Interfering thresholds of radio services and spectrum emission masks from PLT, CATV and ADSL

Haim Mazar (Madjar)
RF Spectrum Department, Ministry of Communications Tel Aviv, Israel
mazarh@moc.gov.il , mazar@ties.itu.int; http://people.itu.int/~mazar/

***Abstract* — Interfering levels are most significant to define compatibility between radio systems. Common equations calculate the threshold levels in terms of power and field-strength. These thresholds are used to protect radio services from interfering radiators, in particular, incidental radiators such as PLT, cable installations and ISM. Assuming the minimum distance from interferer to victim, the spectrum emission mask is calculated. The study provides practical values. Measurements of noise levels and interference support the calculations and provide evidence to the methodology[1].**

Keywords — Antennas and propagation, cable tv, electromagnetic compatibility and interference, electromagnetic radiation, emission masks, ISM, methodology, measurements, Noise figure, noise floor, PLT, radio services, protection levels, spectrum emission mask, thresholds.

I. INTRODUCTION

Radio services are vulnerable to interference. Threshold (sometimes called trigger) levels of the RF power at the victim receiver are commonly used to establish the coexistence and compatibility between radio systems, e.g. cellular and broadcasting. Criteria for the protection of the victim system are established; as shown in Section II, this is carried out based on an acceptable level of receiver sensitivity degradation, which determines a maximum level of interference to system noise ratio and the allowed interference signal at the input to the victim receiver. Based on minimum distances from the interferer to the victim, and common propagation equations, the interferer radiation masks are calculated (Section V). These are maximum allowed emission levels -RF power spectral density (PSD) - for the anticipated scenarios. Of particular interest are the cases where the interferers are incidental such as Power Line Telecommunications (PLT), cable Installations and Industrial Scientific and Medical (ISM) equipment.

Above 30 MHz, the predominant mode of interference from incidental radiators is assumed to be via radiated emissions that are intercepted by radiocommunications equipment, like White Noise. PLT, ISM equipment (e.g., 2.45 GHz µWave ovens) and cable installations - such as cable TV (CATV), DSL, LAN- are similar: their generation of RF energy is essential for the operation and use of the equipment and they all use wide band information with (pseudo) uniform power spectral density (PSD); therefore, the analysis of their interference to terrestrial services can be similar. This paper develops protection requirements, which should be met by unintended radiations. Non-intentional devices can be assessed by limiting their PSD (power per MHz) output.

This paper provides a methodology, power, field-strength thresholds and spectrum emission masks, without referring to the specific receiver characteristics, such as modulation and carrier-to-noise ratio.

Incidental radiators mainly interfere to wanted signals at the edge of the service coverage area. Measuring and monitoring the leakage from incidental radiators is complicated since the signals are noise-like (wide band with uniform PSD) and weak relative to the back ground noise. Specific measurements of noise level in the VHF/UHF bands and testing interference of broadband noise-like simulator to CDMA receiver assist to evaluate the theoretical approach. Keeping leakage down from to a dull roar reduces RFI and also helps to ensure good CATV (PLT and ADSL) network performance and signal quality, as well as keep ingress more manageable [1].

II. CRITERION TO PROTECT RADIO SERVICES

A. Thermal Noise

The Rx sensitivity in dBm (or dBw) equals KTBF + (S/N); in order to degrade the sensitivity by 3 dB (when the interference signal equals the system noise level), the "white-noise" interferer equals the sensitivity minus S/N; thus KTBF + (S/N) - (S/N) = KTBF, unrelated to the specific receiver modulation. The thermal noise PSD at 20°C is -114 dBm/MHz; the equivalent noise level at receiver input is the thermal noise level plus the receiver noise figure and plus man-made noise. Table I reveals the degradation of sensitivity with interference, relative to receiver thermal noise:

TABLE I. *DEGRADATION IN SENSITIVITY*

Interference level relative to receiver thermal noise (dB)	Resultant degradation in sensitivity (dB)
0	3
–6	1
–10	0.5
–20	0.05

