放送システムで用いる識別符号の設計に関する考察
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A New Approach to the Design of Receiver Control Code for Broadcasting System
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1. Introduction

Recently, the systems which transmit identification control codes multiplexed with broadcasting programs and control some actions in receivers have been developed or realized in various countries. For example, there are the emergency warning broadcast, the traffic information broadcast, weather radio and so on. I reported on the emergency warning broadcast within those systems before. In every system, the receiver is always monitoring whether the specific signals come or not and when the required signals are detected, the receiver put required operation in action.

This paper describes some points to be considered when the identification control code is designed on a system that uses digital code as the control code of those systems and form of the suitable code. Especially, in case that control code is used in the broadcasting system, since the interferences are not only random noise but also program sounds, I propose suitable selection method of the code in such conditions. And this paper describes the codes deduced from the result of several considerations on applying the method for the selection of the area classification codes and the characteristics of the codes.

2. Basic consideration for designing identification control code

2.1 The required nature for the identification control code

The basic nature that identification control code should have will be explained by using an example of code signal for the emergency warning broadcast.

(1) Don't mistake program sounds and random noise for the identification control code.

Probability that program sounds or random noises coincide with the identification control code by chance decreases exponentially to very small if the length of the code is made long enough. The probability that coincides by mistake become negligible small value if the length of the code is made about 64 bits even at the system required extremely high reliability like the emergency warning broadcasting system.

(2) Be hard to make mistake by noises and interference on transmission.

In generally, the length of the code become longer, the probability of right reception becomes less as whole code word by noises during transmission. And the receiver circuit is easy to be made by using unit of short length code, too. The short code has advantage by this reason, but the length of the code cannot be simply made short under considering required nature (1). At the signal of the emergency warning broadcasting system 16 bits code is basic code length and it is sent out continuously. When more than 4 times the basic code is received, it is judged that correct signal has been received. The equal characteristic to 64 bits length code can be attained by this judgment.

(3) The code can be composed freely for the requirement from use aspect of the identification control code.

For example, at the signal of the emergency warning broadcasting system, the function that can discriminate the range of service must be provided in addition to the function that shows the emergency warning broadcast. The first discriminating function provides the first category signal and the second category signal for discriminating the degree of importance and the receiver can receive only extremely important broadcast by selecting only the first category signal. The second function provide time data in the signal and receiver activates only when the data coincides with the clock of the receiver. The third function can limit the service area which the emergency warning broadcast intends and the receiver in the area except intended area dose not activate. The identification control code must have flexibility responding to these various requirements.

The signals of the emergency warning broadcasting system are considered to have the fixed code and variable code as shown in Fig. 1. Distinction of the emergency warning broadcast, the first category signal and the second category signal are indicated at the part of the fixed code and the time data, area classification code and so on are transmitted at the part of the variable code.

2.2 The points those should be considered on the selection of code pattern.

The following points are necessary to pay attention on selecting concretely the code pattern to be used as the identification control code.

(a) Don't include the pattern which disturb the word synchronization.

When the receiver is waiting for the identification control code comparing with the coming code pattern one by one now, the correct operation cannot be carried out in case that the same code pattern is included among the transmitted code except right position. Therefore, code pattern should be selected previously so as not to appear at deviating position. At that time, since it is necessary for the same pattern as the fixed code not to appear at the continuous part with the fixed code even in the case that the variable code becomes any pattern at the signal composed as shown Fig. 1, the code pattern usable as the fixed code is rather restricted.

(b) Be difficult to coincide with other code at adding noises and other signals.

It should be made difficult to make error by making distance between code-words wider. At this time, it is also necessary to select the code pattern making the distance with code pattern deviated temporally larger.

In broadcast, the disturbance of program sounds due to the interference of co-channel broadcasting must be considered in addition to noises. This point generates problems especially in the case of sending different identification control code respectively at the same frequency stations. The consideration on selecting the suitable code at this case is described in detail at the following section.

