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EVALUATION OF ELECTRICAL DEVICE INTERFERENCE POTENTIAL TO RADIO ASTRONOMY OBSERVATIONS

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We outline here technical procedures for evaluating the interference potential of an electrical device to radio astronomy observations, assuming that the device is within line-of-sight of the radio astronomy antenna. Two examples are given, one where the device's radiation must be measured, and one where we take the FCC legal radiation limit for that class of device.

Our procedures will follow the worksheet in Tables 1 or 2. The first section of the worksheet in Table 1, "Test Setup Parameters," is used to record the necessary details of the measurement setup shown in Figure 1. The bracketed numbers next to many of the table entries refer to notes below, which give an explanation of the entry and the required equations, in the case of a computed parameter. If data for more than one frequency or a spectrum are available for the device, the three columns at the right side of the worksheet provide space for entries at three different frequencies.

Device Measurement

The test setup shown in Figure 1 is a good standard one. We shall use this configuration in the example below.

An accurate radiated power measurement requires the same precautions as those taken on a standard antenna test range regarding spurious reflections from surrounding objects. If the device under test cannot be ideally isolated, an average of several measurements at well separated test antenna placements should be used. Since most incidental radiators have an unpredictable radiation pattern, measured field strengths should also be averaged over at least three, and preferably more, device orientations with respect to the direction to the test antenna, even under ideal test conditions. A manual turntable might be a convenient device.

For test antenna gains less than about 10 dBi the device-to-test antenna distance should be at least 5 wavelengths or several times the maximum dimension of the device being measured, whichever is greater.

Intensity calibrations are important so make sure that your spectrum analyzer is within the manufacturer's specifications. If you have a known secondary calibration source that you can record with your measurements, this is even better. If you don't have accurate numbers for gains or losses of any elements in the RF path, measure them carefully. A total accuracy of about 1 dB from the antenna terminals to the final record is a good goal. Antenna gains are difficult to measure, so get the best specifications that you can from the manufacturer or antenna designer. Be reasonably careful about measuring the device to antenna distance, since the measured intensity depends on the square of this distance.

An instrument other than a spectrum analyzer can certainly be used, but information

Table 1. Device Measurement Worksheet			
Test Setup Parameters (See Fig. 1)			
Frequency (MHz)			
Wavelength (meters)			
[1] Test Antenna Gain (dBi)			
Test Antenna Distance from Source (D in meters)			
Total Transmission Line Loss (L_{TL} in dB) (negative)			
Preamplifier Gain (G_{PA} in dB) (positive)			
[2] Receiver RF Bandwidth (B_{rf} in MHz)			
Measured Parameter			
[3] Measured Signal Strength (P_{meas} in dBm)			
Signal Character (CW, broadband, pulsed, swept, etc.):			
Computed Parameters			
[4] Antenna Collecting Area (A_{eff} in meters^2)			
[5] Space Loss (L_s in dB) (negative)			
[6] Total Loss (L_{tot} in dB)			
[7] Radiated Power in Passband (P_{rad} in dBW)			
[8] Radiated Power per Unit Bandwidth (P_{ubw} in dBW/Hz)			
Field Strength at Distance			
Selected Distance (R in Meters)			
[9] Field Strength (P_{ex} in dBW/m^2/Hz)			
[10] CCIR Limit (Line) (dBW/m^2/Hz)			
[10] CCIR Limit (Continuum) (dBW/m^2/Hz)			

Table 2. Worksheet for Device with Radiation Limits			
Radiation Limits Parameters			
Frequency (MHz)			
[11] Prescribed Bandwidth (b in MHz)			
[11] Prescribed Distance (r in meters)			
[11] Field Strength Limit (P_{limit} in dBW/m^2)			
Computed Parameters			
[12] Radiated Power in Prescribed Bandwidth (P_{rad} in dBW)			
[13] Radiated Power per Unit Bandwidth (P_{ubw} in dBW/Hz)			
Field Strength at Distance			
Selected Distance (R in meters)			
[9] Field Strength (P_{ex} in $dBW/m^2/Hz$)			
[10] CCIR Limit (Line) ($dBW/m^2/Hz$)			
[10] CCIR Limit (Continuum) ($dBW/m^2/Hz$)			

