CONTEST FOR THE SMALLEST AND MOST EFFICIENT SMALL ANTENNA

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Background

This document describes the rules for a contest for the smallest and most efficient small antenna. The contest is being done within the framework of ACE2, the FP6 Network of Excellence dedicated to antennas [1]. The contest is divided into different classes depending on the frequency band of operation and the design of the antenna. Both single and multi band antennas are considered. Special prizes for the winners in the different classes will be given.

Contents

Introduction

The physical limitations of small antennas are normally characterized in terms of their Q-value. Unfortunately, this approach is not very practical and does not account for losses and the corresponding radiation efficiency. Therefore, we have in this contest concentrated on measurements of the radiation efficiency as a function of frequency. The measured total radiation efficiency will contain both the contribution due to ohmic losses and mismatch, as separate parts and combined. The small antennas in the contest will be provided both by the contributing measurement labs themselves, and by other labs in or outside ACE. All results will be gathered and reported and compared to theoretical limitations for radiation efficiencies of small antennas. To make it more interesting to participate with good antenna designs we will finally select the antennas and labs which are the best in terms of the criteria defined in this document.

1 Definitions and terminology

In this document the following definitions and terminology are used.

We define the *radiation efficiency* as the ratio of the radiated power to the net power delivered to the antenna. The *total radiation efficiency* is defined as the ratio of the radiated power to the maximum available power. The latter is the radiated power of a lossless antenna in free space that is impedance matched to the source impedance, which we assume is 50 Ohms. Thus, the total radiation efficiency includes losses in the antenna itself, losses in the near-in environment of the antenna, and impedance mismatch. The definitions are given by:

$$\begin{cases} Radiation\ Efficiency = \dfrac{P_{rad}}{P_{in}} \\ Total\ \ Radiation\ Efficiency = \dfrac{P_{rad}}{P_{\max}} = \left(1-\left|S_{11}\right|^{2}\right)\dfrac{P_{rad}}{P_{in}} \end{cases}$$

where P_{in} is the net power delivered to the antenna, i.e. the power accepted by the antenna port.

The size of an antenna is defined by the diameter, $2a$, of the smallest possible sphere which completely encloses the antenna. If the antenna is mounted on a ground plane the size can be defined both with and without the ground plane, and we choose here to use both these definitions. The size is given in terms of the wavelength at the lowest frequency of the lowest frequency band.

2 Classes

In order to make the contest as fair and clear as possible the antennas should be submitted to one or several of the classes defined below. It is up to the participants to choose which class or classes their submitted antennas belong to.

The following classes are defined (see also Fig. 2.1);

- Single band (low band)
- Dual band (one low and one high band)
- Triple band
    - Two low bands and one high band
    - One low band and two high bands
- Quadruple band
    - Two low bands and two high bands
    - One low band and three high bands
- Wideband

The frequency bands used in the class definition are given by;

Low bands
824 – 894 MHz (GSM 800)
880 – 960 MHz (GSM 900)

High bands
1710 – 1880 MHz (GSM 1800)
1850 – 1990 MHz (GSM 1900)
1920 – 2170 MHz (WCDMA)

Wideband
A frequency band that covers two octaves. The lowest frequency must be specified by the participant.

Both antennas with and without a ground plane can participate in the contest. For antennas with a ground plane the size of the ground plane shall not be larger than 50 by 100 mm. Also, the size of the antenna must be smaller than the ground plane.

There must be at least three submitted antennas to a specific class in order to select a winner within that class.

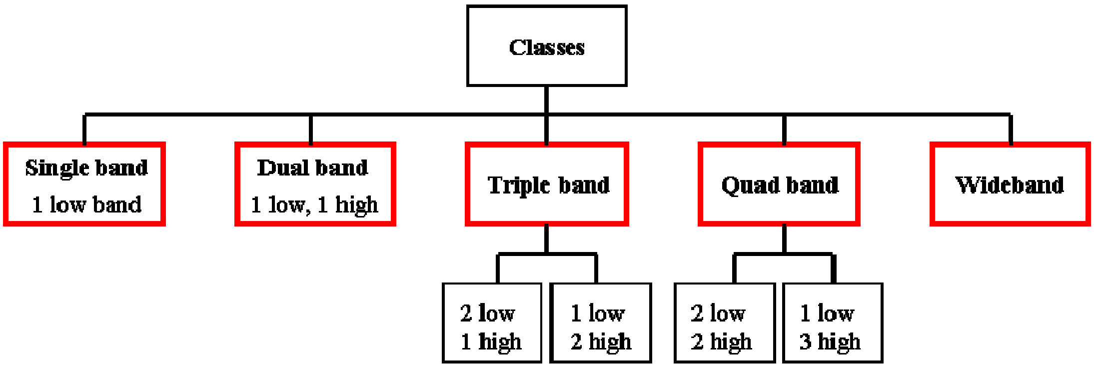

Fig. 2.1. The five classes used in the contest.

