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NEW BARKER's COMPOSITE CODES AS MODULATION SIGNALS IN BROADBAND COMMUNICATION SYSTEMS

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Background. Currently noise-like signals (NLS) are widely used and provide high level of jamming immunity and security in broadband communication systems (BCS) when transmitting confidential information in an open radio channel, especially in emergencies. Increasing the efficiency of the NLS is possible when using more advanced code structures.

Objective. The purpose of this research is to study new Barker's composite codes as modulation signals in broadband communication systems.

Method. Simulation modeling based on MatLab software package and analytical calculation methods are used.

Results. Modeling in the MatLab software package showed the possibility for using new Barker's composite codes as modulation signals in direct spread spectrum systems but efficiency depends on code words length as well as type synchronization signal.

Conclusions. Analysis of research results shows that the new Barker composite codes 21a, 33a, 49, 77a, 121 can be effectively used as modulation code words in broadband systems with direct spectrum expansion.

Keywords: *Barker codes; composite Barker codes; broadband communication systems; autocorrelation function.*

At present time noise-like signals (NLS) allow ensuring high interference immunity of broadband communication systems (BCS) when transmitting confidential information in an open radio channel, especially in emergencies. NLS are used in modern multi-channel communication systems with code division multiplexing (CDMA, WCDMA) such as wireless communication systems of the 802.11 family with direct sequence spread spectrum technology (DSSS) and modern radar systems. Barker's sequences, discovered in 1953, have the best correlation characteristics of all the NLS [1]. Twelve sequences with length N equal to 14 (14a, 14b), 21 (21a, 21b), 22 (22a, 22b), 33 (33a, 33b), 49, 77 (77a, 77b), 121 are described in [2, 3]. Main peak of autocorrelation function (ACF) for these sequences excess the positive side ACF components in N times. Four pairs of new Barker composite sequences were obtained [4], and another 28 new pairs [5], which have the same ACF as sequences described in [2,3]. The possibility of using Barker's new composite sequences as synchronizing signals was investigated [6] and their effectiveness was shown in comparison with sequences described in [2,3]. The efficiency of using new Barker composite sequences as synchronization signals compared to Gold sequences is shown in [7, 8].

In this article authors are being tried to investigate the new Barker composite codes 21a, 33a, 49, 77a, 121 as code words for modulation in systems with direct spread spectrum. Also the Barker composite code 121 and Gold code 127-1 were used as synchronization signals (Fig. 3) [6]. The formation of Gold 127 codes and construction of their ACF was carried out using the MATLAB R2015B program. For the synthesis of Gold 127 codes the preferred polynomials z^7+z^3+1 and $z^7+z^3+z^2+1$ with an arbitrarily chosen initial state of the registers were used.

The purpose of this work is to study new Barker composite sequences as code words (modulation signals) in the systems with direct spread spectrum.

Functional diagram of the MATLAB model

The functional diagram of the model is shown on Fig. 1. Functional diagram has two generators for direct code words (CW) or invers code words (CWinv) sequences and sync pulses (SP) sequences. The pulse generator controls the switch and alternately sends synch pulses and code words into the channel, thus forming a wideband signal (WBS). Structure of WBS cycles is following: SP-CWinv-CW-CWinv-CW-SP-CW-CWinv-CW-CWinv-SP-CW-…

