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A SPECTRAL CHARACTERIZATION OF TAZAKI CODE

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Abstract. *This paper deals with the calculation of power spectral density of Tazaki code. This code can be thought of a charge-constrained code, which is based on Loop-Sum-Zero transition diagram. The calculation of p.s.d.. for Tazaki code was performed using the method of Cariolaro and MATHEMATICA 4.1. The code is quite complex, being described by a state transition diagram with 21 states. So, it was not possible to derive a complete formula describing the coding factor of Tazaki code both as a function of the normalised frequency f_n and the probability p of a mark at the coder input. A representation of the coding factor the equiprobable case p=0.5 is illustrated.*
Keywords: *D.C.-free, Tazaki code, power spectral density*

Introduction

Searching for a D.C.-free code is made possible and also easier by observing several rules [1]:
1. Look for symmetry and make use of it.
2. Assign a suitable set of waveform patterns O to data bits *0* and *1*. The non-zero waveforms should have dual isomorphic waveform patterns in the set, each expecting to compensate the charge of the other. So, the total number of assigned waveforms should be even.
3. Construct a loop-sum–zero transition diagram (LSZ-TD). If the charge accumulation across the loop is zero, the loop is termed LSZ (*Loop-Sum –Zero*) [1, 2]. If the transition diagram contains only LSZ loops, it is referred to as LSZ-TD.

Charge-Constrained Codes

The charge of a coded pattern is denoted by c. And represents the sum of the normalised levels ($\pm 1/2$ for the binary case) of the coded pattern. The charge is computed from the center of the previous codeword [2]. In order to have a D.C.-free code, the accumulated charge must be bounded, i.e. at any time instant i,

$$\left|N_c(i)\right| = \left|\sum_{j=-\infty}^{i} c(j)\right| \le N, \quad N < \infty \tag{1}$$

Tazaki Method

In order to obtain a D.C.-free code based on a LSZ-TD, some steps are necessary [2].
a. Choose suitable codewords attached to data bits *0* and *1*. The codewords should either be balanced or include antipodal pairs.
b. Draw a transition diagram corresponding to data bits (TDDB) that limits the runs of like symbols, both 0 and 1.
c. Use a tree search routine to select the best paths in terms of accumulated charge determined by the word patterns and data.
The TDDB should satisfy the following conditions [2]:
1. it shows symmetry regarding the transition paths associated with dual isomorphic output words;
2. It has strongly connected finite states.
3. The maximum interval between consecutive transitions should be finite (finite zero runs).
This is necessary for synchronisation purposes.
A state s_i is expressed in terms of the coded output o_i^j and the accumulated charge N_c^j [2]

$$s_j = f(N_c^j, o_i^j) \tag{2}$$

The superscript j signifies the current state. The subscript i signals the fact that there are several options out of L regarding the coded output. The function f is determined by the devised TDDB.

To produce a RLL (*run-length-limited*) charge-constrained code, the state TD of the code can be obtained by applying the designed TDDB to a tree search [2] in order to obtain a LSZ-TD, taking into account both the coded waveform pattern o_i and the accumulated charge N_c. Obviously, in any loop, the accumulated charge is zero.

