Cyclical Wave Bolt for Electromagnetic Waves

Vladimir V. Arabadzhi

***Abstract*— The alternative conception of "black body" (in the wave diffraction sense) is represented in this article for electromagnetic waves. Spatial interior construction of black body is presented by thin micro-structure having boundaries like foam or, in other words, cavities or cells (virtual resonators with oscillatory fading) separated from each other by very thin walls of controlled transparency. Temporal control these boundaries (walls) is very fast periodical switching between nonreflecting (opened, transparent) and the reflecting (closed, opaque) states of walls. Therefore the oscillations, caused by these initial conditions, are fading as faster, as we choose smaller the spatial dimensions of virtual resonator. The interior parametric microstructure of black body absorbs any field of any frequency which comes from any direction, if the duration of transparent state of parametric walls is very greater, then the reflecting (opaque) state duration. The scattering of incident wave by the parametric black body is described analytically. Possible practical implementations of parametric black body and parametric "thin black skin" (superwideband and very thin in comparing with the length of the incident wave) are described in this article.**

***Index Terms*— Cyclical Wave Bolt, Virtual Resonator, Absorption, Incident Wave, Initial Conditions, Piercing of Wave Field, Temporal Microstructuring Parameter, Spatial Microstructuring Parameter**

I. Introduction

This paper is devoted to problem of body's visibility reduction in electromagnetic waves, when electromagnetic wave falls on the body protected (target) concerned inside arbitrary closed surface S_0. A simplest and most general illustration of radar problem [1] is presented in Figure 1:

($\hat{\mathbf{I}}$) irradiating source with its database (direction $\mathbf{n}_I$ of incident wave arrival, frequency ω_I, wave length λ_I, polarization $\hat{\mathbf{P}}_I$ and shape S_I of wave front);

($\hat{\mathbf{S}}$) scattering field with its database (direction of scattering wave $\mathbf{n}_S$, polarization $\hat{\mathbf{P}}_S$);

($\hat{\mathbf{R}}$) receiver with its database (direction of receiving $\mathbf{n}_R$, polarization $\hat{\mathbf{P}}_R$).

Generally we consider ensemble of points $\mathbf{r}$ (volume), belonging to body restricted by surface S_0, we shall define as $\hat{V}(S_0)$, i.e. $\mathbf{r} \in \hat{V}(S_0)$. Therefore we form some surface $\bar{S}_0$ shifted inside S_0 in a depth L. Surface $\bar{S}_0$ restricts the "inner body" (volume) inside $\bar{S}_0$ with points $\mathbf{r} \in \hat{V}(\bar{S}_0)$. Combination $\hat{L} \cup \hat{V}(\bar{S}_0) = \hat{V}(S_0)$ of ensembles $\hat{V}(S_0)$ and $\hat{V}(\bar{S}_0)$ of points forms the layer $\hat{L}$ of thickness $L = L[\mathbf{r}(S_0)] = \min_{\mathbf{r}(\bar{S}_0)} \left|\mathbf{r}(S_0) - \mathbf{r}(\bar{S}_0)\right|$, where $\mathbf{r}(S_0) \in S_0$, $\mathbf{r}(\bar{S}_0) \in \bar{S}_0$ are the points of surfaces S_0 and $\bar{S}_0$ accordingly. Electromagnetic incident wave of arbitrary front shape S_I, i.e. $\forall S_I$ (plane, spherical, cylindrical…) is falling to this body with characteristic geometrical scale D_0. Wave frequency ω_I and wave length λ_I of this wave satisfy band conditions $\omega_{\min} \le \omega_I \le \omega_{\max}$ and

$$2\pi c / \omega_{\max} = \lambda_{\min} \le \lambda_I \le \lambda_{\max} = 2\pi c / \omega_{\min}, \qquad (1)$$

where c - light speed in vacuum and borders $\omega_{\min}$, $\omega_{\max}$, $\lambda_{\min}$, $\lambda_{\max}$ satisfy conditions

$$(\omega_{\max} / \omega_{\min}) \gg 1, \quad \lambda_{\min} \ll D_0 \ll \lambda_{\max}. \qquad (2)$$

Arrival direction $\mathbf{n}_I$ ($|\mathbf{n}_I| = 1$), which we are interested in, of the falling wave with direction angles ϑ_I, φ_I is assumed arbitrary, i.e. $0 \le \vartheta_I < \pi$, $0 \le \varphi_I < 2\pi$, taking into account formulas $(\mathbf{n}_I, \bar{\mathbf{x}}) = \sin(\vartheta_I)\cos(\varphi_I)$, $(\mathbf{n}_I, \bar{\mathbf{y}}) = \sin(\vartheta_I)\sin(\varphi_I)$, $(\mathbf{n}_I, \bar{\mathbf{z}}) = \cos(\vartheta_I)$, where $\bar{\mathbf{x}}$, $\bar{\mathbf{y}}$, $\bar{\mathbf{z}}$ are vectors of cartesian basis (where $|\bar{\mathbf{x}}| = |\bar{\mathbf{y}}| = |\bar{\mathbf{z}}| = 1$). General statement of radar problem and problem of body's visibility reduction in electromagnetic waves is illustrated in Figure 1, where $\hat{\mathbf{I}}$ - database of the incident waves ($\mathbf{n}_I$), $\hat{\mathbf{S}}$ - database of scattering waves ($\mathbf{n}_S$), $\hat{\mathbf{R}}$ - database on receivers of scattering waves ($\mathbf{n}_R$). At above conditions we need to reduce scattering of falling wave by the design of wave media parameters distribution inside the layer (coating, skin) $\hat{L}$ of thickness $L \ll \lambda_{\min}, D_0$. Last requirement to layer $\hat{L}$ is connected with the directions $\mathbf{n}_R$ and polarizations $\mathbf{P}_R$, in which receivers measure the scattering field. Generally the body's visibility reduction in electromagnetic waves problem has these wellknown several (not all of course) approaches and directions for solution:

(a) Cloacking. Full suppression of any scattering. Due to a special spatial (constant in time) inside $\hat{L}$ this layer can embroil falling wave inside of itself without any scattering both to backward and forward. Generally, i.e. at arbitrary shape of body S_0, arbitrary frequency ω_I of falling wave, arbitrary shape S_I of falling wave front, arbitrary direction $\mathbf{n}_I$ of falling wave arrival) this solution will give us a special structure $\hat{\mathbf{Y}}[\mathbf{r}] = \hat{\mathbf{Y}}[\mathbf{r}; S_0, S_I, \omega_I, \mathbf{n}_I, \mathbf{P}_I]$ (ensuring the absence of scattering) of layer $\hat{L}$ for each set of parameters S_0, S_I, ω_I, $\mathbf{n}_I$, $\mathbf{P}_I$.

Vladimir V. Arabadzhi, Institute of Applied Physics (Russian Academy of Sciences) , Nizhny Novgorod, Russian Federation, Phone/ +7 952 765 29 77

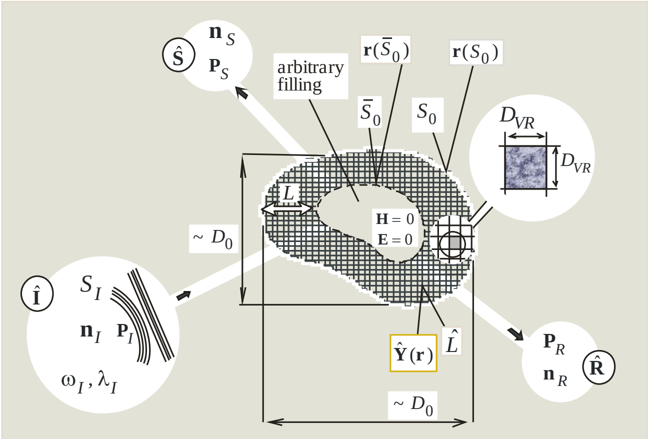

Figure 1

Very beautiful analytical result [2] was obtained for spherical surface S_0 of body protected, for a plane front S_I of incident wave and one frequency ω_I. Authors used a spherical model. We can say "methamaterials", when the structure $\hat{\mathbf{Y}}[\mathbf{r}]$ of layer $\hat{L}$ is tangentially constant (or uniform, i.e. does not depend on the incident wave direction $\mathbf{n}_I$ on spherical surface S_0), and we place this methamaterial on the body (spherical) to be protected. However, authors assumed only plane shape of a front S_I of incident wave. If this shape is spherical within body's volume, for instance, so we will get another structure $\hat{\mathbf{Y}}[\mathbf{r}]$ of layer $\hat{L}$, than we had a for plane surface S_I. On the other hand, taking ellipsoidal S_0 instead spherical S_0 we must get the dependence $\hat{\mathbf{Y}}[\mathbf{r}]$ of $\mathbf{n}_I$, when this vector is not along axis of ellipsoid S_0. The structure $\hat{\mathbf{W}}[\mathbf{r}]$ is sensitively dependent of frequency ω_I and can't be effective for two non identical frequencies simultaneously. Besides above mentioned questions, power density of the field inwardly layer $\hat{L}$ under cloaking must be in $\sim D_0/(L\pi) >> 1$ times greater, than in falling wave. In addition, we must remember, that implementation of desired ratios between phases and amplitudes of discrete elements of cloak structure has a resonant implementation (with reference to one frequency ω_I), i.e. with amplitudes of reactive fields much greater, than in the incident wave.

(b) Conversion of scattering field into the waves with polarization, for which the receivers are non-sensitive [3] (twist-effect). This difficulty on way of the target detection, of course, can be avoided by choose of appropriate receiver.

(c) Absorption of incident wave, conversion of back scattering field into heat (absorption must cause forward scattering) – reduction only back-scattering without reduction forward scattering. Phenomenological definition of the black body of the body states: black body should absorb any incoming wave, but non resonantly, when absorption is accompanied by powerful reactive fields. The last are necessary to guide power of incident wave to the absorbing surface. The case of large body, when $D_0 >> \lambda_I$ is described by geometrical optics [4] – [6]. For a system with time-constant parameters, two absorption patterns are known:

(c1) Nonresonance absorption in a thick layer of a weakly absorbing material of thickness. Such a coating is insensitive to the direction of the incident waves and their frequency, but requires large dimensions

(c2) Resonance absorption by discrete small-sized oscillators generates a high sensitivity to the direction and frequency of the incident waves, as well as to the accuracy of the elements.

Our goal is broadband absorption in a thin layer, not sensitive: to the accuracy of the elements, to the directions of incident waves, to the shape incident wave front. The tool for solving the problem is the modulation of the environment parameters in a layer with a high spatial-temporal resolution.