3. The consideration on the code used for the area classification code.

It is confirmed that the signal system of the emergency warning broadcast can operate even in very far area by long distance propagation at night. At this point, it is considered that the receivers only in the wanted area activate by inserting the area classification code into the signals because of possibilities of unnecessary operation between the broadcasting stations using the same frequency. And the performance of the area classification code must surely be distinguished from the signals for other area. Generally, the code patterns which have relation being difficult to make error each other must be selected as errors are apt to occur among the codes due to noises and other signals according to the increase of number of the area to be discriminated.

The program sounds are main interference rather than random noises when other station is broadcasting at the same frequency in case of considering the area classification code. (The program sounds of the local station become interference when the emergency warning signals transmitted from the remote station.) Attention must be paid as the expected performance cannot often be gotten when the code is selected on the base of usual Hamming distance since the program sounds have deferent nature from random noises in the case that interference is the program sounds. Therefore, the followings describe consideration of code suitable for interference due to the program sounds, selection method of the code, examples of the code and its available performance.

3.1 Selection method of the new code.

Now, let’s consider the case that the code word Ⓐ is received as the code word Ⓑ by error shown in Fig. 2. In this case Hamming distance is 2 and in the case of random noise it is predicted for error probability to decrease to fairly lower than 1 bit error. But in the case of program sounds the errors are apt to occur in groups and for example, error occurs when the 0 output of 4～6 bits width comes out one time at the underlined parts shown in Fig. 2. Such situation occurs many times and it cannot be mentioned that errors decrease higher in comparison with one bit error. However, in the case of right side in Fig. 2 the Hamming distance is same 2 as the left case but it is necessary to have the condition that 0 output occurs two times and that there is part of no error during the times for the error from Ⓒ to Ⓓ. Therefore, when the errors occur in group, it can be mentioned that the latter case makes fewer error than the former case. For describing these difference, at the following section evaluation level will be defined and degree of error- occurrence will be expressed.

[Definition of evaluation level]

At first, make $\mathbf{c} = \mathbf{a} \oplus \mathbf{b}$ ($\oplus$ is addition in modulo 2) for the code word $\mathbf{a} = [\, a_1, a_2, \cdot\cdot, a_n \,]$ and $\mathbf{b} = [\, b_1, b_2, \cdot\cdot, b_n \,]$ (a_i, b_i are 1 or 0). (The weight of **c** is the Hamming distance.)

(i) Evaluation level on the error from **a** to **b.**

b is divided into the blocks by run of 1and 0 and **c** is also divided at the same position as **b.** At this point, the number of blocks that include 1 in the blocks of **c** is defined as the evaluation level on the error from **a** to **b**. For example, at the next example the evaluation level becomes Ⅱ as the blocks that include 1 are two, ⓑ and ⓓ .

$$\mathbf{a} = [\,1 \quad 0 \quad 1 \quad 1 \quad 1 \quad 1 \quad 0 \quad 1\,]$$
$$\mathbf{b} = [\,1 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0 \quad 1\,]$$
$$\mathbf{c} = [\,0 \quad 0 \quad 1 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0\,]$$

ⓐ ⓑ ⓒ ⓓ ⓔ

(ii) Evaluation level on the error from **b** to **a.**

Like (i), **a** is divided into the blocks by run and **c** is divided at the same position as **a**. The upper example becomes

$$\mathbf{a} = [\,1 \quad 0 \quad 1 \quad 1 \quad 1 \quad 1 \quad 0 \quad 1\,]$$
$$\mathbf{c} = [\,0 \quad 0 \quad 1 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0\,]$$

ⓐ ⓑ ⓒ ⓓ ⓔ

The evaluation level becomes Ⅰ as the block includes 1 in **c** is only ⓒ.

[Properties of the evaluation level]

The evaluation level has the following properties.

(1) The evaluation level on the errors between code words depends on direction making error and is not same at any case like above example.
(2) The Hamming distance is equal to or more than the evaluation level.
(3) The evaluation level does not exceed the number of block divided by run in the code word.

3.2 Examples of the codes selected by the definite evaluation level.

When the code length and the minimum evaluation level between code words are given, the maximum number of available code words and concrete examples are shown Table 2 and Fig.3. Many different pattern with the same number of code words can be made at the codes based on the Hamming distance but the available pattern is limited in the case of prescribing the evaluation level and there is a case that only one kind of pattern is available.

