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DIMENSIONING AND EVALUATION OF THE RADIO FREQUENCY ORBITAL RESOURCE

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Abstract: This paper shows a new concept for optimization of Radio frequency spectrum (RFS) orbital resource in international domain. The RFS resource is necessary for proper operation of different telecommunications systems. This resource has three physical dimensions: frequency bandwidth, space coverage area and time. RFS has also quality characteristics: quality (purity) of the spectrum, RFS load, RFS use (consumption), public and professional interest in the use of RFS. A novel model for dimensioning of RFS is described and a short explanation is shown.

Keywords: radiofrequency spectrum, evaluation and dimensioning.

I. INTRODUCTION

The RFS is characterized by its immateriality and have great importance for the application of modern telecommunication technologies [1]. By different authors RFS throughout the world is valued at well over $2 trillion. However its management, through government regulation, is somewhat antiquated, and not in step with new technologies (mobile, broadcasting and space) that place ever greater demand on this scarce resource. The RF has been designated by the United Nations as a limited natural resource [7]. It is a three-dimensional resource with certain quality characteristics and is used by emitting radio frequency power. The spectrum is not an expending resource, but it is nonrefundable, if part of it is used/ not used today, it is impossible to be used tomorrow and cannot be used twice. According to the European Commission recommendations, each country has to make an inventory procedures of its RFS and identify measures for its effective use in the creation of a "Single European Information Space" [2]. This can be done only after proper dimensioning and evaluation of each national RFS. A novel model for evaluation of RFS with concrete application for Spectral Orbit Resource evaluation is described here.

Dimensions of the spectrum for Spectral-orbital resource

The RFS is a three dimensional resource. The most common and universal utilization of the RFS that can be evaluated approximately equally worldwide is spectral-orbit resource. The RF bandwidth (Fig.1) is the width of the spectrum occupied by radio signals of the observed communication system (broadcasting or single casting) **- *B, [Hz].***

The RF bandwidth of the electromagnetic signal can be divided into two main parts:

- parts occupied by the signal (Δf_1, Δf_2, Δf_3),
- parts occupied by parasitic emissions (Δf_4, Δf_5, Δf_6).

Each individual part affects differently RFS price.

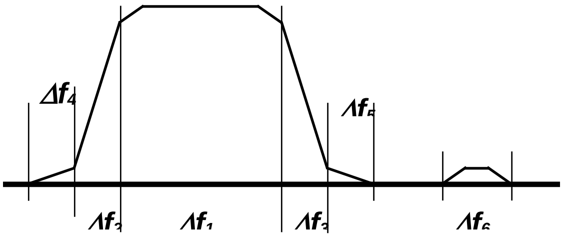

Fig.1. RF bandwidth

Space

This is the volume of space occupied by radio signals or the area covered by radio signals - ***[m3]*** or ***[m2].***

(1) $S = S1+S2 +S3+S4 +S5+S6$

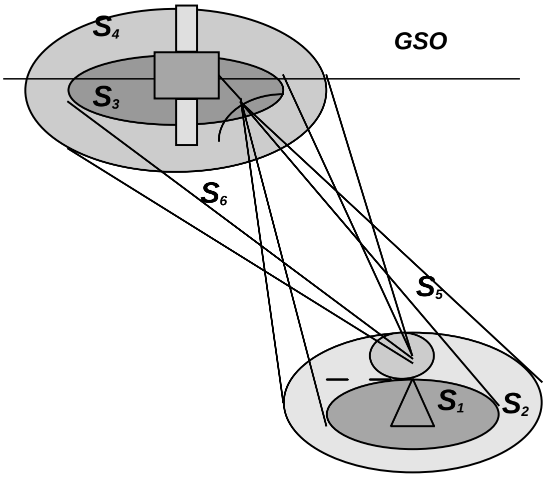

Fig.2. Space of the GSO satellite communications system

Parts of the space of satellite communications system from **Fig.2** are:

S_1- covered region of the earth's surface with the satellite signal (at **-3 dB** relative to the center of the beam);

S_2 - zone of the satellite beam (malabsorption zone from **-3dB** to **-30 dB,** relative to the center of the beam);

S_3- part of the space around the geostationary orbit (GSO) irradiated from the earth station (at **-3 dB** relative to the center of the beam);

S_4 - part of the space around the geostationary orbit at a level of **-3 dB** to **-30 dB** relative to the center of the beam;

S_5, S_6- amounts of space, enclosed by the conical beam satellite.

