1.4.1 that the minimum broadcast field strength for FM coverage is 60 dBμV/m and that FM needs a signal to disturbance noise ratio of 45 dB. This means that for no impairment of FM reception to occur at the coverage boundary, not more than 15 dBμV/m of noise should be received at the roof mounted antenna.

Tram-House Distance *d* (m)	**Tram-Antenna Distance *s* (m)**	**Peak level of interference at antenna (dBμV/m)**	**Estimated quasi-peak level of interference at antenna (dBμV/m)**
5	10.8	75.6	55.6
10	15.1	72.1	52.1
15	19.7	69.3	49.3
30	34.2	63.6	43.6
50	53.9	58.8	38.8
100	104	52.0	32.0

Table 5 - Levels permitted by EN 50121-2 at 100 MHz at an external antenna (calculation includes propagation loss of 24dB/decade).

Following from Table 5, the tram-to-antenna distance required to receive a useable FM signal can be calculated as a function of the received FM signal strength. The period of disruption is the length of time that a tram travelling at its average speed will spend closer than the minimum tram-antenna distance. The duty cycle for disruptions assumes a uniform flow of 10 trams per hour each way, or one tram every 180 seconds.

Table 6 shows the times and distances in the permitted (but less likely) event that a tram is continuously emitting at the peak levels allowed. Table 7 shows times and distances when applying the 20 dB correction to estimate quasi-peak levels.

Received FM signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trams/hr each way (%)
60	3620	1140	100
65	2240	710	100
70	1390	441	100
75	858	275	100
80	531	172	96
85	329	109	60
90	203	69	38
95	126	45	25
100	77.9	29	16
105	48.2	20	11
110	29.9	14	7.7
115	18.5	9.9	5.5
120	11.4	6.4	3.5

Table 6 - Minimum separation distances and corresponding periods of disruption for a tram emitting continuously at the EN 50121-2 levels.

Received FM signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trams/hr each way (%)
60	531	172	96
65	329	109	60
70	203	69	38
75	126	45	25
80	78	29	16
85	48.2	20	11
90	29.9	14	8
95	18.5	10	5.5
100	11.4	6	3.5

Table 7 - Minimum separation distances and corresponding periods of disruption for a tram emitting continuously 20 dB below the EN 50121-2 levels.

1.5.2.2 Interference to DAB Radio

Figure 9 presents the EM noise contours permitted at 220 MHz by EN 50121-2 for a 750V DC rail system within a house sited 5m from the track.

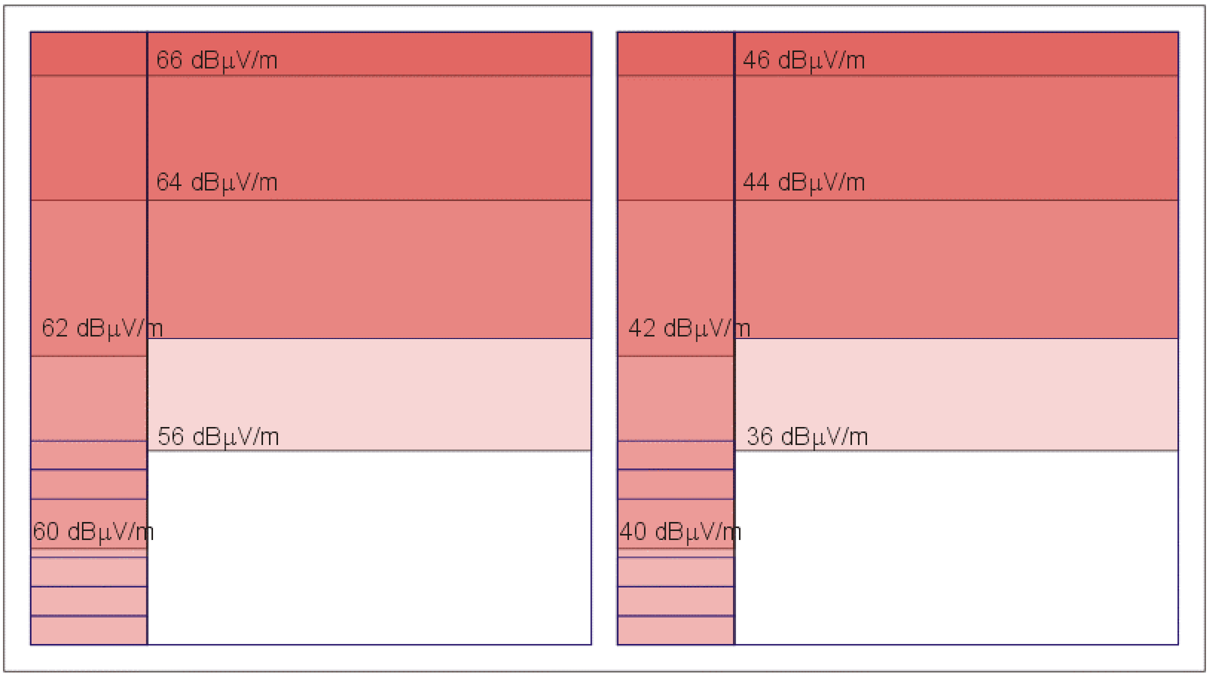

Figure 9 - Levels permitted at 220 MHz by EN 50121-2, rails 5m from the house. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

DAB radio broadcasts are much more robust than FM radio broadcasts and require a 6.5 dB protection ratio. Table 8 presents the volume of the house unable to receive DAB broadcasts on a receiver with an indoor antenna for two tram-house separations as a function of DAB signal strength present externally.

DAB Signal Strength Present Externally (dBµV/m)	**Volume of house unable to receive DAB broadcasts (%)**		
	5m	**10m**	**Interference from internally located devices**
37	100	100	100
…	…	…	…
47	100	100	100
48	100	92	100
49	100	66	100
50	100	50	100
51	95	50	99
52	76	50	95
53	60	50	89
54	50	50	83
55	50	43	76
56	50	0	66
57	50	0	57
58	50	0	49
59	46	0	41
60	33	0	33
61	22	0	27
62	12	0	22
63	3	0	17
64	0	0	12

Table 8 - Volume of house unable to receive DAB broadcasts due to a tram emitting noise 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 50% are due to the internal wall.

Table 9 presents the level of EMI seen at a roof mounted antenna for various tram-house separations and includes the straight-line tram-antenna separations which arise from the geometry noted in Figure 4. Recall from section 1.4.1 that the minimum broadcast field strength for DAB coverage is 37 dBµV/m and that DAB has a protection ratio of 6.5 dB. This means that for no impairment of DAB reception to occur at the coverage boundary, not more than 30.5 dBµV/m of noise should be received at the roof mounted antenna.

Tram-House Distance *d* (m)	Tram-Antenna Distance *s* (m)	Peak level of interference at antenna (dBµV/m)	Estimated quasi-peak level of interference at antenna (dBµV/m)
5	10.8	69.9	49.9
10	15.1	67.0	47.0
15	19.7	64.7	44.7
30	34.2	59.9	39.9
50	53.9	56.0	36.0
100	104	50.3	30.3

Table 9 - Levels permitted by EN 50121-2 at 220 MHz at an external antenna.