4. Selection of the area classification code

The principle of code selection is described at Section 3. Here the further study is going on its application to the real area classification codes.

4.1 The number of the area that can discriminate at the given evaluation level

The number of the area that can discriminate at the given evaluation level becomes the concerning point because the character of the errors among the code words can be estimated with the value of the evaluation level as described later.

The 4 bits within the variable code 16 bits are allotted as invariable bits that are necessary for detection and for discriminating the area classification code and time code. It is determined that the rest of bits, 12 bits, are used for the area classification code. Therefore, it is necessary to seek the number of selectable code words and code pattern in 4096 kinds of code words of 12 bits code length when the evaluation level is determined. But since the method seeking this solution with perfect form is not made clear, the numbers of result sought at the view point of realizing surely at least are shown in Table 3. Here, the codes over the evaluation level Ⅲ are obtained as follows. First the codes of minimum Hamming distance 4 (number of code words is 144) are selected to guarantee the character against random noises. Then, the codes over the evaluation level Ⅲ are sought by removing the code words those do not satisfy the evaluation level Ⅲ from the codes.

The above result shows that the suitable number of codes can be enough ready for using as the codes by the local area or prefecture.

The Table 4 shows the concrete example of the codes. The combination of the codes is possible besides the Table but the number of code words found out becomes the maximum. Each code word shown in the Table is an example of the evaluation Ⅲ (number of code words 66) and the codes of the evaluation Ⅳ ～ Ⅷ can also be realized by selecting the codes, on which ＊ is written, from among these 66 kinds.

4.2 Presumption of the basic operating performance

Next, the possibilities that an area classification code transmitted is coincident with the different area classification code are studied. This study is done under the condition that the detection of the area classification code is done by the decision in bulk of 32 bits combining with the fixed 16 bits that is utilized as word synchronization with the variable code 16 bits. At first, assuming that bit error occurs each bit at equal probability and independently, the probability P_w that the transmitted area classification code coincides with the area classification code that differs by k bits is

$$P_w = P_b{}^k (1-P_b)^{32-k}. \qquad (1)$$

Formula (1) becomes maximum at $P_b = k/32$ and $P_{w\,max}$ becomes

$$P_{w\,max} = \frac{k^k (32-k)^{32-k}}{32^{32}}. \qquad (2)$$

In the case that this value is expressed by the average times of coincidences N_e (the value at the worst condition) per second, the formula becomes

$$N_e = \frac{64 \cdot N}{32} P_{w\,max}. \qquad (3)$$

Here,the above formula is calculated under the condition that at the receiver, codes are compared at the rate of N times of bit rate (64 bit/s) and that the code is detected at least at one time coincidence and it is right thought that the error at the area classification code occurs during only the period when the fixed codes coincide (1/32 of whole time). The value (case of N = 16) of the formula (3) and the average detection time in the case that code signals are continuously transmitted for 15 seconds are shown in Table 5 and Fig. 4.

By the way, since interference cannot say random in the case of application to the area classification, when Hamming distance is used as value of k the above performance cannot be obtained. But, when the evaluation level in Table 4 is used as value of k, it became clear that the characteristics being adapted to the above value can be obtained due to the result from the laboratory experiments in which the various levels of the program sounds are added to the code signal. Fig. 4 shows an example of the results of these experiments and is described as the relation between the Hamming distance between transmitted and received code patterns and the number of detection per 15 seconds and as the relation between the evaluation levels and the number of detection. Each point in the Fig. 4 is the point obtained on the different experiment conditions of code patterns and the program sounds added as interference. Fig. 5 shows the examples of code patterns used in the experiments. The dotted lines are calculated values in the case that interference sounds are under the worst condition assuming interference are random and it is understood that the Fig. 4 shows reasonable changes when the evaluation levels are increased. The other hand, when the Hamming distances are increased (the evaluation level is Ⅰ), the large difference is shown as there are the cases those improvement is little and become worse results more than 1 figure at k = 3.

