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Combined and Comb RCIED Activation Messages Jamming – Two Different Strategies with Similar Names

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The characteristics of combined and comb jamming of RCIED activation messages are presented in this paper. Combined jamming signal is formed as the sum of swept sinusoidal signal and noise signal, while comb jamming signal means that its spectrum has a number of simultaneous discrete equally distant sinusoidal components, eventually further swept. The performances of combined jamming are compared to pure sweep and pure barrage jamming. They are determined on the base of originally developed simulation program implementation.
Comb jamming is analyzed based on its generation from rectangular pulse train. It is presented how the selection of ratio of pulse duration to its period and the number of frequency components in comb signal influence the obtained jamming signal characteristics. It is proved that comb jamming is especially advantageous in relation to sweep jamming when RCIED activation message duration is significantly lower than the sweep cycle period.

Key words: **RCIED; combined jamming; comb jamming; simulation program; Bit Error Rate (*BER*); phasor diagram.**

Introduction

IN our everyday lives we are faced with the threads of constantly evolving methods for Remote Controlled Improvised Explosive Devices (RCIEDs) activation. The improvements of these methods and new jamming principles implementation put the new demands for prevention techniques. It is necessary to develop new jamming techniques or to further develop existing ones.

Various methods are implemented in the realization of RCIED jammers [1 - 12]. The most often implemented techniques in this case include sweep jamming and barrage jamming. In this paper we, at first, have presented the characteristics of very rarely applied method of combined sweep and barrage jamming, which is used in RCIED activation jammer intended for VIP persons protection [5]. Combined jamming is realized as a sum of sweep and noise signal, thus forming one instantaneous signal. When we have studied available literature about RCIED activation jammers, we have not even found explicit statement that such combined jamming was implemented. Its existence is somewhere only indicated emphasizing that different jamming signal generations may be combined [13]. More often, jamming signal types are combined in a different manner: frequency limited barrage jamming signal is generated and the spectrum of such a noise signal is then swept [12 - 15]. The analysis in this paper is focused on the combined jamming of QPSK modulated RCIED activation signal.

Comb jamming is another different jamming strategy with the similar name, but completely different realization. The main goal is to simultaneously generate a number of different discrete frequency components to improve jamming efficiency. Signal frequencies are not continuously present in some frequency band or whole frequency spectrum as at barrage jamming, but on some equal distances (as "teeth" or "comb") or on some in advance specified frequencies [16], [17]. These generated "comb" frequencies may be further swept, like in the realization of radar detection jamming in [18]. The distance between signal frequencies or the selected frequencies guarantee successful jamming as if all frequencies are generated at barrage jamming. This strategy is not often applied for jamming and few of rare existing solutions are presented in [19 - 21].

Sections II to IV are related to the combined jamming, while sections V and VI are related to comb jamming. The theoretical analysis of the developed method for combined jamming is presented in the Section II "Theoretical background of combined jamming". The main features and verification of the simulation program are presented in the Section III "Simulation program description and verification". The results obtained by simulation program application for combined jamming are presented in the Section IV "The results of the simulation". Section V "Comb jamming realization" describes the main methods for comb jamming signal generation, while the Section VI "Comb jamming performances" presents the procedures for comb jamming performances definition and the achieved Bit Error Rate (*BER*) values comparing to pure sweep jamming. At the end, conclusions are in the Section VII.

Theoretical background of combined jamming

Theoretical analysis of combined sweep and barrage jamming is realized based on phasor diagrams, as it is performed in a bit similar example from [22].

Let us suppose that RCIED activation signal is sinusoid of frequency ω with normalized amplitude equal 1. It may be

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presented in a phasor diagram by the vector *AB* with its starting phase φ=0° (Fig.1), or

$$AB = \sin(\omega \cdot t) \tag{1}$$

The sweep component of the jamming signal continuously varies its frequency and in the moment when the frequencies of these two signals are equal, their phases differ for some value φ. In the phasor diagram from the Fig.1 the vector *BC* corresponds to the sweep jamming signal. The jamming signal may be expressed as

$$BC = k \cdot \sin(\omega \cdot t + \varphi) \tag{2}$$

where it is supposed that the ratio of amplitudes is *BC*/*AB*=*k*.

The amplitude of the resultant vector *AC* may be calculated implementing the cosine theorem as

$$AC = \sqrt{AB^2 + BC^2 - 2 \cdot AB \cdot BC \cdot \cos(\pi - \varphi)} \tag{3}$$

For our analysis it is important to calculate the phase of the resultant vector *AC*. It is determined again by the cosine theorem including the value of AC calculated according (3):

$$\alpha = \arccos \frac{AB^2 + AC^2 - BC^2}{2 \cdot AB \cdot AC} \tag{4}$$

Noise signal may be represented as a sum of different frequency sinusoidal components. We suppose that the amplitude of the component at the frequency ω is *CD* and that its starting phase is ψ in relation to the phase of the vector *AC*.