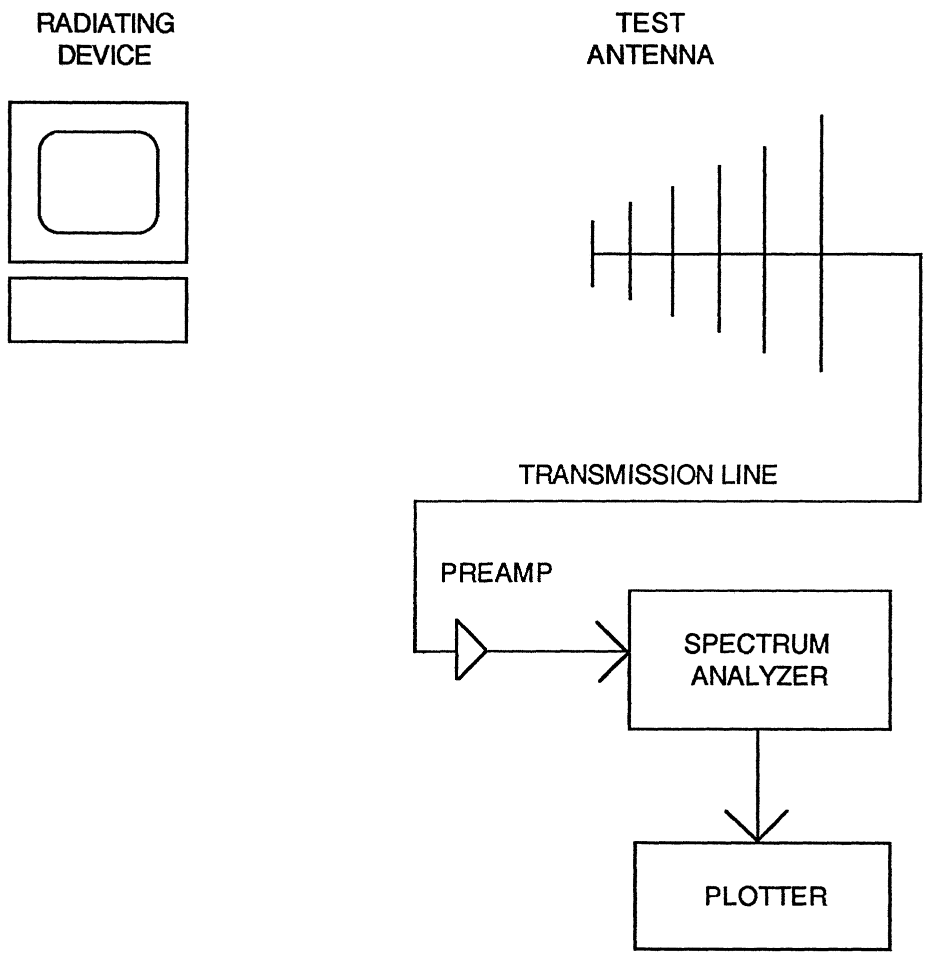
RADIATING
DEVICE
TEST
ANTENNA
TRANSMISSION LINE
PREAMP
SPECTRUM
ANALYZER
PLOTTER

FIGURE 1

about the frequency characteristics of the device radiation is often valuable. The primary disadvantage of a spectrum analyzer is that it spends only a small fraction of its time on any one frequency. If the radiation is pulsed or highly variable in frequency, the spectrum analyzer can be a difficult device for establishing an average power reading. Most spectrum analyzers have a very poor input noise figure, so a preamp is usually required.

Interfering radiation can have such a wide variety of characteristic time scales and frequency spectra that it's hard to generalize on the best measurement parameters. Radio astronomy measurements generally involve long integrations and wide bandwidth so an average intensity over many seconds and more than one Mhz is usually appropriate. Still, some judgement is required because spectral line measurements are particularly sensitive to signal bandwidths of a few kHz, and pulsar observations are sensitive to sharply pulsed radiation with time scales of milliseconds. Be as specific as possible in the "Signal Character" entry of Table 1. Peak intensities can severely overestimate average signal strength, but, if peak-hold is the only way to record some kinds of emissions, a correction can be made, if a duty cycle can be determined.

In the table entries described below we shall write losses as negative numbers in dB and gains as positive numbers and assume this sign convention in the equations.