II. One Dimensional Cyclical Wave Bolt

Let' assume, that some electromagnetic wave with electric vector $\mathbf{E}_I(x-ct)$ (along axis vector $\bar{\mathbf{y}}$) and magnetic vector $\mathbf{H}_I(x-ct)$ (along axis vector $\bar{\mathbf{z}}$), satisfying the relation $\mathbf{E}_I(\xi) = Z_I \mathbf{H}_I(\xi)$, Z_I - wave resistance in vacuum, runs (along axis vector $\bar{\mathbf{x}}$, $|\bar{\mathbf{x}}| = 1$) in vacuum from left to the right. This wave falls on the interval $0 \le x \le L$. Below we'll consider one dimensional boundary problem, where electric field $\mathbf{E}(x,t)$ is always parallel to axis vector $\bar{\mathbf{y}}$ ($\mathbf{E}(x,t),\bar{\mathbf{y}}) = E(x,t)$, $(\mathbf{E}(x,t),\bar{\mathbf{z}}) = 0$) and magnetic field $\mathbf{H}(x,t)$ is always parallel to axis vector $\bar{\mathbf{z}}$ ($\mathbf{H}(x,t),\bar{\mathbf{z}}) = H(x,t)$, $\mathbf{H}(x,t),\bar{\mathbf{y}}) = 0$). Minimum spatial scale $\lambda_{\min}$ of the fields $\mathbf{E}_I(\xi)$ and $\mathbf{H}_I(\xi)$ satisfies the above condition (1), (2). We want to ensure minimum reflected field at $x \le 0$ (running to the left) and minimum wave field at $x \ge L$ (running to the right).

A. *Structure of Cyclical Wave Bolt*

Below we define the structure of cyclical wave bolt (CWB). A large number $N >> 1$ of walls are spaced equidistantly on the spatial interval $0 \le x \le L$ with spatial period

$$D_{VR} = L/(N-1) \tag{3}$$

in the points

$$x = x_n = nD_{VR} \quad (n = 0,1,2,..., N). \tag{4}$$

Each wall of thickness D_w is very thin in contrast with period D_{VR} , i.e.

$$D_w << D_{VR} . \tag{5}$$

Reflection coefficient $R_w(t)$ of each wall is switched alternately in time between transparent state with $R_w = R_{tr}$, where R_{tr} satisfies condition

$$|R_{tr}| << 1 , \tag{6}$$

and opaque state with $R_w = R_{op}$, where R_{op} satisfies condition

$$0 \le 1 - |R_{op}| << 1 . \tag{7}$$

Reflection coefficient $R_w(t)$ of each wall is switched simultaneously for all walls with temporal period

$$T = \tau_{op} + \tau_{tr} \,, \tag{8}$$

where τ_{op} is duration of opaque state of a wall, τ_{tr} is duration of transparent state of a wall. Besides this we connect the time τ_{tr} with the length L by the condition

$$\tau_{tr} c = L \,. \tag{9}$$

The switching from transparent state to opaque one (and back) takes a time τ_{sw}, which satisfies the conditions

$$\tau_{sw} << \tau_{tr}, \tau_{op}, D_{VR} / c \,. \tag{10}$$

Spatial interval between any two adjacent opaque walls represents resonator named below as "virtual resonator" (VR) with own frequencies

$$\omega_n = \pi c n / D_{VR} \tag{11}$$

(where $n = 1,2,3,...$, *i.e. there are no zero own frequency*). VR's lifetime is τ_{op}. During τ_{op} amplitude of the free oscillations in VR falls off in $1/\chi$ times, where

$$\chi = \exp(-\alpha N_r) \,, \tag{12}$$

$\alpha = \alpha(\omega_n)$ - decrement of dissipative fading (we must point relations $\alpha(\omega_1) < \alpha(\omega_2) < \alpha(\omega_3) \ldots$),

$$N_r = c\tau_{op} / D_{VR} \tag{13}$$

is number of wave-runs along VR. So we can state, that cyclical wave bolt (CWB) has transparent (nonreflecting) temporal intervals

$$t_m - \tau_{tr} \le t \le t_m \,, \tag{14}$$

and opaque (reflecting) temporal intervals

$$t_m \le t \le t_m + \tau_{op} \,, \tag{15}$$

where $t_m = mT$, $m = 0,1,2,3,...$ Ideal CWB's temporal structure (with temporal period T) is represented by expression

$$\Phi(t) = |R_w(t)| = \sum_{n=-\infty}^{\infty} \{ I[t - nT] - I[t - nT - \tau_{op}] \} \tag{16}$$

Ideal CWB's spatial structure (with spatial period D_{VR}, see Figure 2 – *b*) is represented by expression

$$\Psi(x) = \sum_{n=1}^{N} \{ I[x - (n-1)D_{VR}] - I[x - (n-1)D_{VR} - D_W] \}, \tag{17}$$

where $I(\xi) = 1$ at $\xi < 0$ and $I(\xi) = 0$ at $\xi \ge 0$.

Temporal (*a*) and spatial (*b*) structures of cyclical wave bolt (gray background shows space-time scales of incident wave) are presented in Figure 2.