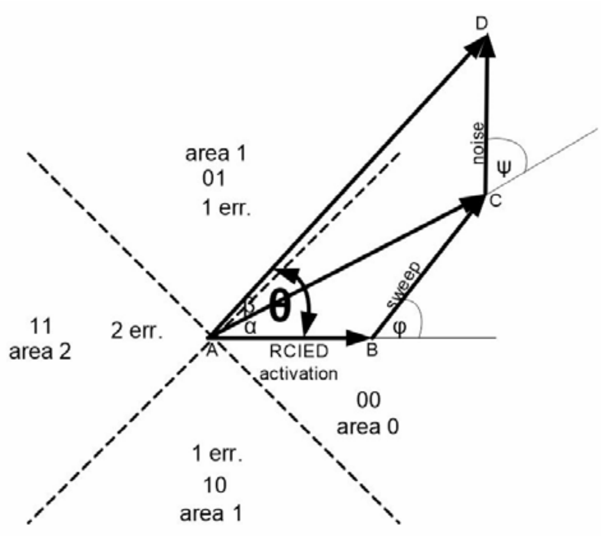

Figure 1. Phasor and constellation diagram for the combined jamming of QPSK modulated RCIED activation signal.

The same procedure as to calculate the vector sum of RCIED activation signal and sweep signal is now implemented to obtain the resultant vector after adding noise signal. The resultant vector *AD* from Fig.1 is

$$AD = \sqrt{AC^2 + CD^2 - 2 \cdot AC \cdot CD \cdot \cos(\pi - \psi)} \tag{5}$$

and the phase of this vector related to the phase of the vector *AC* is

$$\beta = \arccos \frac{AC^2 + AD^2 - CD^2}{2 \cdot AC \cdot AD} \tag{6}$$

The total effect of sweep and barrage jamming is determined on the base of phase angle θ between the resultant vector *AD* and RCIED activation signal *AB*, i.e.

$$\theta = \alpha + \beta \tag{7}$$

In Fig.1 the signal phasor diagram is presented together with the constellation diagram for QPSK modulated signal as one of the MPSK modulated signal variants. In case that the resultant vector *AD* is placed in the area 0, there is no bit error. But, if the vector AD is placed in the area 1, one of the bits forming a symbol is wrong (as in Figure 1). Both bits forming a symbol are incorrect if the resultant vector falls in the area 2. The lines forming the border between the areas in the constellation diagram for QPSK signal are at the angles $\pi/4$ and $3 \cdot \pi/4$ related to the RCIED activation signal phasor.

The analysis procedure presented in this paper may be easily modified to the case of other MPSK signal types. It is only necessary to change the appearance of constellation diagram in Figure 1.

Simulation program description and verification

Phasor analysis of only sweep jamming has been already performed in [8] and [10]. When considering noise jamming, theoretical analysis may be realized on the base of consideration from [23]. However, in [23] it is supposed that interference (noise) signal has lower amplitude than the transmitted signal, meaning that the achieved Symbol Error Rate (*SER*) and Bit Error Rate (*BER*) values are relatively low. In such an example noise level is too low to be implemented for jamming realization, because it may not cause successful jamming. The mathematical analysis of QPSK modulated signal reception in the presence of noise is not simple even when noise level is low and it becomes even more complicated when noise signal level is greater than the regular signal level, as in the jammer application. The complexity of analytical approach in this problem solving is further increased when the third component (sinusoidal component presenting sweep jamming) is included in the analysis. Simulation approach, which we have originally developed, significantly simplifies *SER* and *BER* determination in such a case.

The flow-chart of the simulation program is already presented in [1]. The simulation follows the procedure presented in the previous section of this paper, i.e. the analysis in the simulation is performed according to the graphical presentation from Fig.1. Each simulation step is based on the generation of three uniformly distributed random numbers (*RN*) in the range [0,1]. The first *RN* (*RN1*) is used to calculate the random phase of sinusoidal sweep signal in the moment when the frequency of sweep signal is (approximately) equal to the frequency of RCIED activation signal. Equation (2) is used for this calculation, where the phase of sweep jamming signal is related to *RN1* as $\varphi = 2 \cdot \pi \cdot RN1$. The amplitude of the sweep signal is determined from the simulation input parameter defining the ratio between sweep signal amplitude and RCIED activation signal amplitude. The second and the third random number (*RN2* and *RN3*) are used to determine the amplitude and the phase of barrage jamming signal at the frequency ω of RCIED activation signal. The amplitude and the phase of this signal are determined using the Box-Müller theorem by the expression [24 - 26]:

$$x = \sqrt{-2 \cdot \ln(RN2)} \cdot \cos(2 \cdot \pi \cdot RN3) \tag{8}$$

Simulation program is verified on the simpler examples where the amplitude of jamming signal is at least 5dB lower than the level of RCIED activation signal because the results presenting *BER* and *SER* values for such examples are available in the literature [27], [28]. As far as we know, there are no results in the literature for the relatively higher jamming signal level comparing to the RCIED activation signal. That is why wehave verified the results obtained by our simulation program comparing them to the results from [27], [28], as explained in [1].

The results of the simulation

Fig.2 presents *BER* values as the function of the Energy per Bit to Noise Jamming ratio (E/N_j) for the RCIED activation signal to the noise jamming signal component and Signal to Jamming ratio (S/J) for the RCIED activation signal to the sweep jamming component, both in the combined sweep and barrage jamming signal. The negative value of E/N_j or S/J means that the level of RCIED activation signal is lower than the level of barrage or sweep jamming signal.