3 Criteria

The submitted antennas will be evaluated considering the criteria described here. Note that not all criteria are applicable for all classes and antenna types, see Fig. 3.1.

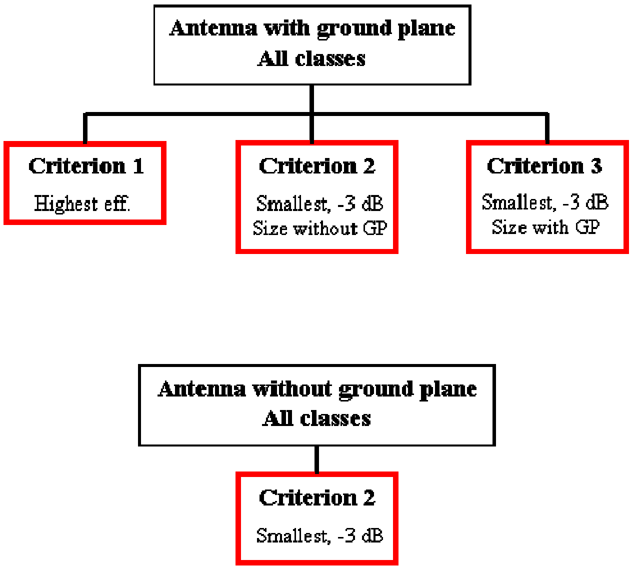

Fig. 3.1. Criteria for the different classes, for detailed explanations see the text.

3.1 Criterion 1 – Highest total radiation efficiency within band

The best antenna is the one that has the highest value of the lowest total radiation efficiency within the specified band, see Fig. 3.2. For multiband antennas the lowest value of the total radiation efficiency within all bands is considered.

This criterion is only applicable for antennas with a ground plane with a maximum size of 50 by 100 mm and the size of the antenna must be smaller than the ground plane, meaning that it must fit within the contour of the ground plane and have a height above the ground plane of maximum 10 mm. More specifically we mean with this that the combined antenna and ground plane unit fits within a rectangular volume of size 50 mm by 100 mm by 10 mm.

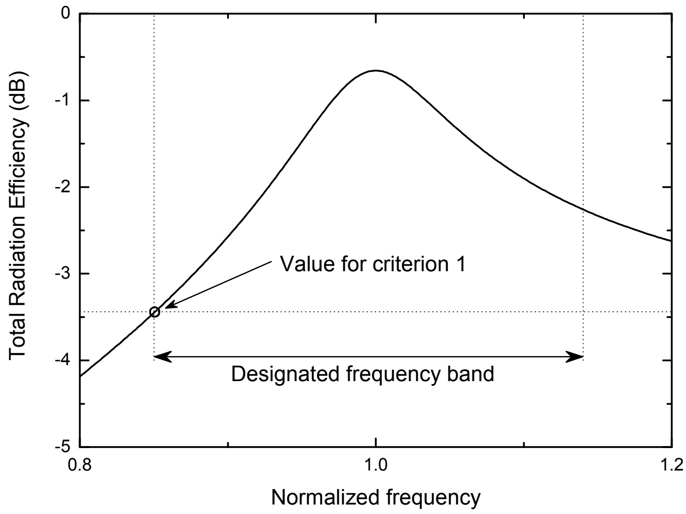

Fig. 3.2. Illustration of criterion 1.

3.2 Criterion 2 – Smallest antenna with a total radiation efficiency better than -3 dB over the whole band

The best antenna is the smallest antenna that has a total radiation efficiency that is better than -3 dB over the whole band, see Fig. 3.3. For multiband antennas the criterion must be fulfilled for all bands.

For antennas with ground plane the size is defined without the ground plane. Size is given in terms of the wavelength at the lowest frequency of the lowest frequency band at which the antenna is supposed to be used. The combined antenna and ground plane unit must fit within a rectangular volume of size 50 mm by 100 mm by 10 mm.