Time

Different telecommunications systems may use the same RFS in the same geographical area based on timing approach. These are the operational time slots when a communication system uses the RFS **- *T,*** month ***(M),*** day ***(d)*** or hour ***(h)*** – Fig.3.

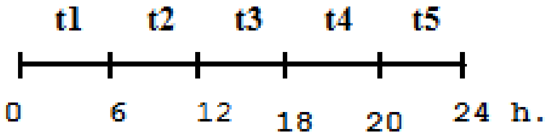

Fig.3. Operational time slots

Quality of RFS

The quality characteristics depend on the communication radio systems and are related to the electromagnetic compatibility of radio systems, therefore in the assessment process should be taken into consideration and the RFS values [5]. Quality parameters depend on the number of working communication systems in the band operating in the same area and radiated RF power from space orbit to Earth. RFS qualitative characteristics determine the radio communications implementation conditions. There are four quality characteristics used in our model.

Quality (purity) of the spectrum

This is a basic electromagnetic characteristics

$Q, [W^{-1}.m^{2}.Hz]$

(2) $Q = 1/N$

where N is the power spectral density of noise and interference in unit space S, measured when the issue communications system does not emit signals

Reducing the value of Q will reduce the market price of RFS.

Load of the radio spectrum

The radio transmitters emit electromagnetic power and loaded the RFS with different signals. The load of the spectrum is the total spectral power emitted by the concerned communication system in concrete geographical coverage space S - $L, [W.m^{-2}.Hz^{-1}]$. The definition of the spectral load is:

(3) $L = K_L.P$,

where P is the emitted power;

K_L is a coefficient depending on the gain of the antenna, attenuation in space and bandwidth of broadcast signals.

Utilisation (consumption) of RFS

The comprehensive measure of spectrum use of the spectrum at a given time and space slot.

(4) $C = L*Q = L/N$

The evaluation of the utilisation of RFS depend of the carrier/interference (carrier/noise) ratio-(C/N) in a separate part of the RF resource. If the system works at a low ratio carrier/interference, it uses less resources to a lower value.

Public and professional interest in the use of RFS - *A*

The interest in the use of certain parts of the RFS sets actual price. It cannot be determined theoretically beforehand because on it affect market conditions and technologies used in the relevant bands and depends on the conditions of distribution of radio waves, the number of consumers (subscribers) and business development in the area under consideration, and regulative obstacles that may slow down the introduction of new more efficient technologies.

Public customer and professional interest to the considered part of the Spectrum-Orbit resource:

$A = FA(A)=mA(i1A1 + i2A2 + i3A3 + i4A4 + i5A5)$,

where $A1$ -$A5$ are importance (a grade of interest) to the different operational customer characteristics of the Spectrum-Orbit resource;

$i1$ - $i5$ are the coefficients proportional to the interest of the customers to the Spectrum for corresponding characteristics;

mA is the coefficient defining the weight of the operational spectrum importance on the Spectrum-Orbit resource assessment

Evaluation of the RFS and spectrum-orbit resource

The evaluation of RFS and spectrum-orbit resource can be made by the following relationship:

(5) $E = F_E[F_B(B)*F_S(S)*F_T(T)]$

where F_B, F_S and F_T are weighting functions of spectral parameters in sizing the resource. They depend on communication system type, its structure and the methods for signal processing quality characteristics. F_E combines spectrum measurement and evaluation methods and parameters with its evaluation functions.

Impact of the RFS bandwidth on the assessment of RFS (Fig.1.)

(6) $$F_B(B) = \sum_{n=1}^{k} C_{Bn}\, Bs_n\, L_{Bn}^{m_B}$$

where $Bs_n = \Delta fs_n$ and $Bi_n = \Delta fi_n$ are parts of the radio frequency bandwidth:

Bs_n are frequency bandwidth, occupied by the useful signal;

Bi_n are frequency bandwidth, occupied by the out band transmissions in assumed radio system.

C_{Bn} are coefficients, proportional to the ratio carrier/interference.

L_{Bn} are coefficients, proportional to the power of the radio signal;

$m_B = K_{mB}*A_B$ is a coefficient determining the severity of the radiofrequency bandwidth in the evaluation of RFS.

