

# NEW PSEUDO RANDOM BINARY SEQUENCE PHASE SHIFT KEYED SIGNALS FOR ELECTRICAL MEASUREMENT

Ian A. Henderson <sup>(1)</sup>

<sup>(1)</sup> Henderland Gate Enterprises, 137 Henderland Road, Bearsden, Glasgow G61 1JA, Scotland  
Phone +141 931 5512 e-mail: ian@henderland-gate.freemove.co.uk

**Abstract** - The two well known digital signals used in system identification are the squarewave and Pseudo Random Binary Sequence (PRBS) signals. In data measurement, symbols with the aid of the identification coding theorems are used to capture information using an identification channel. Previously signal engineering design techniques involving descriptive languages, symbolic codes, shift keyed symbols were used to design new sets of test signal, which were based on the squarewave. These symbols are used to form digital signals for narrowband or wideband multifrequency testing. In this paper, symbolic codes are used to simplify the description of PRBS signals. Phase shift keyed modulation is then used to design new band limited PRBS test signals using a 15 bit Maximum length (M) PRBS. In narrowband frequency response measurement, the bandwidth of these new PRBS signals may be adjusted with the aid of a zoom factor. A new approach to the symbolic description of these phase shift keyed signals is given. It simplifies the software production of these test signals from their measurement zoom codes.

**Keywords** – Multifrequency digital testing; Phase shift keyed modulation; Symbolic codes; Band limited PRBS.

## 1. INTRODUCTION

In multifrequency digital testing [1,2,3], measurement symbols are used to capture information using an identification channel [4]. Signal engineering design techniques, which are based on the identification coding theorems, involve descriptive languages, symbolic codes, shift keyed symbols and symbolic addition [4]. These techniques have been used to design sets of compact, powerful multifrequency digital test signals, which are based on the squarewave [5].

Phase Shift Keyed (PSK) signals [6,7,8,9] 'zoom in' and give accurate narrowband details. Fig. 1 gives a typical application [5] for such a signal. It shows how two zoomed PSK signals may be used to identify a very large, but narrow, closed loop peak in the frequency response of a position control system with an unbalanced load on the output shaft. The test signal with a zoom factor of 4 is used to fill in the detail at the peak [5].

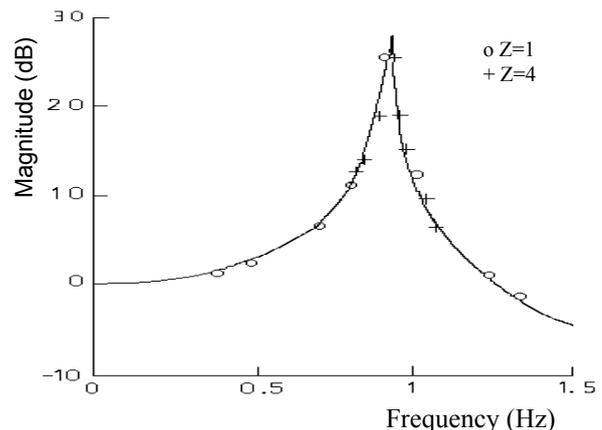


Fig. 1 - Identifying a closed loop peak of a position control system with an unbalanced load

Both impulse testing and multifrequency testing have previously been carried out using Pseudo Random Binary Sequence (PRBS) signals [3,10,11,12]. In this paper a fresh investigation of these signals is made using the identification coding theorems. Previously developed signal engineering design techniques involving descriptive languages, symbolic codes and phase shift keyed modulation are used to design new sets of PRBS test signals. Symbolic codes are used to simplify the description of PRBS signals and PSK modulation is used to design new band limited PRBS test signals using a 15 bit Maximum length (M) PRBS. These are investigated with the aid of a Data Measurement (DM) toolbox for MATLAB [4].

## 2. SYMBOLIC CODES FOR PRBS SIGNALS

Descriptive languages [4,13] and their four symbolic codes (SCs) [8], from the basic SC0 to the sophisticated SC3 form, have been used to design new multifrequency digital measurement signals[8]. Although PRBS are well known [3,10,11,12], they have not been explained in terms of their symbols. The binary symbols a and b cover the two possibilities for binary '1' or +1 V and binary '0' or -1 V. The SC1 form of the description of the 7 bit M PRBS [4] is given by  $a^3b^2ab$ . If  $a=1$  and  $b=0$ , this becomes the familiar 1110010 binary representation. Table I list PRBS from 7 bits to 127 bits in the form of the symbolic codes.

