AiMT Advances in Military Technology
Vol. 6, No. 1, June 2011

Evaluating the Effect of SIGINT Sources Movement to Process Them in the Stationary Reconnaissance Equipment

Z. Matoušek[1] and P. Bučka[2*]

[1]*Department of Electronics, Armed Forces Academy of General M. R. Štefánik,*
Liptovský Mikuláš, Slovakia
[2]*Vice-rector for Education, Armed Forces Academy of General M. R. Štefánik,*
Liptovský Mikuláš, Slovakia

The manuscript was received on 22 October 2010 and was accepted after revision for publication on 15 February 2011.

Abstract:

Signal Intelligence (further SIGINT) is one of the basic types of reconnaissance, results of which provide commanders and headquarters with important information for their right decision-making process. The article focuses on the analysis of SIGINT sources movement effects on processing the signals in stationary devices. Following the derived relations there are the results of corresponding simulations, which describe the relation of electric field intensity, power density and received electromagnetic energy output in SIGINT device location depending on the location and parameters of movable SIGINT sources.

Keywords:

Electrical intensity, electromagnetic energy, power density, power of signal, receiver sensitivity, SIGINT equipment, signal source

1. Introduction

In the reconnaissance equipment, location signals of SIGINT sources have effect the amplitude and phase of which have a determining influence not only on the quality of their processing, but also on their possible analysis, identifying and monitoring. Sources of these signals and reconnaissance means can be distributed in the area,

---

[*] *Corresponding author: Vice-rector for Education, Armed Forces Academy of general M. R. Štefánik, Liptovský Mikuláš, P. O. BOX 45, 03 106 Liptovský Mikuláš 6, Slovakia, phone: +421 903 824 608, fax: +421 960 423 036, E-mail: pavel.bucka@aos.sk*

while the received signals can have various form and values of energetic parameters. In the signal reception location we are interested especially in:

- electric field intensity E [V/m],
- power density P_D [W/m^2],
- received power level P_R [W].

The mentioned energetic quantities of electromagnetic energy in the location of receiving signals depend not only on SIGINT sources parameters (especially on transmitter power and its antenna system properties), but also on the placement of directional characteristics of antennas of sources and reconnaissance sources, the distance between them etc.

2. Areal Arrangement of SIGINT Source and Reconnaissance Equipment

Let us assume the following general case: SIGINT source is moving rectilinearly, while the stationary reconnaissance device is placed in different distances d aside of the source course axis. The situation is shown in Fig. 1.

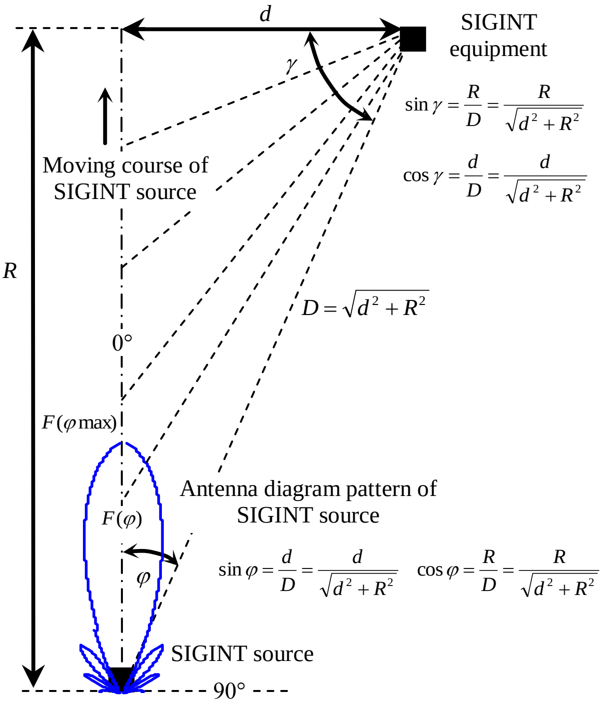

Fig. 1 SIGINT source effect on the reconnaissance equipment placed aside of the course of SIGINT source axis.

where $D=\sqrt{d^2+R^2}$ is the direct distance of the reconnaissance equipment from the SIGINT source [m],

d is the distance between the reconnaissance equipment and course of SIGINT source axis [m],

R is the distance between the SIGINT source and the projection of reconnaissance equipment location from the moving course of SIGINT source axis [m],

$\varphi = \arcsin \dfrac{d}{\sqrt{d^2 + R^2}}$ is the angle between the moving course of SIGINT source axis and the SIGINT source flowline – reconnaissance equipment,

$\gamma = \arcsin \dfrac{R}{\sqrt{d^2 + R^2}}$ is the angle between the vertical line from the reconnaissance equipment location to the course of SIGINT source axis and the flowline reconnaissance equipment – SIGINT source.