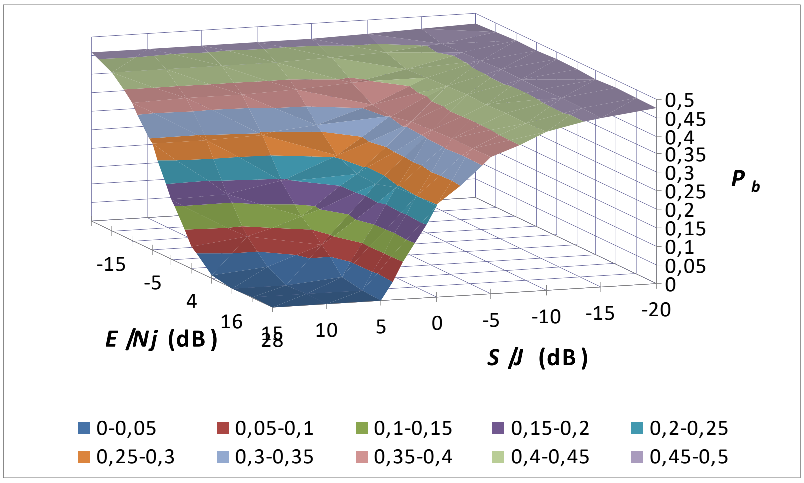

Figure 2. *BER* (P_b) as the function of the ratios E/N_j and S/J

When considering the graph in Fig.2, it may be concluded that the *BER* value tends to 0.5 when the jamming signal level is increased whether only sweep or only barrage jamming is implemented (this statement has been already proved in [10]). Such a situation is illustrated selecting the *BER* value for S/J=-20dB and E/N_j=28dB (approximately only sweep jamming application) or S/J=15dB and E/N_j=-20dB (approximately only barrage jamming application). The same result is obtained when both jamming signal levels are increased in the same time (the obtained *BER* value for S/J=-20dB and E/N_j=-20dB), i.e. when combined sweep and barrage jamming is applied.

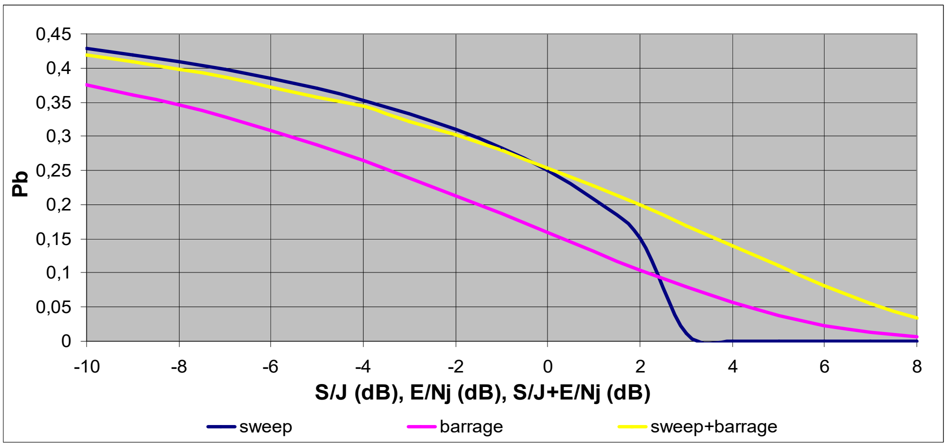

Figure 3. *BER* (P_b) as the function of ratio: a) S/J for sweep jamming,b) E/N_j for barrage jamming and c) equal S/J and E/N_j values for combined sweep and barrage jamming.

Fig.3 presents *BER* as a function of signal/interference (signal/noise) ratio in three cases: a) when only sweep jamming is applied (parameter sweep in Fig.3 legend); b) when only barrage jamming is applied (parameter barrage); c) when combined sweep and barrage jamming is applied (parameter sweep+barrage). In case of sweep jamming the number on the *x*-axis presents the ratio S/J in dB and for barrage jamming the same number corresponds to E/N_j ratio.

When combined jamming is applied, the value on *x*-axis means that both sinusoidal and noise signal have this level (for example, 0 on the *x*-axis means that S/J=0dB and E/N_j =0dB). This is supposed to be the maximum technically achievable output signal level for both jamming types in a jammer.

The results in Fig.3 are presented starting from the relatively low level of the jamming signal comparing to the RCIED activation signal level. In this way the benefits of combined jamming application may be seen for the case of hostile RCIED activation attempt from a low distance. The advantages of combined jamming comparing to barrage jamming are clear from Fig.3 in the whole range of levels from the significantly lower jamming signal level than it is RCIED activation signal level (8dB) till the much higher level of implemented jamming signal (-10dB). The advantages of combined jamming are more emphasized for lower jamming signal levels, which is very important to increase the jamming device range of functioning. For example, the *BER* value is increased 2.5 times for the two signals level ratio 4dB, 2 times for the signals level ratio 2dB and 60% for the signals level ratio 0dB.

The advantages of combined jamming in this range of lower jamming signal levels are even more obvious when comparison is performed to sweep jamming. For the values of *S*/*J*=4dB and more only sweep jamming implementation causes no error (*BER*=0). Such a behaviour may be explained when looking at the phasor and constellation diagram in Fig.1. The low and always the same amplitude of sweep signal (phasor *BC*) comparing to the amplitude of RCIED activation signal (phasor *AB*) may not cause the resultant vector *AC* to cross the boundaries of area 0. The situation is different when noise jamming is considered. In this case the amplitude of jamming signal is variable (according to Gaussian distribution) and the resultant signal vector *AC* may cross the boundaries of the area 0.