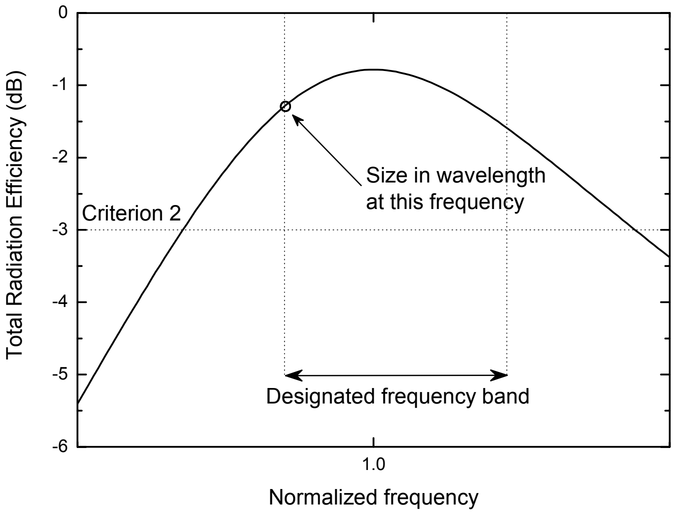

Fig. 3.3. Illustration of criterion 2.

3.3 Criterion 3 – Smallest antenna with a total radiation efficiency better than -3 dB over the whole band – Size including ground plane

The best antenna is the smallest antenna that has a total radiation efficiency better than -3 dB over the whole band, see Fig. 3.3. For multiband antennas the criterion must be fulfilled for all bands.

The size is defined as the diameter of the smallest sphere that encloses the combined antenna and ground plane unit. The size is given in terms of the wavelength at the lowest frequency of the lowest frequency band, or in the case of wideband antennas at the frequency above which the radiation efficiency is better than -3 dB over at least two octaves bandwidth.

4 Submission of antennas

When submitting an antenna to the contest the following points should be addressed;

- How measuring cable shall be mounted and routed
- Required additional devices, such as ferrites etc., must be included
- Type of coaxial connector (preferable SMA)
- Own measured results, if any, should be attached
- Which class(-es) the antenna is submitted to (see ch. 2)
- For antennas belonging to the class “Wideband” the frequency band must be specified

5 Measurements

Antennas submitted to the contest will be evaluated against the criteria described in this document by measurements. The measurements will be done by several labs that possibly are using different measurement methods. Thus, in order to avoid systematic errors and guarantee that the contest is as fair as possible antennas submitted to a specific class will all be measured by one lab using one measurement method.

It should be noted that there must be at least three submitted antennas to a specific class for measurements to be done and selecting a winner within that class.

6 References

[1] ACE – Antenna Centre of Excellence (http://www.ist-ace.org/).
[2] J. S. McLean, "A Re-Examination of the Fundamental Limits on the Radiation Q of Electrically Small Antennas", IEEE Transactions on Antennas and Propagation, vol. 44, No. 5, pp. 672-676, May 1996.

Appendix A – Fundamental limitations of small antennas

In this appendix expressions for the fundamental limitations of small antennas in terms of the radiation efficiency rather than the commonly used Q-value are derived. These expressions will be used as a comparison with measured values for the antennas participating in the contest.

According to McLean [2] the lowest possible radiation Q for a small linearly polarized antenna tuned to resonance by adding a reactive element, can be written as:

$$Q = \frac{1}{(ka)^3} + \frac{1}{ka} = \frac{2\omega_0 W_e'}{P_{rad}} \tag{1}$$

Where a is the radius of the smallest possible sphere which completely encloses the antenna, W_e' the time average electric stored energy and P_{rad} is the total radiated power. We assume the equivalent circuit for the antenna shown in Fig. A1.

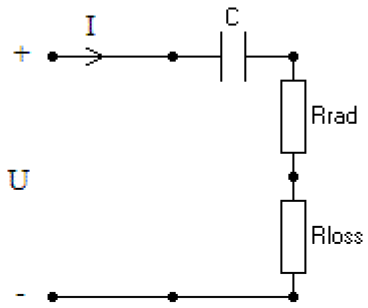

Fig. A1. Equivalent circuit for the small antenna.

The antenna is now matched at ω_0 by putting an inductance in series as is shown in Fig. A2.

