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Abstract

The set of risk-oriented indicators that will characterize the protection of modern information and telecommunication systems from information leakage through technical channels has been substantiated. The set is a hierarchical structure and allows information security risk analysis. Shown the effect of self-masking for parallel presented data during propagation in technical channels of leakage. This effect can be used to protect information from leakage.

Keywords

Informational security, security risk, technical protection of information, self-masking effect, information leakage.

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1. Introduction

In works [1-5] was noted that the operation of any electronic technical means and systems (TMS), which include information and communication systems (ICS), where information data have both serial and parallel representation, is accompanied by undesirable effects, which contribute to the formation of technical channels of leakage of information (TCL). Usually, such effects are side electromagnetic radiation of information signals, their guidance on external conductors and technical means, leakage of these signals into the power supply network and grounding, etc. The formation of these channels at the objects of information activity (OIA) is a threat to information security in terms of violation of the confidentiality of information and requires taking the necessary measures to ensure it [1-5].

A characteristic feature of TCL, as a type of threats, is that their elimination cannot be carried out completely. Theoretically, the complete elimination of the channel is possible under ideal conditions, when the noise is infinite, or there is no signal, or the probability of false and correct receptions is equal to each other, etc. Therefore, there are two aspects regarding the effectiveness of information protection against leakage through technical channels.

First, it is the effectiveness of the substantiation of the goal - based on the requirements of the owner of the information, substantiation of the sufficiency of the conditions of its protection in the TCL. These are conditions that must be met in order for information to be considered protected.

Secondly, it is the cost-effectiveness of achieving the goal - optimization of means and measures for information protection in TCL, i.e. achieving security conditions with the lowest costs.

The first point of view is the main one, because it regulates and reflects the essence of security and answers the question of what should be in the channel. The second point of view regulates the use of means and protection measures and answers the question of how to ensure what should be in the channel.

In work [1], the indicators of information security in TCL for consistent presentation of data, their connection with each other and the connection with the risk of information security are substantiated. Thus, for a given probability of risk, the analytical ratios obtained in work [1] allow the calculation of the limit values of these indicators, which will reliably ensure the specified risk. And vice versa, based on the current indicators, you can find the value of the probability of the risk that they actually provide.

However, the parallel presentation of data is characterized by a self-masking effect, which will positively contribute to the protection of information in TCL and save on the need for masking devices. After all, the channel does not receive informational data, but a certain amount of it, which is determined by the number of parallel bits.

Therefore, there is an urgent task of detailed consideration and analysis of the effect of self-masking of data presented in parallel to ensure the protection of information from leakage through technical channels.

2. Self-masking effect of parallel presented data

In work [1] it was shown that if the probability of information security risk $p_{r.\text{max.allow}}$ is given, then it is possible to match it with the maximum permissible bandwidth of TCL. For parallel presentation of data, it can be found using the formula:

$$C_{\text{paral. max.allow}} = p_{r\,\text{max.allow}} \times C_{\text{paral.max}} , \qquad (1)$$

where $C_{\text{paral. max}}$ – the maximum bandwidth of TLC for parallel presentation of data.

If the risk is given in the form of permissible losses $R_{\text{max.allow.}}$, then the probability $p_{r\,\text{max.allow}}$ can be calculated from the formula [6]:

$$R_{\text{max.allow}} = p_{r\,\text{max.allow}} \times Price , \qquad (2)$$

where *Price* is the full price of the consequences of the threat's implementation.

So, for example, if you set the maximum permissible risk value $R_{\text{max.allow}}$ (this can essentially be considered as a level of protection), then knowing the price of one digit of the data sequence, you can find the maximum permissible risk probability, which will determine exactly the fate of the entire collection of information data that can be leaked and at the same time the state of information security will remain satisfactory. The value of the price of one digit of the sequence can be found as the ratio of the maximum losses, for example, obtained as a result of allegedly leaking all the information, to the minimum number of non-redundant digits containing all the information. If the discharges are redundant, then their price should be proportional to the entropy of the discharge. The price of possible losses *Price* and risk limits $R_{\text{max.allow}}$ should be set by the owner of information resources.

From the point of view of effectiveness, the protection system will be effective if its indicators reliably provide $p_{r.\text{max.allow}}$ and thereby the specified system will prove to guarantee information security with a given risk.