In the range of lower *S*/*J* and E/N_j ratios (0dB or less) sweep and combined jamming have approximately the same *BER* values (the achieved *BER* in the case of sweep jamming is slightly higher, i.e. better, but this difference is negligible). If we want to characterize combined jamming, we may say that in the initial phase of signal level increase it is "improved version of barrage-like jamming" and after that it becomes "sweep-like" jamming.

RCIED activation message duration may be very low. In such a case it is possible that one complete period of the whole frequency range sweep overcomes this message duration. As has been already emphasized in [7], [9], the probability of successful jamming is then modified by the factor

$$P_{dist} = \frac{T_{mess}}{T_{sw}}, T_{mess} \leq T_{sw} \qquad (9)$$

where T_{mess} is RCIED activation message duration and T_{sw} is the period of one complete frequency sweep over the whole frequency bandwidth predicted for sweep signal generation. If the pure sinusoid has been used in sweeping, the BER value obtained in the sweep cycle is modified to

$$BER_{dist\_sw} = BER_{sw} \cdot P_{dist} \qquad (10)$$

where $BER_{dist\text{-}sw}$ is the *BER* value in systems such that RCIED activation message duration is lower than the sweep period. In case of combined jamming application, it may be supposed that BER_{bar} is applicable in cases when there is no coincidence between RCIED activation signal frequency and the generated sweep component frequency of combined signal. The value BER_{comb} is applied when RCIED activation signal frequency corresponds to the sweep signal frequency. This may be summarized in the equation

$$BER_{dist\_comb} = BER_{comb} \cdot P_{dist} + BER_{bar} \cdot (1 - P_{dist}) \qquad (11)$$

where BERdist-comb is the BER value in systems such that RCIED activation message duration is lower than the sweep component period in the combined jamming signal.

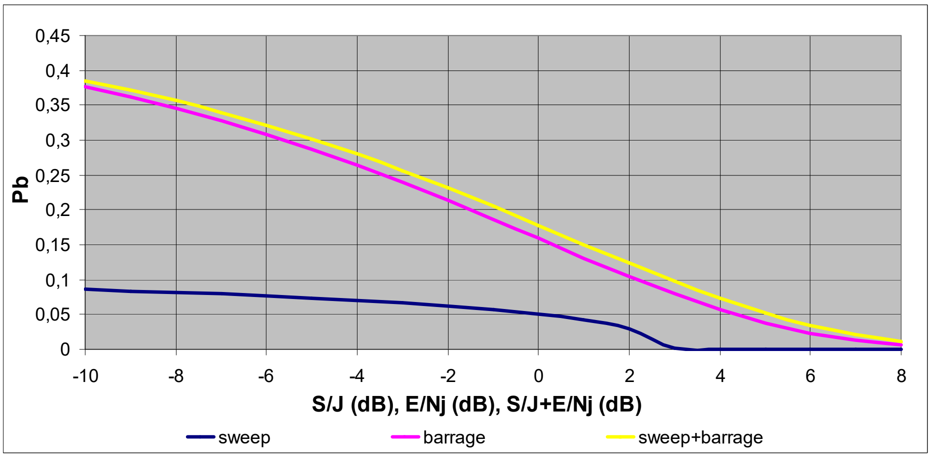

Figure 4. *BER* (P_b) as the function of ratio: a) *S*/*J* for sweep jamming, b) E/N_j for barrage jamming and c) equal *S*/*J* and E/N_j values for combined sweep and barrage jamming when P_{dist}=0.2 for sweep jamming

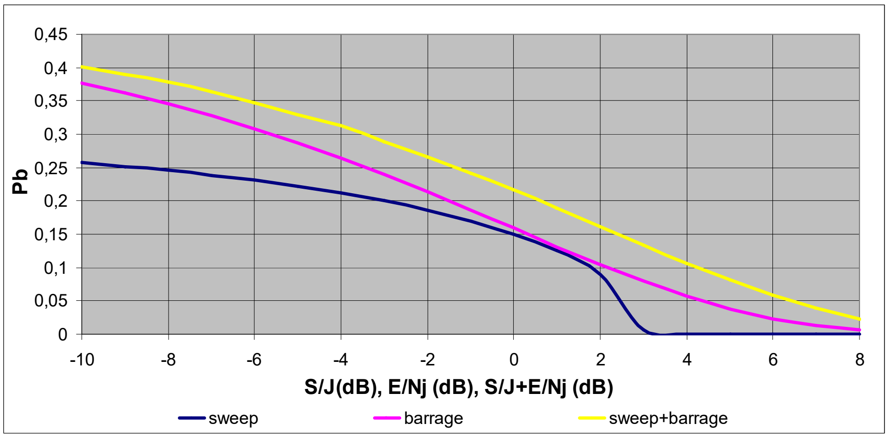

Figure 5. *BER* (P_b) as the function of ratio: a) *S*/*J* for sweep jamming, b) E/N_j for barrage jamming and c) equal *S*/*J* and E/N_j values for combined sweep and barrage jamming when P_{dist}=0.6 for sweep jamming

Figures 4 and 5 present the *BER* values for sweep and combined jamming in case of two P_{dist} values: 0.2 (Figure 4) and 0.6 (Figure 5). Here P_{dist} designates probability of coincidence between RCIED activation signal frequency and sweep signal frequency during the RCIED activation message duration. The third graph in these two Figures is for barrage jamming and it does not depend on P_{dist}. The *BER* values are always higher for combined jamming than they are for sweep and barrage jamming. Based on the comparison of graphs from Figures 3, 4 and 5, it follows that the benefit of combined jamming application over pure barrage jamming increases when P_{dist} is increased, but in the same time this benefit over pure sweep jamming is decreased. The results may be compared in one more manner. Comparing the *BER* values for pure sweep jamming and for combined jamming when the value of P_{dist} is changed from 1 to 0.2 (Figures 3 and 4), it may be concluded that combined jamming in a significant ratio decreases the *BER* values degradation. While this value is degraded nearly 5 times in case of pure sweep jamming (from about 0.43 to 0.09 for $S/J=E/N_j$=-10dB), degradation is not more than 10% when combined jamming signal is implemented (from about 0.42 to 0.38).