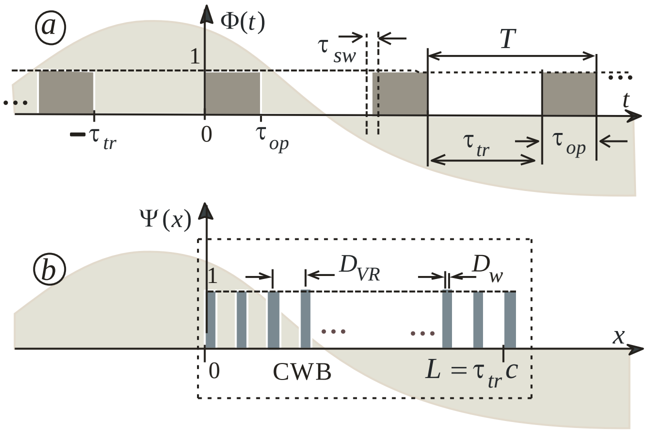

Figure 2

So we can suppose, that opaque state can be realized by good electric conductivity of a wall, for instance. And therefore conductivity can be defined by the following space-time structure

$$\sigma(x,t) = \Phi(t)\Psi(x)G \,, \tag{18}$$

where $G = \text{const}$ is a magnitude of electric conductivity. This structure corresponds to wall reflection coefficient

$$|R_w(t)| = \Phi(t)|R_{op}| + (1 - \Phi(t))|R_{tr}| \,, \tag{19}$$

modulated in time. Note, that the above switching operations (16), (17) piercing wave field instantaneously, is energetically neutral to wave field and corresponds to the following boundary condition

$$\Phi(t)E(x_n, t) = 0 \tag{20}$$

modulated in time in points (4) of walls installation. At moments $t_m = mT$ ($m = 0,1,2,3,...$) all conducting plane walls pierce continuous current distributions of electric $\mathbf{E}$ and magnetic $\mathbf{H}$ wave fields instantaneously (for time τ_{sw}, see condition (10)). At these moments wave field (divided by N opaque walls into a lot of spatial pieces) is becoming the initial condition for the oscillations within each VR. This echelon of opaque walls exists since moments $t_m = mT$ and up to the moments $t_m + \tau_{op}$ for the time τ_{op}. The space-time structure, described by (3) – (18), will be hereinafter called "cyclical wave bolt" (CWB) [7]. In principle, magnetic version of walls opacity can be offered too (when $\sigma(x,t)$ means magnetic conductivity for instance)

$$\Phi(t)H(x_n, t) = 0 \,. \tag{21}$$

Morover, if we have such quick magnetic switches, we would make invisible body with the help of only one controlled wall around body protected. For this we need only fast periodical switching between ideal electric and ideal magnetic reflections with interleaving in time boundary conditions

$$[1 - \tilde{\Phi}(t)]\mathbf{H}(0,t) + \tilde{\Phi}(t)\mathbf{E}(0,t) = 0 \,, \tag{22}$$

where

$$\tilde{\Phi}(t) = \sum_{m=-\infty}^{\infty} \{ I[t - mT] - I[t - mT - (T/2)] \} \,. \tag{23}$$

Space-time diagrams of one dimensional CWB are presented in Figure 3 : (*a*) outside CWB with transparent walls (t_1 , t_2 , t_6 , t_7) and opaque walls ; (*b*) inside CWB with opaque walls (t_3, t_4, t_5, t_8 , t_9).