The technical channel of information leakage with the presentation of data in the form of a parallel code for the purpose of finding bandwidth and other individual indicators is expedient to present as a discrete-continuous channel with a source producing a sequence of sums from *d* - implementations of binary digits (Figure 1).

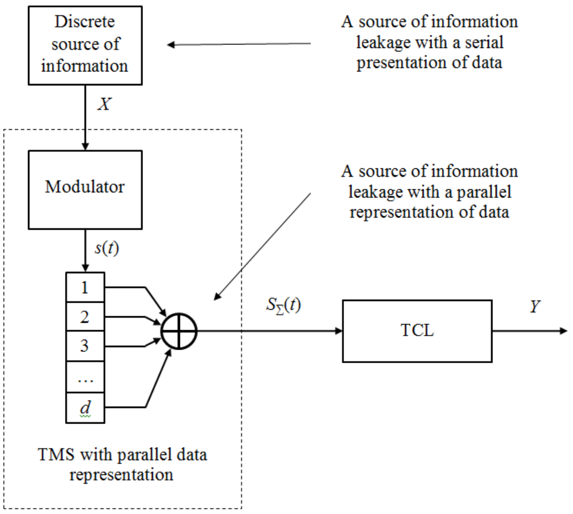

Figure 1: Source of information leakage with parallel presentation of data in TCL

A discrete source of information produces some message – for simplicity, a sequence of binary characters $X = (x_1, x_2, x_3, \ldots)$, where $x = \{0, 1\}$. Each sign x of the sequence X in technical means and systems circulates in the form of continuous implementations of duration T, for example [1]:

$$\begin{aligned} x = 1 \quad &\leftrightarrow \quad s_1(t); \\ x = 0 \quad &\leftrightarrow \quad s_2(t). \end{aligned} \tag{3}$$

In Figure 1, the element that carries out identification (3) is marked with a modulator. The specified sequence is divided into segments of *d* bits, which subsequently circulate synchronously in the form of continuous realizations along parallel lanes.

Total side emissions or guidance of these realizations fall into TCL. As a rule, the data in the TMS circulate synchronously, without phase shifts and have the same duration T, so the total implementation $S_\Sigma(t)$, formed by implementations on parallel tracks, can be represented in the form:

$$S_\Sigma(t) = \sum_{l=1}^{d} s_{x,l}(t)\,. \tag{4}$$

where l – is the parallel track number, $l = 1, 2, \ldots d$; $s_{x,l}(t)$ – is an implementation according to the value of the sign x, determined by relation (3), and takes place on track l - one of the parallel d.

It is obvious that the sum (4) must be different for different forms of realizations of $s(t)$, so for simplicity let $s_1(t)$ and $s_2(t)$ represent a system of unipolar realizations: $s_1(t)$ is some arbitrary realization, and $s_2(t) = 0$. The convenience of this example is that the values of $s(t)$ are proportional to the data x, which means that a number of probability distributions that will take place for x will also be valid for $s(t)$ (Figure 2) .

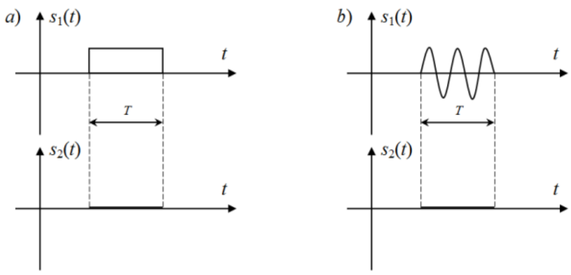

Figure 2: Examples of implementations of binary signs, one of which is zero, in the form:
(a) video signal, (b) radio signal

When adding implementations on parallel tracks, a self-masking effect occurs, which can be used as an additional factor when justifying security indicators in TCL.

The effect of self-masking consists in the fact that each of the parallel circuits of the sequence, like an obstacle, is additively affected by the sum of other parallel circuits. Despite the fact that only known realizations from identity (4) participate in the sum (4), from the total realization $S_\Sigma(t)$ it is possible to determine only which realizations $s_x(t)$ participated, but it is not possible to determine on which tracks (in which stages of the sequence) each of them is located. An exception for unipolar implementations (there is no self-masking effect) can only be the case when all signs of x have the same name (two options - the source emits all "1" or all "0").

