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Masking the SSC's to improve their aperiodic correlations

Texas Instruments

Summary:

The current SSC's [2], have been designed to have low aperiodic auto correlation with the PSC [1]. However, it turns out that the SSC's amongst themselves do not have very good aperiodic cross correlations. This cross-correlation becomes relevant for stage 2 of acquisition in the presence of multiple base stations. Even after averaging over a frame for stage 2 of acquisition, the auto correlation amongst the comma free codes remains high and only about 3.0 dB below the maximum correlation value. We propose a simple modification, to mask the current SSC's with an extended pseudo noise (PN) code, to significantly improve SSC cross correlation and in turn the comma free codes cross correlation. After 1 frame of averaging for stage 2 we find that the cross correlation amongst the comma free codes is reduced to about 11.8 dB below the main peak.

The acquisition stages 1, 2 complexity is unchanged. Further the cross correlation with the PSC [1] is unchanged. Also all SSC's maintain their orthogonality with the PSC implying that the performance of stage 1 of acquisition is not impacted.

1.0 Current SSC

Letting A = {0, 0, 0, 0, 0, 0,1,1} and B = {0, 1, 0, 1, 0, 1, 1, 0} and the sequence

Z = {A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A, A} ---*(1)*

The current SSC structure is shown in figure (1) below:

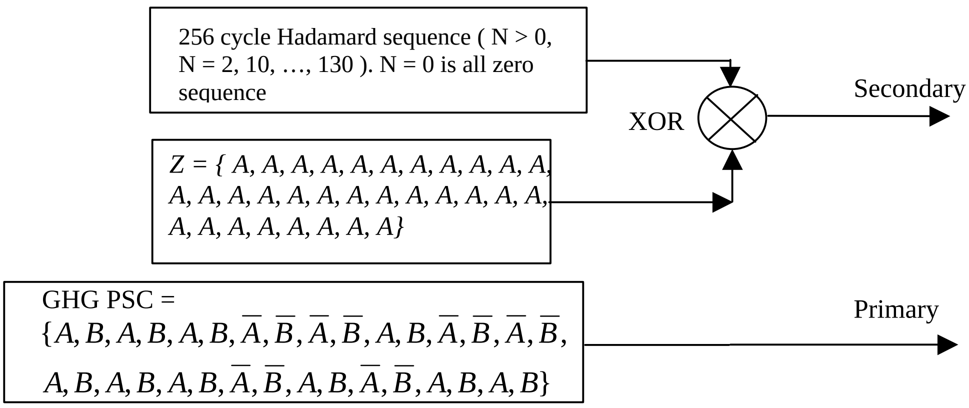

Figure 1: The current SSC sequences derived from the Golay sequence A are given. The primary and secondary code words are converted to real valued sequences by the transformation '0'->'+1', '1'->'-1'.

The maximum aperiodic side lobe (MAS) of the (GHG PSC + SSC) with the GHG PSC is shown in table (2) below [1, table 2]:

SSC code number	Main peak, at frequency error (kHz)		MAS of (GHG PSC + proposed SSC) to GHG PSC, at frequency error (kHz)	
	0 kHz	*10 kHz*	0 kHz	*10 kHz*
1	256	*120*	80	*63*
2	256	*120*	78	*63*
3	256	*120*	80	*63*
4	256	*120*	66	*63*
5	256	*120*	82	*63*
6	256	*120*	78	*63*
7	256	*120*	80	*63*
8	256	*120*	70	*63*
9	256	*120*	80	*63*
10	256	*120*	74	*63*
11	256	*120*	80	*63*
12	256	*120*	70	*63*
13	256	*120*	86	*63*
14	256	*120*	74	*63*
15	256	*120*	80	*63*
16	256	*120*	66	*63*
17	256	*120*	80	*63*

Table 1: MAS of the (GHG PSC + SSC) to the GHG PSC is shown [1].

