Constant Envelope Multiplexing Scheme for Three Equal Power Signals

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***Abstract*—This paper presents a mathematical design of a CEM (Constant Envelope Multiplexing) scheme for three equal power signals to achieve any target CEM power efficiency. The proposed scheme assumes that the chip pulses have one or two sample magnitude values. The design method and the results can be applied to a new satellite navigation system such as KPS (Korea Positioning System.)**

Keywords—constant envelope multiplexing, chip pulse, navigation satellite system, KPS

I. Introduction

All the currently working navigation satellites transmit several DS-SS (Direct-Sequence Spread-Spectrum) signals simultaneously at an identical carrier frequency. Unlike usual CDMA (Code Division Multiple Access) systems, the signals have distinct bit and chip rates and spreading sequences. Furthermore, the signals have distinct chip pulses unless transmitted with an identical phase. For low complexity of signal generation and reception, every chip pulse has a single magnitude or two. The signals are up- or down-converted to particular carrier frequency offsets in the case of the Galileo E5 [1].

Due to the limited operation environment of a satellite, the payload aboard for generation and transmission of the navigation signals has many strict constraints, for example, in its power consumption, weight, and volume. In order for the navigation signals to reach the receivers on the Earth, CEM (Constant Envelope Multiplexing) schemes are employed for high HPA (High Power Amplifier) efficiency [2-9]. The CEM guarantees that the baseband samples at the input of an up-converter have an identical magnitude.

When more than two signals are multiplexed, a simple linear combination cannot achieve the constant envelope and their intermodulation is additionally transmitted to arbitrarily achieve a constant envelope. However, the intermodulation component behaves as random noise to receivers and can be seen as the inevitable power loss in CEM for HPA efficiency. The ratio of the power sum of the signals excluding the intermodulation to the total signal power is the CEM power efficiency.

In this paper, a CEM design is provided for three equal power signals to meet an arbitrary CEM power efficiency requirement. It is assumed that the CEM is a linear combination of the signals and their intermodulation and that a signal can have two sample magnitudes at most.

II. Proposed CEM Scheme

The equal power condition can be met in two different approaches – instantaneous power and the average. If we assume equal instantaneous powers, all the samples of the three signals have an identical magnitude and their signs are only determined by their chip pulses and the chip bits of their spreading sequences as well as the navigation data bits in the case of data signals. However, a simple simulation can show that the CEM power efficiency cannot exceed 75% with CEM schemes based on linear combination.

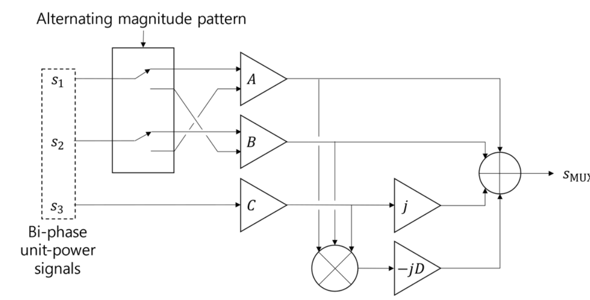

Fig. 1. Block diagram of the proposed CEM scheme.

A higher efficiency can be achieved if we allow different powers for the signals. Under the given requirement of equal powers, we can resolve the low efficiency problem by taking the average power approach. In this paper, we assume that a pair of baseband bi-phase unit-power signals, $s_1(t), s_2(t) = \pm 1$ alternately have two different magnitude values, A and B which appear with an identical probability of 0.5. The other baseband bi-phase unit-power signal, $s_3(t) = \pm 1$ has a single constant magnitude, C. The requirement of equal average powers is achieved with

$$A^2 + B^2 = 2C^2. \tag{1}$$

Fig. 1 shows the block diagram of the proposed CEM scheme with

$$s_{\text{MUX}} = G_1 s_1 + G_2 s_2 + jCs_3(1 - ABDs_1 s_2), \tag{2}$$

where $(G_1, G_2) = (A, B)$ or (B, A) with probability of 0.5 for each. When the target CEM power efficiency is given by $\eta, 0 < \eta \le 1$, it can be easily derived that the CEM coefficients should be