3. Characteristics of SIGINT Sources Parameters

Let us assume SIGINT source using the rectangular aperture antenna size $a \times b$, with the defined coefficient of aperture utilization $\nu = 0.7$ Beam function $F(\varphi)$ of this antenna in the horizontal level can be defined by the relation [1]

$$F(\varphi) = F_{EP}(\varphi) K(\varphi), \tag{1}$$

where $F_{EP}(\varphi) = (1 + \cos\varphi)$ is the beam function of the equiphase surface element,

$K(\varphi) = \left[\dfrac{\sin\left(k \frac{a}{2} \sin\varphi\right)}{k \frac{a}{2} \sin\varphi} \right]$ is the interference function of rectangular aperture,

a is the size of rectangular aperture in horizontal level [m],

b is the size of rectangular aperture in vertical level [m],

$k = 2\pi / \lambda$ is the wave number [m^{-1}].

Rectangular aperture antenna gain in the direction of maximum radiation $G_{T\max}$ can be defined from the following equation

$$G_{T\max} = 0.7 \frac{4\pi A}{\lambda^2}, \tag{2}$$

where $A = ab$ is the surface of SIGINT source antenna [m^2],

λ is the wave length of electromagnetic energy [m].

Directional function $F(0 \div 90)$ of rectangular aperture antenna of SIGINT source in the first quadrant of horizontal level can be defined by the equation [1]

$$F(0 \div 90) = F_{EP}(0 \div 90) K(0 \div 90), \tag{3}$$

where $F_{EP}(0 \div 90) = \left(1 + \dfrac{R}{D}\right)$ is the directional function of equiphase surface element in the first quadrant of horizontal level,

$K(0 \div 90) = \left[\dfrac{\sin\left(k \dfrac{ad}{2D} \right)}{k \dfrac{ad}{2D}} \right]$ is the interference function of rectangular aperture in the first quadrant of the horizontal level.

Graph of standard intensity directional characteristic of the above defined rectangular aperture antenna in the first quadrant of horizontal level for selected values of frequency f can be seen in Fig. 2.

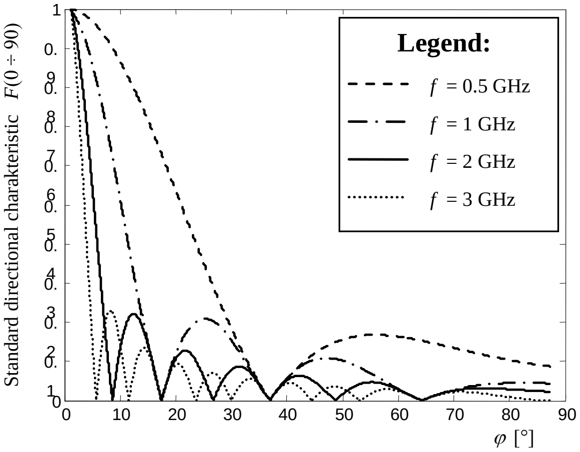

Fig. 2 Standard intensity directional characteristic of rectangular aperture antenna in the first quadrant of horizontal level for selected values of frequency

Depending on the shape of directional characteristic of SIGINT source antenna and the angle φ, which is the function of distances R and d, the level of effective radiated power $P_{ef}(\varphi)$ is changing towards the reconnaissance equipment. The value of effective radiated power of SIGINT source $P_{ef}(\varphi)$can be defined by the following equation [3]

$$P_{ef}(\varphi) = P_T G_{T\max} \left[\frac{F(\varphi)}{F(\varphi_{\max})} \right]^2 \qquad \text{[W]}, \qquad (4)$$

where $\dfrac{F(\varphi)}{F(\varphi_{\max})}$ is the standard intensity directional function of SIGINT source antenna,

P_T is the output of SIGINT source transmitter [W],

G_T is the gain of SIGINT source antenna [2].