B. I/N RATIO of –20 dB CRITERION

ITU Radio Regulations allocate RF bands to radiocommunications services (such as broadcasting, land mobile, radio-location and satellite). The I/N ratio of –20 dB criterion is proposed to protect these services from unintentional radiators and non-allocated emissions; e.g., ITU-R BT.1895 [2] “recommends 2” “that the total

[1] Paper to be presented at COMCAS 11 on 7 Nov 2011

interference at the receiver from all radiations and emissions without a corresponding frequency allocation in the Radio Regulations should not exceed 1% of the total receiving system noise power". 1% of the total receiving system noise power is I/N ratio of –20 dB. For incidental radiator, this paper proposes" I/N ratio of –20 dB". Actually, the difference between "I/N ratio of –20 dB" and "I/N ratio of –10 dB" is an increase of the incidental interfering signal of only 0.37 dB: 10 log (1.1) - 10 log (1.01). Moreover, for cellular systems, the thermal noise and maximum range is not the only performing criterion: as frequency reuse is performed; in many cases range will not be a limiting issue, and capacity impacts the cell density.

III. SCENARIOS, ASSUMPTIONS AND DISTANCES

A. Assumptions to calculate the interfering thresholds

A practical assumption is that the interfering device is one source origin. Free space propagation is assumed from incidental radiator to victim; no wall attenuation. Those are the assumed values to protect the radio services (see abbreviations in the next section):

1) The receiver noise floor is dominated by the thermal noise: no man-made or other noises;

2) The tolerated desensitisation of the terrestrial receivers is 0.05 dB, the allowed interfering signal is 20 dB below the thermal noise: therefore, the trigger power level is KTBF-20 dB[2];

3) Cellular Terminals' and broadcasting receivers' isotropic antenna gains: Gr (dBi) = 0 and L_F (dB) =0;

4) Macrocellular Base Stations (BS) antenna gain: Gi (dBi) =15 and L_F (dB) =3;

5) Fixed stations antenna gain: Gi (dBi) = 15 and L_F (dB) =3;

6) Radiolocation stations Gi (dBi) =23 and L_F (dB) =3;

7) Noise Figure (F) of 5 dB (value typical to victim Rx);

8) RF reference 460 MHz.

Trigger levels and incidental radiators' power masks can be calculated based on these values. Different assumptions will change the results. The dB's are preserved; e.g. Noise Figure of 7 dB instead of 5 dB results in 2 dB higher power, field-strength triggers and power masks.

B. Expected distance from incidental radiators to victims

In order to calculate the permitted emission from any incidental radiators, its distance from the victim receivers should be assumed. As incidental radiators are operated also indoors, the minimum distance between unintentional device and any station (such as cellular, fixed, broadcasting video and audio) is as low as:

–1 m between incidental radiator and cellular or broadcasting terminals, indoor;

–10 m to macrocellular base-stations or TV ant. outdoor;

–10 m to fixed stations, outdoor[3];

–100 m to Radiolocation stations, outdoor.

These minimum separation distances are taken into account when studying the protection against radiation. The distances define the allowed peak PSD of incidental radiator.

IV. METHODOLOGY

References [3] and [4], based mainly on Israeli contributions, served the ITU regional agreement GE06 to protect the mobile and the fixed services from the digital TV (also a wide band signal with uniform PSD). Based on the same methodology, the interfering thresholds and incidental radiators' masks are calculated here. For the expected distances specified previously, trigger levels and maximum allowed incidental radiator peak-power values are derived.

V. CALCULATED THRESHOLDS AND EMISSION MASKS

A. Definitions

F : receiver noise figure (dB);

B: bandwidth (BW) of the incidental radiator[4] (MHz);

g_i: receiver antenna gain (numeral);

G_i: receiver ant gain (dBi);

L_F: antenna cable feeder loss (dB);

f: reference frequency (MHz);

$P_{terminal}$: power trigger level/MHz at cellular handset and broadcasting video and audio terminal (dBm)

P_{BS}: power trigger level/MHz @ Base Station ant input (dBm)

P_{RL}: trigger level/MHz at radiolocations station (RL) (dBm)

$E_{terminal}$: Field-strength Level/MHz at terminals (dBμV/m)

E_{BS}: Field-strength Level/MHz at Base Station (dBμV/m)

Any new system needs to be determined only by its Noise Figure, G_i and L_F parameters, in order to calculate the power and field-strength triggers.

