# A concept of application of dedicated spatially-distributed sources of electromagnetic interference

Dariusz Gibalski*[a], Zenon Szczepaniak[b], Józef Jarzemski[a], Mariusz Łuszczyk[a]
[a]Military Institute of Armament Technology, ul. Prym. St. Wyszyńskiego 7, 05-220 Zielonka, Poland; [b] Faculty of Electronics, Military University of Technology, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, Poland

## ABSTRACT

The paper comprises the concept of application of low cost devices creating an active interference by emitting low power, which results in an effect comparable to that obtained with the use of expensive high power devices. Modern radars have many mechanisms that increase their resistance to interference, including active ones. In order to address this issue the use of synchronized sources of the interference is proposed. These sources generate signals in specific frequency bands that correspond to the working frequency of the device to be interrupted. The paper describes the concept of creating a dedicated, spatial interference with the use of miniature, microwave oscillators, which are synchronized by a signal intercepted from the device being interrupted.

**Keywords:** interference, radar, injection-locking, synchronization, jamming

## 1. INTRODUCTION

Nowadays, thanks to the dynamic technological development of the last few decades, in parallel with the development of radar technology, several different ways of combating and counteracting radio-electronic reconnaissance have been developed. For this purpose, there are used techniques like: physical destruction and disruption of proper operation (passive or active), modification of the electrical properties of the medium (ionization of the space, or the use of absorbing and / or scattering substances) and modification of the radio signature of the objects (changing the RCS, masking). [1]

In the overwhelming majority, in terms of effectiveness, the methods above can be considered comparable and usually complementary. However, in case of the effective conduct of warfare, the optimization of the cost-to-effect ratio has become increasingly important. In such future approach and in the context of restrictions on the availability of precision missile systems, the "superiority" of the idea of using active interfering devices is clearly noticeable. In particular, devices, which are characterized by a relatively low cost of implementation and, despite the low output power, can provide an effect comparable to that obtained using expensive high-power devices or "stealth" technology.

This paper describes the idea of creating interference characterized by the above-mentioned properties, obtained by application of a specific method of using miniature sources of active interference. This method concerns the creation of a spatially-distributed interference.

In order to maintain the operational capabilities on the battlefield the modern radars have many mechanisms increasing their resistance to interference, e.g. tuning in a wide frequency range, automatic selection of the least distorted frequency, high frequency selectivity, spatial selectivity, high dynamics of receiving systems with automatic gain control, elimination of non-synchronous and stationary interference, protection against information overload or interference bearing. Taking into consideration the issues presented above, in the authors' opinion, the most adequate solution seems to be the use of synchronized sources of active interference, which generate signals in the specific frequency bands, corresponding to the operating frequency of the device being interrupted. Known and current solutions in operation, based on noise sources or digitally controlled with frequency synthesis, in order to provide the required efficiency, require wide frequency band (and higher output power level), or selective work (resulting in the need for additional mechanisms of their "online" control, depending on the signal of the interfering device). Therefore, it was proposed to create dedicated, active spatial interference, using miniature microwave oscillators, synchronized by injection signal from an interrupted device.

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# 2. THE BASICS OF DISTURBING THE RADARS

## 2.1 General characteristics of potential interference objects

The currently used radar devices, depending on their purpose, use different operating frequency bands in the microwave range (Table 1).

Table 1. Typical radar frequency bands.

| No | Purpose | Frequency band [GHz] |
|---|---|---|
| 1 | Detection of aerial objects and guidance of aviation | 0.2 – 6.0 |
| 2 | Detection of intercontinental ballistic missiles | 0.4 – 0.5 |
| 3 | Air traffic management | 1.2 – 1.4 |
| 4 | Control of landing of an aircraft | 2.7 – 36.0 |
| 5 | Ground-to-ground missiles management | 2.8 – 3.0 |
| 6 | IFF identification | 0.9 – 1.1 |
| 7 | Measurement of height of air objects | 2.7 – 9.5 |
| 8 | Fire control of anti-aircraft systems | 1.2 – 38.0 |
| 9 | Detection of mobile ground objects and battlefield surveillance | 9.2 – 16.5 |

It is assumed in the paper that further considerations refer to radar devices, listed in the first row of Table 1.