Notes on Table 1:

[1] The test antenna gain is in dB relative to an isotropic radiator. Occasionally, a gain relative to a half-wave dipole is given in an antenna's specifications. This would be 1.64 dB lower than the gain relative to isotropic. The gain applies to the antenna pattern maximum, so the device under test must be at the peak gain direction for this number to be valid.

[2] The receiver RF bandwidth is sometimes called the frequency resolution on a spectrum analyzer. We don't mean the video bandwidth which has to do with post-detection smoothing.

[3] The measured signal strength is the power level at the input to the spectrum analyzer in dB relative to 1 milliwatt. If the signal intensity is significantly variable, use an average over a time which is long compared to the variability time scale, if possible. Note any signal characteristics that might affect the accuracy of this average power measurement.

[4] The effective antenna collecting is computed from

$$A_{eff} = \frac{\lambda^2 G}{4\pi}$$

where λ is the wavelength in meters, and G is the antenna power gain as computed by

$$G = 10^{\frac{gain\ in\ dBi}{10}}$$

[5] The space loss is the ratio of the antenna collecting area to the total area of the sphere with a radius equal to the distance from the radiating device to the antenna.

$$L_s(dB) = 10\log_{10}\frac{A_{eff}}{4\pi D^2}$$

where D is the device-to-antenna distance in meters.

[6] The total loss is the algebraic sum of the total transmission line loss and the space loss (both negative) plus the preamplifier gain.

$$L_{tot} = L_{TL} + L_s + G_{PA}$$

[7] The radiated power in the passband is the algebraic difference of the measured signal strength (dBm) and the total loss minus 30 dB to convert from dBm to dBW. Since L_{tot} is usually negative, $P_{meas} - L_{tot} > P_{meas}$.

$$P_{rad}(dBW) = P_{meas} - L_{tot} - 30$$

[8] The radiated power per unit bandwidth is the radiated power in the passband divided by the receiver RF bandwidth less 60 dB to convert from MHz to Hz.

$$P_{ubw} = P_{rad} - 10\log_{10}B_{rf}(MHz) - 60$$

[9] The field strength at a selected distance from the radiating device is computed to find the radiation strength to be expected at the feed of a radio telescope and compare it with the radiometer sensitivity from the CCIR tables (below). The field strength is the radiated power per unit bandwidth divided by the area of the sphere whose radius is the selected distance.

$$P_{ex} = P_{ubw} - 10\log_{10}(4\pi R^2)$$

[10] CCIR Report 224-7 published two tables which give computed harmful fields strength limits for the radio astronomy bands under the assumption of receiver bandwidths equal to the allocated radio astronomy band width for continuum measurements and equal to a typical spectral line measurement resolution bandwidth. These values, interpolated between the radio astronomy bands, if necessary, may be entered into your worksheet for comparison with the computed field strength above. Use the CCIR table column labeled "Spectral power flux-density" to get power levels in units compatible with P_{ex}. Copies of the CCIR Report 224-7 tables are attached at the end of this report.

Devices with Published Radiation Limits

In the absence of specific device measurements or when a class of potential sources of interference are being considered, we can use the FCC radiation limits on the device class as a starting point for our interference evaluation. The worksheet for these calculations is in Table 2.

Notes on Table 2.

[9][10] See the notes on Table 1 for an explanation of these parameters.

[11] Because of the wide variety of radiating devices covered by the FCC rules, the units of the field strength limits are not always consistent. The most common units for incidental radiators, such as computers, are microvolts per meter at a specified distance, typically 3 meters. Sometimes you have to hunt for some of the information needed for our calculations. For example, the applicable bandwidth for the radiation limit on computing devices is given in ANSI Standard C63.4-1992 "Methods of Measurement of Radio Noise Emissions from Low Voltage Electrical and Electronic Equipment in the Range 9 kHz to 40 GHz." To convert microvolts per meter to Watts per square meter use Ohm's law with the impedance of free space:

$$P_{limit}(dBW/m^2) = 10\log\frac{10^{-12}E^2}{376.7}$$

where E is in μV/m.

[12] The radiated power in the prescribed bandwidth is the power equivalent of the field strength limit, P_{limit}, divided by the area of the sphere whose radius is the prescribed distance.

$$P_{rad} = P_{limit} + 10\log(4\pi r^2)$$

[13] The radiated power per unit bandwidth is the radiated power in the prescribed bandwidth, P_{rad}, divided by the prescribed bandwidth, b, less 60 dB to convert from MHz to Hz:

$$P_{ubw} = P_{rad} - 10\log_{10}b(MHz) - 60$$

Examples

To illustrate some typical numbers that might be entered in the worksheets, two examples are presented here. One is a measurement of a microwave oven, and the other is a calculation for computer workstations.