Comb jamming realization

Comb spectrum characteristic may be realized in several ways. Three methods are the most often applied in time domain [17]: rectangular pulse train, filtered pulse train and pseudorandom sequence. After the desired frequency spectrum is achieved in low frequency band by one of these three methods, the generated time sequence is used to modulate a carrier, thus shifting the spectrum to the necessary frequency band.

Rectangular pulse train is the well studied method and its spectrum is well known. If provided that A is amplitude of pulse, T is the period of pulse signals repeating and τ is the time duration of each pulse, the signal power spectrum may be presented by an expression [17]

$$P(f) = \sum_{k=0}^{\infty} \frac{A^2 \cdot \tau^2}{T^2} \cdot \frac{sin^2\left(\frac{k \cdot \pi \cdot \tau}{T}\right)}{\left(\frac{k \cdot \pi \cdot \tau}{T}\right)^2} \qquad (12)$$

The uniform discrete spectrum components in this case are modified (multiplied) according to the law $(\sin(x)/x)^2$, as obvious from (12). This means that necessary jamming signal power has to be higher than if the frequency spectrum is completely uniform. The reason is that even the minimum jamming frequency component must be at least equal to the predefined power threshold and that all other components have the power higher than the threshold value. In case of uniform power spectrum it is enough that all components have the threshold power. Multiplication factor $\sin(x)/x$ in the frequency spectrum is practically eliminated if the generated rectangular pulses are shaped by the adequate low-pass filter to obtain the second already emphasized signal variant – filtered pulse train [16]. The third signal variant – pseudorandom sequence is important, because there is no need to generate very short ("Dirac-like") impulses (as for the rectangular pulse train) or even to adequately shape these impulses (as for filtered pulse train). At pseudorandom sequence the signal amplitude is constant during the whole bit-time [16].

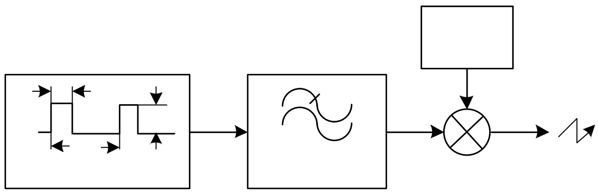

Figure 6. Block-scheme of the comb jammer

Our analysis in this paper is based on generation of rectangular pulse train as the most general signal form in a comb jammer. The block-scheme of such a solution is presented in Figure 6.

The pulse train of the desired characteristics is generated in Rectangular Waveform Generator (RWG). Frequency range of the generated signal is then limited in the low-pass filter (LPF). The third step is to shift the generated signal to the necessary frequency band. This is realized in the modulator (MOD). The desired frequency band is variable and adjusted using the modulation frequency in the programmable oscillator (POSC). Oscillator programmability allows successful jamming in case that it is necessary to cover the wide frequency range in the jamming process. In such a case it is possible to successively sweep the comb-shaped signal over frequency bands. At the end the generated jamming signal is transmitted by transmit antenna (T_x).

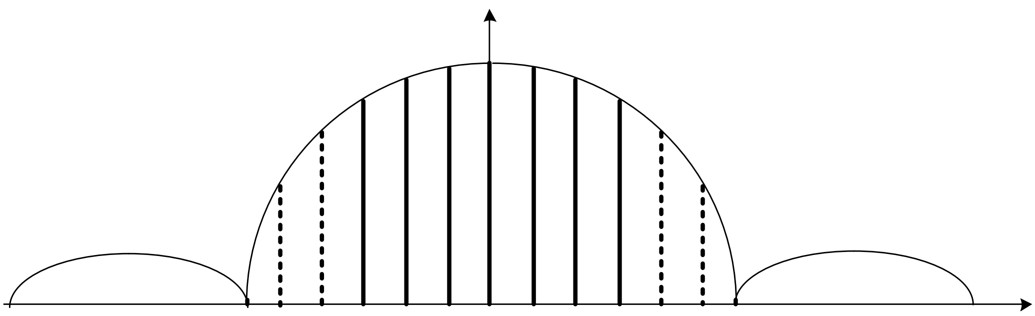

Figure 7. Jamming frequency components realized by the schematic in the Fig.6 for $K=T/\tau$=6, i=3

Let us now suppose that jamming is realized starting from the rectangular pulse train such that $K=T/\tau$. In this case there are total $2 \cdot K+1$ frequency components in the main lobe. The situation is illustrated by the graph from Fig.7 for the example $K=T/\tau$=6. The LPF in Figure 6 passes frequency components from k=0 till k=3 (parameter i=3), while frequency components from k=4 to k=6 are attenuated (eliminated). The frequencies between k=0 and k=3 cause jamming and among them the lowest level has the component at k=3. The effect of comb jamming is estimated based on this component with the lowest level.