The tram-to-antenna distance required to receive a useable DAB signal can be calculated as a function of the received DAB signal strength and the period of disruption can be estimated. Table 10 and Table 11 present minimum tram-antenna separation and period of disruption as a function of received signal strength at the antenna.

Received DAB signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trams/hr each way (%)
37	1040	331	100
40	733	236	100
44	462	151	84
48	292	97	54
52	184	63	35
56	116	42	23
60	73.3	28	16
64	46.2	19	11
68	29.2	14	7.6
72	18.4	9.9	5.5
76	11.6	6.5	3.6
80	7.3	0	0

Table 10 - Minimum separation distances and corresponding periods of disruption for a tram emitting continuously at the EN 50121-2 levels.

Received DAB signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trams/hr each way (%)
37	104	38	21
40	73.3	28	16
44	46.2	19	11
48	29.2	14	7.6
52	18.4	9.9	5.5
56	11.6	6.5	3.6
60	7.3	0	0

Table 11 - Minimum separation distances and corresponding periods of disruption for a tram emitting continuously 20 dB below the EN 50121-2 levels.

1.5.2.3 Interference to Band IV DVB-T Reception

Figure 10 presents the EM noise contours permitted at 530 MHz by EN 50121-2 for a 750V DC rail system within a house sited 5m from the track.

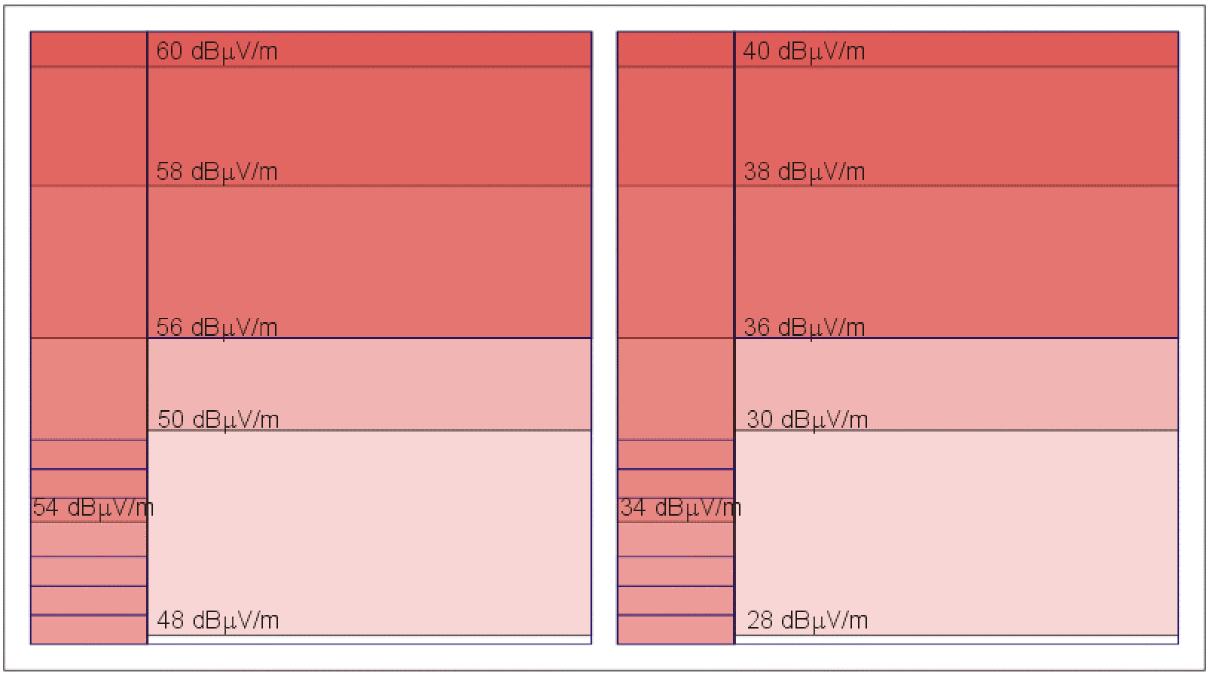

Figure 10 - Levels permitted at 530 MHz by EN 50121-2, rails 5m from the house. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

Figure 11 presents the EM noise contours permitted between 230 MHz and 1 GHz for three devices (positioned at the black circles) meeting CISPR 22 Class B.

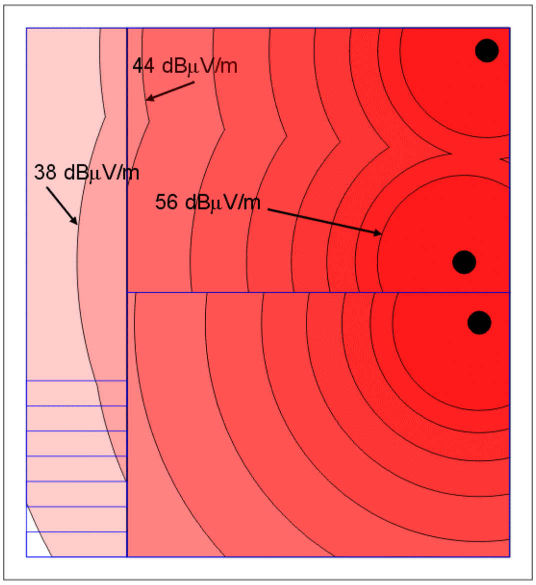

Figure 11 - Emission levels permitted between 230 MHz and 1 GHz from three devices meeting CISPR 22 (EN 55022) Class B. The contours are 2 dB steps.

It can be seen that, assuming the tram is emitting at a quasi-peak level 20 dB below the peak level in EN 50121-2, it introduces much less electromagnetic noise into the home than the three devices just meeting CISPR 22 limits. Table 12 presents the volume of the house unable to receive DVB-T broadcasts on a receiver with an indoor antenna as a function of the DVB-T signal strength present externally.

DVB-T Signal Strength Present Externally (dBµV/m)	Volume of house unable to receive DVB-T broadcasts (%)	
	Tramline-house separation	Interference from internally located devices
	5m	
56	49	100
58	24	100
60	4.4	100
62	0	99
64	0	85
66	0	65
68	0	45
70	0	30

Table 12 - Volume of house unable to receive DVB-T broadcasts due to a tram emitting 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations.

Table 13 presents the level of EMI seen at a roof mounted antenna for various tram-house separations and includes the straight-line tram-antenna separations which arise from the geometry noted in Figure 4. Recall from section 1.4.1 that the minimum broadcast field strength for Band IV DVB-T coverage is 56 dBµV/m and that a signal to disturbance noise ratio of 20 dB is required. If it is assumed that the antenna is directional (as is common for TV antennas) and there is a 10 dB attenuation away from the antenna axis, then for no impairment of DVB-T reception to occur at the coverage boundary, not more than 46 dBµV/m of noise should be received at the roof mounted antenna.