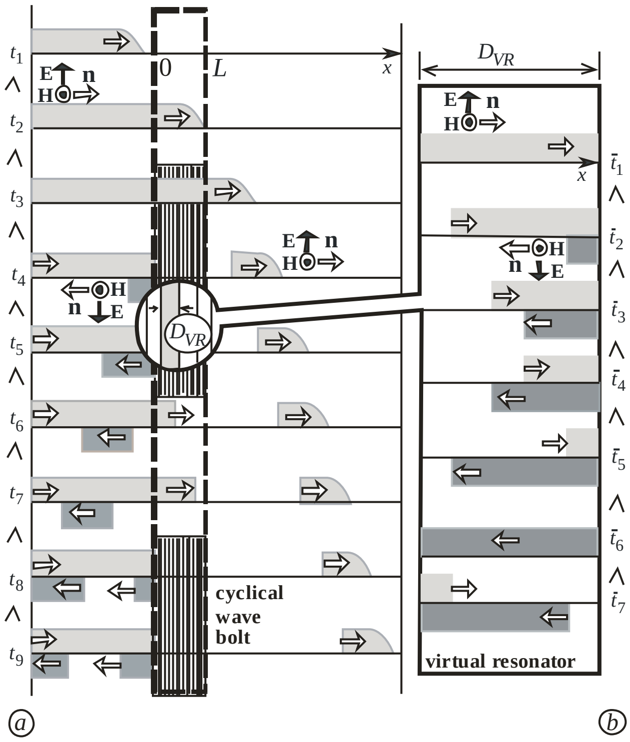

Figure 3

2. *Estimation of Reflections from Cyclical Wave Bolt*

We consider temporal representation for exterior and interior waves of CWB. To satisfy above mentioned aims we will search the desirable relations between following parameters N_r, T, D_{VR}, α, L, τ_{tr}, τ_{op}. At first we can state the obvious condition $\tau_{tr} >> \tau_{op}$, under which other relations should be considered. At moment $t = 0$ (and up to the moment $t = \tau_{op}$, Figure 1 – b) each wall becomes opaque in the time τ_{sw}. Wave field between adjacent walls becomes the initial conditions inside VR with very high minimum own resonant frequency $\omega_1 = \pi c / D_{VR}$. Finite electric conductivity (20) of opaque walls causes exponential oscillation fading inside VR. In the time τ_{op} wave will make $N_r = \tau_{op} c / D_{VR}$ runs along VR and have amplitude in $1/\chi$ times less, than initial amplitude, where $\chi = \exp(-\alpha N_r) \le e^{-2}$, $\alpha = 1/Q$ – fading decrement ($Q \ge 2$ is resonant quality factor), caused by finite electric conductivity $G < \infty$ (24). On the lowest own frequency $\omega = \pi c / D_{VR}$ of VR we estimate the quality factor as $Q = D_{VR} / D_{sk} = \sqrt{G\mu_0 \pi c D_{VR} / 2}$, where $D_{sk} = \sqrt{2 / G\omega\mu_0}$ - thickness of skin layer in the VR's wall, ω - frequency of wave field, μ_0 - magnetic permeability of vacuum. To ensure the oscillation mode of attenuation in the resonator it is desirously $Q \ge 2$, to ensure the impermeability of the closed walls of the resonator, the condition $D_w \ge 2D_{sk}$. We can estimate time averaged reflection coefficient $|R_{CWB}|$ of CWB as a sum $|R_{CWB}| \le |R_1| + |R_2|$, where $|R_1|$ – component of reflection coefficient $|R_1| \approx \tau_{op} / T << 1$, corresponding to the opaque intervals (15) of CWB, $|R_2|$ – component of reflection coefficient $|R_2| \approx \tau_{tr} \chi / T$, corresponding to microscale waves (with spatial scales $\le D_{VR}$ and temporal scales $\le D_{VR} / c$), which have not enough time ($\tau_{op} << T$) to relax inside VR to zero. As we always need smaller value $|R_{CWB}|$, therefore let search for minimum $|R_{CWB}|$ by varying the ratio $\nu = \tau_{op} / T$ (i.e. $(\partial / \partial \nu)|R_{CWB}| = 0$ at $\nu = \nu_{\text{opt}}$). Hereinafter we obtain minimum value

$$|R_{CWB}|_{\min} = \Gamma = (\ln A) / A << 1 \qquad (24)$$

at $(\tau_{op} / T)_{\text{opt}} = \Gamma << 1$, and $A = \alpha M_x / M_t >> 1$, where

$$M_t = T / \tau_{op} = 1/\nu \qquad (25)$$

is temporal microstructuring parameter of CWB and

$$M_x = L / D_{VR} \qquad (26)$$

is spatial microstructuring parameter CWB. The expressions (24) and (26) mean, that at any $\alpha \le 0.5$ the thin layer $0 \le x \le L$ ($L / \lambda_I << 1$) can absorb very quickly (during the time τ_{op}) and periodically (with temporal period T) the consequent little portions (of length $L = cT$) of any long incident wave, if we take sufficiently large microstructuring parameter M_x. Therefore, planning to obtain reflection coefficient $|R_{CWB}| = \Gamma$ (we point, that $\Gamma = \Gamma(L, T, M_x, M_t, \alpha)$) we must use the following microstructuring parameters

$$M_t = (T / \tau_{op})_{\text{opt}} = 1/\Gamma >> 1$$

and $$M_x = L / D_{VR} = f(\Gamma)/(\Gamma\alpha) >> 1, \qquad (27)$$

where $f(\xi)$ is such a function, which gives us $f[\ln(\xi)/\xi] = \xi$ or inverse function to $\ln(\xi)/\xi$.

In the above CWB description, the problem is not formulated in strict form for the system of Maxwell's equations with instantaneous values of the fields, with boundary conditions that vary in time, with finite conductivity of walls. Such a problem can not be solved analytically strictly (as combined boundary problem for the entire microstructure as a whole and in the time representation in addition) even in one dimension representation. In the above, it was assumed that the walls are arranged equidistantly. At first glance, one can expect unaccounted-for spatial resonances in the propagation of waves. But nothing prevents us from placing walls in the points $x = x_n = nD_{VR} + \xi_n$ with small random deviations ξ_n from spatial period D_{VR}, with $< \xi_n >= 0$ and $\left(< \xi_n^2 >\right)^{1/2} << D_{VR}$, which excludes any spatial resonances. Since the operations of switching on and off the conductivity of the walls control the dissipative parameter of the system (switching frequency is far from plasmonic resonance and the field does work on the moving charges of the conductor), then such a commutation can not introduce instability into the system (radiation into resonator).

III. Three Dimensional Black Body

Now we can formulate CWB structure in tree-dimensional case. Now we can formulate CWB structure in three-dimensional case. Let's fill the volume $\hat{V}(S_0)$ (with characteristic spatial scale $\sim D_0$, Figure 1) by the foam-like structure, consisting of the little empty three dimensional volumes (with characteristic space scale $\sim D_{VR}$) separated from each other by thin (with thickness $\sim D_w << D_{VR} << D_0$) walls of transparency controlled, analogous with above walls. Relations (24) – (27) are qualitative applicable to the three-dimensional CWB, when $\Gamma << 1$.

Main resemblance with one-dimensional case: (a) 3-D virtual resonators do not have zero own frequency (due to boundary condition on the "metallic" walls, when they are opaque) with minimum own frequency $\omega_{\min} \approx \pi c / D_{VR}$; (b) the fields $\mathbf{E}$, $\mathbf{H}$ "zeroizing" in opaque states of walls takes the same small time $\sim \tau_{op}$. In 3-D case the attenuation in the virtual resonators can be provided not only by the walls, but also by miniature vibrators placed inside them, tuned to resonance absorption at the frequencies (11). Such vibrators do not scatter the field at the frequency of the incident wave (when walls are transparent) and are effective only with the opaque walls of the resonators. If $\Gamma = \Gamma(L, T, M_x, M_t, \alpha) << 1$, (see (24) – (27)), we can use the black layer $\hat{L}$ (or black skin) of thickness L instead black body with dimension D_0, when $L < D_0$. Hereinafter, the area $\hat{V}(\bar{S}_0)$ (see Figure 1) can be filled by arbitrary objects, because one can state $\mathbf{E} = 0$, $\mathbf{H} = 0$ inside surface $\bar{S}_0$.