Analyzing the information collected in the table above, it should be pointed, that typical constructions of specific radar devices are designed for much smaller operating frequency ranges, which are only a fragment of the bands presented above, corresponding to a specific group of devices. This is the effect of the limitations of the available technologies and commonly used standards for the production of microwave components and devices being build-up components of radars nowadays. Additional restrictions are also introduced by national and international legal regulations in the field of frequency management. As a result, in real radar devices, obtaining operating bands exceeding 20% of the radar carrier frequency becomes problematic, especially when it is connected with the need to generate high-power microwave signals, typical in such devices. Therefore, in connection with use of high power signals, more and more stringent design requirements and narrowing of the radar bandwidth are observed. This, in fact, leads to the simplification of the design of interference sources. At the same time, modern radars, especially those for military use, have a wide spectrum of tools, which increase their resistance to interference. In particular, those should be mentioned:

- operating frequency tuning function (manual frequency selection and / or pulse-to-pulse tuning) with automatic selection of the least interfered frequency;
- high frequency selectivity of transceivers;
- spatial selectivity of antenna directional characteristics;
- high dynamic range of receivers;
- automatic gain control function;
- coding function of transmission signals;
- non-synchronous interference prevention systems (DEFRUITER);
- stationary interference prevention systems (TES, site map);
- false alarm level stabilization systems (CFARs);
- function to determine the angular location of the source of interference (bearing).

## 2.2 Determination of the range of the radar in the conditions of active interference

The range of the pulsed radar in a free space ($R_0$), without interference, ignoring the influence of the environment on the radar antenna characteristics and the atmospheric attenuation, is determined by equation 1 [2, 8]

$$R_0 = \sqrt[4]{\frac{P \cdot \tau \cdot G^2 \cdot \lambda \cdot^2 \sigma}{(4\pi)^3 \cdot V \cdot F \cdot k \cdot T_{0.} \cdot \Delta f}} \tag{1}$$

where:

*P* - output power in pulse;
$\tau$ - pulse duration;
*G* - directional gain of radar antenna;
$\lambda$ - wavelength corresponding to the operating frequency;
$\sigma$ - effective surface reflection of an airborne object (RCS)
*F* - noise figure of the radar receiver;
*V* - visibility coefficient, defining the threshold ratio of reflected pulse power to the average noise power of the radar receiver;
*k* - Boltzmann constant (k = 1,38 · 10-23 [W·s/K]);
$T_0$ - receiver path temperature in degrees [K]);
$\Delta f$ - bandwidth of the radar receiver.

Product value: $k \cdot T_0 \cdot F \cdot \Delta f$ determines, in the above equation, the noise power of the receiver $P_{szw}$.

$$P_{szw} = k \cdot T_0 \cdot F \cdot \Delta f \tag{2}$$

Then, by excluding all elements, except those describing the parameter $P_{szw}$, from under the root in equation 1 and substituting a new variable C:

$$C = \sqrt[4]{\frac{P \cdot \tau \cdot G^2 \cdot \lambda \cdot^2 \sigma}{(4\pi)^3 \cdot V}} \tag{3}$$

one can write the equation for the range of the radar in free space, as a function inversely proportional to the radar receiver's noise power (Equation 4):

$$R_0 = C \frac{1}{\sqrt[4]{P_{szw}}} \tag{4}$$

In the conditions of active external interference, due to the addition of the receiver's noise power with interference noise power, the equation for the radar range takes form described by equation 5.

$$R_z = C \frac{1}{\sqrt[4]{P_{szw} + P_{szz}}} \tag{5}$$

It should be mentioned, however, that in the case of active, non-noise interference, due to the fact that its power, in general, significantly exceeds the noise power of the radar receiver, the second element in the root can be omitted when assessing the effectiveness of interference [1].