K_{mB} is a common coefficient to assess the impact of the radiofrequency bandwidth on the evaluation of the RFS.

A_B is the professional interest for the utilisation of the radio frequency range.

(7) $$F_B(B) = \sum_{n=1}^{k} C_{Bn}\,(Bs_n + Bi_n)\, L_{Bn}^{m_B}$$

Impact of the space occupied by the signal at the evaluation of the RFS

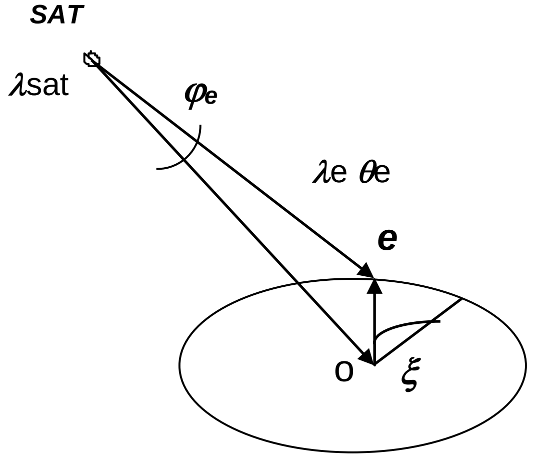

Fig.4. GSO Satellite system

The area (Fig.2), which is loaded with radio signals can not be used by other systems with the same radio frequencies. The influence of the space in the assessment of the RFS is:

(8) $$F_S(S) = \sum_{n=1}^{k} S_n\, i_n$$

where **Sn** are the separate space parts;

$\mathbf{i}_n$ are coefficients dependent on the quality of the signal level, and the interest in RFS in this area:

$\mathbf{i}_n = \mathbf{Q}_{Sn} + \mathbf{L}_{Sn} + \mathbf{A}_{Sn}$;

$\mathbf{Q}_{Sn}$ are coefficient, depending on the quality of the analyzed space RFS;

$\mathbf{L}_{Sn}$ are coefficients depending on the load of analyzed space RFS;

$\mathbf{A}_{Sn}$ are coefficient, depending from the interest of analyzed space RFS;

$\mathbf{m}_S = \mathbf{m}_S(\mathbf{C}_S)$ is a common factor of gravity of space covered with signal evaluation of the RFS. It can be simplified as:

$\mathbf{m}_S = \mathbf{K}_S . \mathbf{C}_S$,

$\mathbf{K}_S$ is the common factor for determining the influence of the area covered by the signal in the evaluation of the RFS.

$\mathbf{C}_S$ is factor defined by the average utilization of RFS in space covered with signal.

For the spectrum-orbit resource would be:

(9) $F = \sum_{n=1}^{k}$ [illegible]

The coefficients S_n in (8,9) for satellite microwave system can be expressed (with some restrictions) through an angle of antenna beams: From Fig.2:

(10) $S_n = K_{sn} \,.\, \varphi_n^2$,

for the segments S_n and $S_{(n-1)}$:

(11) $S_{\square n} = S_n - S_{(n-1)} = K_{sn}\,(\varphi_n^2 - \varphi_{(n-1)}^2)$,

and more specifically:

(12) $S_n = \sum_{e=1}^{k} (S_{kn}(\lambda_{sat}, \lambda_0, \theta_0, \xi_e, \varphi_e, \lambda_e, \theta_e))$

where λ_{sat} is the satellite longitude *of GSO (Fig.4);*

λ_{sat} is the longitude of the center of the satellite beam*;*

θ_0 is the latitude of the center of the satellite beam*;*

ξ_e is the crawling corner in the determination of control points;

φ_e is the width of the satellite beam;

λ_e is the longitude of setpoint ***e;***

θ_e is the latitude of set point ***e.***

Influence of operational time islot on the assessment of the RFS

If the communication system uses **RFS** at intervals, or some operators use this resource together with time-division, the assessment is carried out for each time interval (**Fig.5**).