Comb jamming performances

Table 1 presents the amplitude ratio of the rectangular signal to the minimum sinusoidal component which constitutes the comb signal after passing the LPF. The columns in the table correspond to the ratio T/τ while rows correspond to the number of the generated sinusoidal components in a T_x besides the one in the centre of the pass-band (Fig.6). If it is necessary to determine the *BER* value as a function of the rectangular signal amplitude, the value of interference *J* for sweep jamming in Figure 3 has to be increased taking the corresponding value of Ratio of the Rectangular wave Signal Amplitude to the Minimum Comb Jamming Signal Amplitude *(a(f))* from Table 1. When *BER* is determined, it means that the graph in Figure 3 is shifted left for the value from the Table 1.

Table 1. Ratio of the Rectangular wave Signal Amplitude to the Minimum Comb Jamming Signal Amplitude (a(f))

$a(f)$ (dB)	$K=T/\tau=3$	$K=T/\tau=4$	$K=T/\tau=5$	$K=T/\tau=6$
i=1	11.19	12.95	14.56	15.96
i=2	17.21	15.96	16.4	17.21
i=3		22.5	19.92	19.49
i=4			26.6	23.23
i=5				29.94

The benefits of comb jamming implementation comparing to sweep jamming are especially obvious in case when RCIED activation message is very short, i.e. when its duration is lower than it is the period of one sweep cycle (similar as for combined jamming). This is illustrated by the graph in Fig.8. Three of four lines in Fig.8 are taken over from the previous figures: the line for sweep signal from Fig.3, the line for sweep signal and P_{dist}=0.2 from Fig.4 and the line for sweep signal and P_{dist}=0.6 from Fig.5. The fourth line corresponds to comb jamming when it is K=5 and i=2. If the frequency spectrum of such a comb signal is additionally swept, the RCIED activation message for P_{dist}=0.2 will be surely once jammed as it is K=5 (the sweep period needs to be 5 times shorter than in the case of pure sweep jamming). Fig.8 is an illustration that higher and even significantly higher value of *BER* (Probability of Bit Error - P_b) may be reached when comb jamming is applied than with pure sweep jamming of short-duration RCIED activation message. The statement is valid for relatively high amplitude of rectangular pulse train: it must be at least 14dB higher than the RCIED activation message level when it is P_{dist}=0.2, or at least 17.5dB higher when it is P_{dist}=0.6.

Effect of decreasing the rectangular jamming signal duration (τ) in relation to its period (T) may be analyzed based on the expression (12). We may analyze an example from Fig.7 where the number of jamming frequency components is 7. The central lob frequency bandwidth becomes wider as τ decreases, thus contributing to more uniform amplitude of frequency peaks between k=0 and k=3. As now the amplitude of the frequency component at k=3 (which has the lowest level of the considered components) is relatively higher comparing to the component at k=0, it may be concluded that it is important to implement as short as possible impulses duration τ. But, due to the effect of the multiplication factor τ/T in (12), the absolute value of the frequency components amplitudes is decreased. It is necessary to compensate the effect of this attenuation by the greater pulse amplitude A (higher signal amplification in the method realization). The emphasized two opposite effects lead to the problem of optimum τ (or, in other words, optimum τ/T) definition in the sense of minimum signal emission power when the value of K is a priori known. This problem solving will be the subject of our future analysis.

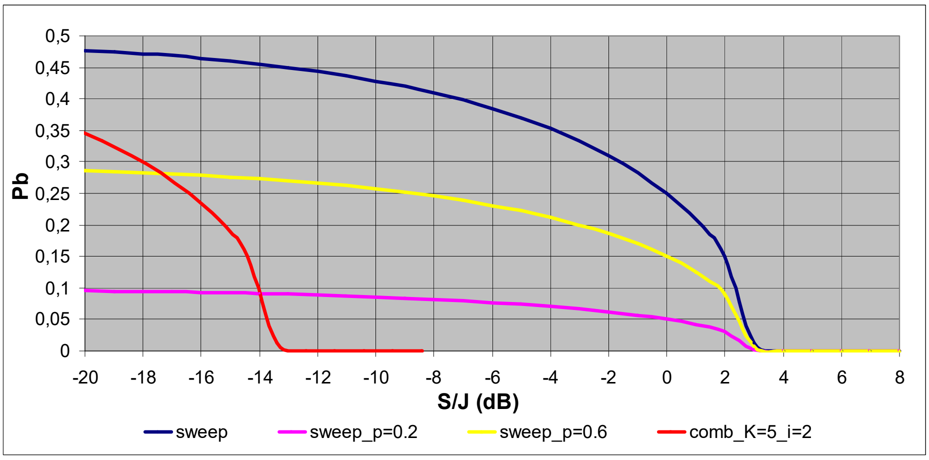

Figure 8. Performances of comb jamming comparing to sweep jamming the short-duration RCIED activation message

Conclusions

In this paper we have presented the characteristics of two RCIED activation message jamming strategies: combined and comb jamming. The performances of combined and comb jamming are compared to the most often implemented jamming strategies: sweep and barrage jamming. Although having the similar names, these strategies are very different in their realization principles and the achieved spectrum characteristics. Their common characteristic is that they relax the need to have a very high-speed pure sweep jamming in case of very short RCIED activation messages.