Assuming, that the spectrum of the interference signal corresponds to the bandwidth of the receiver of the interrupted radar, the ratio of the radar range in the conditions of interference, to its range in free space ($R_z$ / $R_0$) can be described using the spectral density of noise (equation 6):

$$\frac{R_z}{R_0} = \sqrt[4]{\frac{S_{szw}}{S_{szw} + S_{szz}}} \tag{6}$$

where:

$S_{szw}$ - spectral density of the receiver's noise, equal:

$$S_{szw} = k \cdot T_0 \cdot F \tag{7}$$

$S_{szz}$ - spectral density of noise interference at the receiver's input, equal:

$$S_{szz} = \frac{S_z G_z G_s \lambda^2}{(4\pi R_n)^2} \tag{8}$$

where:

$S_z$ - noise spectral density at the output of the interference transmitter;
$G_z$ - directional gain of the interference transmitter antenna;
$G_s$ - directional gain of the radar antenna in the direction of the source of interference;
$\lambda$ - wavelength corresponding to the frequency of interference;
$R_n$ - distance of the interference transmitter from the disturbed radar.

Describing the ratio of the spectral density of noise interference at the input of the receiver to the spectral density of the receiver's noise (equation 9) as the K factor:

$$\frac{S_z G_z G_s \lambda^2}{(4\pi R_n)^2 \, kT_0 F} = K \tag{9}$$

the ratio of the radar range in disturbed conditions to its range in free space, i.e. the radar range degradation factor, can be described by equation 10:

$$\frac{R_z}{R_o} = \frac{1}{\sqrt[4]{1+K}} \tag{10}$$

Similarly, the range of radar under noise conditions can be described by equation 11:

$$R_z = R_0 \frac{1}{\sqrt[4]{1+K}} \tag{11}$$

### 2.3 Estimation of the impact of active noise interference on the detection range of a radar

The impact of an active interference on the radar detection range, in a selected direction, or in a selected sector, as a function of the interference power density and the distance from the source of interference, can be estimated using equation 5. However, one should remember about the simplifying assumptions adopted at the beginning, i.e. about ignoring the impact of such factors as: field conditions, atmospheric attenuation or polarization of antennas, and about the assumption of direct visibility of the antennas of the disturbed radar and sources of interference.

Additionally, based on equation 9, the value of the real degradation factor $K$ for the considered radar and the analyzed disturbances can be determined.

Due to the fact, that the assessment of the impact of disturbances on the radar detection range requires a lot of calculations, taking into account the considerable number of radar parameters, sources of interference and even the detected airborne object, it becomes necessary to perform these analyzes using computer simulation. In addition, the method usually used to assess radar resistance to interference, i.e. an estimation of the range reduction in the main antenna lobe, is quite difficult to use in situations, where there is more than one interference transmitter and they are arranged at different distances and azimuths relative to the device being interrupted.

Therefore, to carry out the necessary calculations and illustrate the impact of interference on the radar detection range in various configurations, the authors have used the program developed at the Institute, enabling the optimal selection of the interference method, depending on the tactical task. The program is made with the use of the tools of the Matlab environment [3, 4]. In particular, it allows the range degradation factor K for any number of interference transmitters located in different directions and distances relative to the radar to be calculated. It takes into account: the shape of the radar antenna characteristics and the directional gain of radar antennas and interference transmitters. It is also possible to generate in any area a randomly distributed cloud of miniature interference transmitters (jammers) with specific output power levels.

# 3. THE IDEA OF CREATING ACTIVE SPATIAL INTERFERENCE

## 3.1 Characteristics of active spatial interference

The key factor, which have been already mentioned in the introduction to this paper, indicating the real need to develop a system for generating spatial interference, is (next to the obvious need to counteract the enemy means) optimization of the cost / effect factor - society must, after all, function efficiently, both during and after the armed conflict.