Tram-House Distance *d* (m)	Tram-Antenna Distance *s* (m)	Peak level of interference at antenna (dBµV/m)	Estimated quasi-peak level of interference at antenna (dBµV/m)
5	10.8	63.8	43.8
10	15.1	60.9	40.9
15	19.7	58.6	38.6
30	34.2	53.8	33.8
50	53.9	49.9	29.9
100	104	44.2	24.2

Table 13 - Levels permitted by EN 50121-2 at 530 MHz at an external antenna.

It can be seen that the estimated quasi-peak level at the antenna would be insufficient to disrupt DVB-T reception, even at the closest separation of 10.8m. However, in the event that a train emits continuously at the level permitted by EN 50121-2, the peak level of interference at the antenna would disrupt DVB-T reception at an 84m separation at the boundary of DVB-T coverage. Table 14 presents the minimum separation and period of disruption as a function of received signal strength for a tram emitting continuously at the EN50121-2 limits.

Received DVB-T signal strength at the external antenna (dBµV/m)	**Minimum tram-antenna distance *s* (m)**	**Period of disruption for each tram passage (s)**	**Disruption duty cycle @ 10 trams/hr each way (%)**
56	84	31	17
58	67	26	14
60	53	22	12
62	42	18	10
64	33	15	8
66	26.6	13	7
68	21.1	11	6
70	16.8	9.2	5.1
72	13.3	7.6	4.2
74	10.6	0	0

Table 14 - Minimum separation distances and corresponding periods of disruption for a tram continuously emitting at the EN 50121-2 levels. The antenna has a 10 dB off-axis rejection.

1.5.2.4 Interference to Band IV Analogue TV

Analogue TV is transmitted in the same bands as DVB-T. Therefore, the permitted noise contours shown in Figure 10 are also relevant to analogue TV. Given a minimum broadcast field strength of 65 dBµV/m, a 50 dB protection ratio and an antenna with a 10 dB off-axis rejection, for no impairment to occur at the boundary of coverage, not more than 25 dBµV/m of noise should be present at the television antenna (assuming the noise source is not sited in line with the antenna).

Table 15 presents the percentage of the house volume which is unable to receive analogue TV broadcasts on a receiver with an indoor antenna for three tram-house separations (assuming a 20 dB correction to obtain quasi-peak levels) and for the configuration of domestic devices in Figure 8 as a function of the analogue TV signal strength present externally.

Analogue TV Signal Strength Received Externally (dBµV/m)	**Volume of house unable to receive Analogue TV broadcasts (%)**			
	Tramline-house separation			**Interference from internally located devices**
	5m	**10m**	**15m**	
65	100	100	100	100
…	…	…	…	…
72	100	100	100	100
74	100	100	55	100
76	100	71	50	100
78	98	50	50	100
80	63	50	26	100
82	50	48	0	100
84	50	8.5	0	100
86	49	0	0	100
88	24	0	0	100
90	4.4	0	0	100
92	0	0	0	99
94	0	0	0	85
96	0	0	0	65
98	0	0	0	45
100	0	0	0	30

Table 15 - Volume of house unable to receive Analogue TV broadcasts due to a tram emitting 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 50% are due to the internal wall.

The levels of EMI seen at a roof mounted antenna presented in Table 13 are also relevant to analogue TV. If it is assumed that the antenna is directional (as is common for TV antennas) and there is a 10 dB attenuation away from the antenna axis, then analogue TV reception is protected at the boundary of coverage at a 94m separation. Table 16 and Table 17 present the minimum separation and period of disruption as a function of received signal strength for trams emitting at and 20 dB below the EN50121-2 limits.

Received Analogue TV signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trains/hr each way (%)
65	944	302	100
68	668	215	100
72	422	138	76.6
76	266	88.9	49.4
80	168	57.9	32.2
84	106	38.4	21.3
88	66.8	25.9	14.4
92	42.2	18.0	10.0
96	26.6	12.8	7.1
100	16.8	9.2	5.1
104	10.6	0	0

Table 16 - Minimum separation distances and corresponding periods of disruption for a tram continuously emitting at the EN 50121-2 levels. The antenna has a 10 dB off-axis rejection.

Received Analogue TV signal strength at the external antenna (dBµV/m)	Minimum tram-antenna distance *s* (m)	Period of disruption for each tram passage (s)	Disruption duty cycle @ 10 trains/hr each way (%)
65	94.4	34.7	19.3
66	84.1	31.4	17.5
68	66.8	25.9	14.4
70	53.1	21.5	12.0
72	42.2	18.0	10.0
74	33.5	15.2	8.4
76	26.6	12.8	7.1
78	21.1	10.9	6.1
80	16.8	9.2	5.1
82	13.3	7.6	4.2
84	10.6	0	0

Table 17 - Minimum separation distances and corresponding periods of disruption for a tram continuously emitting 20 dB below the EN 50121-2 levels. The antenna has a 10 dB off-axis rejection.

1.5.2.5 Interference to GSM-900

Figure 12 presents the EM noise contours permitted at 920 MHz by EN 50121-2 for a 750V DC rail system within a house sited 5m from the track.

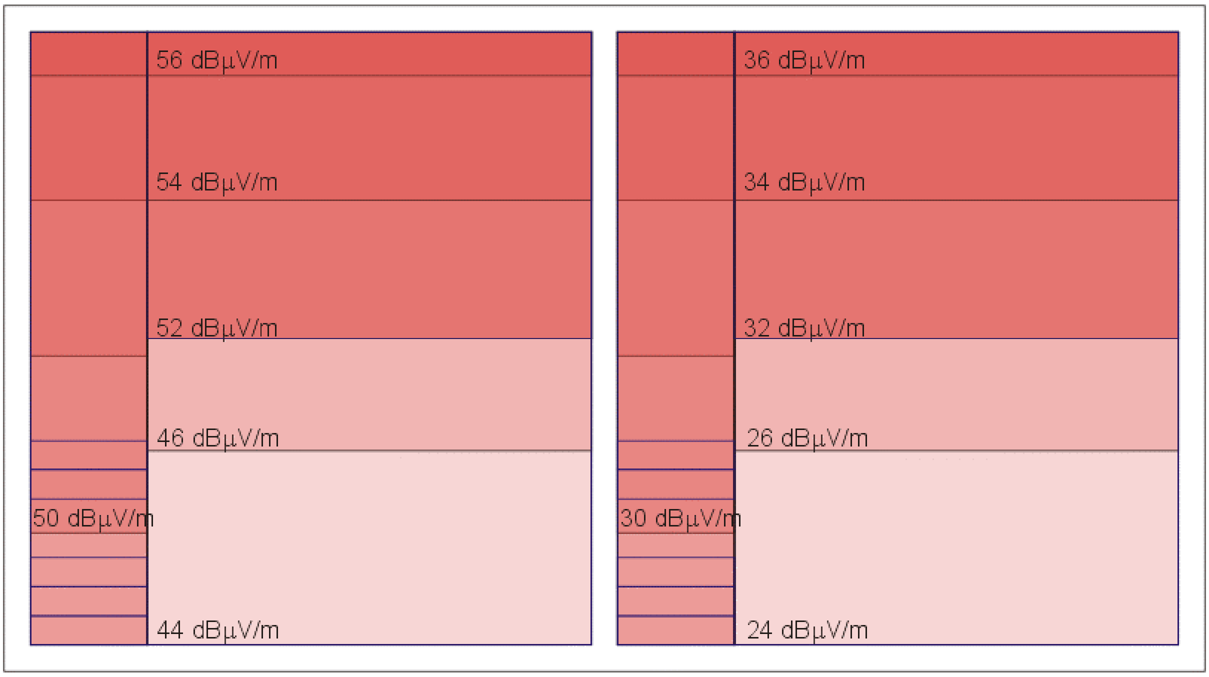

Figure 12 - Levels permitted at 920 MHz by EN 50121-2, rails 5m from the house. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