$$A = \sqrt{\frac{\eta - \sqrt{(4\eta - 3)\eta}}{3}} \tag{3}$$

$$B = \sqrt{\frac{\eta + \sqrt{(4\eta - 3)\eta}}{3}} \tag{4}$$

$$C = \sqrt{\frac{\eta}{3}} \tag{5}$$

$$D = \frac{3}{\eta}, \tag{6}$$

TABLE I. COEFFCIENTS FOR THE PROPOSED CEM SCHEME

CEM power efficiency	***A***	***B***	***C***	***D***
93%	0.192967	0.763390	0.556776	3.225806
94%	0.177743	0.771410	0.559762	3.191489
95%	0.161473	0.779269	0.562731	3.157895
96%	0.143762	0.786977	0.565685	3.125000
97%	0.123956	0.794545	0.568624	3.092784
98%	0.100787	0.801982	0.571548	3.061224
99%	0.070982	0.809297	0.574456	3.030303
100%	0.000000	0.816497	0.577350	3.000000

where we assumed $A < B$ without loss of generality. Table I shows the examples of the CEM coefficients obtained from (3)-(6) for various power efficiencies. Fig. 2 shows the CEM output sample constellation for various power efficiencies. In these figures, we can see that all the constellation points are well aligned on a circle whose radius corresponds to the constant envelope and that the sample constellation gets more similar to that of the unequal power QAM (Quadrature Amplitude Modulation) as the target CEM power efficiency is increased. If the target CEM power efficiency is 100%, the intermodulation component is not transmitted and the CEM coefficients are $A = 0, B = \sqrt{2/3}, C = \sqrt{1/3}$. In this case, s_1 and s_2 are alternately transmitted in-phase by TDM (Time Division Multiplexing) using two thirds of the total transmit power while s_3 is continuously transmitted in quadrature phase using a third of the total transmit power. This results in the unequal power QAM constellation with the in-phase power twice the quadrature phase power.

III. CONCLUSIONS

A CEM scheme for three equal power signals was designed for possible application in a new frequency band or satellite navigation system, including KPS (Korea Positioning System) [10-12]. Analytical expressions were provided for the CEM coefficients to achieve any desired CEM power efficiency. The proposed scheme not only resolves the 75% efficiency limit of equal instantaneous power condition but can achieve any high efficiency up to 100%. The proposed CEM scheme design is coupled with the chip pulse design. The proposed CEM scheme assumes that one of the three signals has a single constant magnitude and the other two signals have two, alternately, with an identical probability of 0.5. Therefore, the chip pulse design is reduced to pattern optimization of the sample magnitudes and signs considering the spectrum, interference, and performance of the candidate signals.

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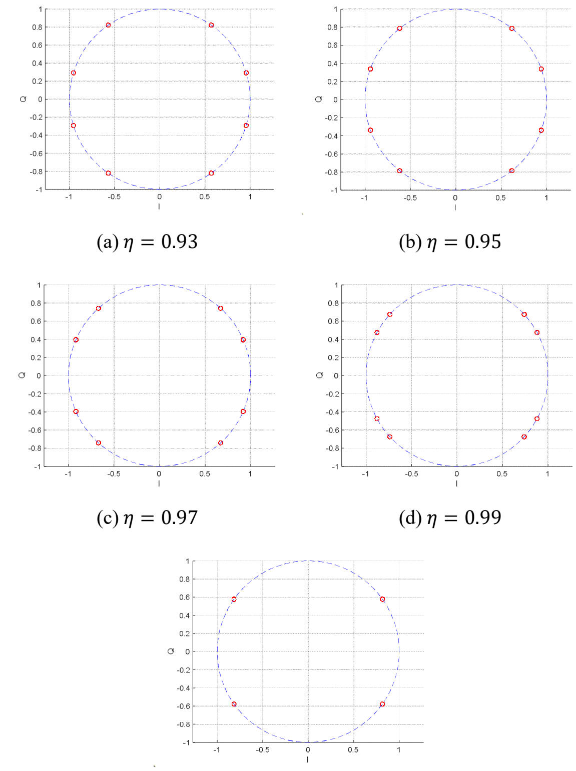

(a) $\eta = 0.93$ (b) $\eta = 0.95$ (c) $\eta = 0.97$ (d) $\eta = 0.99$ (e) $\eta = 1$

Fig. 2. Examples of the CEM ouptut sample constellation.

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