Percentage of the value of effective radiated power of SIGINT source $P_{ef}(\varphi)$ of rectangular aperture antenna in the first quadrant of horizontal level towards the reconnaissance equipment depending on the change of distance R of SIGINT source on the axis of its course for selected values of distances d of reconnaissance equipment from the axis of moving course of SIGINT source is shown in Fig. 3.

4. Intensity of Electromagnetic Field in the Reconnaissance Equipment Location

The reconnaissance equipment has been placed aside of axis of rectilinear moving course of SIGINT source, whose electromagnetic radiation affects the reconnaissance equipment antenna. The dependence of effective value of intensity of electromagnetic field E_{ef} in the reconnaissance equipment location is defined by the equation [3]

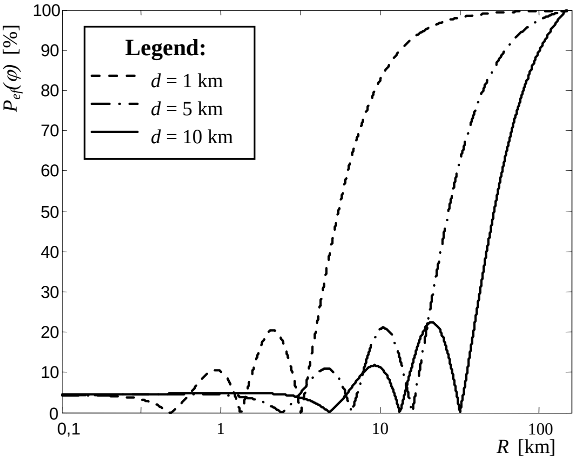

Fig. 3 Percentage of the value of effective radiated power of SIGINT source $P_{ef}(\varphi)$ of rectangular aperture antenna in the first quadrant of horizontal level towards the reconnaissance equipment depending on d and R

$$E_{ef} = \frac{\sqrt{30 P_V G_V}}{D} \frac{F(\varphi)}{F(\varphi_{\max})} \quad \text{[V/m]}. \tag{5}$$

Effective value of electromagnetic field intensity in decibels $E_{ef[dB]}$ can then be defined by the equation

$$E_{ef[dB]} = 20 \log E_{ef} \quad \text{[dB]}. \tag{6}$$

Following the above mentioned facts and according to the relations (5) and (6) it is possible to define the course of relations of electromagnetic field intensity $E_{ef[dB]}$ in the reconnaissance equipment location depending on the change of distance R of SIGINT source on the axis of its moving course for the selected values of distance d of reconnaissance equipment from the axis of the moving course of SIGINT source. The simulation results for the rectangular aperture SIGINT source antenna where carrier wave f = 1 GHz power P_T = 10 W can be seen in Fig. 4.

5. Power Density of Electromagnetic Energy in the Location of Reconnaissance Equipment

Power density of electromagnetic energy P_D in the location of reconnaissance equipment can be defined by the following equation [3, 4]

$$P_D = \frac{E_{ef}^2}{Z_{VP}} = \frac{P_V G_V}{4\pi D^2}\left(\frac{F(\varphi)}{F(\varphi_{\max})}\right)^2 \qquad [\mathrm{W/m^2}]. \tag{7}$$

Power density of electromagnetic energy in decibels $P_{D[dB]}$ can then be defined by the equation