Table I – Symbolic description of pseudo random binary sequence signals

No of bits	Symbolic Description for PRBS Signals
7	$a^3bab^2$
15	$a^4b^3ab^2a^2bab$
31	$a^5b^3a^2ba^3babab^4ab^2aba^2b^2$
63	$a^6b^5ab^4a^2b^3abab^2a^4bab^3a^2b^2ab^2aba^2ba^3ba^2b^2ababab$
127	$a^7b^4a^3ba^4b^2aba^2b^2ab^6ab^3ab^2a^2b^3aba^3baba^2ba^2b^5a^2b^2a^2babab^2a^3b^2a^4ba^2bab^4abababa^5bab^2abab^3a^2ba^3b^3$

Periodic auto correlation may be found using symbols where the product of like symbols, aa or bb, gives a and unlike, ab or ba, gives b [4]. For example, the periodic auto correlation for the 7 bit M PRBS gives

<i>0 delay</i>	<i>1 delay</i>	<i>2 delay</i>		<i>6 delay</i>	<i>7 delay</i>
aaabbab	aaabbab	aaabbab		aaabbab	aaabbab
aaabbab	aabbaba	abbabaa	etc	baaabba	aaabbab
aaaaaaa	aababbb -1/7	abbaaab -1/7		baababb -1/7	aaaaaaa

The DM toolbox [4] was developed to evaluate the periodic auto correlation function and the % power at each harmonic number from the symbolic code description of digital test signals. Fig. 2 gives the time waveform and symbolic code for a 15 bit PRBS signal. The DM toolbox was used to obtain the periodic auto correlation function and % power against harmonic number graphs of Fig. 3 and Fig. 4 respectively. In this design, as the power was required to be mainly in 3 or 4 dominant harmonics, the 15 bit M PRBS signal was chosen. It should be noted that its periodic auto correlation is an approximate impulse in the time domain while its spectrum has a sinc function (sin x/x) shape in the frequency domain.

### 3. PHASE SHIFT KEYED PSEUDO RANDOM BINARY SEQUENCE SIGNALS

Modulation by phase shift keying [6,7,8,9] may be applied to a squarewave carrier where a compact modulated signal is produced by a carrier which is Phase Shift Keyed