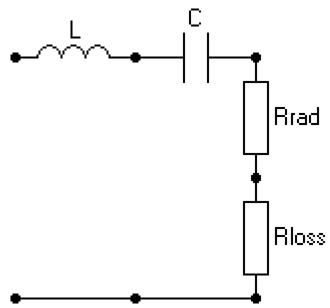

Fig. A2. Equivalent circuit for the small antenna including series matching inductance.

For matching at ω_0 the inductance must be:

$$\omega_0 L = \frac{1}{\omega_0 C} \;\Rightarrow\; L = \frac{1}{\omega_0^2 C} \tag{2}$$

Using (1) and the equivalent circuit in Fig. A2 we can express the Q-value as:

$$Q = \frac{2\omega_0 W_e'}{P_{rad}} = \frac{2\omega_0 \frac{1}{2} C \left|U_C\right|^2}{R_{rad}\left|I\right|^2} = \frac{\omega_0 C \left|\frac{I}{j\omega_0 C}\right|^2}{R_{rad}\left|I\right|^2} = \frac{1}{\omega_0 R_{rad} C} \tag{3}$$

The input impedance of the antenna including the matching inductor is given by:

$$Z_a(\omega) = R_{rad} + R_{loss} + j\omega L + \frac{1}{j\omega C} = \ldots = R_{loss} + R_{rad}\left(1 + jQ\frac{\omega^2 - \omega_0^2}{\omega\omega_0}\right) \tag{4}$$

The next step is to connect a generator with an internal impedance *R* as is shown in Fig. A3, whereby the efficiencies can be determined as:

Radiation efficiency, $e_{rad} = \dfrac{P_{rad}}{P_{in}} = \dfrac{R_{rad}}{R_{rad} + R_{loss}}$ (5)

And the total radiation efficiency, $e_{totrad} = \dfrac{P_{rad}}{P_{max}} = e_{rad}\left(1 - \left|r\right|^2\right)$ (6)

Where the reflection coefficient *r* is given by $r = \dfrac{Z_a - R}{Z_a + R}$ (7)

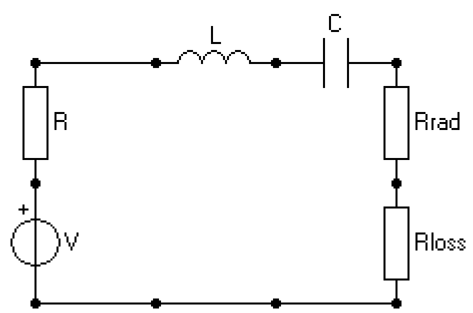

Fig. A3. Matched antenna connected to generator with internal impedance R.

The quantities in (5) – (7) can all be measured. The reflection coefficient, *r*, is at the resonance frequency ω_0.

$$r_{\omega_0} = \frac{R_{loss} + R_{rad} - R}{R_{loss} + R_{rad} + R} \;\Rightarrow\; R_{loss} + R_{rad} = R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} \tag{8}$$

The radiation resistance can by using (5) be expressed as.

$$R_{rad} = e_{rad}\left(R_{rad} + R_{loss}\right) = e_{rad} R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} \tag{9}$$

Using (4), (8) and (9) in (7) we get.

$$|r|^2 = \frac{\left(R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} - R\right)^2 + \left(e_{rad} R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right)^2}{\left(R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} + R\right)^2 + \left(e_{rad} R\frac{1+r_{\omega_0}}{1-r_{\omega_0}} Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right)^2} = \frac{4r_{\omega_0}^2 + \left[e_{rad}\left(1+r_{\omega_0}\right)Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right]^2}{4 + \left[e_{rad}\left(1+r_{\omega_0}\right)Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right]^2}$$

$$\Rightarrow\; 1-|r|^2 = \frac{4\left(1-r_{\omega_0}^2\right)}{4 + \left[e_{rad}\left(1+r_{\omega_0}\right)Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right]^2}$$

And the total radiation efficiency becomes.

$$e_{totrad} = e_{rad}\left(1-|r|^2\right) = \frac{4\left(1-r_{\omega_0}^2\right)e_{rad}}{4 + \left[e_{rad}\left(1+r_{\omega_0}\right)Q\frac{\omega^2-\omega_0^2}{\omega\omega_0}\right]^2} \tag{10}$$

The expression (10) is used for comparing the measured antennas with fundamental limitations whereby the Q-value is determined by the physical size through (1). Since the radiation efficiency, e_{rad}, is slowly varying with frequency we use the value at the resonance frequency, ω_0, in (10). In the following the total radiation efficiency given by (10) is plotted for a few examples.