We must point that this parametric structure has two basic states:

(a) transparent state (with almost completely transparent walls, ideally - free space or vacuum) during temporal intervals (18);

(b) an opaque state (with almost completely reflecting walls, ideally a foam-like structure with opaque thin weakly absorbing walls between bulk vacuum cells, i.e. microscale resonators) during temporal intervals (15). Outside such a structure, there is scattering (without absorption) of a wave incident on it from outside. Within this structure, damping of the oscillations generated by the initial conditions (fragments of waves trapped inside the structure in the previous transparent state) occurs. The duration of the opaque state is sufficient for almost complete attenuation of the oscillations in virtual resonators during the time τ_{op}. The smaller the dimensions of the resonators, the faster the oscillations decay in them. Below we will formulate the approach to problem of wave diffraction on the base of above parametric black body (or black skin) of thickness L and time period T (see Figure 2).

A. *Time-Translation Operator*

In accordance with causality principle in electodynamics temporal derivatives of electric $\mathbf{E}$ and magnetic $\mathbf{H}$ fields at some moment t can be expressed as functional $\hat{\Lambda}$ and $\hat{\Delta}$ of spatial distributions of electromagnetic fields at the same moment, i.e. $\partial\mathbf{E}(\mathbf{r},t)/\partial t = \hat{\Lambda}[\mathbf{E}(\mathbf{r},t), \mathbf{H}(\mathbf{r},t)]$, $\partial\mathbf{H}(\mathbf{r},t)/\partial t = \hat{\Delta}[\mathbf{E}(\mathbf{r},t), \mathbf{H}(\mathbf{r},t)]$ and consequently for $\Delta t << T$ we obtain

$$\mathbf{E}(\mathbf{r}, t+\Delta t) \approx \mathbf{E}(\mathbf{r},t) + [\partial\mathbf{E}(\mathbf{r},t)/\partial t)]\Delta t,$$
$$\mathbf{H}(\mathbf{r}, t+\Delta t) \approx \mathbf{H}(\mathbf{r},t) + [\partial\mathbf{H}(\mathbf{r},t)/\partial t)]\Delta t.$$

Step by step with many temporal steps $N_t >> 1$ and sufficiently small temporal step $\Delta t = T / N_t$ we can obtain time time-translation operators for waves in vacuum

$$\mathbf{E}(\mathbf{r}, t+T) = \bar{\Lambda}\{\mathbf{E}(\mathbf{r},t), \mathbf{H}(\mathbf{r},t)\},$$
$$\mathbf{H}(\mathbf{r}, t+T) = \bar{\Delta}\{\mathbf{E}(\mathbf{r},t), \mathbf{H}(\mathbf{r},t)\}. \quad (28)$$

B. *Zero Operator*

Let's define spatial zero operator $\hat{Z}(\mathbf{r})$ as: $\hat{Z}(\mathbf{r}) = 1$ at $\mathbf{r} \notin \hat{V}(S_0)$ and $\hat{Z}(\mathbf{r}) = 0$ at $\mathbf{r} \in \hat{V}(S_0)$. We assume high effectiveness of CWB (fading of the field inside CWB during time $\tau_{op} << T$) and on n-th step we can use initial conditions

$$\tilde{\mathbf{E}}_n(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_n), \quad \tilde{\mathbf{H}}_n(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_n), \quad (29)$$

where $\tilde{\mathbf{E}}_n(\mathbf{r})$ and $\tilde{\mathbf{H}}_n(\mathbf{r})$ are spatial distribution of fields $\mathbf{E}$, $\mathbf{H}$ at the moment $t_n = nT$ immediately before beginning of next opaque state of CWB.

C. *Scattering by Black Body*

On the base of any initial conditions $\tilde{\mathbf{E}}_{n-2}(\mathbf{r})$, $\tilde{\mathbf{H}}_{n-2}(\mathbf{r})$ at the moment $t_{n-2} = (n-2)T$ we calculate (via propagation operators $\hat{\mathbf{\Phi}}$, $\hat{\mathbf{\Psi}}$) spatial distributions

$$\mathbf{E}(\mathbf{r}, t_{n-1}) = \bar{\Lambda}\{\tilde{\mathbf{E}}_{n-2}(\mathbf{r}), \tilde{\mathbf{H}}_{n-2}(\mathbf{r})\},$$
$$\mathbf{H}(\mathbf{r}, t_{n-1}) = \bar{\Delta}\{\tilde{\mathbf{E}}_{n-2}(\mathbf{r}), \tilde{\mathbf{H}}_{n-2}(\mathbf{r})\} \quad (30)$$

of the fields $\mathbf{E}$, $\mathbf{H}$ at the moment $t_{n-1} = (n-1)T$. Applying zero operator $\hat{Z}(\mathbf{r})$ to the distributions (46), we obtain initial conditions for the next step of diffraction process

$$\tilde{\mathbf{E}}_{n-1}(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_{n-1}), \quad \tilde{\mathbf{H}}_{n-1}(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_{n-1}). \quad (31)$$