Figure 11, shown earlier, presents the EM noise contours permitted between 230 MHz and 1 GHz for three devices (positioned at the black circles) meeting CISPR 22 Class B.

The peak (not estimated quasi-peak) levels allowed at 920 MHz by EN 50121-2 allow a level of noise comparable to that seen from the three modelled devices just meeting CISPR 22 Class B. Table 18 presents the cumulative volume of the home experiencing various field strengths for both estimated quasi-peak values and peak values allowed by EN50121-2, compared to the field strengths from three devices just meeting CISPR 22 Class B.

Noise Field Strength (dBµV/m)	**Cumulative volume of house (%)**				
	Tram-house separation				**Interference from internally located devices**
	5m	**5m**	**10m**	**15m**	
	Est. Quasi-Peak	**Peak**	**Peak**	**Peak**	
56	0	5	0	0	6
54	0	25	0	0	10
52	0	50	0	0	15
50	0	50	10	0	30
48	0	50	50	0	45
46	0	65	50	28	65
44	0	100	50	50	85
42	0	100	73	50	99
40	0	100	100	58	100
38	0	100	100	100	100
36	5	100	100	100	100

Table 18 - Noise field strength levels inside the house due to a tram at various distances from the house (using both estimated quasi-peak and peak levels) compared with 3 electrical devices just meeting CISPR 22 Class B.

1.5.3 Scenario 2 Results - Mainline Railway

1.5.3.1 Interference to FM Radio

Figure 13 presents the EM noise contours permitted at 100 MHz by EN 50121-2 for a 25kV AC rail system within an office sited 10m from the track.

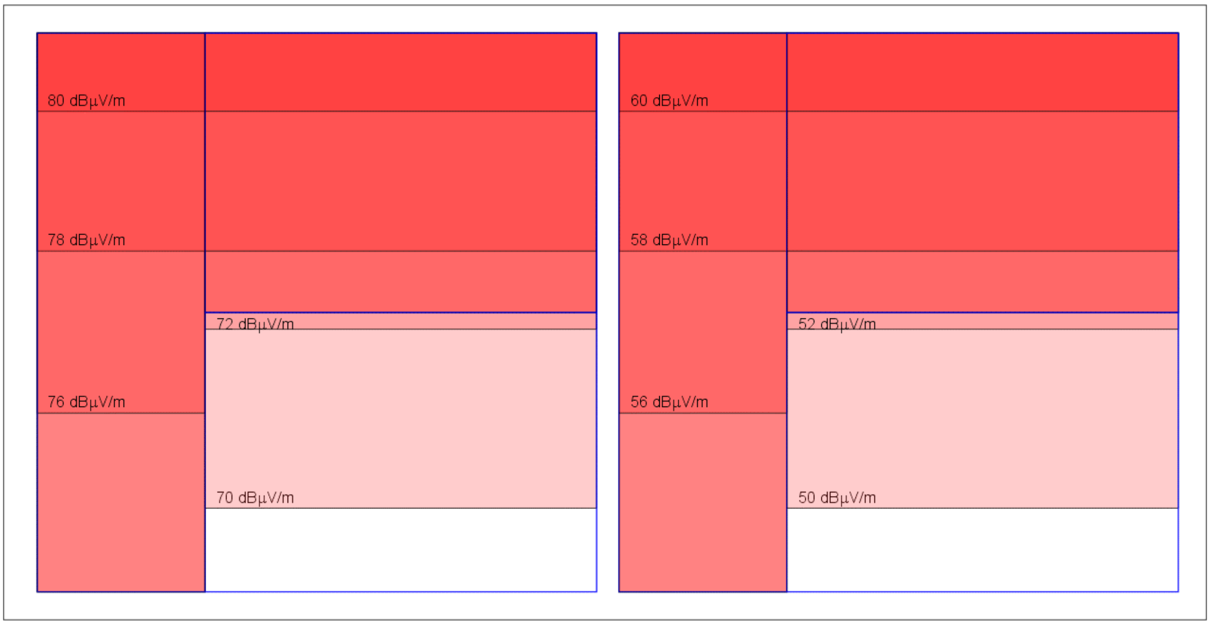

Figure 13 - Levels permitted at 100 MHz by EN 50121-2, rails 10m from the office. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

Figure 14 presents the EM noise contours permitted between 30 MHz and 230 MHz for four devices (positioned at the black circles) meeting CISPR 22 Class B.

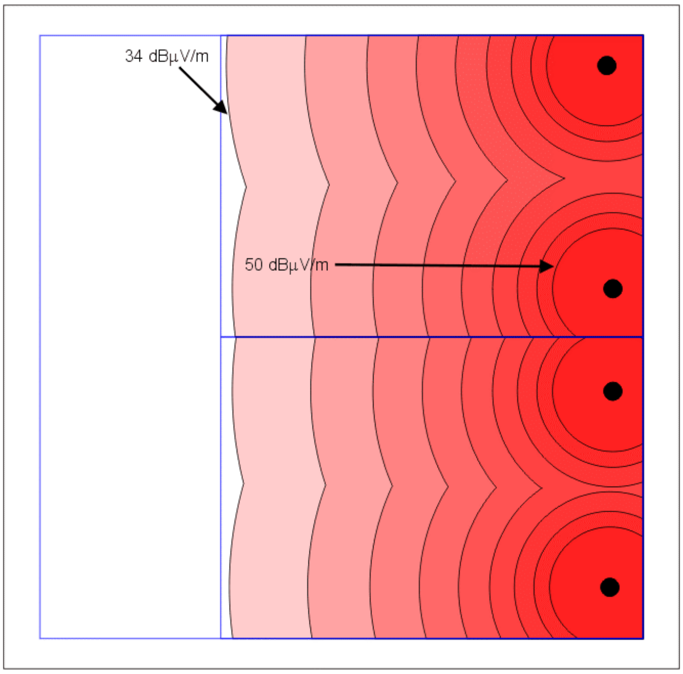

Figure 14 - Emission levels permitted between 30 and 230 MHz from four devices meeting CISPR 22 (EN 55022) Class B. The contours are 2 dB steps.