B. Threshold levels

The Rx thermal noise power KTBF at non-loss isotropic antenna for a BW =1 MHz and a typical Noise Figure (F) of 5 dB equals:

$$\text{KTBF/1 MHz} = -114 + 5 = -109 \text{ dBm/MHz} \quad (1)$$

$$\text{KTBF-20dB (1MHz)} = -109\text{dBm} - 20\text{dB} = -129\text{dBm/MHz} \quad (2)$$

As 0 dB antenna gain is related to cellular handsets and broadcasting receivers, this is also the PSD level to protect the terminals from incidental radiators (for 1MHz signal).

$$P_{terminals} \text{ (1 MHz)} = -129 \text{ dBm/MHz} \quad (3)$$

In order to calculate the power level at the BS receiver input, Gi(dBi)=15 and LF(dB)=3 (15dBi -3dB=12 dBi) are included, to get power trigger level at antenna input:

$$P_{BS} \text{ (1MHz)} = -129\text{dBm/MHz} - 12 \text{ dB} = -141 \text{ dBm/MHz} \quad (4)$$

In order to calculate the power level at the radiolocation (RL) receiver input, Gi(dBi)=23 and LF(dB)=3 (23 dBi -3 dB =20 dBi) are included, to get power trigger level:

$$P_{RL}\text{(1MHz)} = -129 \text{ dBm/MHz} - 20\text{dB} = -149 \text{ dBm/MHz} \quad (5)$$

Conversion of the Electrical Field (dBμV/m) at antenna input to power (dBm):

$$P(\text{dBm}) = E(\text{dB}\mu\text{V/m}) - 77.21 - 20\text{Log } f(\text{MHz}) + Gi - LF \quad (6)$$

[2] The PSD level and BW=1 MHz are used at next equations

[3] The incidental radiator may not be at victim's antenna boresight

[4] Referring to PSD balances the calculations to 1 MHz

As the equivalent power noise level at receiver input (noise figure, 1 MHz reference and RF 460 MHz) is identical, the difference in field-strengths' thresholds is derived from the different gains (minus losses), at base-station, fixed and radiolocation antennas. Assuming free space propagation and no-wall attenuation, the conversion of victim field-strength to the interfering transmitted power is independent of RF.

$$-129 \text{ (dBm)} = E(\text{dB}\mu\text{V/m}) - 77.21 - 53.25 \quad (7)$$

$$E_{terminal} \text{ (1MHz)} = \mathbf{1.5} \text{ (dB}\mu\text{V/m)} \quad (8)$$

$$E_{BS}/\text{MHz} = E_{fixed}/\text{MHz} = 1.5(\text{dB}\mu\text{V/m}) - 12\text{dB} = \mathbf{-10.5}(\text{dB}\mu\text{V/m}) \quad (9)$$

$$E_{RL}/\text{MHz} = 1.5 \text{ (dB}\mu\text{V/m)} - 20 \text{ dB} = \mathbf{-18.5}(\text{dB}\mu\text{V/m}) \quad (10)$$

C. Allowed incidental radiators' spectrum emission masks

The incidental radiators' mask depends on RF, as propagation varies with RF; for the same distance, the threshold power increases with RF: 20 dB per decade. For 460 MHz, using free space propagation d: distance in meters (not km):

$$L_{bf} = -27.6 + 20 \log f + 20 \log d \text{ (dB)} \quad (11)$$

The maximum allowed incidental radiators (IR) peak-power at f = 460 MHz for the terminals **1 m** from IR P_{IR}:

$$P_{IR} \text{ (dBm/MHz)} = P_{terminal}\text{(dBm/MHz)} + L_{bf} = -129 - 27.6 + 20 \log f + 20 \log d = -129 - 27.6 + 20 \log 460 + 20 \log 1 = -129 - 27.6 + 53.3 \approx \mathbf{-103 \text{ (dBm/MHz)}} \quad (12)$$

To exemplify the RF influence, for 230 MHz the threshold is 6 dB lower **-109 (dBm/MHz)** and for 920 MHz the threshold is 6 dB higher **-97 (dBm/MHz)** .