The characteristics of combined sweep and barrage jamming are first analyzed in this paper. This jamming method is not often implemented in practical jammer solutions and, as far as we know, it is not analytically modelled in the theory. We have analyzed it for the case that RCIED activation message is transmitted using QPSK modulated signals. In order to overcome the problem of complicate mathematical analysis, we have developed our original simulation program to simplify jamming method performance analysis. The simulation program accuracy is verified comparing its results to the *BER* graphs of channel characteristics in the presence of the white Gaussian noise and sinusoidal interference disturbances for relatively low level of these disturbances. Such results may be found in the available literature [27], [28]. The simulation program is not limited to the analysis of only QPSK signals. It may be easily modified to be implemented for other modulation signal types.

The combined jamming method is especially suitable for the implementation when the RCIED activation signal level is relatively high comparing to the jamming signal level. For such signal characteristics the benefits are very obvious in relation to sweep jamming, because combined jamming expands the possibilities of RCIED activation prevention for the range of several dBs. In case that jamming signal power is higher than the RCIED activation signal power, the possibilities of combined jamming are better or minimum approximately the same as the possibilities of other two jamming techniques (barrage or sweep).

The characteristics of comb jamming are analyzed for the example of its generation by rectangular pulse train. Similar to barrage jamming, this is a wide-band jamming strategy in each time interval, but with discretely generated jamming signal frequency components. Comparing to barrage jamming, the power of comb jamming signal is lower, because jamming signal components are generated in the limited frequency band and on discrete frequencies, not continually in the whole frequency band [29]. The advantages of comb jamming are especially obvious when RCIED activation message duration is multifold lower than the sweep cycle period at pure sweep jamming. In this case sweeping the comb-like frequency spectrum assures that the jamming signal frequency is at least once jammed during the RCIED message time interval. The reliability of comb jamming is regulated by selecting the number of simultaneously generated signal frequencies in a comb, the ratio of pulse duration to its period (τ/T) and pulses amplitude (A).

References

[1] MARINKOVIĆ-NEDELICKI,V., LEBL,A., MILEUSNIĆ,M., PETROVIĆ,P.: *Combined Jamming in RCIED Activation Prevention, 19th International Symposium*, INFOTEH Jahorina 2020, Jahorina, 18-20. March 2020., ISBN: 978-1-7281-4775-8, pp. 1-6 DOI: 10.1109/INFOTEH48170.2020.9066329.

[2] WILGUCKI,K., URBAN,R., BARANOWSKI,G., GRĄDZKI,P., Skarźyński,P.: *Automated protection system against RCIED*, In Proc. Military Communication Institute (MCI), 2012.

[3] POISEL,R.: *Modern Communications Jamming Principles and Techniques*, Second Edition, Artech House, Boston/London, 2011.

[4] WILGUCKI,K., URBAN,R., BARANOWSKI,G., GRĄDZKI,P., SKARŹYŃSKI,P.: *Selected Aspects of Effective RCIED Jamming*, Military Communications and Information Technology: A Trustred Cooperation Enabler, Vol. 1, Warsaw 2012., pp. 71-82.

[5] MILEUSNIĆ.M., PAVIĆ,B., MARINKOVIĆ-NEDELICKI,V., PETROVIĆ,P., LEBL,A.: *Development, realization and testing the variant of the device for VIP persons protection in the extended frequency range (20MHz-6GHz) with the reduced total power (300W)*, tehničko rešenje – novi proizvod na projektu tehnološkog razvoja TR32051 pod nazivom "Razvoj i realizacija naredne generacije sistema, uređaja i softvera na bazi softverskog radija za radio i radarske mreže", 2017.

[6] D'ORO,S., GALLUCIO,L., MORABITO,G., PALAZZO,S.: *Efficiency Analysis of Jamming-based Countermeasures against Malicious Timing Channel in Tactical Communications*, 2013 IEEE International Conference on Communications ICC, Budapest, June 2013.

[7] MILEUSNIĆ,M., PAVIĆ,B., MARINKOVIĆ-NEDELICKI,V., PETROVIĆ,P., MITIĆ,D., LEBL,A.: *Analysis of jamming successfulness against RCIED activation*, 5th International Conference IcETRAN 2018, Palić, June 11-14, 2018., Proceedings of Papers, pp. 1206-1211, ISBN 978-86-7466-752-1, the best paper award in the section of telecommunications.

[8] MILEUSNIĆ,M., PETROVIĆ,P., PAVIĆ,B., MARINKOVIĆ-NEDELICKI,V., MATIĆ,V., LEBL,A.: *Jamming of MPSK Modulated Messages for RCIED Activation*, 8th International Scientific Conference on Defensive Technologies OTEH 2018., Belgrade, October 11-12. 2018., pp.380-385, ISBN 978-8681123-88-1.

[9] MILEUSNIĆ,M., PAVIĆ,B., MARINKOVIĆ-NEDELICKI,V., PETROVIĆ,P., MITIĆ,D., LEBL,A.: *Analysis of jamming successfulness against RCIED activation with the emphasis on sweep jamming, Facta Universitatis*, Series Electronics and Energetics, Vol. 32, No. 2, June 2019, https://doi.org/10.2298/FUEE1902211M, ISSN: 0353-3670, pp. 211-229., the extended version of the paper from the IcETRAN 2018.

[10] MARINKOVIĆ-NEDELICKI,V., LEBL,A., MILEUSNIĆ,M., PETROVIĆ,P., PAVIĆ,B.: *BER Calculation for Sweep Jamming of MPSK Modulated RCIED Activation Message Signals*, 18th International Symposium „INFOTEH Jahorina 2019, Jahorina, 20-22. March 2019., ISBN: 978-1-5386-7073-6, pp. 1-6, DOI: 10.1109/INFOTEH.2019.8717747.