$$P_{D[dB]} = 10\log P_D \qquad [\mathrm{dB}]. \tag{8}$$

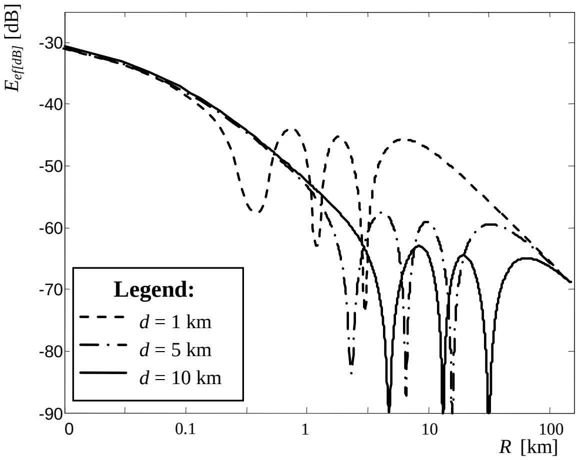

Fig. 4 Dependence of electromagnetic field intensity $E_{ef[dB]}$ *on d and R*

Similarly to intensity of electric field, using the equations (7) and/or (8) it is possible to define the course of dependence of power density of electromagnetic energy $P_{D[dB]}$ in the reconnaissance equipment receiver location depending on the distance change *R* SIGINT source on the axis of the moving course for selected values of distance *d* between the reconnaissance equipment and the axis of its SIGINT source moving course. The simulation results for rectangular aperture antenna of signals source where carrier wave f = 1 GHz power P_T = 10 W are shown in Fig. 5.

6. Signal Power at the Input of Reconnaissance Equipment Receiver

The calculation of signal power at the input of reconnaissance equipment receiver is performed for omnidirectional antenna and also for differently oriented beam antenna of reconnaissance equipment. Maximum of directional characteristic is oriented towards the axis of signals source movement or upright to this axis. If we know the parameters of the reconnaissance equipment antenna, we can define the value of received power at the input of the receiver by the general equation [3, 4]

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi D}\right)^2 \left[\frac{F(\varphi)}{F(\varphi_{\max})}\right]^2 \left[\frac{F(\gamma)}{F(\gamma_{\max})}\right]^2 \qquad [\mathrm{W}] \tag{9}$$

where $\left[\frac{F(\gamma)}{F(\gamma_{\max})}\right]^2$ is the standard power directional function of reconnaissance equipment antenna,

G_R is the gain of reconnaissance equipment antenna.

6.1. Reconnaissance Equipment with Omnidirectional Antenna

If we use an omnidirectional antenna in the reconnaissance equipment, it is possible to modify the equation (9) into the form [3, 4]

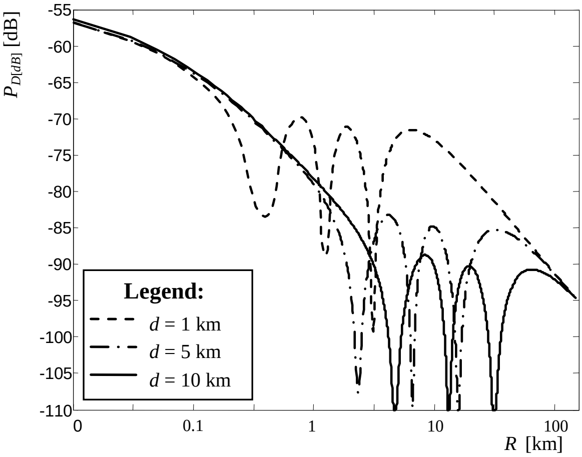

Fig. 5 Dependence of power density of electromagnetic energy $P_{D[dB]}$ *on d and R*

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi D}\right)^2 \left[\frac{F(\varphi)}{F(\varphi_{\max})}\right]^2 \sqrt{\sin^2\gamma + \cos^2\gamma} \qquad \text{[W]}. \qquad (10)$$

The dependence of received power value P_R on the output of omnidirectional antenna of reconnaissance equipment depending on the distance change R of SIGINT source on the axis of its movement for selected values of distance d between the reconnaissance equipment and the axis of the SIGINT source movement following the equation (10) is shown in Fig. 6.

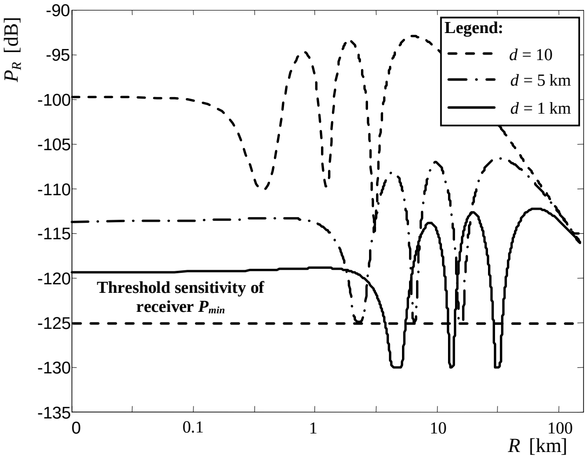

Fig. 6 Dependence of power value P_R on the output of omnidirectional antenna of the receiver on d and R

6.2. Reconnaissance Equipment with Beam Antenna

If we use the beam rectangular aperture antenna as the reconnaissance equipment antenna, then we can define the directional function of this antenna by the following equation [1]

$$F(\gamma) = F_{EP}(\gamma) K(\gamma), \tag{11}$$

where $F_{EP}(\gamma) = (1 + \cos\gamma)$ is the directional function of equiphase surface element,

$K(\gamma) = \left[\dfrac{\sin\left(k\dfrac{a}{2}\sin\gamma\right)}{k\dfrac{a}{2}\sin\gamma} \right]$ is the interference function of rectangular aperture.