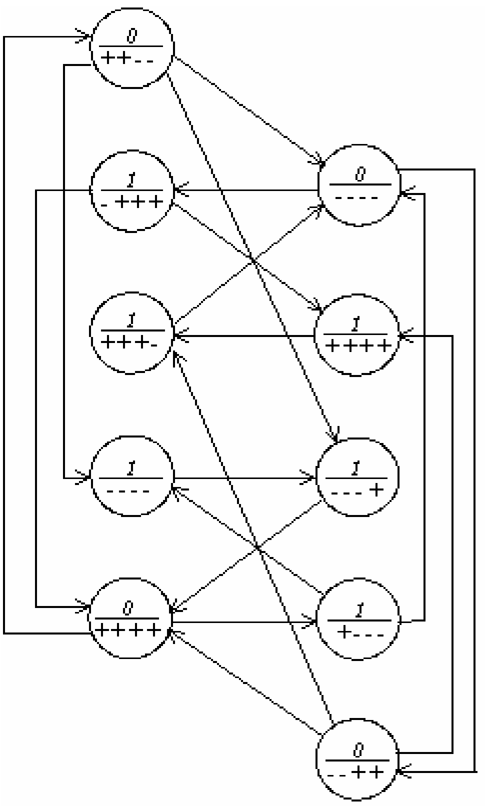

Figure 1 TDDB of Tazaki code

The tree search routine of Tazaki [2] has the following steps:

1. Start with an arbitrary coded pattern out of the output function set $O = \{o_1(t), o_2(t), \cdots o_L(t)\}$ and a suitable accumulated charge N_c^1, preferably zero, to have

$$s_1 = f(N_c^1, o_i^1) \tag{3}$$

2. Consider all possible transitions from o_i to other members of the output function set, according to TDDB. If more than two options are available, select the best two (attached to data bits *0* and *1*).

3. For the resulted coded patterns denoted as o_{i+1} and o_{i+2} possessing charges c_{i+1} and c_{i+2}, respectively, define the new states as

$$\begin{aligned} s_2 &= f(N_c^2, o_{i+1}^2), \quad N_c^2 = N_c^1 + c_{i+1} \\ s_3 &= f(N_c^3, o_{i+2}^3), \quad N_c^{32} = N_c^1 + c_{i+2} \end{aligned} \tag{4}$$

4. If s_2 or s_3 coincides with s_1 with respect to both the coded output and accumulated charge, merge such state into s_1.

5. Proceed with the tree search from the resulted states s_{i+1} and/or s_{i+2}, performing the steps 1 through 4.

Table 1. A D.C.-free code with 26 states

State	0		1	
	New state/ codeword	Charge	New state/ codeword	Charge
1	2/++−−	0	3/+−−−	-1
2	14/−−−−	-2	9/−−++	-1
3	4/−−++	-1	24/−−−+	-2
4	5/++++	+1	10++++	+1
5	17++−−	+1	6/+−−−	0
6	7/−−++	0	9/−−−+	-1
7	8/++++	+2	13/+++−	+1
8	20++−−	+2	19+−−−	+1
9	5/++++	+1	10/++++	+1
10	18/−−−−	-1	11/+++−	+2
11	21/−−−−	0	12/−−−−	0
12	8/++++	+2	9/−−−+	-1
13	18/−−−−	-1	23/−−−−	-1
14	15/−−++	-2	16/−+++	-1
15	1/++++	0	25/++++	0
16	5/++++	+1	10/++++	+1
17	18/−−−−	-1	23/−−−−	-1
18	4/−−++	-1	22/−+++	0
19	18/−−−−	-1	23/−−−−	-1
20	21/−−−−	0	12/−−−−	0
21	7/−−++	0	26/−+++	+1
22	2/++−−	0	13/+++−	+1
23	5/++++	+1	24/−−−+	-2
24	1/++++	0	25/++++	0
25	14/−−−−	-2	13/+++−	+1
26	17/++−−	+1	11/+++−	+2

If all the new states that resulted from the tree search can be merged into any previously appearing states within finite transition times, the desired LSZ-TD was obtained.