The maximum allowed incidental radiator peak-power P_{IR} at f = 460 MHz for cellular BS **10 m** from incidental radiators:

$$P_{IR} \text{ (dBm/MHz)} = P_{BS} \text{ (dBm/MHz)} + L_{bf} = -141 - 27.6 + 53.3 + 20\log 10 \approx \mathbf{-95(dBm/MHz)} \quad (13)$$

The maximum allowed incidental radiators peak-power P_{IR} at f = 460 MHz for the radiolocation **100 m** from the device:

$$P_{IR} \text{ (dBm/MHz)} = P_{RL} \text{ (dBm/MHz)} + L_{bf} = -149 - 27.6 + 53.3 + 20\log 100 \approx \mathbf{-83(dBm/MHz)} \quad (14)$$

For the distances (incidental radiator to victim; see distances in parenthesis in *Table II* row 3), the following trigger levels (non-dependent on RF) and maximum allowed incidental radiator peak-power values are derived:

TABLE II. *TRIGGER LEVELS AND MAX PEAK-POWER*

Power and field-strength per 1 MHz	**indoor** Cellular terminal, radio or TV	**outdoor** Macrocellular base-station and fixed station	**Outdoor** Radiolocation station
Power Trigger Level (dBm)	**-129**	**-141**	**-149**
Field-strength Trigger Level (dBµV/m)	**1.5**	**-10.5**	**-18.5**
Max incidental radiator peak-power (dBm)	**-103** (1meter)	**-95** (10meter)	**-83** (100 meter)

VI. MEASUREMENTS AND TESTS

In order to assess the interference from CATV, [5] is an Israeli contribution to ITU-R testing over-the-air signals, thermal noise and man-made noise measured on 20 February 2003. In VHF we measured 10 dB increase above the thermal noise, in urban area; Fig. 1 is the measurement set-up and Fig. 2 depicts how man-made noise increases only by **2 dB** the KTBF level at UHF in rural area:**–89.76** dBm (the measured noise level) - **-92** dBm (the UHF set-up noise level). So at least for the rural case at 466 MHz the man-made noise is relatively minor.

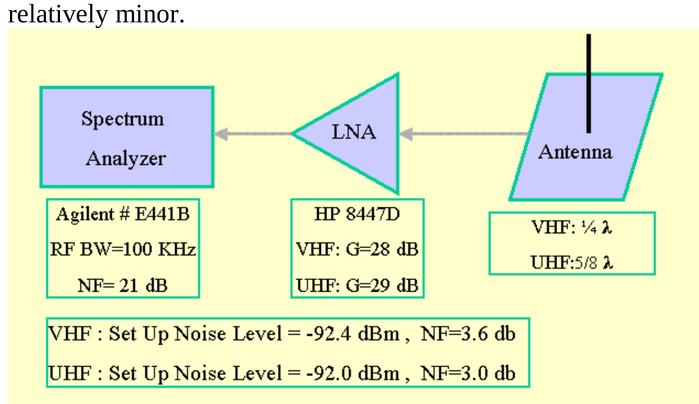

Fig. 1 Measurement set up [5]