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	248	8	16	8	32	8	16	8	64	8	16	8	32	8	16	8	128
2	8	240	248	16	8	32	24	16	8	64	56	16	8	32	24	16	8
3	16	248	240	8	16	24	32	8	16	56	64	8	16	24	32	8	16
4	8	16	8	224	120	240	120	32	8	16	8	64	24	48	24	32	8
5	32	8	16	120	224	120	240	8	32	8	16	24	64	24	48	8	32
6	8	32	24	240	120	224	136	16	8	32	24	48	24	64	40	16	8
7	16	24	32	120	240	136	224	8	16	24	32	24	48	40	64	8	16
8	8	16	8	32	8	16	8	200	56	112	56	224	56	112	56	64	8
9	64	8	16	8	32	8	16	56	200	56	112	56	224	56	112	8	64
10	8	64	56	16	8	32	24	112	56	192	200	112	56	224	168	16	8
11	16	56	64	8	16	24	32	56	112	200	192	56	112	168	224	8	16
12	8	16	8	64	24	48	24	224	56	112	56	192	72	144	72	32	8
13	32	8	16	24	64	24	48	56	224	56	112	72	192	72	144	8	32
14	8	32	24	48	24	64	40	112	56	224	168	144	72	192	184	16	8
15	16	24	32	24	48	40	64	56	112	168	224	72	144	184	192	8	16
16	8	16	8	32	8	16	8	64	8	16	8	32	8	16	8	232	24
17	128	8	16	8	32	8	16	8	64	8	16	8	32	8	16	24	232

Table 2: The MAS over all the 256 chip time shifts of the SSC to SSC is shown for 0 Hz. frequency error. The main peak of an SSC correlation with itself is 256. We can see that the MAS are quite bad due to Walsh Hadamard codes used for SSC's. For example, the MAS from SSC(2) to SSC(3) is 248 (row 2, column 3). Similarly MAS from SSC(4) to SSC(6) is 240 (row 4, column 5).

Even after a 1 frame of averaging for the different comma free codes in [2], we find that the aperiodic cross correlations amongst the different comma free codes remains high, particularly at multiples of 8 chip shifts. The reason for this is apparent from figure (1), where in we can see that due to the use of Walsh codes for the SSC's, their aperiodic cross correlations will be quite bad. Figure (2) plots the aperiodic auto and cross correlation of all the comma free codes (1-32) with all the comma free codes (1-32) for a time shift of 8 chips and a non-coherent averaging over 1 frame (16 slots). We can notice the following two things

(1) The aperiodic auto correlation of the comma free codes is high (up to 180) even after 1 frame averaging. The normalized maximum correlation is 256, implying that the aperiodic auto correlation could be only 3.0 dB below the main peak. This will be a problem during soft hand off situations when a lower power (more than 3dB down) target base station, is 8 chip offset from the main base station, and has the same comma free code but a different frame timing. The frame timing of the main base station will be mistaken for that of the target base station in this case. Hence, the aperiodic auto correlation of the comma free codes should be reduced.

(2) The aperiodic cross correlation of the comma free codes is also high (up to 130) even after 1 frame averaging. The normalized maximum correlation is 256, implying that the aperiodic cross correlation could be only 6.0 dB below the main peak in the worst case. This would mean that if there is a second base station whose synchronization channel (SCH) is received 8 chips apart from the first base station, then depending the relative powers, base station two could adversely affect the stage 2 of acquisition for the first base station.

It turns out that all shifts in the multiples of 8 chips have bad cross correlation properties as given above with the time shift for 8 chips being the worst case, which is plotted here. Thus, the aperiodic cross correlation of the SSC's and in turn of the comma free codes should be reduced.