Tazaki Code

The code designed by Tazaki with the tree search routine, starts from the TDDB in figure 1. The resulted LSZ - state transition diagram with 26 states is illustrated in figure 2. This is a Moore-type FSSM and is also described by the Table 1. The states 4, 9 and 16 coincide and can be merged into the same state. The same is valid for the groups {11, 20} and {13, 17, 19}.
Re-numbering the states results in the situation depicted in Table 2. The code is described by a Mealy state transition diagram with 21 states, which is represented in figure 3

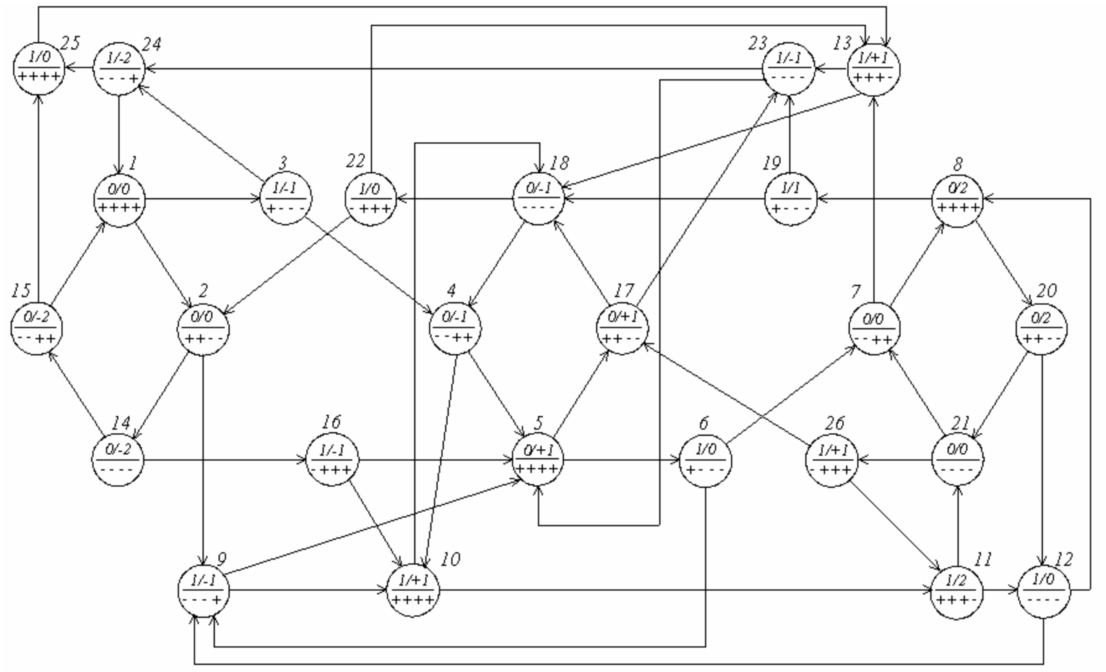

Figure 2 State transition diagram of Tazaki code with 26 states

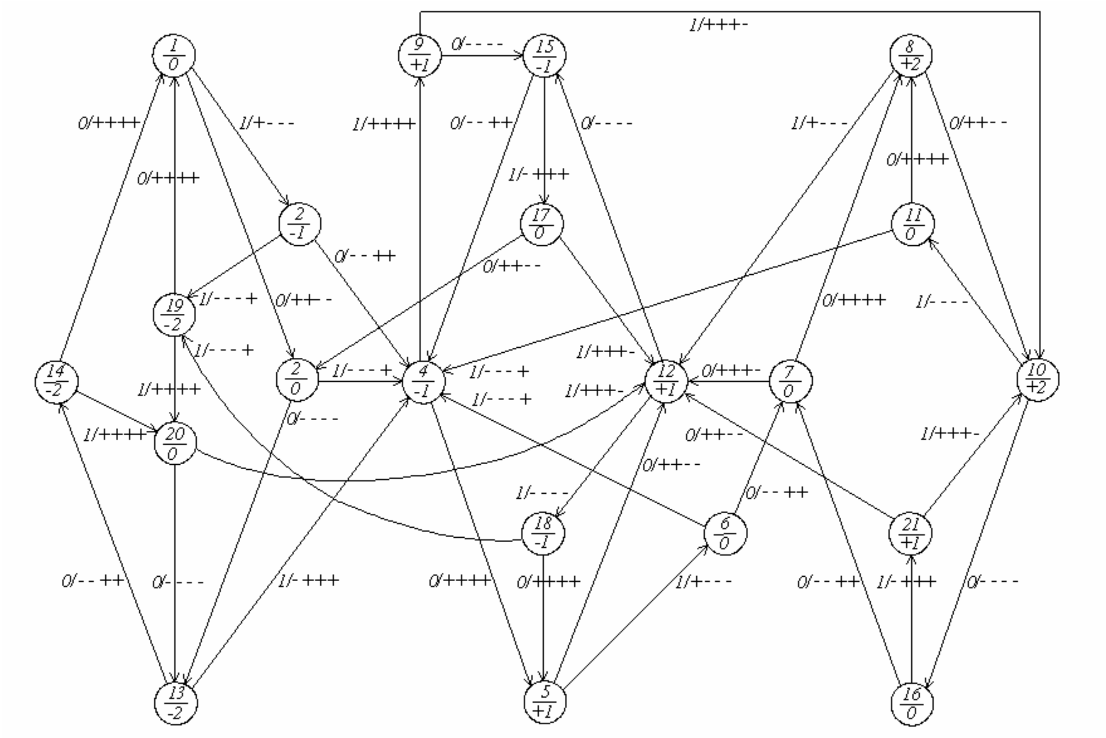

Figure 3 State transition diagram of Tazaki code with reduced number of states

The numerator of the fraction denotes the state number, while the denominator stands for charge value.

Table 2 Tazaki code with reduced set of states

State	0		1	
	New state/ codeword	Charge	New state/ codeword	Charge