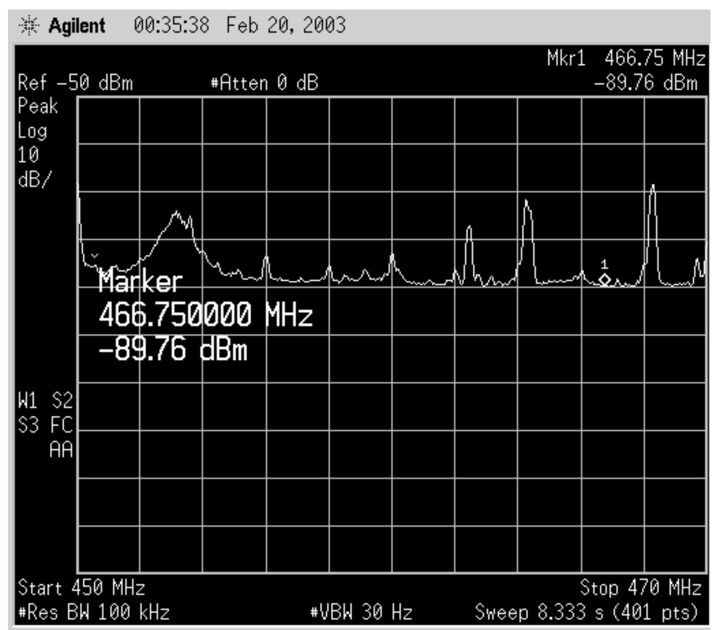

Fig. 2 UHF results in rural area (Beit Yizhak) [5]

In order to assess the interference to CDMA receivers from DVB-T (broadband noise-like signal), [6] is an Israeli contribution to ITU-R providing calculations based on the methodology described at this paper and tests on 26 January 2003; the bold values (1 dB maximal deviation of measured and calculated degradation) support the methodology.

TABLE III MEASURED SENSITIVITY DEGRADATION [6]

Interference Level dBm	Equal noise level calculated dBm	Sensitivity measured dBm	Sensitivity degrade measured dB	Sensitivity degrade calculated dB
No interference	-111	-127	**0**	**0**
-114	-109	-125	**-2**	**-1.8**
-111	-108	-123	**-4**	**-3**
-108	-106	-122	**-5**	**-4.8**
-105	-104	-120	**-7**	**-7**

Fig. 2 and Fig. 3 measured on 21September 2011 depict a CATV QAM 256 (10 dBmV downstream wanted signal), white noise (-30 dBmV level, below and above the QAM RF) and analog TV signals (above QAM RF, 17 dBmV for the video signal) measured in BW 300 kHz and different VBW (video filter in Fig. 3): the QAM 256 (like QAM 8, 16, 64 and QPSK) CATV signal is indeed very similar to the white noise. The resistance (to transfer voltage to power) is 75 Ohms[i].