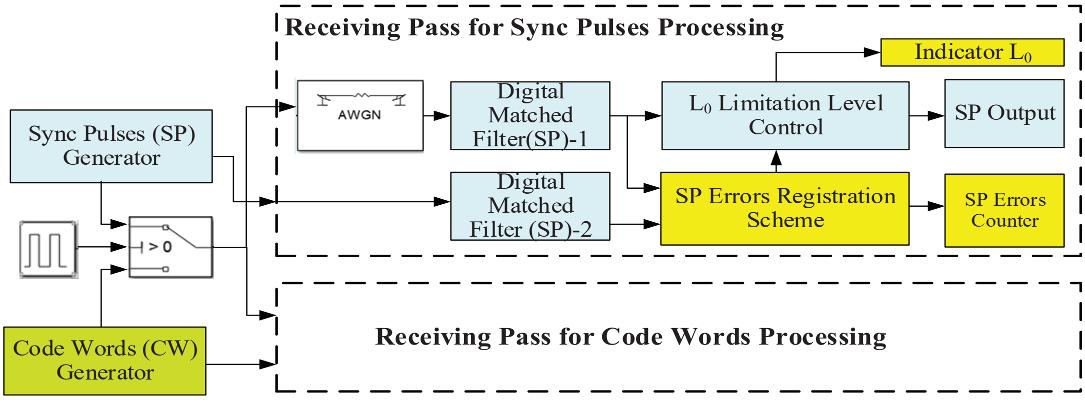


Fig. 1. Functional diagram of the NLS reception mode model

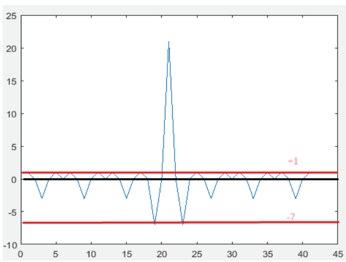
The scheme on Fig. 1 is divided into two identical paths: the path of receiving and processing sync pulses (SP) and the path of receiving and processing code words (CW and CWinv). The AWGN block adds white Gaussian noise to the input broadband signal. The noise level is set by the SNR [dB] parameter of the AWGN block.

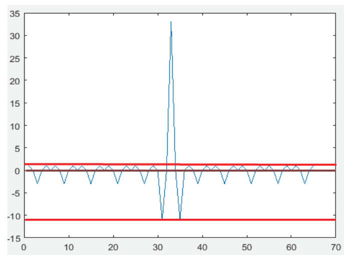
In the path of reception and processing of sync pulses, the first digital matched filter (DMF) (SP)-1 isolates sync pulses susceptible to the effects of interference and noise from the mixture of NLS and noise. At the output of DMF-1, both correctly received sync pulses and false triggering pulses are formed.

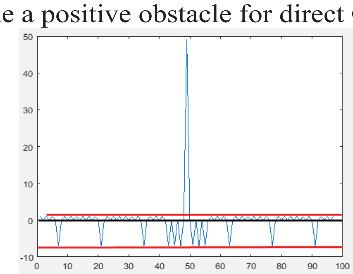
The second digital matched filter (SP)-2 with a noiseless and interference-free NLS emits "reference" sync pulses. In the error registration scheme, the correctly accepted ones that coincide with the "reference" ones are excluded from the mixture of correct and false pulses, only the pulses of false triggering remain, which are counted by the SP errors counter.

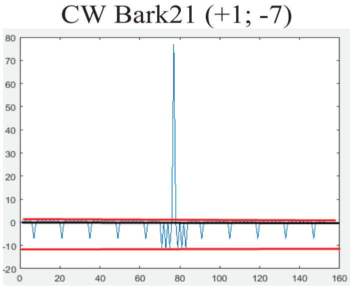
Each false positive pulse through the Lo limit control circuit increases the Lo limit threshold until the noise and spurious components will be compensated. The Lo indicator fixes the limit level.

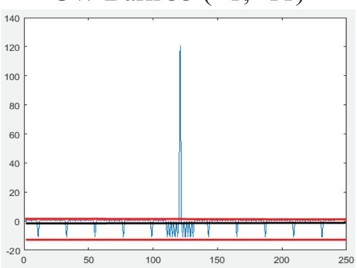
On Fig. 2 CW Bark21, Bark33, Bark49, Bark77, Bark121 ACF in case using sync pulses Bark121 and Gold127 are shown. On Fig. 3 you can see output signals at the receiving and processing sync pulses and code words (as an example, SP Gold127 plus CW Bark21 and SP Bark121 plus CW Bark21 are taken). Fig. 3 shows that the structure of the cycle is not disturbed, direct and inverse CW alternate. It can be also seen that negative ACF emissions of inverse CW become a positive obstacle for direct CW.