Further

$$\mathbf{E}(\mathbf{r}, t_n) = \bar{\Lambda}\{\tilde{\mathbf{E}}_{n-1}(\mathbf{r}), \tilde{\mathbf{H}}_{n-1}(\mathbf{r})\},$$
$$\mathbf{H}(\mathbf{r}, t_n) = \bar{\Delta}\{\tilde{\mathbf{E}}_{n-1}(\mathbf{r}), \tilde{\mathbf{H}}_{n-1}(\mathbf{r})\} \quad (32)$$

$$\tilde{\mathbf{E}}_n(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_n), \quad \tilde{\mathbf{H}}_n(\mathbf{r}) = \hat{Z}(\mathbf{r})\mathbf{E}(\mathbf{r}, t_n) \quad (33)$$

and so on. So this scattering model can be called "scattering on initial conditions" instead of the usual "scattering by boundary conditions". Physically, this model means the periodic sequence of operations presented in Table 1. It should be noted that the black body version described here does not formulate any boundary conditions on the surface of the blackbody, and the surface of the black body itself is determined to within the thickness L of the absorbing layer $\hat{L}$. In the simplest case when wave front of falling wave is parallel to plane of thin black parametric disk with diameter D_0 (thickness of disk $d_0 << D_0, \lambda_I$), an approach (28) – (33) gives scattered field as produced by unidirectional Huygens's plane source (with amplitude equal to inverted amplitude of falling wave), which gives complete cancellation of falling wave for $D_0 >> \lambda_I$ behind disk and partial cancellation for $D_0 << \lambda_I$ as elementary Huygens's source, which try to compensate incident wave field behind the scattering black body.

Table 1. The interchange of microstructure operations over the wave field in time.

Physical processes	Time interval
CWB walls are transparent, outside waves are coming into CWB (into layer $\hat{L}$)	$-\tau_{tr} \le t \le -\tau_{sw}$
CWB switch on, conversion incident wave to waves of high frequencies (17)	$-\tau_{sw} \le t \le 0$
dissipative fading of waves inside VR, zeroizing $\mathbf{E}$, $\mathbf{H}$ for $\mathbf{r} \in \hat{L}$	$0 \le t \le \tau_{op} - \tau_{sw}$
CWB walls become transparent, waves leave CWB (outside layer $\hat{L}$)	$\tau_{op} - \tau_{sw} \le t \le \tau_{op}$
CWB walls are transparent, falling wave is coming into CWB (into layer $\hat{L}$)	$\tau_{op} \le t \le T - \tau_{sw}$
… and so on …	…

For instance, this condition cause that black body do not change polarization of incident wave. Polarization of black body scattering field (forward scattering) is the same with polarization of incident wave [5].

D. Control of Reflection Coefficient of Plane

In the article [8] it is shown strictly that an ideally conducting plane, cut across the electric field of the incident wave into periodically located conducting bands, provides a reflection coefficient close to zero. Thus, the connection of conductive strips with electronic keys allows to control the coefficient of reflection as (6) – (7). In the next step, we replace the conductive plane by the metal grid (equivalent to the metal plane for long incident waves) with electronic keys inserted into the periodic discontinuities of the grid wires. Above we assumed instant metallization ((16) – (18)) of walls of parametric structure (black body, black skin). Virtual resonator (VR) is a basic element of above structure. Structure of cubic virtual resonator is presented in Figure 4. Cubic VR (Figure 4 – *a*), for instance, consists of six plane cubic faces. Below we will consider briefly one possible version of the plane wall of transparency controlled (Figure 4 – *b*). Quadratic metallic grid is opaque, when all wires are connected electrically. This grid will become transparent, when we cut each wire into a lot of many of little pieces. Connecting these pieces by optoelectronic switches, we obtain wall of transparency controlled. One cubic face is formed as a grid structure by metallic pieces of wire with length h_{gr} and diameter $\bar{h}_{gr} << h_{gr}$, optoelectronic switches [9] and optic fibers. The last are supplying the light pulses of duration τ_{op} and with temporal period T (see Figure 2 – *a*) to control inputs of very fast miniature optoelectronic switches, which give electric connection between nearest pieces of wire. The last are connecting pieces of wire as shown in Figure 4 – *b*.