Microwave Oven

Figure 2 shows the measured spectrum of a microwave oven around 2450 MHz using an 8 dBi gain log periodic antenna at a distance of 6.1 meters. The transmission line loss was 1.5 dB, and no preamplifier was used. The RF bandwidth of the spectrum analyzer was 300 kHz. Table 3 shows the completed worksheet for the measured power level of the peak of feature A at about 2425 MHz in Figure 2.

Comparison of the computed field strength at a distance of 2 km at the bottom of Table 3 with the CCIR continuum limit must take account of the fact that the signal strength is not at the measured power level across the full passband of a typical continuum receiver. The width of the nearest radio astronomy band of 2700 MHz, for which the CCIR limit is taken, is 10 MHz. If we average the strength of signal A in Figure 2 across 10 MHz it would be about 5 dB lower than the measured -42 dBm. Across a 300 MHz bandwidth, the average power would be about 18 dB lower, or about -60 dBm. Changing from 10 to 300 MHz bandwidth would also reduce the harmful continuum limit by 7 dB from -247 to -254 dbW/m^2/Hz. The net effect is to make the difference between the harmful limit and the computed field strength at 2000 meters roughly the same for spectral line and continuum.

Computer Workstations

Table 4 shows a completed worksheet for a computer workstation, which is designated by the FCC as a Class B Computing Device. The FCC radiation limit on this device between 216 and 1000 MHz is 200 and 500 μV/m, respectively, at a distance of 3 meters as measured with a 100 kHz receiver bandwidth. The distance selected for the field strength calculation is approximately the distance from the GBT control room to the feed area on that telescope. The purpose is to see how much shielding of the telescope operator's and astronomer's work areas will be required. The calculated field strength is for one computer. Four workstations would produce an average power level 6 dB higher than shown in Table 4.

BACK

FIGURE 2 , BACK, VERTICAL POL.