CW Bark21 (+1; -7)


CW Bark 33 (+1; -11)


CW Bark 49 (+1; -7)


CW Bark 77 (+1; -11)


CW (SP Bark 121) (+1; -11)

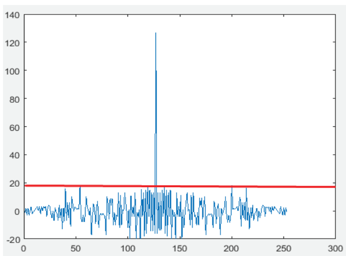
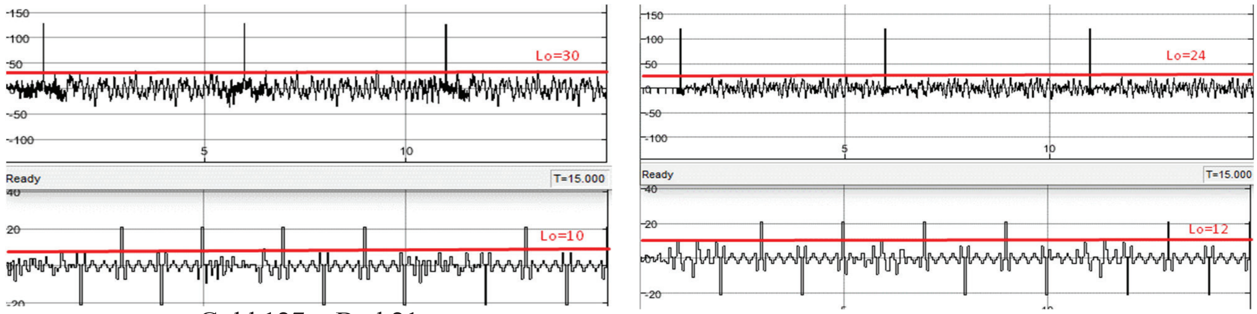

CW (SP Gold 127-3) (+20; -20)

Fig. 2. CW ACF Bark21, Bark33, Bark49, Bark77, Bark121 with SP Bark121 and Gold127



Gold 127 + Bark21 Bark121 + Bark21

Fig. 3. Output signals at the receiving and processing path for CW + SP

Signals comparison was carried out according to the criterion of the ACF peak losses in percentages for different noise level, which is presented as SNR (Signal-to-Noise Ratio). The effectiveness for different types of CW was evaluated by the criterion of the SP ACF peak losses:

$$P(\%) = L_0/A, \quad (1)$$

where L_0 is the threshold level for error-free reception; A is the amplitude of the synchronization pulse, which is equal to the code's length.

The CW effectiveness for different types of SP was evaluated by the parameter:

$$\Delta P_{CW}(\%) = P_{Bar/Bar}(\%) - P_{Bar/Gold}(\%), \quad (2)$$

where $P_{Bar/Bar}(\%)$ and $P_{Bar/Gold}(\%)$ are the losses of ACF peak selection for CW when using composite Barker codes or Gold codes as SP.

Research results

The results of the efficiency evaluation according to the criterion of the CW ACF peak losses with different types of SP are shown in tables 1…4 respectively.

Table 1. CW ACF peak losses in caseSP Gold 127

SNR dB	Bark 21	Bark 33a	Bark 49	Bark 77	Bark 121
30	47,60%	42%	36%	34%	21%
25	47,60%	44%	38%	35%	23%
20	52,40%	45%	40%	36%	24%
10	66,70%	56%	48%	42%	30%
5	85,70%	70%	57%	48%	36%
0		97%	76%	62%	48%
-3			96%	77%	61%
-5				93%	74%
-6					81%

Table 2. SP Gold 127 ACF peak losses for different CW

SNR dB	CW 21	CW 33	CW 49	CW 77	CW 121
30	29,10%	27%	27%	27%	21%
25	29,90%	28%	28%	28%	23%
20	31,50%	29%	30%	30%	24%
10	37,80%	35%	35%	35%	30%
5	44,90%	41%	41%	41%	36%
0	57,50%	53%	54%	52%	48%
-3	70,10%	64%	65%	64%	61%
-5	81,10%	75%	76%	75%	74%
-6	87,40%	82%	81%	81%	81%

Table 3. CW ACF peak losses for SP Bark 121

SNR dB	Bark 21	Bark 33	Bark 49	Bark 77	Gold 127
30	57,10%	45%	36%	29%	27%
25	59,50%	48%	38%	29%	28%
20	61,90%	52%	39%	31%	30%
10	78,60%	64%	47%	38%	36%
5	95,20%	74%	56%	45%	43%
0		98%	74%	61%	55%
-3			97%	77%	67%
-5				93%	79%
-6					87%

Table 4. Peak Losses SP Bark 121 ACF for different CW

SNR dB	CW 21	CW 33	CW 49	CW 77	CW G127
30	22,30%	33%	25%	27%	24%
25	23,10%	32%	24%	26%	23%
20	24,00%	33%	26%	28%	24%
10	28,10%	39%	31%	33%	30%
5	36,40%	43%	37%	39%	36%
0	49,60%	54%	48%	49%	48%
-3	63,60%	64%	60%	59%	59%
-5	76,00%	73%	72%	70%	70%
-6	83,50%	80%	78%	77%	76%

CW ACF peak losses diagrams in cases SP Gold 127 and Bark 121 are shown in Fig. 4…7. SP Gold 127 and Bark 121ACF peak losses for different CW are also shown in these figures.