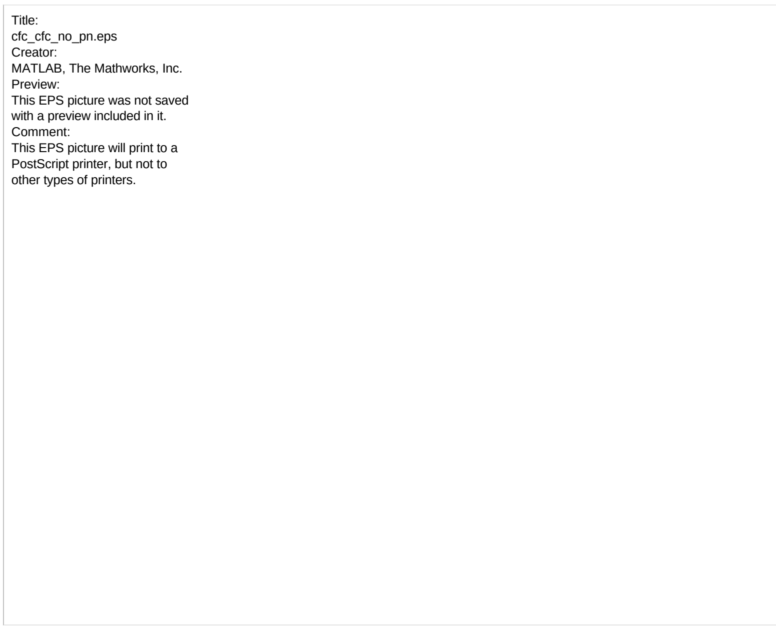

Figure (2): The aperiodic cross correlation of the comma free codes (1-32) to themselves is shown for a time shift of 8 chips and a non-coherent averaging for stage 2 over 1 frame *duration. The x-axis represents ((comma_free_code(i)-1)*32+comma_free_code(j)), i = 1, 2, …, 32 and j = 1, 2, …, 32.*

2.0 Proposed modification for SSC's

We propose to make a small modification to significantly improve the SSC correlations without increasing the stage 2 complexity.

We propose a new Z given by;

$$Z = \{\overline{A}, \overline{A}, \overline{A}, \overline{A}, A, \overline{A}, \overline{A}, A, \overline{A}, A, A, \overline{A}, \overline{A}, A, A, A, A, A, \overline{A}, \overline{A}, \overline{A}, A, A, \overline{A}, A, A, A, \overline{A}, A, \overline{A}, A, \overline{A}\}$$

---*(2)*

Comparing to equation (1) we can see that the proposed sequence Z is simply obtained by modulating the Z in equation (1) by an extended pseudo noise (PN) code of length 32. The proposed SSC structure is shown in figure (2) below:

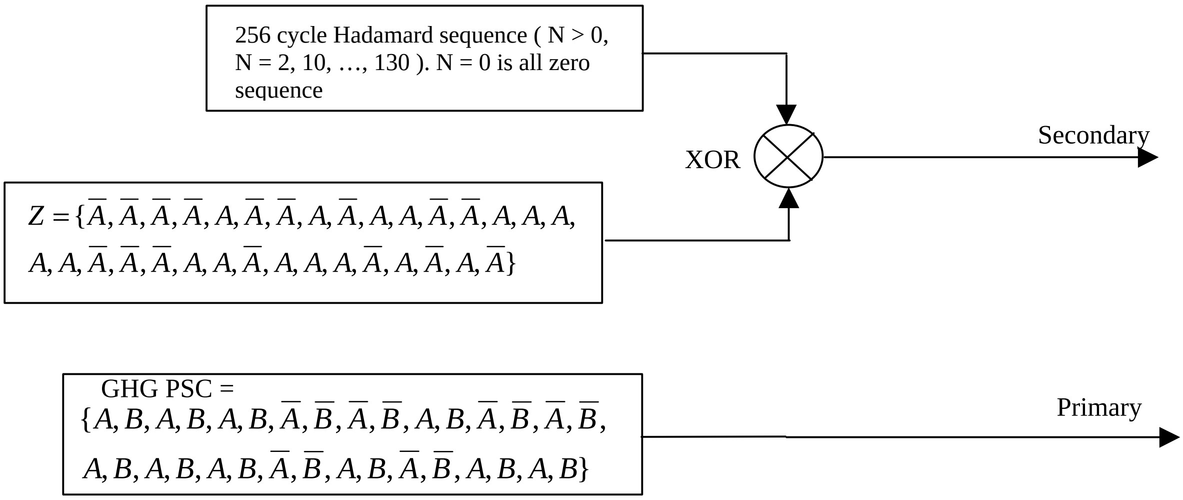

Figure 3: The modification for current SSC sequences is shown. The primary and secondary code words are converted to real valued sequences by the transformation '0'->'+1', '1'->'-1'.