It is clear that error characteristics interfered with non-random noises like the program sounds also can be estimated by the formula (3) from above result, in the case that the evaluation level is used as the value of k. It is considered that the performance shown in Table 5 can be attained when the codes shown in Table 4 are used, since the codes are selected so as to satisfy the value of the evaluation level.

4.3 Performance as the area classification code.

4.2 describes the basic performance of codes prescribed with the evaluation level by comparing the values of the calculation with those of experiment, but the following points must be considered for estimating the operating performance when the real receivers receive the area classification code.

(1) The result of Fig. 4 is obtained on the condition that the criterion at the detection of the codes in the receivers is set so that the most errors occur in order to compare with the calculated values, but the number of the error detection reduce for the criterion used in the real receivers.

(2) In the case of the program sounds, the errors from 0 to 1 are less frequent than the errors from 1 to 0 because the levels around the signal frequency, 640 Hz for code 0, are

higher than that around the signal frequency, 1024 Hz for code 1. Fig. 4 is the experiment result in the case of errors from 1 to 0, however, when the errors occur using the code in Table 4 errors from 0 to 1 need to occur also. Therefore, the values in Table 5 are improved.

(3) The values of Table 5 are the number of errors in the case that all the variable codes are transmitted as the area classification codes and the number of errors per unit of time reduce by 1/3 or 2/3 if the codes are transmitted alternately with the time codes.

Integrating the above points, the performance obtained in the case of using the codes in Table 4 is presumed as shown in Table 6. These values correspond to the case that S/I are 20～15 dB (S : the signal level of the program sounds from the local station, I : the interference level of the code signals received from the far station) at the area where the allotted code patterns are in the relation that error occur most easily.

Further, in the case that the receivers are made to activate by receiving the desired codes of more than two times at the detection of the codes, it is possible to decrease times of the unneeded activation to less than the values shown in Table 6.

By the way, the relation between S/I and unneeded activation is important point at consideration on the co-channel interference. Generally, in the case that the levels of the code signals are low at the output of the sound detection in the receivers, the code signals themselves are hardly received. Conversely, in the case that that the levels of the code signals are high, times of unneeded activation decrease either because the code signals are surely received and make hardly error to different codes. There is the condition of the easiest occurrence for the unneeded activation between them and the results of the experiments in the laboratory show that the unneeded activation occurs most frequently when S/I is about 20～15 dB. However, the following results are obtained that the unneeded activation don't almost decrease in the range that S/I is 25～5 dB on average of time because the program sounds have wide range of rate of no-sound period, distribution of levels and frequencies and so on.

When error occurrence is discussed with D/U of received signal, it is necessary to consider with levels of code signals and program sounds at the output of the sound detection circuit in the receiver considering its AGC characteristics. For example, when electrical wave of the local station is storong, the code detection circuit doesn't operate even at silent sounds because the code signals from the far station are suppressed. Actually, further it is considered that situation is complicated under influence of fading of the electrical wave, sensibility of each receiver and so forth. These points will be expected to be hereafter studied synthetically including the field experiment.

5. Conclusion

This paper describes the points to be considered at using the identification control code in the broadcasting system and especially proposes the method of selecting the suitable code in the case that interference of non-random like program sounds is added.

Here, this method is applied to selection of the area classification code in the emergency warning broadcasting system but this principle is considered to be able to be utilized at other wide field.

Further, the above mentioned some studied results are contributed to discussion at the Radio Technical Council.

Lastly, I express thanks to persons of the various field who gave me the various guidance and discussion.