The effect of self-masking when presenting data in the form of a parallel code increases with increasing d. At the same time, summation (4) introduces a certain uncertainty into the sequence of information data X – loss of information. Obviously, the amount of lost information will be expressed as the difference between the entropies at the output of the source $H(X)$ and at the output of the sources with parallel representation of data $H(S_{\sum}(t))$.

If we assume that there are no interferences, errors and any other distortions in the TCL, then the TCL can be used as a demodulator of the total $S_{\sum}(t))$. Then for unipolar signals according to relation (4):

$$Y_{\Sigma} = \sum_{l=1}^{n} x_l \,. \tag{5}$$

As is known, the amount of mutual information in the channel, taking into account the parallel representation of data, can be expressed by the formula:

$$I(X;Y) = H(X) - H(X/Y) = H(Y) - H(Y/X)\,. \tag{6}$$

Since the output of the channel is formed as a sum (4) without the participation of any random processes, then the entropy $H(Y/X)$ = 0 bits. In this regard, the desired entropy, which describes the loss of information during parallel representation, can be found using the formula:

$$H(X/Y) = H(X) - H(Y)\,. \tag{7}$$

In essence, the conditional entropy $H(X/Y)$ is a measure of uncertainty, or a quantitative description of the information lost in the parallel representation of data.

Regardless of the number of parallel discharges d, the entropy of a discrete source of information with a sequential representation of data is expressed by the formula [7-8]:

$$H(X) = \lim_{n\to\infty} \frac{1}{n} \sum_{k=1}^{2^n} p(X_k^n) \log_2 \frac{1}{p(X_k^n)}\,, \tag{8}$$

where n – is an arbitrary but fixed length of the sequence $X^n = (x_1, x_2, x_3, \ldots, x_n)$, which produces a discrete source of information; $p(X_k^n)$ – is the probability of the combination X^n of length n with number k, k = 1, 2, 3,..., n.

For the Bernoulli distribution, entropy (8) is equal to:

$$H(X) = p_x \log_2 \frac{1}{p_x} + (1 - p_x) \log_2 \frac{1}{1 - p_x}\,, \tag{9}$$

where p_x is the probability of a specific x, for example, $x = 1$.

With equal probability of signs in digits, the entropy of the source $H(X)$ = 1 bit. In the binary system, this is the maximum value of the entropy of the source calculated for one binary digit.

In order to reveal the self-masking effect and find the entropy of the channel output $H(Y)$, let the discrete information source have a Bernoulli distribution for simplicity:

For <u>$d = 1$</u>, all data circulates on one track, there is no parallel representation of data, the total implementations coincide with the implementations of serial data:

$$S_{\Sigma}(t) = s_x(t)\,. \tag{10}$$

From the values of $S_{\sum}(t)$ entering the channel input, it is possible to clearly determine the realizations of $s_x(t)$ and the value of x produced by the source, $x = y$. At the same time, the entropy $H(Y) = H(X)$, since $p_x = p_y$. Obviously, there is no loss of information:

$$H(X/Y) \underset{d=1}{=} 0\,\text{bit}\,. \tag{11}$$

For <u>$d = 2$</u>, data circulate in two parallel lanes, total realizations represent the sum of two realizations:

$$S_{\Sigma}(t) = s_{x,1}(t) + s_{x,2}(t)\,. \tag{12}$$

This time it becomes obvious that according to some implementations of $S_{\sum}(t)$ it is no longer possible to unambiguously assign the values x on the tracks, as they vibrated on the output of the sources. It can be clumsily shown on the example taken for simplicity of the system of unipolar implementations with different truth tables for x_l, which can be on parallel tracks, l = 1, 2, and the total sums of their implementations (Table 1). With whom, it is also obvious that:

$$Y_{\Sigma} = y_1 + y_2 = x_1 + x_2 = x_2 + x_1\,. \tag{13}$$

Table 1

Tables of truth for x on 2 parallel tracks and the sum of their implementations

№$_x$	x_1	x_2	$S_{\Sigma}(t)$	№$_s$	Y_{Σ}	y_1	y_2
1	0	0	0	1	0	0	0
2	0	1	$s_1(t)$	2	1	?	?
3	1	0				?	?
4	1	1	$2s_1(t)$	3	2	1	1