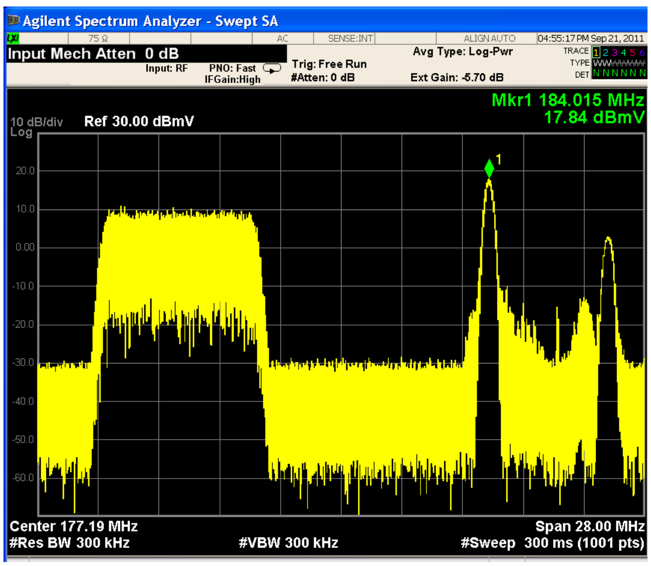

Fig. 3 QAM 256 CATV, Noise & Analog TV, VBW 300 kHz

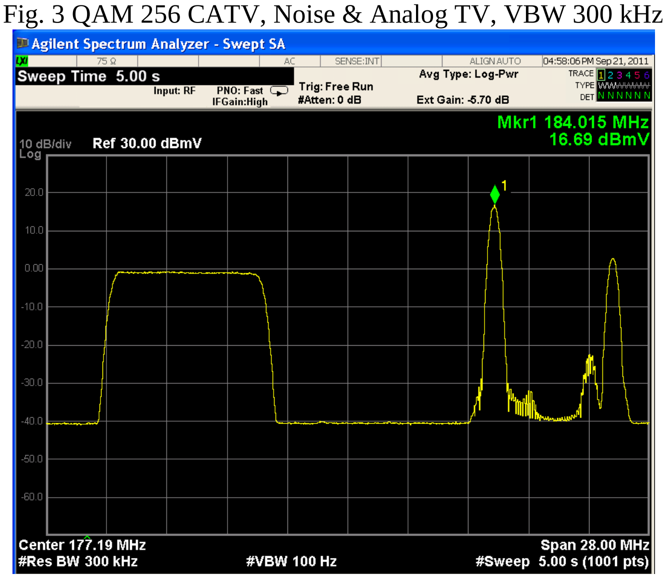

Fig. 4 QAM CATV vs. Noise and Analog TV, VBW 100 Hz

VII. RESULTS AND SUMMARY

Based on calculations and tests, this paper provides useful values to protect radiocommunication services from PLT, cable installations (CATV and ADSL) and ISM, emitting unintended radiations. The tolerated desensitisation of the terrestrial receivers is **0.05 dB**; the allowed interfering signal is 20 dB below the noise threshold; the trigger level is KTBF-20 dB. The worst case scenario is to protect the **indoor** victims, such as cellular handsets and broadcasting receivers (video and audio); as they are only 1 meter from the incidental radiator. To provide adequate protection to weak-signal operations by the primary services in the VHF/UHF frequency range, radiation from non-intentional devices should not exceed a maximum of **1.5 dBμV/m in a 1 MHz BW**, measured indoor at a distance of **1 metre from the device**; see additional values in *Table II*. The field-strength is independent of frequency, assuming free-space propagation and no-wall attenuation. The power limit does depend on RF; at a RF of **460** MHz, the maximum allowed peak-power is **-103 dBm/MHz**; at **920** MHz, the threshold is 6 dB higher: **-97 dBm/MHz**. The worst case scenario to protect the **outdoor** terrestrial services is a cellular base-station or fixed station, **10 meters from the device**. For this case the maximum incidental radiator peak-power at 460 MHz equals **-95 dBm/MHz.**

The thresholds and the spectrum emission masks may be also used to define signal leakage tasks, to deny degraded performance to radiocommunications. This paper can be generalised to avoid interference from UWB, and mutual interference between radiocommunication services; the only change is the protection criterion; instead of I/N = -20 dB; it should be I/N = -6 dB.

REFERENCES

[1] R. Hranac's Leakage in an All-Digital World, Communications Technology, 1 March 1, 2009 (continued 1 May 2009)

[2] Recommendation ITU-R BT.1895 (05/2011) Protection criteria for terrestrial Broadcasting systems

[3] Recommendation ITU-R M.1767 Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis

[4] Recommendation ITU-R F.1670 : Protection of fixed wireless systems from terrestrial digital video and sound broadcasting systems in shared VHF and UHF bands

[5] Noise level measurements at VHF + UHF for recommendation ITU-R P.372-8: Radio Noise http://www.itu.int/md/R03-WP3J-C-0043/en

[6] Interference levels from DVB T to cellular CDMA, in the band 470-862 MHz http://www.itu.int/md/R00-WP8A-C-0257/en

[i] The egress (unwanted emitted signal) of a CATV signal from well maintained cable plant, splitters, taps and cables is attenuated about 90-100 dB. Thus the measured CATV signal of 10 dBmv over 75 Ohms is equivalent to: 10 (wanted signal dBmv) -60 (dBmv to dBV)-10 log 75 (resistance)+30 dBW to dBm) **-38.7** dBm; therefore only bad infrastructure may cause interference to radiocommunications. However, the upstream (return channel) is 50 dBmv (40 dB higher) and egress may exceed **-38.7** dBm + 40 dB – 90 dB = -88.7 dBm