Therefore, as a result of a critical analysis of previously used methods of interference on radar systems, the idea of developing a new method  has been developed, based on the principle of creating active interference using sets of low-cost, miniature, low-power jammers. As a result, due to the use of a specific method of their use, i.e. arrangement in a specific space in the radar environment, despite of the low output power, they can provide an effect comparable to that obtained using the expensive, high-power devices. Such small interference emitters, scattered randomly in space, produce a stable zone of degradation of the radar range, and their bearing, or attempts to destroy, are practically impossible. In addition, in the case of disturbed devices characterized by a higher level of side lobes of the antenna characteristics, it is expected, that the effect of interference will be multiplied. This solution is also free of restrictions characteristic of high-power disturbances, usually generated by single sources, affecting only the direction of the disturbance transmitter carrier. Then, only objects located in the narrow sector are protected, and the source of interference can be relatively easily destroyed, following the bearing and indicating its location to the enemy's means of fight.

As a result,  the analyzes clearly have confirmed the need to develop new kind of interference transmitters, characterized by:

- small size;
- low weight;
- low production cost;
- simplicity of design;
- wide range of operating temperatures;
- low sensitivity to interference / destructive pulses.

Ultimately, sources of this type should be the main elements of the spatial interference system, which assumes the use of packages of small transmitters, carried out by a rocket carrier with a cassette head, or unmanned aerial vehicles into the air space in the surroundings of the disturbed radar.

## 3.2 Simulation of spatial noise interference impact on a radar

Depending on the mutual configuration of the disturbed radar and the interference transmitters used, the observed impact of spatial interference on the radar detection range varies and strongly depends on the shape of the antenna characteristics of the radar. In addition, the situation changes dynamically during the movement of the antenna characteristics.

Assuming that the bandwidth of the noise signal is greater than the bandwidth of the disturbed radar receiver, interference at the receiver of the radar appears with the power $P_{szz}$ described by equation 12, which is the sum of the power of the interference signals coming from the $i$ number of noise transmitters located on different distances and azimuths in the space around the radar:

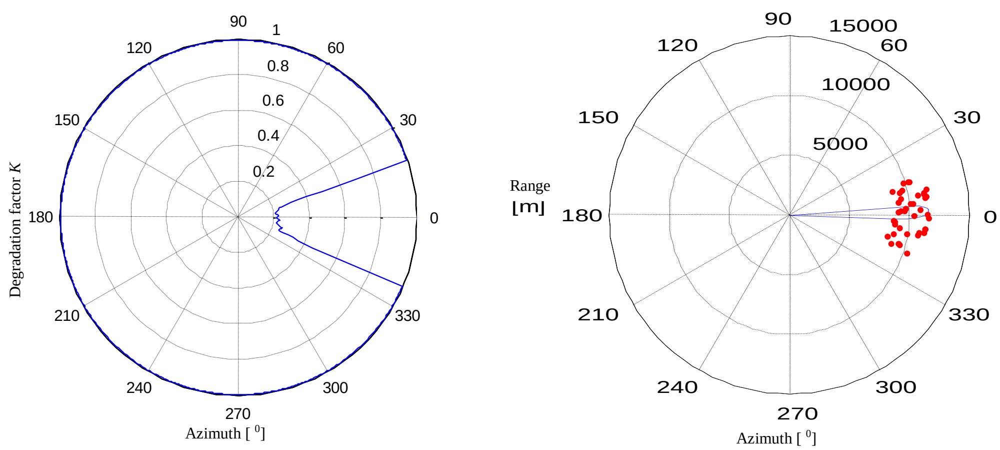
$$P_{szz} = \sum_i \frac{G_s(\beta_i) S_{zi} \cdot \Delta f \cdot G_{ni} \cdot \lambda^2}{\left(4\pi R_i\right)} \tag{12}$$

where:

$G_s(\beta_i)$ - antenna gain of the radar in the direction of the i$^{th}$ source of interference;
$G_{ni}$ - antenna gain of the i$^{th}$ source of interference.