From Table 1 it is possible to designate the next:

– if $S_\sum(t)$ = 0, then it means that i on the first, i on the other parallel data lanes x can uniquely have the value x = 0. There is no negligence, shards $x_1 = x_2 = y_1 = y_2 = 0$;

– if $S_\sum(t) = s_1(t)$, then it means that either in the first lane x = 0 and on the other x = 1, or on the other hand, on the first x = 1 and on the other x = 0. That is, if given parallel to the representations, spread back at the X sequence, then in positions that will give the lanes the complete insignificance of something that the source produced a combination of 1,0 or 0,1;

– if $S_\sum(t) = 2s_1(t)$, then it means that i on the first, i on the other parallel data lanes x can uniquely have a value – 1. There is no uncertainty because $x_1 = x_2 = y_1 = y_2 = 1$.

At the same time, the entropy of the channel output:

$$H(Y)=\frac{1}{2}(p_x^2\log_2\frac{1}{p_x^2}+2(1-p_x)p_x\log_2\frac{1}{2(1-p_x)p_x}+$$
$$+(1-p_x)^2\log_2\frac{1}{(1-p_x)^2}). \quad (14)$$

Uncertainty of parallel representation:

$$H(X/Y)\underset{d=2}{=}(1-p_x)p_x\log_2 2=(1-p_x)p_x. \quad (15)$$

The ratio is obtained from formula (7) by writing formula (9) as the mathematical expectation of even digits calculated for one digit. As an example, it looks like this:

$$H(X)=\frac{1}{2}(p_x^2\log_2\frac{1}{p_x^2}+2(1-p_x)p_x\log_2\frac{1}{(1-p_x)p_x}+$$
$$+(1-p_x)^2\log_2\frac{1}{(1-p_x)^2}) \quad (16)$$

Ratio (15) can be easily transformed into (9) and conversely (9) into (16).

For <u>d = 3</u>, data circulating on three tracks, the total implementations will represent the sum of the three implementations:

$$S_\Sigma(t)=s_{x,1}(t)+s_{x,2}(t)+s_{x,3}(t). \quad (17)$$

Similarly, as for two parallel tracks, it is obvious that for some realizations of $S_\sum(t)$ it is also not possible to uniquely determine the combination of x values on the tracks (Table 2).

Similar considerations can be made for the data in Table 2 as for the data in Table 1 corresponding to $d = 2$. However, it should be noted that for d = 3, which corresponds to eight combinations of three-bit binary data, only four enter the channel realizations from which only combinations consisting only of x = (0, 0, 0) and x = (1, 1, 1) can be uniquely determined.

Channel output entropy:

$$H(Y)=\frac{1}{3}(p_x^3\log_2\frac{1}{p_x^3}+3(1-p_x)^2p_x\log_2\frac{1}{3(1-p_x)^2p_x}+$$
$$+3(1-p_x)p_x^2\log_2\frac{1}{3(1-p_x)p_x^2}+(1-p_x)^3\log_2\frac{1}{(1-p_x)^3}). \quad (18)$$

The uncertainty of the parallel representation can be obtained by representing the entropy $H(X)$ as the mathematical expectation of triple digits calculated for one digit:

$$H(X)=\frac{1}{3}(p_x^3\log_2\frac{1}{p_x^3}+3(1-p_x)^2p_x\log_2\frac{1}{(1-p_x)^2p_x}+$$
$$+3(1-p_x)p_x^2\log_2\frac{1}{(1-p_x)p_x^2}+(1-p_x)^3\log_2\frac{1}{(1-p_x)^3}), \quad (19)$$

$$H(X/Y)\underset{d=3}{=}(1-p_x)^2p_x\log_2 3+(1-p_x)p_x^2\log_2 3. \quad (20)$$

Table 2

Tables of truth for x on 3 parallel tracks and the sum of their implementations

№$_x$	x_1	x_2	x_3	$S_\sum(t)$	№$_s$	$Y_\sum$	y_1	y_2	y_3
1	0	0	0	0	1	0	0	0	0
2	0	0	1	$s_1(t)$	2	1	?	?	?
3	0	1	0				?	?	?
4	1	0	0				?	?	?
5	1	1	0	$2s_1(t)$	3	2	?	?	?
6	1	0	1				?	?	?
7	0	1	1				?	?	?
8	1	1	1	$3s_1(t)$	4	3	1	1	1