Reference

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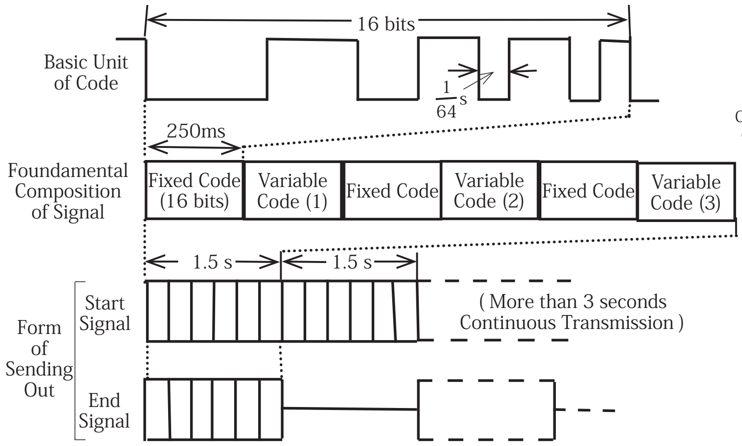


Fig 1 Proposed signal composition for Emergency Warning Broadcast

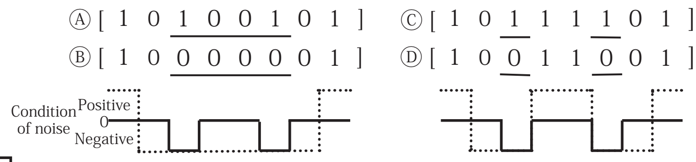
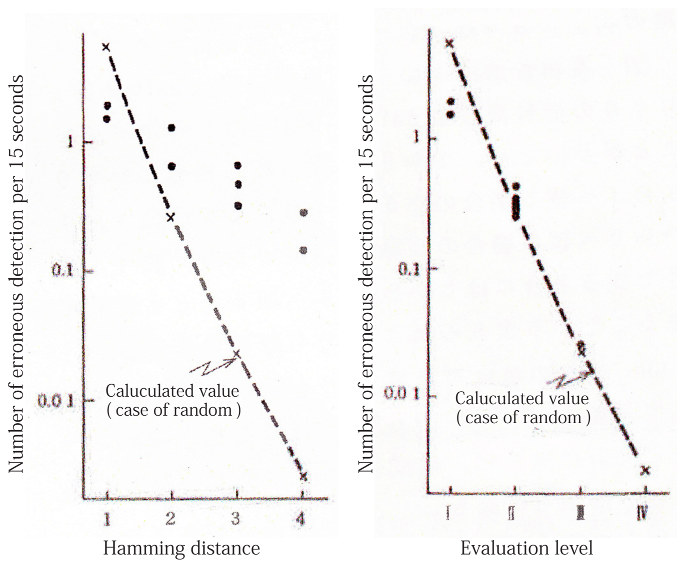


Fig. 2 A Example of the Case That a Code Word Makes Error to Another Different Code Word and the Condition of Noises at the Case

(1) Length of Code:4 Level Ⅱ	(2) Length of Code:5 Level Ⅲ	(3) Length of Code:6 Level Ⅳ
0 0 1 1	0 0 0 1 0	0 0 1 0 0 1
0 1 0 1	0 1 0 0 1	0 1 0 0 1 0
0 1 1 0	1 0 1 0 1	1 0 0 1 0 0
1 0 0 1	(The Numbers of Code Word 3)	(The Numbers of Code Word 3)
1 0 1 0		
1 1 0 0		
(Only One Code at the Numbers of Cord Word 6)		

Fig. 3 Exsanples of the Codes Prescribing the Evaluation Level



(a) Relation between Hamming distance and erroneous detection

(b) Relation between evaluation level and erroneous detection

(Interference by program sounds S/I = 15 dB. Codes are continuously sent out each 0.5 seconds. Coincidence detection is done when more than one coincidence occurs by comparing code pattern with 16 times of bit-rate)

Fig 4

(a) Hmming distance 1, Level Ⅰ	(b) Hamming distance 4
T 1100 1101 0011 0100	T 1100 1101 0011 0100
R 1100 1101 0011 0000	R 1100 1100 0000 0000
(c) Levei Ⅱ	(d) Level Ⅲ
T 1100 1101 0011 0100	T 1101 1100 1010 1000
R 1100 0100 0011 0100	R 1100 1100 0010 0000

T : Transmitting code pattern R : Receiving code pattern

Fig. 5 Examples of transmitting and receiving code pattern used in experiments

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表

Table 1 The code pattern suitable for the fixed code (＊1)