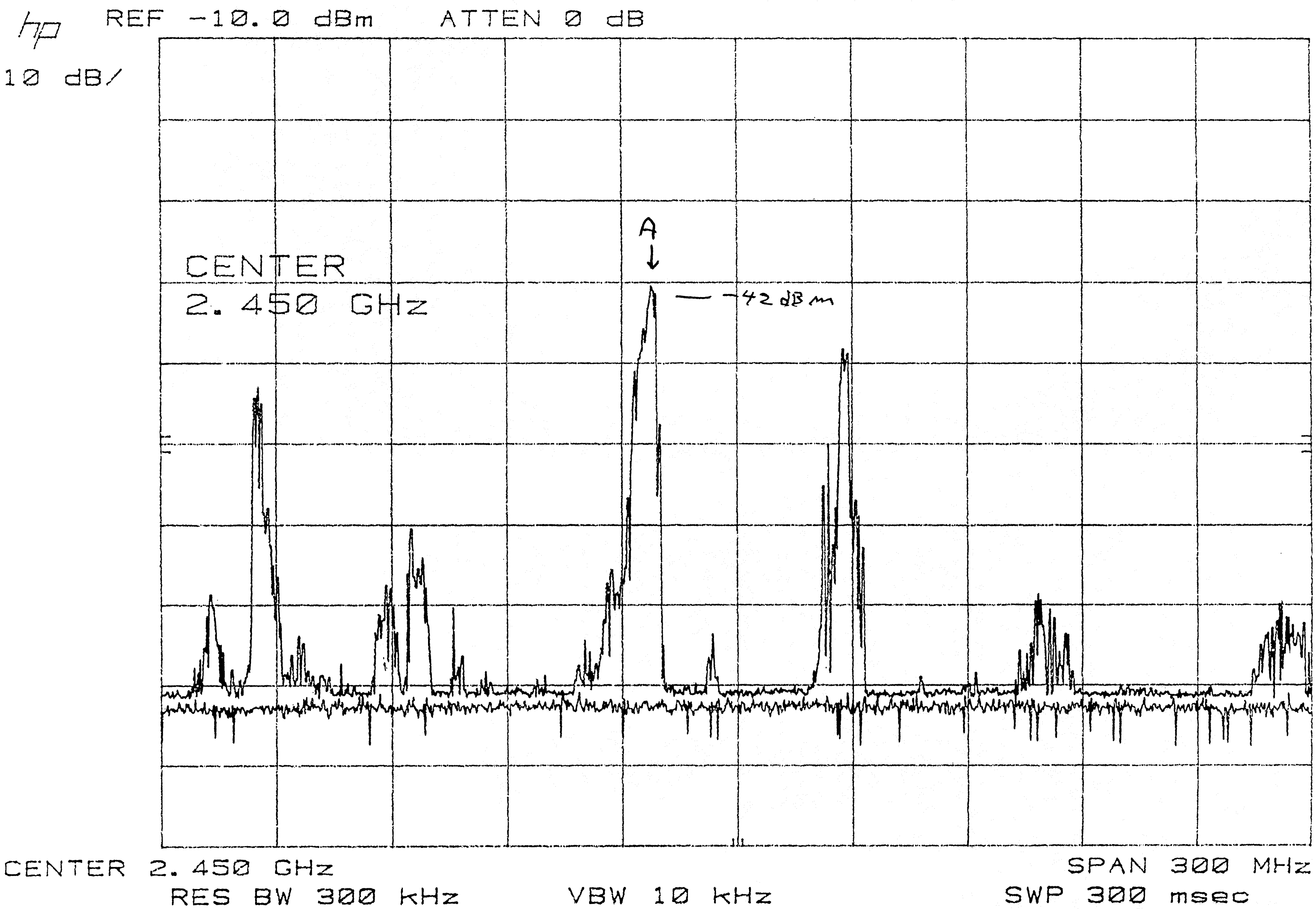

Table 3. Worksheet for Microwave Oven Measurement (Peak A in Figure 2)			
Test Setup Parameters (See Fig. 1)			
Frequency (MHz)		2425	
Wavelength (meters)		0.124	
[1] Test Antenna Gain (dBi)		+8	
Test Antenna Distance from Source (D in meters)		6.1	
Total Transmission Line Loss (L_{TL} in dB) (negative)		-1.5	
Preamplifier Gain (G_{PA} in dB) (positive)		---	
[2] Receiver RF Bandwidth (B_{rf} in MHz)		0.3	
Measured Parameter			
[3] Measured Signal Strength (P_{meas} in dBm)		-42	
Signal Character (CW, broadband, pulsed, swept, etc.):			
Noisey but generally constant during spectral sweep.			
Computed Parameters			
[4] Antenna Collecting Area (A_{eff} in meters^2)		0.0077	
[5] Space Loss (L_s in dB) (negative)		-47.8	
[6] Total Loss (L_{tot} in dB)		-49.3	
[7] Radiated Power in Passband (P_{rad} in dBW)		-22.7	
[8] Radiated Power per Unit Bandwidth (P_{ubw} in dBW/Hz)		-77.5	
Field Strength at Distance			
Selected Distance (R in Meters)		2000	
[9] Field Strength (P_{ex} in dBW/m^2/Hz)		-154.4	
[10] CCIR Limit (Line) (dBW/m^2/Hz)		-234	
[10] CCIR Limit (Continuum) (dBW/m^2/Hz)		-247	
Excess power above CCIR spectral line limit (dB)		79.6	

Table 4. Worksheet for Class B Computing Devices			
Radiation Limits Parameters			
Frequency (MHz)	300	1000	
[11] Prescribed Bandwidth (b in MHz)	0.1	1	
[11] Prescribed Distance (r in meters)	3	3	
[11] Field Strength Limit (P_{limit} in dBW/m^2)	-99.7	-91.7	
Computed Parameters			
[12] Radiated Power in Prescribed Bandwidth (P_{rad} in dBW)	-79.2	-71.2	
[13] Radiated Power per Unit Bandwidth (P_{ubw} in dBW/Hz)	-129.2	-131.2	
Field Strength at Distance			
Selected Distance (R in meters)	100	100	
[9] Field Strength (P_{ex} in $dBW/m^2/Hz$)	-180.2	-182.2	
[10] CCIR Limit (Line) ($dBW/m^2/Hz$)	-244	-240	
[10] CCIR Limit (Continuum) ($dBW/m^2/Hz$)	-258	-254	
Excess power above CCIR continuum limit (dB)	77.8	71.8	