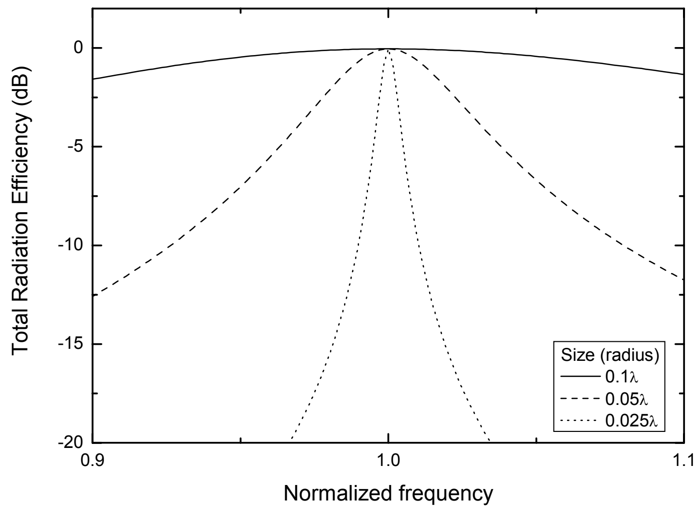

Fig. A4. Total radiation efficiency given by (10) for different antenna sizes. $e_{rad} = 0$ dB, $r_{\omega_0} = -10$ dB.

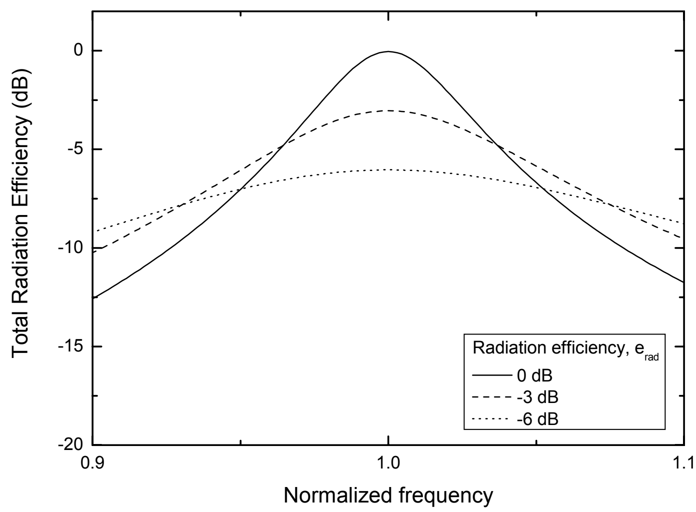

Fig. A5. Total radiation efficiency given by (10) for different e_{rad}*. Antenna size (radius)* 0.05λ *and* $r_{\omega_0} = -10$ dB.

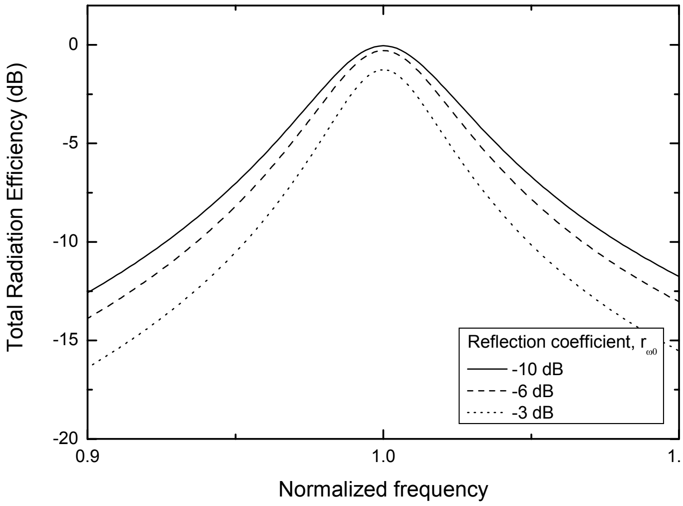

Fig. A6. *Total radiation efficiency given by (10) for different reflection coefficients,* r_{ω_0}. *Antenna size (radius)* 0.05λ *and* $e_{rad} = 0$ dB.