For <u>d = 4</u>, with data circulating on four lanes, the total realizations will represent the sum of the four realizations:

$$S_\Sigma(t)=s_{x,1}(t)+s_{x,2}(t)+s_{x,3}(t)+s_{x,4}(t). \quad (21)$$

The truth tables for x on parallel tracks and the sums of their realizations are presented in table 3.

From the data in Table 3, it can be seen that for $d = 4$, which corresponds to sixteen combinations of four-bit binary data, only five realizations enter the channel, from which only combinations consisting only of x = (0, 0, 0, 0) and x = (1, 1, 1, 1).

Channel output entropy:

$$H(Y)=\frac{1}{4}(p_x^4\log_2\frac{1}{p_x^4}+4(1-p_x)^3p_x\log_2\frac{1}{4(1-p_x)^3p_x}+$$

$$+6(1-p_x)^2 p_x^2 \log_2 \frac{1}{6(1-p_x)^2 p_x^2} + 4(1-p_x) p_x^3 \log_2 \frac{1}{4(1-p_x) p_x^3} +$$

$$+(1-p_x)^4 \log_2 \frac{1}{(1-p_x)^4}) \cdot \qquad (22)$$

Table 3

Tables of truth for *x* on 4 parallel tracks and the sum of their implementations

№$_x$	x_1	x_2	x_3	x_4	$S_\Sigma(t)$	№$_s$	Y_Σ	y_1	y_2	y_3	y_4
1	0	0	0	0	0	1	0	0	0	0	0
2	0	0	0	1	$s_1(t)$	2	1	?	?	?	?
3	0	0	1	0				?	?	?	?
4	0	1	0	0				?	?	?	?
5	1	0	0	0				?	?	?	?
6	0	0	1	1	$2s_1(t)$	3	2	?	?	?	?
7	0	1	0	1				?	?	?	?
8	1	0	0	1				?	?	?	?
9	0	1	1	0				?	?	?	?
10	1	0	1	0				?	?	?	?
11	1	1	0	0				?	?	?	?
12	0	1	1	1	$3s_1(t)$	4	3	?	?	?	?
13	1	0	1	1				?	?	?	?
14	1	1	0	1				?	?	?	?
15	1	1	1	0				?	?	?	?
16	1	1	1	1	$4s_1(t)$	5	4	1	1	1	1

The uncertainty of the parallel representation can be obtained by representing the entropy *H(X)* as the mathematical expectation of four digits calculated for one digit:

$$H(X) = \frac{1}{4}(p_x^4 \log_2 \frac{1}{p_x^4} + 4(1-p_x)^3 p_x \log_2 \frac{1}{(1-p_x)^3 p_x} +$$

$$+6(1-p_x)^2 p_x^2 \log_2 \frac{1}{(1-p_x)^2 p_x^2} + 4(1-p_x) p_x^3 \log_2 \frac{1}{(1-p_x) p_x^3} +$$

$$+(1-p_x)^4 \log_2 \frac{1}{(1-p_x)^4}) \cdot \qquad (23)$$

$$H(X/Y) \underset{d=4}{=} (1-p_x)^3 p_x \log_2 4 + \frac{6}{4}(1-p_x)^2 p_x^2 \log_2 6 +$$

$$+(1-p_x) p_x^3 \log_2 4 \, . \qquad (24)$$

For an arbitrary number of tracks *d*, the total realization for arbitrary forms of realizations $s_x(t)$ is determined by formula 4. For unipolar realizations taking into account the weight of the combination $wt = \sum_{l=1}^{d} x_l$ – the number of units on parallel tracks, the total implementation can be found somewhat differently, due to permutations:

$$S_\Sigma(t) = \sum_{l=1}^{d} s_{x,l}(t) = \sum_{wt=0}^{d} C_d^{wt} s_1(t) \, , \qquad (25)$$

where $C_d^{wt} = \frac{d!}{wt!(d-wt)!}$ is the number of permutations of *wt* units in a combination of length *d*.