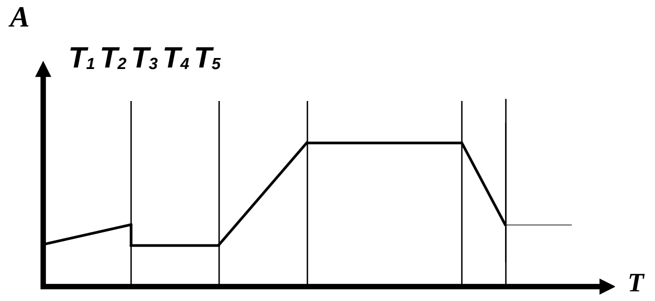

Fig.5. Impact of operational time slots on the assessment of the RFS

(13) $F_T(T)=m_T*\sum_{n=1}^{k}(A_{Tn}*T_n)$,

where T_n are the specific operating slots;

A_{Tn} are the coefficients, proportionate interest of subscribers to issue resource in this time slots;

m_T is factor determining the severity of operational time on the assessment of RFS.

Impact of spectrum utilisation on the RFS assessment

The coefficients which determine the utilisation of the spectrum (C_{Bn} and C_S) are included in defining the the different parameters in RFS evaluation ***(9),(13).***

$Fc(C) = mc(n1C1 + n2C2 + n3C3 + n4C4 + n5C5)$,

where $C1$ - $C5$ are the parts of the Spectrum-Orbit resource in which the signal to noise ratio should be assumed flat. These are parst of the space, of the frequency band or time slots.

$n1$ - $n5$ are the coefficients proportional to the signal loaded the Spectrum in the corresponding elementary part of the Spectrum-Orbit resource;

mc is the coefficient defining the weight of the spectrum utilisation on the Spectrum-Orbit resource assessment

Effect of the load spectrum on the estimate of RFS

The grade of the load of the spectrum impact on the spectrum consumption by the satellite communication system:

The spectrum load is defined by the energy spectral density of the power flux of the considered system signals through unit area in the given part of the frequency band and in given point of the space throw separate time slots.

$FP(P) = mP(e1P1 + e2P2 + e3P3 + e4P4 + e5P5)$,

where $P1$ -$P5$ are the elementary part of the Spectrum-Orbit resource in which the power flux should be assumed flat. They are part of the space, of the frequency band or time slots.

$e1$ - $e5$ are the coefficients proportional to the signal loaded the Spectrum in the corresponding elementary part of the Spectrum-Orbit resource;

mP is the coefficient defining the weight of the spectrum load on the Spectrum-Orbit resource assessment.

The load of the spectrum is determined for the part of the space and for each part of the frequency band in the separate time intervals:

L_{Bn} are coefficients, proportionate to the level of the signal in question bands;

L_{Sn} are coefficients proportional to the signal level in the covered with signal space part.

Impact of the quality of spectrum over the evaluation of the RFS

Q_{Sn} are coefficients depending on the quality of the RFS. They are used in the above written formulas.

Impact of public and professional interest on the utilisation of spectrum

The public and professional interest in the utilisation of spectrum is described by the coefficients A_B , A_{Sn} and A_{Tn}.

Defining the price of the spectrum

The price of RFS V is determined by its dimensions, by its qualitative parameters, and the extent of its use.

After simplifying **(**5**)** it becomes:

(14) $E=FE*B*S*T$,

(15) *where* $F_E = K_E{*}A{*}P{*}Cd$,

(16) $Cd = 10{*}\lg C$, *[dB]*,

(17) $E= KE1{*}A{*}B{*}S{*}T{*}P{*}C$, *[Hz.m2.t.W.dB]*,

or for the or spatial beam:

(18) $E= K_{E2}{*}A{*}B{*}\square^{2}{*}T{*}P{*}C$, $[Hz{*}deg^2{*}t{*}W{*}dB]$,

where *t* is month (M), hour (h) or day (d).
The price of the RFS resource is:

(19) $V = F_V\,.\mathbf{E}$, *[USD]*

(20) $V = F_V\,.F_E[F_B(B).F_S(S).F_T(T)]$, *[USD]*

It can be introduced a price per unit for resource V0:

(21) $V_0=V/E$, $[USD{*}\,Hz^{-1}{*}m^{-2}{*}\,t\,{*}W^{-1}{*}dB^{-1}]$

The price of RFS would be:

(22) $V=V_0{*}B{*}S{*}T{*}P{*}C$, *[USD]*

The spectral-orbital resource dimension is:

(23) $USD{*}Hz^{-1}{*}deg^{-2}{*}t^{-1}{*}W^{-1}{*}dB^{-1}$

The market price of the RFS is determined by customers and operators through auctions. The unit price of the range may vary depending on the characteristics of the RFS.