Defining the received power value P_R at the input of beam rectangular aperture antenna has been performed for following situations:

a) directional characteristic of the reconnaissance equipment antenna is oriented in a parallel way with the axis of SIGINT source moving course,
b) directional characteristic of the reconnaissance equipment antenna is oriented across the axis of SIGINT source moving course.

Ad a)

For the first situation in relation (a) to Fig. 1, it is necessary to define the directional function of the beam rectangular aperture antenna of the reconnaissance equipment in the first quadrant of the horizontal level by the equation

$$F(0 \div 90) = F_{EP}(0 \div 90) K(0 \div 90), \tag{12}$$

where $F_{EP}(0 \div 90) = \left(1 + \dfrac{R}{D}\right)$ is the directional function of equiphase surface element in the first quadrant of horizontal level,

$$K(0 \div 90) = \left[\frac{\sin\left(k\dfrac{ad}{2D}\right)}{k\dfrac{ad}{2D}} \right]$$ is the interference function of the rectangular aperture in the first quadrant of horizontal level.

Following the equation (9) and (12), it is possible to define the course of dependence of received power value P_R at the output of receiver beam antenna which is oriented in a parallel way with the axis of SIGINT source moving course depending on the distance change R of the SIGINT source at the axis of its movement for the selected values of distance d of the reconnaissance equipment from the axis of the SIGINT source moving course (Fig. 7).

Ad b)

For the second situation in relation (b) to Fig. 1, it is necessary to define the directional function of rectangular aperture antenna of reconnaissance equipment in the fourth quadrant of horizontal level by the equation

$$F(270 \div 0) = F_{EP}(270 \div 0)\,K(270 \div 0), \tag{13}$$

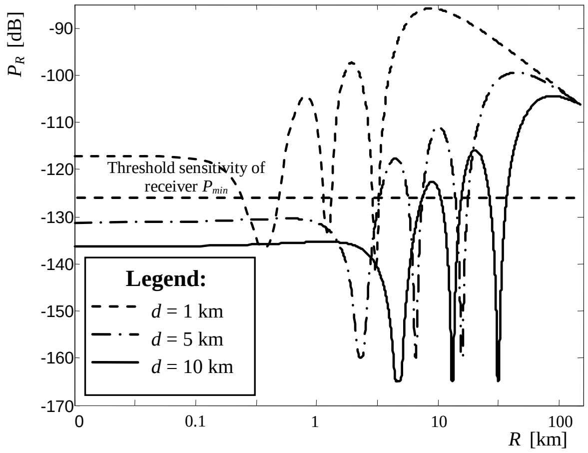

Fig. 7 Dependence of power value P_R at the output of receiver beam antenna oriented in a parallel way with the axis of SIGINT source moving course P_R on d and R

where $F_{EP}(270 \div 0) = \left(1 + \dfrac{d}{D}\right)$ is the directional function of equiphase surface element in the fourth quadrant of horizontal level,

$$K(270 \div 0) = \left[\frac{\sin\left(k\dfrac{aR}{2D}\right)}{k\dfrac{aR}{2D}} \right]$$ is the interference function of rectangular aperture in the fourth quadrant of horizontal level.

In relation to the equations (9) and (13), it is possible to define the course of dependence of received power value P_R at the output of receiver beam antenna, which is oriented across the axis of SIGINT source moving course depending on the distance change R of SIGINT source on the axis of its moving course for the selected values of distance d of reconnaissance equipment from the axis of SIGINT source moving course (Fig. 8).