The MAS of the (GHG PSC + proposed SSC) with the GHG PSC is shown in table (3) below

SSC code number	Main peak, at frequency error (kHz)		MAS of (GHG PSC + proposed SSC) to GHG PSC, at frequency error (kHz)	
	0 kHz	*10 kHz*	0 kHz	*10 kHz*
1	256	*120*	80	*63*
2	256	*120*	72	*63*
3	256	*120*	74	*63*
4	256	*120*	80	*63*
5	256	*120*	72	*63*
6	256	*120*	66	*63*
7	256	*120*	66	*63*
8	256	*120*	74	*63*
9	256	*120*	80	*63*
10	256	*120*	82	*63*
11	256	*120*	82	*63*
12	256	*120*	74	*63*
13	256	*120*	72	*63*
14	256	*120*	80	*63*
15	256	*120*	72	*63*
16	256	*120*	72	*63*
17	256	*120*	88	*63*

Table 3: MAS of the (GHG PSC + proposed SSC) to the GHG PSC is shown. Comparing to values in table (1) we can see that MAS of (GHG PSC + current SSC) to GHG PSC is the same as for the proposed SSC's implying that stage 1 performance is unchanged.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	95	72	64	64	72	72	72	80	56	64	104	104	72	72	88	88	72
2	72	97	64	64	72	72	80	72	64	56	104	104	72	72	88	88	80
3	64	64	89	64	72	80	72	72	104	104	56	64	88	88	72	72	64
4	64	64	64	103	80	72	72	72	104	104	64	56	88	88	72	72	88
5	72	72	72	80	97	72	72	72	72	120	88	80	80	72	120	120	96
6	72	72	80	72	72	95	72	72	120	72	80	72	88	80	120	120	104
7	72	80	72	72	72	72	87	48	80	88	120	72	120	120	80	64	72
8	80	72	72	72	72	72	72	105	8	88	80	72	120	120	64	80	104
9	56	64	104	104	72	120	80	88	97	72	88	88	80	96	88	96	128
10	64	56	104	104	120	72	88	80	72	95	88	88	96	80	96	88	72
11	104	104	56	64	88	80	120	72	88	88	87	88	80	96	80	96	80
12	104	104	64	56	80	88	72	120	88	88	88	105	96	80	96	80	80
13	72	72	88	88	80	72	120	120	80	96	80	96	95	88	72	80	104
14	72	72	88	88	72	80	120	120	96	80	96	80	88	97	80	72	88
15	88	88	72	72	120	120	80	64	88	96	80	96	72	80	89	64	72
16	88	88	72	72	120	120	64	80	96	88	96	80	80	72	64	103	72
17	72	80	64	88	96	104	72	104	128	72	80	80	104	88	72	72	93

Table 4: The MAS of the proposed SSC to proposed SSC is shown for 0 Hz. frequency error and over 256 chip offsets. The main peak of an SSC correlation with itself is 256. Comparing to table (2) we can see that the maximum MAS has reduced from 248 to 128.

Comparing tables (1), (3) we can see that first of all, the aperiodic correlation properties of the (GHG PSC + current SSC) to GHG PSC are almost the same as those of the (GHG PSC + proposed SSC) to GHG PSC. Hence, the stage 1 of acquisition is not impacted by the proposed change in SSC sequences. Now, similar to figure (2), figure (3) below shows the worst case (for time shift of 8 chips) aperiodic auto and cross correlation of the SSC's with the proposed modification.