For the general case, the channel output and input entropies will have the form:

$$H(Y) = \frac{1}{d}\sum_{wt=0}^{d} C_d^{wt}(1-p_x)^{d-wt} p_x^{wt} \log_2 \frac{1}{C_d^{wt}(1-p_x)^{d-wt} p_x^{wt}} . \qquad (26)$$

$$H(X) = \frac{1}{d}\sum_{wt=0}^{d} C_d^{wt}(1-p_x)^{d-wt} p_x^{wt} \log_2 \frac{1}{(1-p_x)^{d-wt} p_x^{wt}} . \qquad (27)$$

The uncertainty of the parallel representation can be found using formula (7). With an infinite increase in the number of parallel lanes, it will take the form:

$$H(X/Y) = \lim_{d\to\infty} \frac{1}{d}\sum_{wt=0}^{d} C_d^{wt}(1-p_x)^{d-wt} p_x^{wt} \log_2 C_d^{wt} \, . \qquad (28)$$

The obtained relation (28) establishes the relationship between the amount of information that falls on one binary bit on average and is lost for a Bernoulli discrete source of information and a system of unipolar implementations when data is presented in parallel by *d* bits.

Formula (28) is relatively difficult to analyze, but at least the following can be seen from it:

- if d > 1 and probability $0 < p_x < 1$ entropy *H(X/Y)* > 0, i.e. self-masking effect is present and can be used in TCL;
- when substituting small values of *d* into formula (7) with a fixed probability within $0 < p_x < 1$, the entropy *H(X/Y)* increases.

Channel throughput, as the maximum amount of mutual information (6), which is transmitted over all possible distributions of the source, which on average corresponds to one bit of the sequence, can be expressed by the ratio:

$$C = 1 - H(X/Y) = \lim_{d\to\infty}\left[1 - \frac{1}{d}\sum_{wt=0}^{d} \frac{C_d^{wt}}{2^d} \log_2 C_d^{wt}\right] . \qquad (29)$$

The ratio (29) is obtained based on the fact that the maximum entropy *H(X)* at the output of the source is reached with equal probability *x*.

The graph of the dependence of the bandwidth of the channel during parallel presentation of data on the number of parallel bits is as shown in Figure 3.

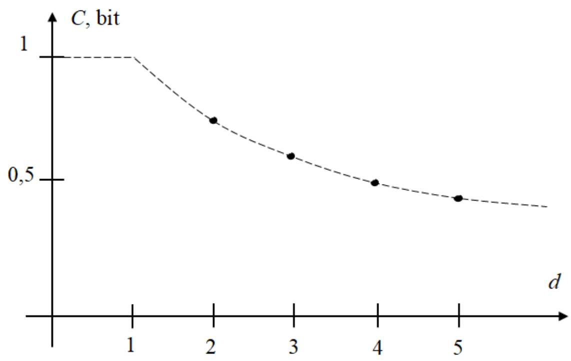

Figure 3: Examples the graph of the dependence of the entropy *H(X/Y)* on the number of parallel discharges *d*

3. Conclusions

The effect of self-masking of parallel presented data during propagation in TCL is shown. It consists in the fact that the data implementations, being synchronously on parallel tracks of the TMS, emit electromagnetic energy not separately, but in total. These radiations, as well as guidance that can be carried out from these radiations, enter the TCL. Due to self-masking, total implementations formed by adding implementations in parallel circuits do not always allow reliable determination of the sequence data produced by the source of information.

The conditional entropy of a source with a sequential representation relative to a parallel representation is substantiated. It characterizes the amount of information that pertains to one binary bit on average and is lost for a Bernoulli discrete source of information and a system of unipolar implementations when data is presented in *d* bits in parallel. It is shown that starting from two parallel discharges and above, this entropy is different from zero and increases in a certain way.

The ratio for the channel capacity for the system of unipolar implementations, which are formed by the parallel representation of the discharges without taking into account the interference in the channel, is obtained. A graph of the dependence of this bandwidth on the number of parallel discharges is plotted, from which it is observed that it decreases with an increase in the number of parallel discharges, that is, a decrease in the security risk and an increase in the self-masking effect. This effect can be used to protect information from leakage.

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