Table 19 presents the percentage of the office volume which is unable to receive FM broadcasts on a receiver with an indoor antenna for five train-office separations (assuming a 20 dB correction to obtain quasi-peak levels) and for the configuration of devices in Figure 14 as a function of the FM signal strength present externally.

FM Signal Strength Present Externally (dBµV/m)	**Volume of office blocked (%)**					
	Train-office separation					**Interference from internally located devices**
	10m	**20m**	**30m**	**50m**	**100m**	
60	100	100	100	100	100	100
…	…	…	…	…	…	…
80	100	100	100	100	100	100
82	100	100	100	100	100	82
84	100	100	100	100	100	70
86	100	100	100	100	100	70
88	100	100	100	100	65	70
90	100	100	100	100	65	59
92	100	100	100	100	39	47
94	100	100	100	65	0	36
96	100	100	100	65	0	27
98	100	100	73	60	0	17
100	100	99	65	0	0	8
102	100	65	64	0	0	4
104	100	65	29	0	0	2
106	78	56	0	0	0	< 1
108	65	24	0	0	0	< 1
110	61	0	0	0	0	< 1
112	51	0	0	0	0	< 1
114	26	0	0	0	0	< 1
116	4	0	0	0	0	< 1
118	0	0	0	0	0	< 1

Table 19 - Volume of office unable to receive FM broadcasts due to a train emitting 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 65% are due to the internal wall.

Table 20 presents the level of EMI seen at a roof mounted antenna for various train-office separations and includes the straight-line train-antenna separations which arise from the geometry noted in Figure 6. Recall from section 1.5.2.1 that for no impairment of FM reception to occur at the coverage boundary, not more than 15 dBμV/m of noise should be received at the roof mounted antenna.

Train-Office Distance *d* (m)	**Train-Antenna Distance *s* (m)**	**Peak level of interference at antenna (dBμV/m)**	**Estimated quasi-peak level of interference at antenna (dBμV/m)**
10	16.2	86.4	66.4
30	35.5	78.2	58.2
50	55.3	73.6	53.6
100	105	66.9	46.9
300	305	55.8	35.8
500	505	50.5	30.5
1000	1005	43.3	23.3

Table 20 - Levels permitted by EN 50121-2 at 100 MHz at an external antenna.

Following from Table 20, the train-to-antenna distance required to receive a useable FM signal can be calculated as a function of the received FM signal strength. The period of disruption is the length of time that a train travelling at its average speed will spend closer than the minimum train-antenna distance.

Received FM signal strength at the external antenna (dBµV/m)	**Using peak level**		**Using est. quasi-peak level**	
	Minimum train-antenna distance *s* (m)	**Period of disruption for each train passage (s)**	**Minimum train-antenna distance *s* (m)**	**Period of disruption for each train passage (s)**
60	15300	1070	2240	161
64	10400	730	1530	112
68	7080	499	1040	78
72	4820	342	708	55
76	3290	234	482	39
80	2240	161	329	28
84	1525	112	224	21
88	1039	78	153	16
92	708	55	104	12
96	482	39	70.8	10
100	329	28	48.2	8.4
104	224	21	32.9	7.2
108	153	16	22.4	6.3
112	104	12	< 16.2	0
116	70.8	10	< 16.2	0
120	48.2	8.4	< 16.2	0
124	32.9	7.2	< 16.2	0
128	22.4	6.3	< 16.2	0
132	< 16.2	0	< 16.2	0

Table 21 - Minimum separation distances and corresponding periods of disruption for a train emitting at and 20 dB below the EN 50121-2 levels.

1.5.3.2 Interference to DAB Radio

Figure 15 presents the EM noise contours permitted at 220 MHz by EN 50121-2 for a 25kV AC rail system within an office sited 10m from the track.

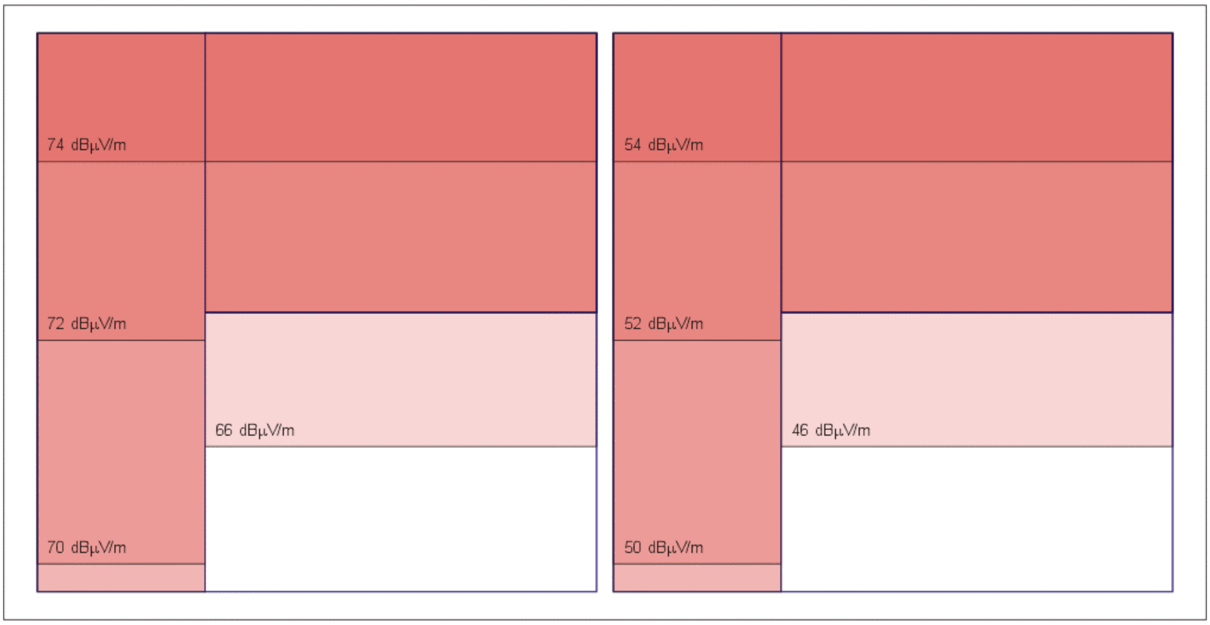

Figure 15 - Levels permitted at 220 MHz by EN 50121-2, rails 10m from the office. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

DAB broadcasts are much more robust than FM radio broadcasts and require a 6.5 dB protection ratio against noise. Table 22 presents the volume of the office unable to receive DAB broadcasts on a receiver with an indoor antenna for various track-office separations, compared with the configuration of devices shown in Figure 14, as a function of the DAB signal strength present externally.