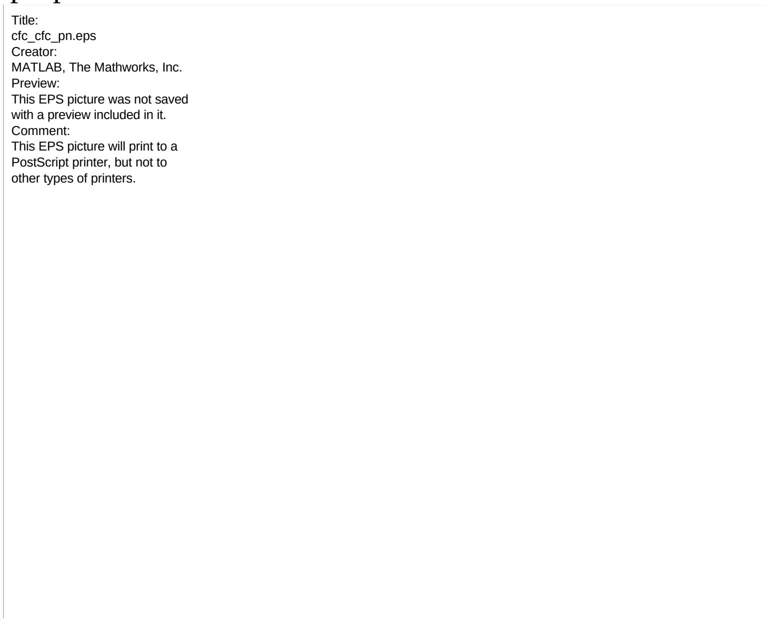

*Figure (3): The aperiodic cross correlation of the comma free codes (1-32) to themselves is shown for a time shift of 8 chips and a non-coherent averaging for stage 2 over 1 frame duration with the proposed modification. The x-axis represents ((comma_free_code(i)-1)*32+comma_free_code(j)), i = 1, 2, …, 32 and j = 1, 2, …, 32. We can see that both the aperiodic auto and cross correlation of the comma free codes is significantly reduced.*

We can now see that both the aperiodic auto and cross correlation of the comma free codes is now reduced to about a maximum of 66 which is about ***11.8*** dB below the maximum correlation of 256. As mentioned before the time shift of 8 chips is the worst case. The proposed modification is also found to have good cross correlation for all the other time shifts including all multiples of 8 chips. Since the cross correlations for the other time shifts are less than those for the 8 chip offset it implies that the worst case cross correlation for the modified SSC's is ***11.8 dB*** below the desired maximum correlation value. Thus, we can see that the aperiodic cross correlation properties of the SSC's and the comma free codes have been improved significantly.

As for complexity, we can see that the demodulation of the SSC's can still employ the length 16 Walsh Hadamard transform. The modulating PN code can be removed before feeding the inputs into the Walsh Hadamard tranform. Hence, there is no complexity increase for the proposed change in SSC's.

3.0 Conclusions and proposal

We have proposed a slight modification to the current SSC sequences so that the SSC to SSC cross correlation is much lower without any increase in stage 2 complexity. The reduced cross correlation is expected to improve the stage 2 acquisition performance in presence of multiple base stations.

References

[1] Texas Instruments, "Secondary synchronization codes (SSC) corresponding to the Generalised Hierarchical Golay (GHG) PSC", Tdoc R1-99574, Cheju, Korea, June1-4, 1999.
[2] TS 25.213, 3rd Generation Partnership Project (3GPP), Technical Specification Group (TSG), Radio Access Network (RAN), Working Group 1 (WG1), Spreading and Modulation (FDD).

-------------------------Begin proposed changes to Tdoc 25.213 --------------------------------

5.2.3 Synchronisation codes

5.2.3.1 Code Generation

The Primary code sequence, C_p is constructed as a so-called generalised hierarchical Golay sequence. The Primary SCH is furthermore chosen to have good aperiodic auto correlation properties.

Letting a = <x_1, x_2, x_3, …, x_{16}> = <0, 0, 0, 0, 0, 0, 1, 1, 0, 1,0, 1, 0, 1, 1, 0> and

~~b = <x_1, x_2, x_3, …, x_8, x_1, x_2, x_3, …, x_8 >.~~

b = <x_1, x_2, x_3, …, x_8>.

The PSC code is generated by repeating sequence 'a' modulated by a Golay complementary sequence.

Letting $y = < a, a, a, \bar{a}, \bar{a}, a, \bar{a}, \bar{a}, a, a, a, \bar{a}, a, \bar{a}, a, a >$

The definition of the PSC code word C_p follows (the left most index corresponds to the chip transmitted first in each time slot):

C_p=<y(0),y(1),y(2),...,y(255)>.

Let the sequence $Z = \{\bar{b}, \bar{b}, \bar{b}, \bar{b}, b, \bar{b}, \bar{b}, b, \bar{b}, b, b, \bar{b}, \bar{b}, b, b, b, b, b, \bar{b}, \bar{b}, \bar{b}, b, b, \bar{b}, b, b, b, \bar{b}, b, \bar{b}, b, \bar{b}\}$ ~~z = <b, b, b, b, b, b, b, b, b, b, b, b, b, b, b, b>~~.. Then the Secondary Synchronization code words, {C_1,…,C_{17}} are constructed as the position wise addition modulo 2 of a Hadamard sequence and the sequence *z*.

-----------------------------------End proposed changes to Tdoc 25.213 ------------------------