BLACK BODY AS AN ANTENNA AND TRANSMITTER COMBINATION

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Abstract

In the presented report energy balance characteristics of the black body radiation is reviewed on the basis of the antenna technology concept. It shows that electromagnetic energy may be traced to energy performance of an equivalent link line. The report introduces such concepts as equivalent virtual transmitter power defined by the Black Body temperature and size, as well as the virtual antenna characterized with constant gain equal 4 and chaotic polarization. The presented review results in determination of passive radar range equations.

Keywords: Plank Law, Raley-Jeans approximation, radio thermal emission, passive radar, radar range, antenna.

1. LEVELS OF THERMAL RADIO EMISSIONS

Corrected expressions for spectral density of thermal radio emission of a Black Body (BB) are got in the work [1] for Raley–Jeans Approximation. Formulas are calculated for work in both scales, the scale of frequencies, and the scale of wavelengths. For the frequency scale formula is the following:

$$\mathrm{dP}(\mathrm{f},\mathrm{T}) = \frac{2\pi k \mathrm{T} \mathrm{f}^2}{\mathrm{c}^2}\mathrm{df} \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right], \qquad (1)$$

where

df – an infinitely narrow bandwidth [Hz]
f - a point on the scale of frequency [Hz]
T-absolute temperature BB [K],
c – speed of the light
k - Boltzmann constant, equal 1,38 10^{-23} [J/K];

A similar formula for the scale of wavelengths have the form:

$$\mathrm{dP}(\lambda,\mathrm{T}) = \frac{2\pi c k \mathrm{T}}{\lambda^4}\mathrm{d}\lambda \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right], \qquad (2)$$

where
$d\lambda$ is an infinitely small interval of wavelength [m], λ is a point on the scale of wavelengths [m].

We can notice that in both formulas, m^2, presented in the square brackets, means «from the square meter of surface BB».

Specific radiometric system is designed to receive reception of thermal signals in certain bandwidth or wavelength. The corresponding total radiated power may be obtained by the integration of expressions (1) and (2).

$$\mathrm{P_{tot}}(\mathrm{f_1},\mathrm{f_2},\mathrm{T}) = \frac{2}{3}\frac{\pi k \mathrm{T}}{\mathrm{c}^2}\left(\mathrm{f}_2^3 - \mathrm{f}_1^3\right) \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right] \qquad (3)$$

$$\mathrm{P_{tot}}(\lambda_1,\lambda_2,\mathrm{T}) = 2\pi k \mathrm{T}\left(\frac{1}{\lambda_2^3} - \frac{1}{\lambda_1^3}\right) \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right] \qquad (4)$$

2. DIRECTIVITY OF THERMAL RADIO EMISSION

Directivity power of thermal radio emission of an elementary area BB is described by the law cos θ, where θ is the angle between local normal and direction on the observation point (Lambert's Law). It is obvious, that the contribution into a signal at a reception point is brought only segmental surfaces of BB, which is visible from a point of reception [2]. This circumstance makes it possible to reduce emission of volumetric BB to the emission of Black surface.

Indeed, in terms of power flux density in a far point of observation , radiation of 3D BB is equivalent to radiation of Black surface, the shape and dimensions of which correspond to the projection of real BB on a plane perpendicular to the line "BB-point of observation". Because the radiation pattern of emission of a Black surface has an axial symmetry with the maximum, which is always directed to the point of observation and, as it was mentioned above, it is described by the law cos θ, the gain is always equal 4.

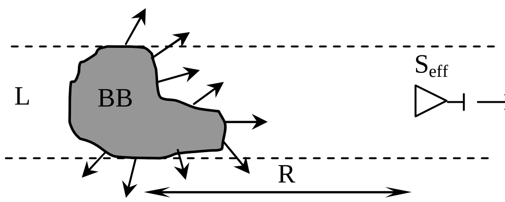
Effective equivalent transmitter power in watts is equal to the product of the levels of radiation, described by equation (3) and (4) and the surface area of the above projection BB.

3. POLARIZATION OF RADIATION

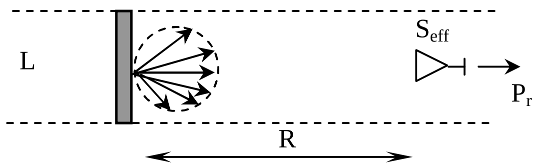
In any sufficiently remote from BB point of space, electromagnetic wave is a spherical wave with chaotic polarization. As all states of polarization are equally probable on the output of any specific receiving antenna, only half of the power that may be received by total matching of polarization states of the receiving antenna and falling on it field.

4. POWER RELATIONS OF THE LINK

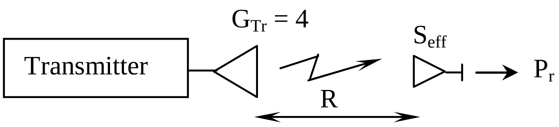
Thus, the link «BB is a receiver at the point of observation» that reduces to the usual link, as it is shown in Fig. 1.



a) the line of passive radar



b) a replacement of 3D BB on the flat black surface



c) Equivalent radio link

Fig. 1. Passive radar as common radio link

As it is known, the power output of the receiving antenna in link for the case of free space is described by the Friis formula

$$P_r = \frac{P_{Tr} G_{Tr} S_{eff}}{4\pi R^2}, \qquad (5)$$

where

P_{Tr} - power of transmitter,

G_{Tr} - gain,

S_{eff} - reception area of the receiving antenna,

R - the length of the link.

As it was mentioned above, the gain is always equal 4. What concerns the power of equivalent transmitter, it is determined by the product of expression (3) or (4) to the square projection BB observed from the point of reception of S_t. Thus, the power of signal at the output of the receiving antenna can be written for the scale of frequencies in the following products:

$$P_r = \frac{2\pi k T}{3 c^2}\left(f_2^3 - f_1^3\right) S_t \times 4 \times \frac{1}{4\pi R^2} \times S_{eff} \times 0{,}5. \qquad (6)$$

In the formula (6) the first term represents the power of equivalent transmitter, the second - the gain of the virtual antenna and the third multiplier takes into account the sphericity of emitted waves. The fourth multiplier describes the quality of the receiving antenna and by fifth factor the unavoidable polarized losses during receiving emission are taken into account. In a more laptop form, the equation (6) has the form:

$$P_r = \frac{k T\left(f_2^3 - f_1^3\right) S_t \cdot S_{eff}}{3 c^2 R^2}. \qquad (7)$$

If the receiving power is put equal to smoothness of receiving channel of the passive radar P min, we get the equation for the range of passive radar.

$$R_{max} = \sqrt{\frac{k T\left(f_2^3 - f_1^3\right) S_t \cdot S_{eff}}{3 c^2 P_{min}}}. \qquad (8)$$

This equation can be regarded as an analogue of a well-known basic equation of the primary radar (see, for example, [3]).

Expressions (6 - 8) relate to the case when BB - radar target is point target. Similar expressions can be obtained for the case when the angular dimensions BB exit beyond the beam of the receiving antenna.

In addition, these equations can be easily transformed for the case of radio radiation of the Gray Bodies.

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