DAB Signal Strength Present Externally (dBµV/m)	Volume of office unable to receive DAB broadcasts (%)			
	10m	20m	30m	Interference from internally located devices
37	100	100	100	100
40	100	100	100	100
42	100	100	100	96
44	100	100	100	79
46	100	100	100	70
48	100	100	100	70
50	100	100	100	68
52	100	100	100	56
54	100	100	100	44
56	100	100	77	34
58	100	94	65	25
60	100	65	65	15
62	89	65	43	7
64	65	53	0	4
66	65	7	0	2
68	54	0	0	< 1
70	30	0	0	< 1
72	4	0	0	< 1
74	0	0	0	< 1

Table 22 - Volume of office unable to receive DAB broadcasts due to a train emitting narrowband noise 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 65% are due to the internal wall.

Table 23 presents the the level of EMI seen at a roof mounted antenna for various train-office separations. Recall from section 1.5.2.2 that for no impairment of DAB reception to occur at the coverage boundary, not more than 30.5 dBµV/m of noise should be received at the roof mounted antenna.

Train-House Distance *d* (m)	**Train-Antenna Distance *s* (m)**	**Peak level of interference at antenna (dBµV/m)**	**Estimated quasi-peak level of interference at antenna (dBµV/m)**
10	16.2	81.6	61.6
20	25.7	77.6	57.6
30	35.5	74.8	54.8
50	55.3	70.9	50.9
100	105	65.4	45.4
300	305	56.1	36.1

Table 23 - Levels permitted by EN 50121-2 at 220 MHz at an external antenna.

The train-to-office distance required to receive a useable DAB signal can be calculated as a function of the received DAB signal strength and the period of disruption can be estimated. Table 24 presents minimum tram-antenna separations and periods of disruption (given an average train speed of 28.7 m/s) as a function of received signal strength at the antenna.

Received DAB signal strength at the external antenna (dBµV/m)	Using peak level		Using est. quasi-peak level	
	Minimum train-antenna distance *s* (m)	Period of disruption for each train passage (s)	Minimum train-antenna distance *s* (m)	Period of disruption for each train passage (s)
37	5820	411	582	46
40	4120	293	412	34
44	2600	187	260	23
48	1640	120	164	17
52	1040	77	104	12
56	653	51	65.3	9.6
60	412	34	41.2	7.9
64	260	23	26.0	6.7
68	164	17	16.4	5.4
72	104	12	< 16.2	0
76	65.3	10	< 16.2	0
80	41.2	7.9	< 16.2	0
84	26.0	6.7	< 16.2	0
88	16.4	5.4	< 16.2	0
92	< 16.2	0	< 16.2	0

Table 24 - Minimum separation distances and corresponding periods of disruption for a train continuously emitting at the EN 50121-2 levels and at 20dB below the EN 50121-2 levels.

1.5.3.3 Interference to Band IV DVB-T Reception

Figure 16 presents the EM noise contours permitted at 530 MHz by EN 50121-2 for a 25kV AC rail system within an office sited 10m from the track.

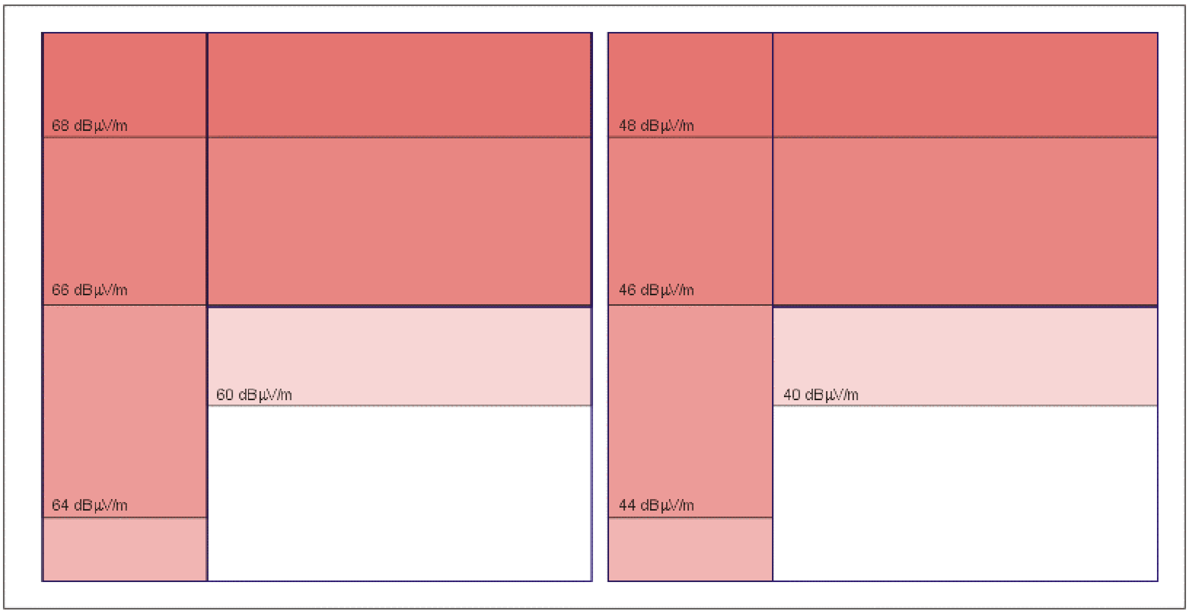

Figure 16 - Levels permitted at 530 MHz by EN 50121-2, rails 10m from the office. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

Figure 17 presents the EM noise contours permitted between 230 MHz and 1 GHz for four devices (positioned at the black circles) meeting CISPR 22 Class B.

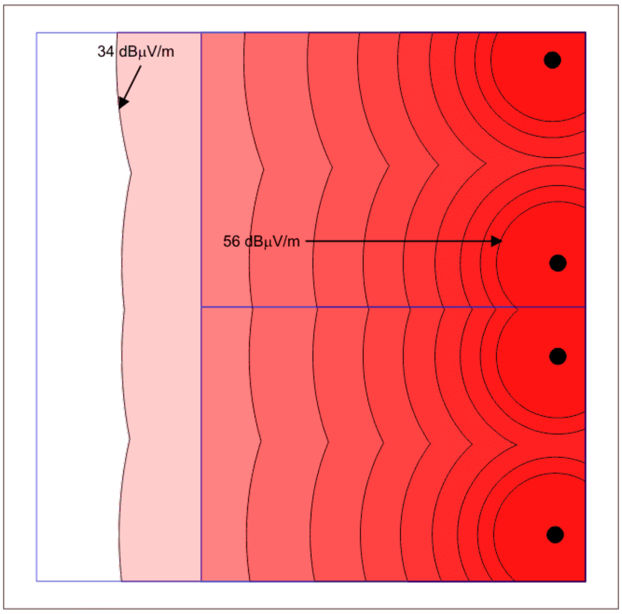

Figure 17 - Emission levels permitted between 230 MHz and 1 GHz from four devices meeting CISPR 22 (EN 55022) Class B. The contours are 2 dB steps.

Table 25 presents the volume of the office unable to receive DVB-T broadcasts on a receiver with an indoor antenna for various track-office separations, compared with the configuration of devices shown in Figure 14, as a function of the DVB-T signal strength present externally.