[11] MIETZNER,J., NICKEL,P., MEUSLING,A., LOOS,P., BAUCH,G.: *Responsive communications jamming against radio-controlled improvised explosive devices*, IEEE Communications Magazine, Vol. 50, Issue 10, pp. 38-46, October 2012.

[12] LEBL,A., MILEUSNIĆ,M., PAVIĆ,B., MARINKOVIĆ-NEDELICKI,V., PETROVIĆ,P.: *Programmable Generator of Pseudo-White Noise for Jamming Applications*, 27th Telecommunications Forum (TELFOR), November 26-27, 2019., Proceedings of Papers, pp. 1-4, ISBN 978-1-7281-4790-1, DOI: 10.1109/TELFOR48224.2019.8971203.

[13] Phalanx, Intelegent Safety Systems: New Hybrid RCIED Jammer Intelligent & Reactive Radio-controlled Designed to Prevent Improvised Explosive Devices, http://www.phalanxsafety.com/assets/phalanx-rcied-jammer-rev5.pdf

[14] Geospatial World, Counter RCIED Systems, https://www.geospatialworld.net/article/counter-rcied-systems /, July 2014.

[15] Phantom Technologies LTD, Tactical HF-UHF-VHF Jammer Very High Output Power – Model RCJ 5KW Output Power, December 2017., https://phantom-technologies.com/wp-content/uploads/2017/12/RCJ-FM.pdf.

[16] FRATER,M.R., RYAN,M.: *Electronic Warfare for the Digitized Battlefield*, Artech House, 2001., ISBN: 1-58053-271-3.

[17] BLACK,B.A.: *On the Generation of Waveforms Having Comb-Shaped Spectra*, NRL Memorandum Report 619, Naval research Laboratory, May 1988.

[18] BLUME,R.J., LESKO,N.J.: *Swept Comb Method of Jamming*, United States Patent Number 5,943,001, 24th August 1999.

[19] IRITEL, VHF/UHF Jammer 1kW Fully Automated Radio Surveillance and Jamming System.

[20] PETROVIĆ,P.: *Generator of jamming signals - GEMOS*, technical solution, 1990.

[21] PETROVIĆ,P.: *Development of new generation of GEMOS devices and signal classifier based on DSP Technology*, technical solution, 1999.

[22] VOUYIOUKAS,D., CONSTANTINOU,P.: *Performance Degradation of Analog FM System Due to Spread Spectrum Overlay*, IEEE Transactions on Broadcasting, Vol. 49, No. 2, June 2003, pp. 113-123.

[23] LUKATELA,G.: *Statistical Theory of Telecommunications and Theory of Information*, Građevinska knjiga, Beograd, 1981., (in Serbian).

[24] BOX,G.E.P., MÜLLER,M.E.: *A note on the generation of normal deviates*, The Annals of Mathematical Statistics, vol. 29, no. 2, pp. 610-611, 1958.

[25] MÜLLER,M.E.: *A Comparison of Methods for Generating Normal Deviates on Digital Computers*, Journal of the ACM, vol. 6, issue 3, pp. 376-383, July 1959.

[26] GOODMAN,J.: *Lecture Notes on Monte Carlo Methods*, Chapter 2: Simple Sampling of Gaussians, Courant Institute of Mathematical Sciences, NYU, 26. August 2005.

[27] Recommendation ITU-R SM.1235, Performance Functions for Digital Modulation Systems in an Interference Environment (Questions ITU-R 44/1 and ITU-R 45/1), 1997.

[28] Defense Information Systems Agency, Defense Spectrum Organization, Joint Spectrum Centrum Annapolis, Maryland 21402, Consulting Report: Communications Receiver Performance Degradation Handbook, Document Control No. JSC-CR-10-004, August 2010.

[29] . Frater,M.R., Ryan,M.: *Electronic Warfare for the Digitized Battlefield*, Artech House, 2001, ISBN: 1-58053-271-3.

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Kombinovano i "comb" ometanje poruka aktiviranja RCIED – dve različite strategije sa sličnim imenom

Karakteristike kombinovanog i češljastog ("comb") ometanja poruka za aktiviranje RCIED prikazane su u ovom radu. Signal kombinovanog ometanja formira se kao suma sinusoidalnog signala prebrisavanja i signala šuma dok signal češlja znači da njegov spektar ima veći broj istovremenih međusobno jednako udaljenih sinusoidalnih komponenti, koje se eventualno dodatno prepuštaju prebrisavanju. Performanse kombinovanog ometanja se porede sa klasičnim prebrisavanjem i sa klasičnim ometanjem šumom. One su određene primenom originalno razvijenog simulacionog programa.

Ometanje češljastim signalom se analizira na osnovu njegovog generisanja iz povorke pravougaonih impulsa. Prikazano je kako izbor odnosa trajanja impulsa u odnosu na njihovu periodu i broj generisanih frekvencijskih komponenti u signalu češlja utiču na dobijene karakteristike ometajućeg signala. Dokazano je da češljasto ometanje ima naročito prednosti u odnosu na ometanje prebrisavanjem kada je trajanje poruke za aktiviranje RCIED značajno kraće nego što je perioda prebrisavanja.

Ključne reči: **RCIED, kombinovano ometanje, ometanje češljem, simulacioni program, *BER*, fazorski dijagram.**