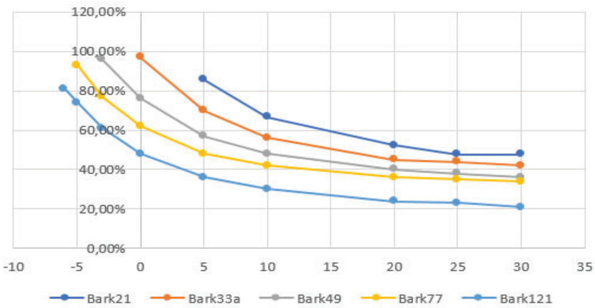


Fig. 4. CW ACF peak losses for SP Gold 127

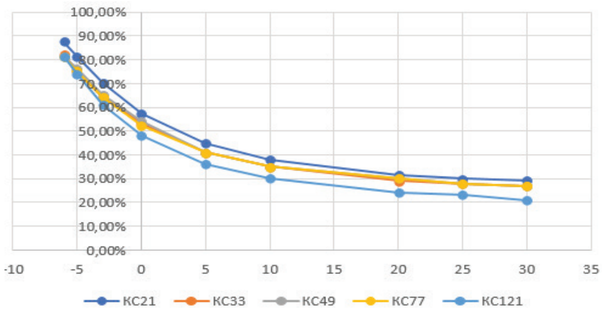


Fig. 5. SP Gold 127 ACF peak losses for different CW

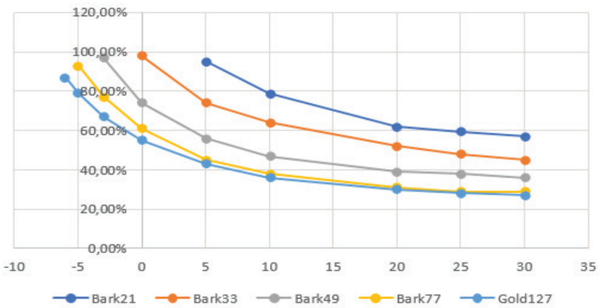


Fig. 6. CW ACF peak losses for SP Bark 121

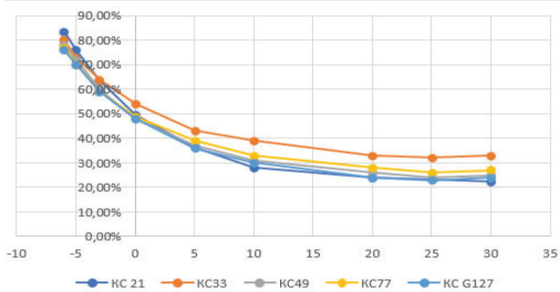


Fig. 7. SP Bark 121 ACF peak losses for different CW

Effectiveness calculation for different CW is shown in table 5.

Table 5. CW effectiveness (ΔP_{CW})

SNR dB	Bark 21	Bark 33a	Bark 49	Bark 77	Bark 121
30	9,50%	3%	0%	-5%	6%
25	11,90%	4%	0%	-6%	5%
20	9,50%	7%	-1%	-5%	6%
10	11,90%	8%	-1%	-4%	6%
5	9,50%	4%	-1%	-3%	7%
0		1%	-2%	-1%	7%
-3			1%	0%	6%
-5				0%	5%
-6					6%

Effectiveness calculation for SP in case different CW was done by the formula (see results in table 6):

$$\Delta P_{SP}\ (\%) = P_{SP\ Bar/Bar}\ (\%) - P_{SP\ Bar/Gold}\ (\%), \qquad (3)$$

where: $P_{SP\ Bar/Bar}$ (%) and $P_{SP\ Bar/Gold}$ (%) – SP ACF losses Barker composite code and Gold code for different CW.