DVB-T Signal Strength Present Externally (dBµV/m)	Volume of office unable to receive DVB-T broadcasts (%)			
	10m	20m	30m	Interference from internally located devices
56	100	100	100	100
…	…	…	…	…
62	100	100	100	100
64	100	100	65	82
66	100	76	65	70
68	100	65	58	70
70	78	65	0	70
72	65	37	0	59
74	61	0	0	47
76	50	0	0	36
78	19	0	0	27
80	0	0	0	17
82	0	0	0	8
84	0	0	0	4
86	0	0	0	2
88	0	0	0	< 1

Table 25 - Volume of office unable to receive Band IV DVB-T broadcasts due to a train emitting narrowband noise 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 65% are due to the internal wall.

Table 26 presents the the level of EMI seen at a roof mounted antenna for various train-office separations and includes the straight-line train-antenna separations which arise from the geometry noted in Figure 6. Recall from section 1.5.2.3 that for no impairment of DVB-T reception to occur at the coverage boundary, not more than 36 dBµV/m of noise should be received at the roof mounted antenna.

Train-House Distance *d* (m)	Train-Antenna Distance *s* (m)	Peak level of interference at antenna (dBµV/m)	Estimated quasi-peak level of interference at antenna (dBµV/m)
10	16.2	75.3	55.3
20	25.7	71.3	51.3
30	35.5	68.5	48.5
50	55.3	64.6	44.6
100	105	59.1	39.1
300	305	49.8	29.8

Table 26 - Levels permitted by EN 50121-2 at 530 MHz at an external antenna.

Given the minimum signal strength and the protection ratio, the estimated quasi-peak level at the antenna would be sufficient to disrupt DVB-T reception at a 150 m separation. If it is assumed that the antenna is directional (as is common for TV antennas) and there is a 10 dB attenuation away from the antenna axis, then DVB-T reception is protected at a 47m separation. Table 27 presents the minimum separation and period of disruption as a function of received signal strength, assuming a directional antenna.

Received DVB-T signal strength at the external antenna (dBµV/m)	**Using peak level**		**Using est. quasi-peak level**	
	Minimum train-antenna distance *s* (m)	**Period of disruption for each train passage (s)**	**Minimum train-antenna distance *s* (m)**	**Period of disruption for each train passage (s)**
56	473	38	47.3	8.3
58	376	31	37.6	7.6
60	299	26	29.9	7.0
62	237	22	23.7	6.4
64	188	18	18.8	5.9
66	150	16	< 16.2	0
68	119	13	< 16.2	0
70	94.4	12	< 16.2	0
72	75.0	10	< 16.2	0
74	59.6	9.2	< 16.2	0
76	47.3	8.3	< 16.2	0
78	37.6	7.6	< 16.2	0
80	29.9	7.0	< 16.2	0
82	23.7	6.4	< 16.2	0
84	18.8	5.9	< 16.2	0
86	< 16.2	0	< 16.2	0

Table 27 - Minimum separation distances and corresponding periods of disruption for a train continuously emitting at and 20 dB below the EN 50121-2 levels.

1.5.3.4 Interference to Band IV Analogue TV

Analogue TV is transmitted in the same bands as DVB-T. Therefore, the permitted noise contours shown in Figure 16 are also relevant to analogue TV. Given a minimum broadcast field strength of 65 dBµV/m, a 50 dB protection ratio and an antenna with a 10 dB off-axis rejection, for no impairment to occur at the boundary of coverage, not more than 25 dBµV/m of noise should be present at the television antenna (assuming the noise source is not sited in line with the antenna).

Table 28 presents the percentage of the house volume which is unable to receive analogue TV broadcasts on a receiver with an indoor antenna for three different train-house separations (assuming a 20 dB correction to obtain quasi-peak levels) and for the configuration of domestic devices in Figure 17, as a function of the analogue TV signal strength present externally.

Analogue TV Signal Strength Present Externally (dBµV/m)	Volume of office unable to receive Analogue TV broadcasts (%)			
	10m	20m	30m	Interference from internally located devices
65	100	100	100	100
…	…	…	…	…
82	100	100	100	100
84	100	100	65	82
86	100	76	65	70
88	100	65	58	70
90	78	65	0	70
92	65	37	0	59
94	61	0	0	47
96	50	0	0	36
98	19	0	0	27
100	0	0	0	17
102	0	0	0	8
104	0	0	0	4
106	0	0	0	2
108	0	0	0	< 1

Table 28 - Volume of office unable to receive Band IV Analogue TV broadcasts due to a train emitting narrowband noise 20 dB below the EN 50121-2 levels and to internal equipment meeting CISPR 22 Class B as a function of received signal strength. Distances are train-house separations. NB the plateaux at 65% are due to the internal wall.

The levels of EMI seen at a roof mounted antenna presented in Table 26 are also relevant to analogue TV. If it is assumed that the antenna is directional (as is common for TV antennas) and there is a 10 dB attenuation away from the antenna axis, then analogue TV reception is protected at the boundary of coverage at a 530 m separation. Table 29 presents the minimum separation and period of disruption as a function of received signal strength for trains emitting at and 20 dB below the EN50121-2 limits.

Received Analogue TV signal strength at the external antenna (dBµV/m)	**Using peak level**		**Using est. quasi-peak level**	
	Minimum train-antenna distance *s* (m)	**Period of disruption for each train passage (s)**	**Minimum train-antenna distance *s* (m)**	**Period of disruption for each train passage (s)**
65	5310	376	531	42
68	3760	267	376	31
72	2370	171	237	22
76	1500	110	150	16
80	944	71	94.4	12
84	596	47	59.6	9.2
88	376	31	37.6	7.6
92	237	22	23.7	6.4
96	150	16	< 16.2	0
100	94.4	12	< 16.2	0
104	59.6	9.2	< 16.2	0
108	37.6	8	< 16.2	0
112	23.7	6	< 16.2	0
116	< 16.2	0	< 16.2	0

Table 29 - Minimum separation distances and corresponding periods of disruption for a train continuously emitting at and 20 dB below the EN 50121-2 levels.

1.5.3.5 Interference to GSM-900

Figure 18 presents the EM noise contours permitted at 920 MHz by EN 50121-2 for a 25kV AC rail system within an office sited 10m from the track.