In Figs. 6, 7 and 8 there are the dependences of power values P_R at the input of the reconnaissance equipment receiver for the analyzed antenna systems of this equipment in case of distance change R of SIGINT source at the axis of its moving course rating from 10 ÷ 150 km and selected values of distances of reconnaissance equipment from the axis of the SIGINT source moving course d in the range 1 ÷ 10 km. The mentioned courses match with the usage of SIGINT source antenna with the rectangular aperture, where the frequency of carrier $f = 1$ GHz power $P_T = 10$ W.

7. Conclusion

Simulations results show the big segmentation of graphs of received power P_R, in which there are quite many maximums and minimums of received signal from the SIGINT source. These maximum and minimum values are shifted according to the distance between the reconnaissance equipment and the axis of SIGINT source course d and the distance R of SIGINT source at the axis of its moving course. Segmentation of the graphs of received power is increasing with the increasing frequency of the carrier frequency of the SIGINT source signal.

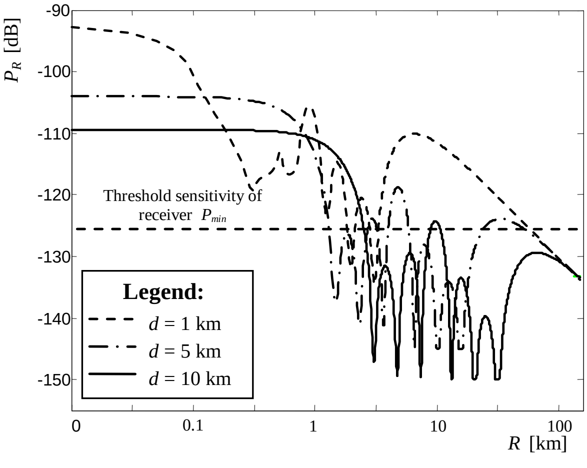

Fig. 8 Dependence of power value P_R at the output of receiver beam antenna oriented across the axis of SIGINT source movement d and R

Signals from SIGINT source will be detected by means of reconnaissance equipment just in case their output level exceeds the threshold sensitivity of the reconnaissance equipment receiver $P_{\min}$ (in case of simulations $P_{\min} = -125$ dB).

In terms of the number of minimum values of received power P_R (loss of signal), it is more convenient to use the antenna system in the stationary reconnaissance equipment with the widest radiating characteristic. The mentioned minimum values can be compensated using other reconnaissance equipment, whose distance d from the axis of SIGINT source moving course secures the compensation of minimum values of received power P_R of the first station.

When using beam antenna in the reconnaissance equipment, the minimum values of the received power P_R are more distinct. For all of them, if the directional characteristic of the antenna is oriented in a parallel way with the axis of SIGINT source moving course, a lower level of signal at the input of reconnaissance equipment receiver responds to shorter distances R of SIGINT source on the axis of its moving course. If the directional characteristic of the antenna of reconnaissance equipment is oriented across the axis of SIGINT source moving course, a lower level of signal at the input of reconnaissance equipment receiver responds to longer distances R of the SIGINT source on the axis of its moving course.

To eliminate the loss of signal in the reconnaissance equipment, it is possible to use e.g.:

- aiming the directional characteristic of the reconnaissance equipment antenna towards the maximum signal direction,
- simultaneous usage of several reconnaissance equipments dislocated in the area so that they can compensate the minimum values of received power P_R.

The above mentioned simulation results can be practically used in field conditions when meeting the objectives of electronic reconnaissance (optimization of arrangement and orientation of reconnaissance equipment in the surrounding), furthermore when solving tasks of the adaptation of antenna systems of reconnaissance equipment to the current electromagnetic scene or when securing the external protection of receivers in the radio networks.

References

[1] SOMEDA, CG. *Electromagnetic Waves.* 2nd ed. Boca Raton (USA) : CRC Press, 2006. ISBN 0-8493-9589-5.

[2] DORF, RC. *The Electrical Engineering*. 3rd ed. Boca Raton (USA) : CRC Press, 2006. ISBN 0-8493-7339-5.

[3] COLLIN, RE. *Foundations for Microwave Engineering.* 2nd ed. New York : Wiley-Interscience, 2001. ISBN 0-7803-6031-1.

[4] CHRISTIANSEN, R. and ALEXANDER, Ch. K. *Standard Handbook of Electronic Engineering.* 5th ed. New York : McGraw-Hill, 2005, ISBN 0-07-138421-9.