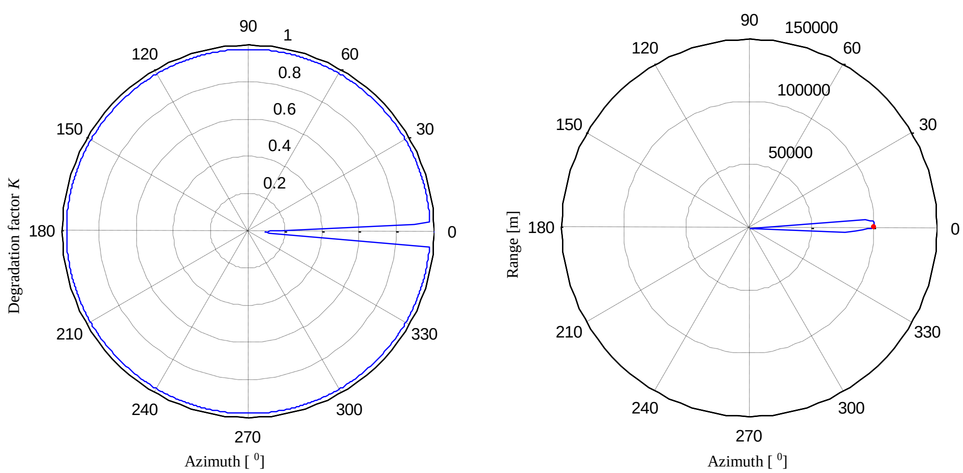
Examples of reducing the detection range of radar as a result of using various types of interference emitters are presented in Figures 1-6. The following sources of interference (jammers) have been used in the analysis:

- high-power noise transmitters with an antenna with directional gain of 3 dB, placed on aircraft located at a distance of 100 km from the disturbed radar, generating noise interference with a spectral density of 10 W/MHz;
- miniature low-power noise transmitters with antennae with directional gain of 0 dB, in the form of packages consisting of 20 pieces randomly scattered in an area of 2 km radius, generating noise interference with a spectral density of 0.001 W/MHz each.



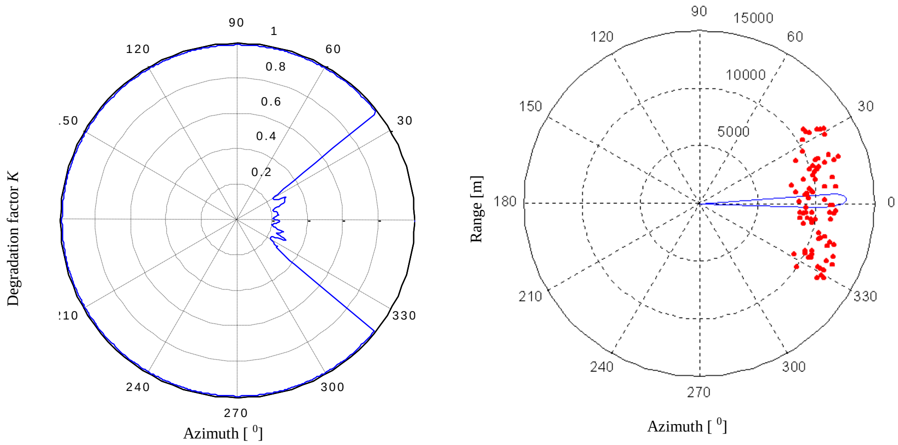
a) The reduction of the detection range of radar.
b) Radar antenna characteristics and jammers.

Figure 1. "Ideal" radar disturbed by 2 low-power interference transmitters' packages.



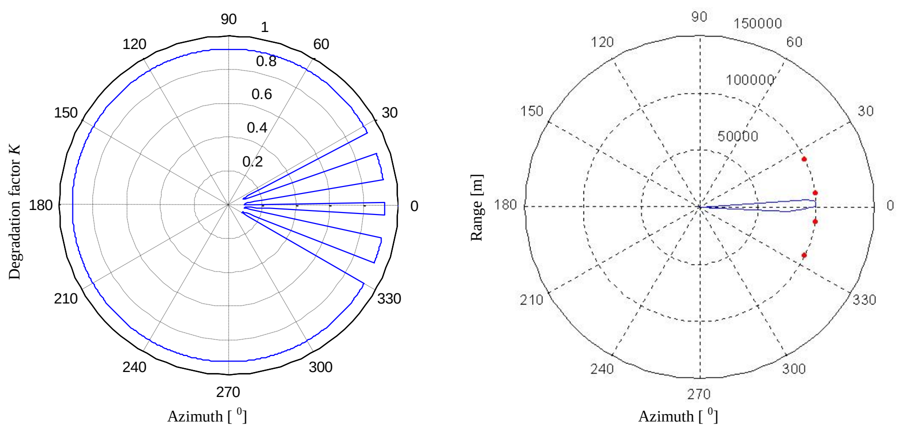
a) The reduction of the detection range of radar.
b) Radar antenna characteristics and jammer.