1	0000 1110 0110 1101		
2	0011 1100 1000 1101	＊	＊ Probability at which distance 1 occurs on combination with variable code pattern is slightly large.
3	0011 1110 0010 0101		
4	0011 0000 1111 0101		
5	0000 1111 0011 0101	＊＊	＊＊ simple pattern and not suitable for the Emergency Warning Signal
6	0000 1100 1011 1101	＊	
7	0011 0000 1011 1101		
8	0000 1111 0110 0101		
9	0001 1111 0010 0101		
10	0011 1100 1001 0101	＊＊＊	＊＊＊ run of length 1 are many
11	0011 1011 0000 1101	＊	
12	0010 0111 1100 0101		
13	0001 1111 0010 1001	＊＊＊＊	＊＊＊＊ restriction for variable code pattern is large
14	0010 0011 1110 0101		
15	0011 0111 1000 0101	＊	
16	0000 1111 0101 1001	＊＊＊＊	
17	0000 1011 1100 1101		
18	0010 0111 1001 0101	＊＊＊	

(＊1) The condition of selection : ① Number of 1 and 0 are equl. ② Distance between codes at shifted position are limited 6 to 10 and rate of 8 is high. (Distance becomes large for eather the first signal and second signal which reverses the polarity of the fixed code of the first signal.) ③ The same pattern as the fixed code dosen't arise even if it connects with any variable code. (The first, 15th and 16th bits of the variable code are previously set to be 0,0,0 (or 1,1,1) and it is necessary for them to be the invariable bits.)

Table 2 Relation between minimum evaluation level between codes words and the maximum number of code words

Length of code \ Evaluation level	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ	Ⅷ
1	2							
2	4	2						
3	8	3	2					
4	16	6	2	2				
5	32	10	3	2	2			
6	64	20	6	3	2	2		
7	128	35*	9	4	2	2	2	
8	256	70*	13*	8	3	2	2	2

＊ Maximum value found up to now

Table 3 Number of code words with code length 12 for the prescribing evaluation level (the value found up to now)

Minimum evaluation level	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ	Ⅷ	Ⅸ～ⅩⅠ
Number of code words	4096	924	66	28	10	6	3	3	2

Table 4 Examples of code suitable for the area classification code

	Evaluation level Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
1	0001 0110 1011				
2	0001 1001 1101				
3	0001 1010 1110				
4	0001 1011 0011				
5	0001 1100 0111	＊			
6	0010 1011 0101	＊		＊	＊
7	0010 1011 1010				
8	0010 1101 1100	＊			
9	0010 1110 0011				
10	0011 0001 1011	＊			
11	0011 0010 0111				
12	0011 0100 1101	＊	＊		
13	0011 0111 0010				
14	0011 1001 0110	＊			
15	0011 1010 1001				
16	0100 0110 0111				
17	0100 1010 1011			＊	
18	0100 1100 1110				
19	0101 0011 0110				
20	0101 0011 1001				
21	0101 0101 0011	＊	＊		
22	0101 0110 1100	＊			＊
23	0101 1001 1010	＊			
24	0101 1010 0101	＊	＊		
25	0101 1101 0100				
26	0110 0010 1101				
27	0110 0100 1011	＊			
28	0110 0111 0100	＊			
29	0110 1001 1001	＊	＊		
30	0110 1010 0010				
31	0110 1101 0010			＊	
32	0111 0010 1010	＊	＊		
33	0111 0101 1000				
	34 ～ 66: Compliments of 1 ～ 33	Omission			
	(Reference) Minimum Humming distance 4	4	6	6	8

Compliments of No. 24

Table 5 Caluculated values of the avarrage number of erroneous detection as the k bits different area classification codes (in the of random interference)

k	1	2	3	4	5
Avarrage number of erroneous detection per second	3.7×10^{-1}	1.8×10^{-2}	1.5×10^{-3}	1.9×10^{-4}	3.0×10^{-5}
Avarrage number of erroneous detection per 15 seconds	5.6	2.7×10^{-1}	2.3×10^{-2}	2.8×10^{-3}	4.6×10^{-4}