Examples

Some of the factors included in the above expressions can be discussed, because they depend on the particular communication system, market conditions, economic development and regulations. In the following example our model is used for evaluation of a satellite communications system (**Fig.2**), where would be heeded only the area of the Earth's surface ($\boldsymbol{S_1,S_2}$):

(24) $F_S(S)=m_S(i_1S_1 + i_2S_2)$, or
$F_S(S)=K_S.C_S.[(Q_{S1}+L_{S1}+A_{S1}).S_1+(Q_{S2}+L_{S2}+A_{S2}).S_2]$

The assessment of RFS with area covered by the antenna beam is:

(25) $F_S(S) = K_S.C_S.[(Q_{S1}+L_{S1}+A_{S1}).K_{s1}.\ \varphi_1^2+ +(Q_{S2}+L_{S2}+A_{S2}).K_{s2}.(\varphi_2^2-\varphi_1^2)]$

For an antenna for satellite position, if $\varphi_2 < 3^0$ and the elevation of the satellite above the horizon is $h > 30\varphi$:

(26) $K_{s1} = K_{s2} = K_{ss}$, and
$F_S(S) = K_S\ .\ K_{SS}\ .C_S.\ [(Q_{S1}+L_{S1}+A_{S1}).\ \varphi_1^2+ +(Q_{S2}+L_{S2}+A_{S2})\ .\ (\varphi_2^{\,2}- \varphi_1^2)]$

And the coefficient for assessment of the Spectrum-Orbit resource is:

(27) $E = K_S\ .\ K_{SS}\ .C_S[(Q_{S1}+L_{S1}+A_{S1}).\varphi_1^2+ +(Q_{S2}+L_{S2}+A_{S2}).(\varphi_2^2-\varphi_1^2)+$
$+K_{mB}.A_b(C_{B1}.B_1.+ C_{B2}\,(B_2+B_3)+ T(A_{T1}T_1+A_{T2}T_2+A_{T3}T_3)]$

The value of the Spectrum-Orbit resource is:

(28) $V = V_0 . E$

By averaging the parameters can be obtained a simple expression, convenient for practical calculations:

(29) $V = V_0 * B * \varphi^2 * T * P . C$

The main features of satellite TV system are given in Appendices 30 Radio Regulations.

Table 1

Coefficient	**Unit**	**Value**	**dB**
V_0	***USD. Hz-1.deg-2. .h-1.W-1.dB*-1**	10^{-9}	
B	***MHz***	**27**	
φ	degrees	**2**	
T[month]	**hours**	**720**	
P	**W**	**60**	
C	***dB***		**28**
V_1	**USD/hour**	**181**	
V_2	**USD/month**	**130,637**	

The following values are available as results in *Table 1*. These results are just one example of the application of the methods described:

$C_{B1} = 28;$ $_{CB2} = 15;$ $C_S = 25$ dB;
$K_S . K_{SS} = 2.10^{15}$; $F_B(B) = K_{mB} = 10$;
$L_{S1} = -177$ dBW $Hz^{-1} m^{-2}$;
$L_{S2} = -180$ dBW $Hz^{-1}.m^{-2}$;
$A=0.1$ to 10,
in dependence of the market conditions.
$A_{S1} = 1$; $A_{S2} = 0.5$;
V_0 is defined for: $\varphi = 1^0$;
$C=1$ dB; $P=1$ W.
$F_T(T)=1$, if the resources are used through the whole time.

CONCLUSION

During the annual economic meetings in Davos export are presented reports in various fields of economy and technology. The average annual price of the total worldwide used RFS is estimated at over 2 trillion dollars. The exact market value of the RFS is determined by the operators and governments. Proposed here measurement and evaluation model can be used for comparing different spectral resources and different communications systems. Terms and conditions, related to public clients and professional interest depends on the situation and their values [5, 6, 7]. Many different adjustment factors and decision support systems [6] may be incorporated by the model for future improvements depending of concrete case and economical factors. Proposed model is predominantly designed for the use of evaluation of spectral orbital resource, some modifications of area coverage measures must be taken for the use in ground mobile and broadcasting services.

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