Figure 2. "Ideal" radar disturbed by 1 high-power interference transmitter on the aircraft.



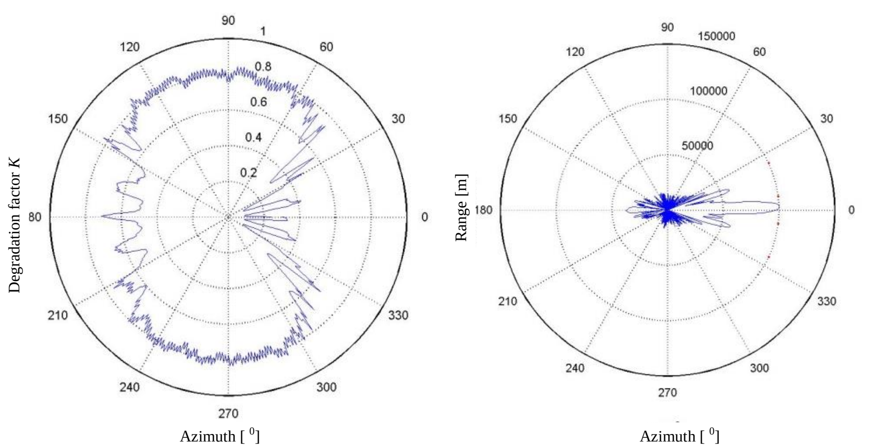

a) The reduction of the detection range of radar. b) Radar antenna characteristics and jammers.

Figure 3. "Ideal" radar disturbed by 4 low-power interference transmitters' packages.



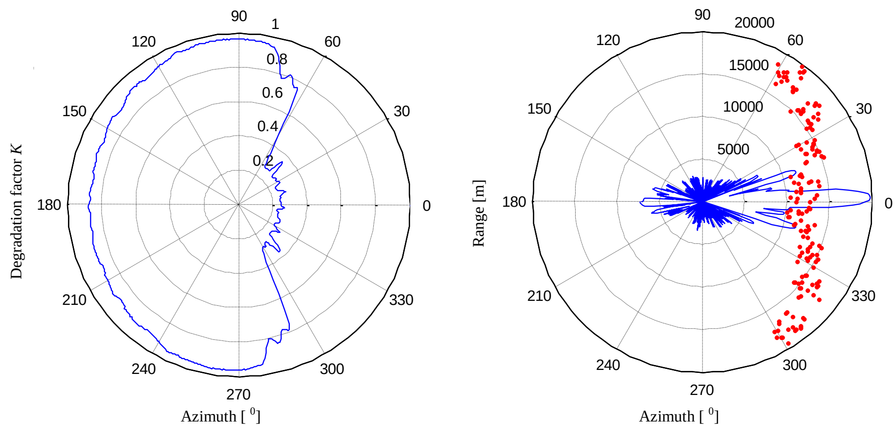

a) The reduction of the detection range of radar. b) Radar antenna characteristics and jammers.

Figure 4. "Ideal" radar disturbed by 4 high-power interference transmitters on the aircraft.




a) The reduction of the detection range of radar. b) Radar antenna characteristics and jammers.

Figure 5. Typical radar disturbed by 4 high-power interference transmitters on the aircraft.




a) The reduction of the detection range of radar.

b) Radar antenna characteristics and jammers.