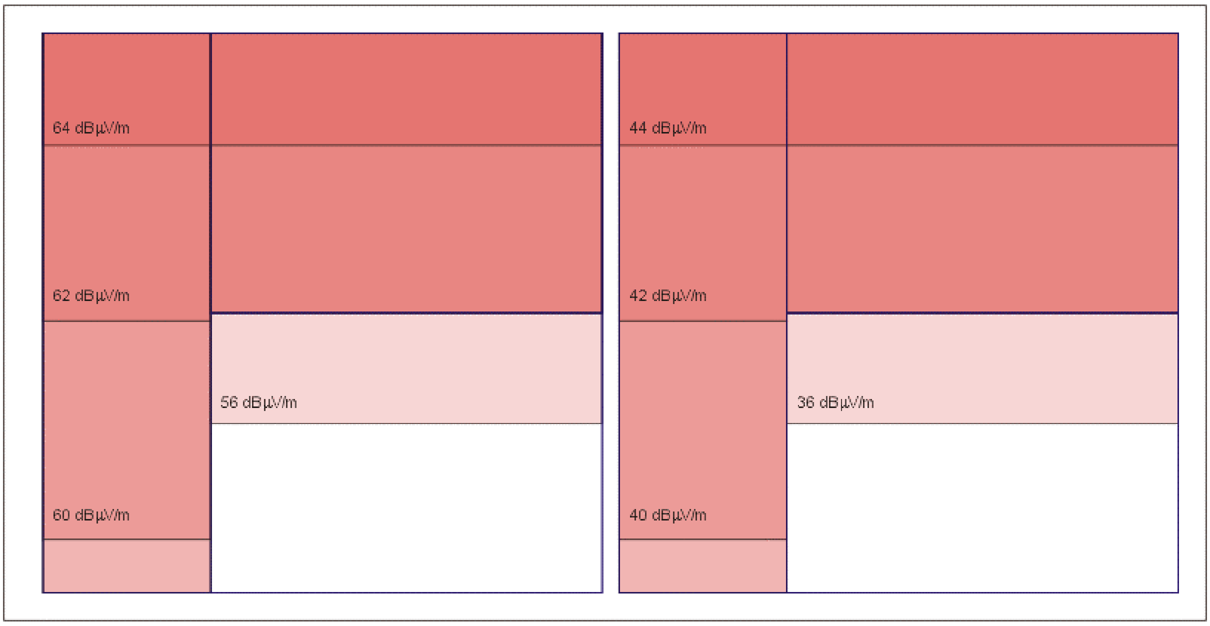

Figure 18 - Levels permitted at 920 MHz by EN 50121-2, rails 10m from the office. Left: peak levels (derived directly from the standard); right: estimate of quasi-peak levels (to calculate interference to radio service).

The peak levels allowed by EN 50121-2 allow a level of noise comparable to that seen from the four modelled devices meeting CISPR 22 Class B. Table 30 presents the cumulative volume of the office experiencing various field strengths.

Noise Field Strength (dBµV/m)	**Cumulative volume of house (%)**					
	Train-house separation					**Interference from internally located devices**
	10m	**10m**	**20m**	**30m**	**50m**	
	Est. Quasi-peak	**Peak**	**Peak**	**Peak**	**Peak**	
66	0	0	0	0	0	< 1
64	0	20	0	0	0	< 1
62	0	50	0	0	0	< 1
60	0	62	0	0	0	< 1
58	0	65	40	0	0	< 1
56	0	79	65	2	0	2
54	0	100	65	59	0	4
52	0	100	78	65	0	8
50	0	100	100	65	65	17
48	0	100	100	100	65	27
46	0	100	100	100	65	36
44	20	100	100	100	100	47

Table 30 - Noise field strength levels inside the office due to a train at numerous distances from the office compared with four electrical devices just meeting CISPR 22 Class B.

1.5.4 Modelling Addendum

It can be conjectured that, following from the Radiocommunications Agency-funded research, appropriate measurement methods and limits would be set on the levels of continuous EMI emitted by trains and trams. Furthermore, it can be conjectured that the limits set will provide some degree of protection to radio services. For the purpose of this work it would be useful to estimate the general level of such limits.

One approach to such an estimate is to assume that:

- the modified standards will include permitted continuous emission limits;
- these limits will cause levels experienced in an RCLI environment next to the railway boundary to be no worse than those caused by devices just meeting CISPR 22 Class B.

While this approach does not take account of any technical difficulties inherent in reducing any emission levels it can be seen below that the limits indicated by such an approach lie below the current limits in EN50121-2:2000 but above the generic industrial (EN 61000-6-4) limits (it can be argued that the railway environment is essentially industrial and should ultimately meet industrial limits; thus such limits are the most stringent that could reasonably be expected).

The assumed levels follow the form of the CISPR 22 limits, being more stringent between 30 and 230 MHz (compared to the limits between 230 MHz and 1 GHz).

For both scenarios this approach results in very similar levels being predicted. The limits predicted are equivalent to 52 dBμV/m measured in a quasi-peak detector at 10m from the train between 30 and 230 MHz, relaxing to 59 dBμV/m between 230 MHz and 1 GHz. While such reductions (around 40 dB in the FM band for the 25 kV rail system limits) seem draconian, it must be remembered that the current limit is a peak limit. It must also be noted that specifying a quasi-peak limit is inappropriate for a moving source, as discussed by Konefal *et al* [3].

The following tables present how such levels would affect radio services received via external antennas.

Received FM signal strength at the external antenna (dBµV/m)	**Train/tram-antenna distance *s* (m)**	**For tram geometry**	**For train geometry**
		Period of disruption for each tram passage (sec)	**Period of disruption for each train passage (sec)**
60	348	115	29
64	237	80	22
68	162	56	16
72	110	40	13
76	75	29	10
80	51	21	9
84	35	16	7
88	24	12	6
92	16	9	5
96	11	5.8	0
100	7.5	0	0

Table 31 - Minimum separation distances and corresponding periods of disruption for a train emitting continuously at a hypothetical quasi-peak limit of 52 dBµV/m at 10 m, interfering with an external FM antenna (calculation includes propagation loss of 24dB/decade).

Received DAB signal strength at the external antenna (dBµV/m)	**Train/tram-antenna distance *s* (m)**	**For tram geometry**	**For train geometry**
		Period of disruption for each tram passage (sec)	**Period of disruption for each train passage (sec)**
37	119	42	13
40	84	31	11
44	53	22	9
48	33	15	7
52	21	11	6
56	13	8	0
60	8.4	0	0

Table 32 - Minimum separation distances and corresponding periods of disruption for a train emitting continuously at a hypothetical quasi-peak limit of 52 dBµV/m at 10 m, interfering with an external DAB antenna.

Received DVB-T signal strength at the external antenna (dBµV/m)	**Train/tram-antenna distance *s* (m)**	**For tram geometry**	**For train geometry**
		Period of disruption for each tram passage (sec)	**Period of disruption for each train passage (sec)**
56	45	19	8
60	28	13	7
64	18	10	6
68	11	6	0
72	7.1	0	0

Table 33 - Minimum separation distances and corresponding periods of disruption for a train emitting continuously at a hypothetical quasi-peak limit of 59 dBµV/m at 10 m, interfering with an external DVB-T antenna.

Received Analogue TV signal strength at the external antenna (dBµV/m)	**Train/tram-antenna distance *s* (m)**	**For tram geometry**	**For train geometry**
		Period of disruption for each tram passage (sec)	**Period of disruption for each train passage (sec)**
65	501	163	40
68	355	117	30
72	224	76	21
76	141	50	15
80	89	33	11
84	56	23	9
88	35	16	7
92	22	11	6
96	14	8	0
100	9	0	0

Table 34 - Minimum separation distances and corresponding periods of disruption for a train emitting continuously at a hypothetical quasi-peak limit of 59 dBµV/m at 10 m, interfering with an external Analogue TV antenna.

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