Table 6. SP Barker composite code and Gold code effectiveness, ΔP_{SP} (%)

SNR dB	CW 21	CW 33	CW 49	CW 77	CW G127
30	-6,80%	6%	-2%	0%	0%
25	-6,80%	4%	-4%	-2%	-2%
20	-7,50%	4%	-4%	-2%	-2%
10	-9,70%	4%	-4%	-2%	-1%
5	-8,50%	2%	-4%	-2%	-3%
0	-7,90%	1%	-6%	-3%	-2%
-3	-6,50%	0%	-5%	-5%	-3%
-5	-5,10%	-2%	-4%	-5%	-4%
-6	-3,90%	-2%	-3%	-4%	-5%

Analysis of the code words effectiveness (Table 5) shows that in case of using composite Barker codes as code words together with composite Barker code 121 as a sync pulses is less effective than the use of composite Barker codes as code words together with the Gold code 127.

Due to the fact that it is not possible to use Barker 121 composite code word together with Barker 121 sync pulse, a effectiveness comparison was made in case of Barker 121 code word with the Gold 127 code as a sync pulses. In addition combination Gold 127 (CW) and Barker 121 (SP) was researched. Results show that the ACF peak losses of the Gold 127 codeword with Barker 121 sync pulses are greater for 5…7% than the ACF peak losses of the Barker 121 code word with Gold 127 sync pulse in the range of SNR range (-6…30) dB.

Analysis of the sync pulses effectiveness (Table 6) shows that in case of using Barker 121 composite code as a sync pulses for different code words is more effective than Gold 127.

Conclusions

1. Analysis of research results shows that the new Barker composite codes 21a, 33a, 49, 77a, 121 can be effectively used as code words in broadband systems with direct spectrum expansion.
2. It is not recommended to use composite Barker codes 21a, 33a, 49, 77a, 121 with Barker 121 sync code. It is better to use Gold 127 as sync code in this case. Effectiveness of Gold 127 as sync code in comparison to Barker 121 sync code is as follows:
   - CW Barker 21a – 9.5…11.9% for SNR (5…30) dB;
   - CW Barker 33a – 1.0…8.0% for SNR (0…30) dB;
   - CW Barker 49a – 0.0…1.0% for SNR (-3…30) dB;
   - CW Barker 77a – 0.0…5.0% for SNR (-5…30) dB;
   - CW Barker 121 – 5.0…7.0% for SNR (-6…30) dB.
3. Taking into account that not all composite codes were considered in this work, it is desirable to additionally research composite codes 21b, 33b, 49 (Nev2-Nev4), 77b, 121 (Nev2-Nev4) as code words.

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Максимов В.В., Носков В.І., Храповицький І.А.
Нові композитні коди Баркера в якості сигналів модуляції в системах широкосмугового зв'язку

Проблематика. В даний час широко використовуються шумоподібні сигнали (ШПС), які забезпечують високу захищеність систем широкосмугового зв'язку (ШСЗ) від навмисних завад та безпеку при передачі конфіденційної інформації у відкритому радіоканалі, особливо в екстрених ситуаціях. Підвищення ефективності ШПС можливе з використанням більш досконалих кодових структур, зокрема, нових методів побудови кодових послідовностей Баркера, що використовуються в системах бездротового зв'язку з технологією прямого розширення спектру послідовності.

Мета досліджень. Метою роботи є дослідження нових композитних кодів Баркера в якості сигналів модуляції в системах з прямим розширенням спектра за допомогою моделювання.

Методика реалізації. Використовуються аналітичні методи розрахунку, а також імітаційне моделювання в пакеті програм MatLab.

Результати досліджень. Моделювання в середовищі MatLab нових композитних кодів Баркера в якості сигналів модуляції в системах з прямим розширенням спектра показало, що ці коди доцільно використовувати в таких системах, але їх ефективність залежить як від довжини кодового слова, так і від виду синхросигналу.

Висновки. Аналіз результатів моделювання в пакеті програм MatLab показало, що нові композитні коди Баркера 21a, 33a, 77 та 121 мають високу ефективність в системах зі широкосмуговими сигналами, що використовують технологію прямого розширення спектру.

Ключові слова: *коди Баркера; композитні коди Баркера; широкосмугові системи зв'язку; автокореляційна функція.*