Figure 6. Typical radar disturbed by 4 low-power interference transmitters' packages.

## 4. INJECTION-LOCKED SYNCHRONIZED MICROWAVE OSCILLATORS, AS A SOURCE OF ELECTROMAGNETIC INTERFERENCE

Due to the fact that modern radars have many mechanisms to prevent interference (the most important ones are listed in section 2.1), in the authors' opinion, the greatest effectiveness of interference on a radar can be obtained only as a result of using active sources of interference. This thesis is clearly confirmed by the analysis carried out in the previous chapters.. Therefore, the concept was originally considered to build the proposed system of spatial interference, based on miniature transmitters of the noise interference. The examples of simulation tests presented in section 3.2 show that, in principle, this is the correct assumption. However, such a solution forces the use of broadband transmitters, or selective with the possibility of re-tuning. This, unfortunately, results in the need of use higher levels of output power in the first case, or in the second case, the need of extending (complicating) the transmitter design with elements that enable control of the interference signal in accordance with the radar signal.

As a result of the conducted tests and subsequent analyzes, it has been found, that the mentioned limitations, associated with the use of noise sources, can be eliminated by using synchronized sources of active interference, e.g. in the form of digitally controlled transmitters with frequency synthesis.

Therefore, it is proposed, in order to ensure the most simplified design (and thus better resistance to external factors and cheapest implementation) to use the analog microwave oscillators with injection-locking. Such transmitters, in the form of miniature, microwave oscillators dedicated to specific radar band and synchronized with its signal, are devoid of the disadvantages of noise sources. Additionally, with a relatively simple design, they are able to generate interference in the radar frequency band, depending on the probe signal [5]. As a result, an oscillator of this type can be a kind of "intelligent" source of the interference signal, which may adapt in an analogue way, the generated signal to the parameters of the radar signal. A typical block diagram of the injection-locked oscillator [5] is shown in Figure 7.

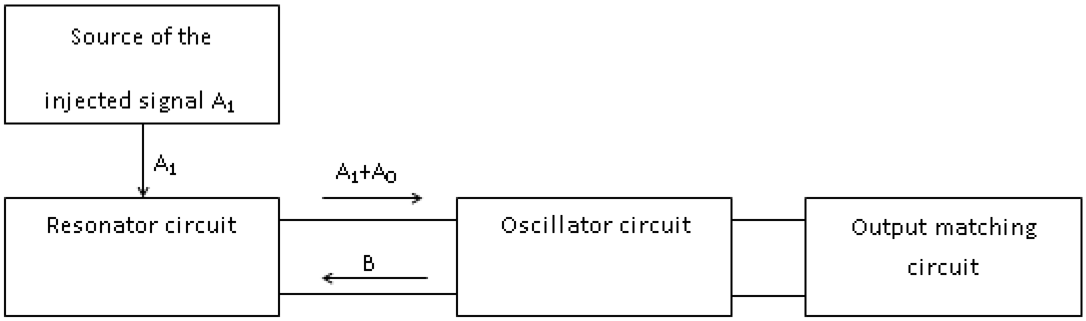



Figure 7. General block diagram of the injection synchronized oscillator.

As numerous publications show, the phenomenon of injection-lockingis quite widely used in practically designed microwave oscillators, used in, among others, radio communication systems [5]. However, due to the fact, that the base source for all solutions based on this phenomenon is the publication of R. Adler [6], the application of injection-lockingfor the purpose of disturbing the microwave radars, requires certain modifications, in order to "adjust" the mechanism proposed by Adler.

The main problem here is the fact, that the theory presented by Adler and the calculations presented do not take into account the specificity of microwave systems, associated with the use of high frequencies. In addition, many authors assume that the resonant circuit (passive part) of the oscillator is characterized by high Q parameter, which strongly narrows the oscillator's synchronization band. As a result, it is possible to synchronize it by external signals only with a very small frequency range. This is very undesirable fact when the disturbance of the radar with variable frequency of the transmitted signal is considered. Then, it is necessary to design the oscillator, which will ensure a sufficiently wide synchronization band, enabling locking the oscillator at any frequency injected from the disturbed device, i.e. radar. This, however, corresponds with reduction of the Q parameter during the design of the oscillator.