1	2/++−−	0	3/+−−−	-1
2	13/−−−−	-2	4/−−++	-1
3	4/−−++	-1	19/−−−+	-2
4	5/++++	+1	9/++++	+1
5	12/++−−	+1	6/+−−−	0
6	7/−−++	0	4/−−−+	-1
7	8/++++	+2	12/+++−	+1
8	10/++−−	+2	12/+−−−	+1
9	15/−−−−	-1	10/+++−	+2
10	16/−−−−	0	11/−−−−	0
11	8/++++	+2	4/−−−+	-1
12	15/−−−−	-1	18/−−−−	-1
13	14/−−++	-2	4/−+++	-1
14	1/++++	0	20/++++	0
15	4/−−++	-1	17/−+++	0
16	7/−−++	0	21/−+++	+1
17	2/++−−	0	12/+++−	+1
18	5/++++	+1	19/−−−+	-2
19	1/++++	0	20/++++	0
20	13/−−−−	-2	12/+++−	+1
21	12/++−−	+1	10/+++−	+2

As the selected TDDB provides an increased DSV for Tazaki code, the energy is transferred to low-frequency zone of the spectrum [3].

The coding factor of the Tazaki code was calculated based on [3-8] and is represented in figure 4 for $p = 0.5$.

The charge is constrained to the interval (-2, +2), as seen from Tables 1 and 2. This provides the D.C.- free feature, which is also evidenced in figure 4.

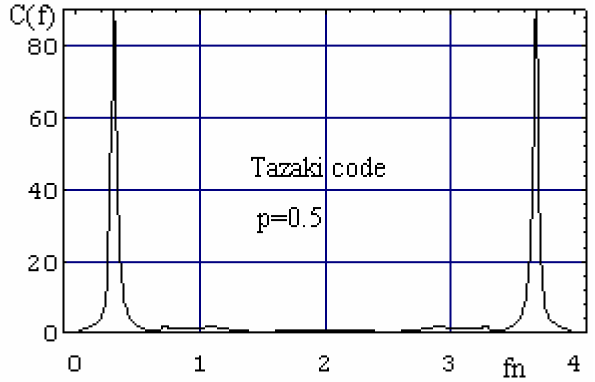

Figure 4 Coding factor of Tazaki code

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