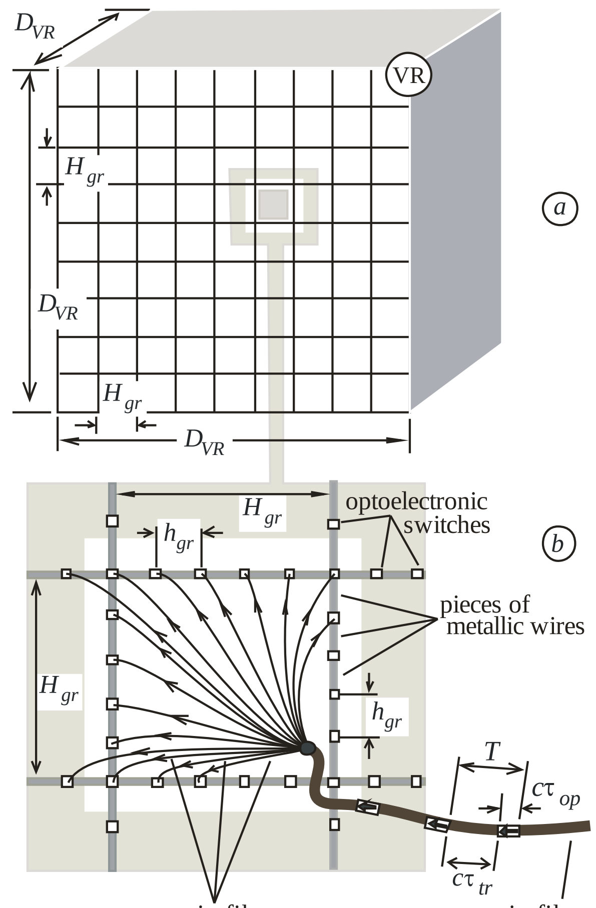

Figure 4

The lengths of optic fibers are tuned to ensure simultaneous arrival of light pulses to all optoelectronic switches. Hereinafter we specify the desired proportions between parameters of grid structure: $h_{sw} << h_{gr} < H_{gr} << D_{VR} << \lambda_{\min}$. At present, it is of no fundamental complexity to obtain laser pulses of duration $\sim 10^{-10}$ s (required duration τ_{op} of opaque state of VR walls) and optically controlled electronic switches through fiber optic (see Figure 4-b) switches with a switching frequency $f_{sw} \approx 1.5 \times 10^{11}$ Hz (or time $\tau_{sw} \approx 7 \times 10^{-10}$ s of switching, [9]). Using (24)-(27), at reflection coefficient $\Gamma = 0.2$ and thickness $L = 2.4$ m, we obtain $N = L / D_{VR} = 80$, $\alpha = 0.5$, $T / \tau_{op} = 8$, $T \approx L / c = 8 \times 10^{-9}$ s, $\tau_{op} = 10^{-9}$ s. For a more desirable thickness $L = 0.6$ m of a microstructure, we obtain estimates (for the same $\Gamma = 0.2$ and $\alpha = 0.5$) : $N = 80$, $T / \tau_{op} = 8$, $T \approx 2 \times 10^{-9}$ s, $\tau_{op} = 2.5 \times 10^{-10}$ s. On the other hand, taking into account that at 300^0 K metals give Maxwellian relaxation time $\tau_m \approx 1.25 \times 10^{-15}$ s, plasmonic frequency $f_p \approx 10^{15}$ Hz and plasmonic wavelength $\lambda_p \approx 4 \times 10^{-7}$ m [10], we can estimate roughly the limit for miniaturization of absorbing microstructure

$D_{VR} = 10^3 \times \lambda_p = 4\times10^{-4}$ m, $L = 3.2\times10^{-2}$ m, $T = 10^{-10}$ s, $\tau_{op} = 1.25\times10^{-11}$ s.

IV. Conclusion

Now we formulate the main qualitative statements as consequences of the presented article:

(a) System with parameters constant in time can't allow us to design thin absorptive skin for: arbitrary shape of body to be protected, superwideband falling waves of arbitrary shape of incident wave front and incident wave direction;

(b) If having very fast and very microscale space-time modulations of media parameters ($R_w(t)$, for instance) often seems preferable to use values of parameters, being averaged in time ($< R_w(t) >_t$, for instance), to describe long slow waves in this media. But this not it is correct in above case;

(c) Above it was shown, that media parameters modulations with space-time superresolution allows to design thin parametric skin to absorb falling waves of both arbitrary frequencies and directions. This result was obtained via consideration of initial value problem (without complex amplitudes). Often seems attractive to use complex amplitudes of sinusoidal oscillations for description of physical model. But this is not convenient way in above case too. All models, which are adequately described by complex amplitudes, always can be reduced to the combination of electric chains with parameters constant in time. The above case can't be reduced to these chains;

(d) Space-time superresolution was used above for conversion of frequency of falling waves into waves of space-time scales caused by space-time scales of the used parametric microstructure CWB (by virtual resonators with walls of transparency controlled). Walls, becoming opaque, are making instant piercing of current spatial distribution of electromagnetic field. This spatial distribution becomes initial conditions to further oscillations inside virtual resonators up to "zeroizing" $\mathbf{E}$, $\mathbf{H}$. This permits to absorb step by step periodically any long slow wave by a small portions in size L and duration L/c. Moreover, we need not know anything about frequency ω_I, length λ_I, polarization $\mathbf{P}_I$, arrival direction $\mathbf{n}_I$ and front shape S_I of this wave and shape S_0 of absorbing black body (or its skin).

(e) The difficulty in constructing an effective thin broadband absorbing layer on the basis of time-constant parameters of the medium is that in a system with constant parameters, the absorption process and the scattering process occur continuously. In the model considered, the absorption (for waves of very high frequency $\omega \ge \pi c / D_{VR} >> \omega_I$ in virtual resonators) and back scattering (reflection of low-frequency incident waves) occur in relatively very short intervals of time $\tau_{op} >> T$, when the walls of the virtual resonators are opaque.

(f) Body protected and covered by black skin is black body. We can cut body protected into a set of arbitrary pieces. These pieces will become black bodies after covering them by black skin.

(g) Above described black parametric skin does not have any inner connections between virtual resonators along the surface S_0. Therefore we can make any cutting (if necessary) of skin along any line without any damage.

V. References

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Arabadzhi, Vladimir V. senior researcher, Ph.D.
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Education: Gorky State University, 1978, profession-radiophysics (01.04.03), Ph.D.–1994, topic "Investigation methods active cancellation low frequency waves". Professional interests: (a) searching for solutions of boundary value wave problems, which admit us to design absorbing coating of the thickness mach smaller than absorbed wavelength and without information on the direction and frequency band of incident waves. This aim is achieved by use of very small and very quick controlled elements of coating. These solutions are parametric and can't be reduced to the combination of electric chains with parameters constant in time. (b) design of floating devises, which convert boat oscillations into a periodical sequence of one polarity stream pulses ("wave engine"). Professional carrier: NIRFI (1978-1981), IAP(RAS) (beginning from 1981).