Another problem is the use of reflective-type models describing the phenomenon of injection and admittance representation of individual circuit elements [7]. This approach is very difficult to implement in practice, especially in the case of microwave technology, where it would be more adequate and natural to use a transmission model using scattering coefficients. Partly, these problems were eliminated by D. Sommer and N. J. Gomes in [5], who presented a S-matrix-based reflection model, and demonstrated the possibility of designing oscillators with a wide synchronization band.

The above-mentioned issues, along with other quite numerous simplifications and understatements, presented in the available publications mean, that the use of injection-locked oscillators as the sources of the interference, requires the development of new, dedicated mathematical model, which will then be used to construct a real oscillator. This is the subject of ongoing research work of the authors of this paper.

## 5. CONCLUSIONS

On the basis of the research results obtained so far, it can be clearly stated, that the idea of disturbing the radars with the use of miniature packages of synchronized transmitters creating spatial interference in the area around the radar, is the correct conception. As demonstrated in subsection 3.2, by the use of very low power transmitters, one can interact with a radar very effectively, even more effectively compared to the use of higher-power transmitters. In the case of modern radars, the creation of the effective interference, limiting or preventing detection, by the use of single transmitters (even with high output power), is only possible in the direction of the source of interference (carrier of the transmitter). The distance position of the carrier and the objects located in a narrow sector are then masked. The interference carrier, as a signal source, also exposes its presence. As a result, even single radar can determine the location of the maximum disturbance signal (bearing) and, acting in a system with other radars, can indicate the location of the disturbance carrier to active combat agents. In addition, one should not forget that the use of aircrafts equipped with high-power jammers, especially above their own positions, masks their location for enemy radars, but also effectively interferes with their own devices. There will be no such problem, when low-power interference transmitters are used, that are located in the distant, from our own, position, in enemy radar dislocation zone.

An analysis of the available literature gives the conclusion, that there is a possibility to design an extremely interesting and, as the content of the previous chapter shows, very practical solution of interference transmitters, "tailored" to specific radars. .The examples of the use of injection-locked oscillators presented by different authors are often not adapted for use in the design of microwave devices, or they present idealized models, based on assumptions impeding their practical implementation in the real designs. However, the analysis carried out by the authors of this paper and preliminary simulation tests have shown, that it is possible to design and apply a real dedicated microwave oscillator that will be adapted to be synchronized with a typical radar signal. This will be possible in the future works, mainly thanks to the constant development of new dedicated mathematical model, which takes into account all the aspects related to real microwave design, that are missing in the analyzed publications.

## REFERENCES


[1] Wakin, S. A. and Szustow, L. N., [The rules of radio-electronic countermeasures], Wydawnictwo MON, Warszawa (1972).

[2] Szczurek, M. R, [Radar devices and their utilization], Wydawnictwa Komunikacji i Łączności, Warszawa (1961).

[3] Zalewski, A. and Cegieła, R, [Matlab – numerical calculations and their applications], Wydawnictwo NAKOM, Poznań (1998).

[4] MathWorks Training Services, “MATLAB Fundamentals MLBE418V1”, The MathWorks (2018).

[5] Sommer, D. and Gomes, N. J., “Wide-Locking Bandwidth Optically Injection-Locked Oscillators: S-Parameter Design and Modulation Effects”, IEEE Transactions On Microwave Theory And Techniques, VOL. 43, NO. 7 (1995).

[6] Adler, R., “A study of locking phenomena in oscillators”, Proceedings of the I.R.E. and Waves and Electrons, vol. 34, pp. 351-357 (1946).

[7] Kurokawa, K., “Injection Locking of Microwave Solid-State Oscillators”, Proceedings Of The IEEE, VOL. 61, NO. 10 (1973).

[8] Kroszczyński, J, [The technique of modern radiolocation], Wydawnictwa Komunikacji i Łączności, Warszawa (1975).