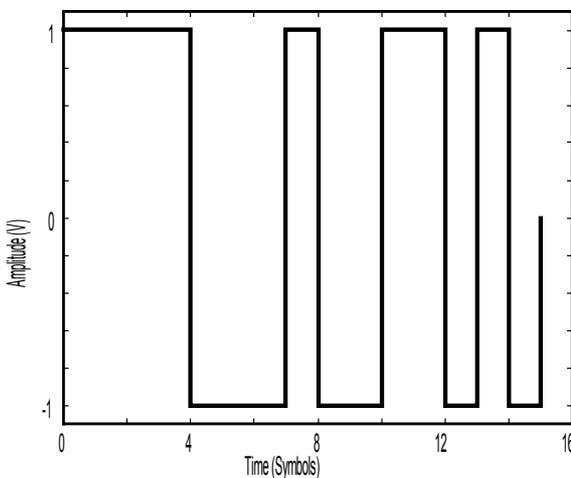


Fig. 2- Time waveform of 15 bit pseudo random binary signal

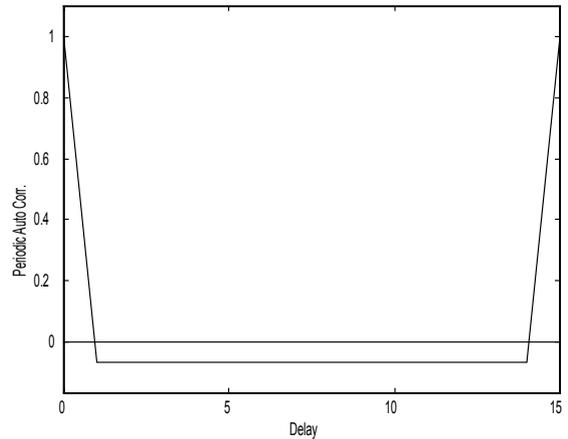


Fig. 3 – Periodic auto correlation function against delay for 15 bit M PRBS

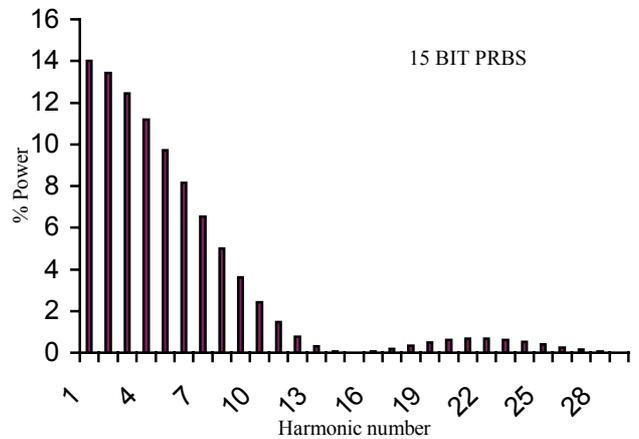


Fig. 4 – % power against harmonic number for 15 bit M PRBS

(PSK) by a compact modulating signal. The spectral signature of a PSK sequence consists of upper and lower side bands about a central suppressed squarewave fundamental carrier frequency. If the suppressed carrier harmonic number is  $h_c$  and the dominant harmonic numbers of the modulating signal are  $h_n$ , the upper harmonic number array and lower harmonic number array consist of  $h_c + h_n$  and  $h_c - h_n$  respectively. In this way, the test signal energy is concentrated into twice the original number of dominant harmonics, which are available with the chosen modulating signal. This must favour modulation with a measurement code, which has a low number of dominant harmonics. A bandwidth comparison may be made using the normalised bandwidth,

$$B_N = \pm \frac{100m}{NZ} \tag{1}$$

where  $Z$  is the range zoom factor,  $N$  is the number of modulating signal bits and  $m$  is its maximum dominant harmonic number. The number of PSK Symbols for  $N_c$  carrier symbols,

$$N_{PSK} = NN_cZ \text{ where } Z=1,2,3,4,\text{etc} \tag{2}$$

With the aid of Z, a portion of a frequency response record may be detailed.

In digital PSK modulation, each modulating symbol is multiplied by Z and by the number of carrier bits, while the phase of the carrier is synchronised such that its phase is changed by 180 degrees every time the modulating code changes its logical level. There are alternate repetitions of the full cycle (ab) or the complement (ba) of the squarewave carrier when the phase of the squarewave is changed by 180 degrees due to the modulating signal changing its symbol or logic level. The PSK version of the 15 bit PRBS signal will give 6 or 7 dominant harmonics which is sufficient to give detailed information at the peak of a closed loop frequency response.

Consider the 15 bit PRBS, which has the coding symbols aaaaabbbabbaabab or  $a^4b^3ab^2a^2bab$ . PSK symbols are obtained by replacing a and b of the modulating symbols by (ab) and (ba) respectively when Z=1. In terms of the subcode, S, a is replaced by S and b is replaced by  $\uparrow S$ . Hence, this gives  $S^4 \uparrow S^3 S \uparrow S^2 S^2 \uparrow S S \uparrow S$ , ab where S=ab and  $\uparrow S$ =ba. According to all previous PSK designs the 15 bit M PSK-Z symbols are  $S^{4Z} \uparrow S^{3Z} S^Z \uparrow S^{2Z} S^{2Z} \uparrow S^Z S^Z \uparrow S^Z$ , ab.

However, while carrying out the research for this paper, it became obvious that a much better symbolic description with the zoom factor would include the zoom factor along with the code for the squarewave carrier. The PSK measurement zoomed code is then  $S^4 \uparrow S^3 S \uparrow S^2 S^2 \uparrow S S \uparrow S$ ,  $(ab)^Z$ . For a given modulating signal and zoom factor, this is a big improvement in the description of the signal. Hence summarising

**M PRBS**       $a^4b^3ab^2a^2bab$

**M PSK**       $S^4 \uparrow S^3 S \uparrow S^2 S^2 \uparrow S S \uparrow S$ ,  $(ab)^Z$

where Z =1,2,3,4 etc. There is an enormous reduction in the complexity [4,13] of the PSK symbolic code. Even as Z is increased with a corresponding large increase in the total number of binary symbols, there is no change in the complexity.

#### 4. RESULTS USING THE DATA MEASUREMENT TOOLBOX FOR MATLAB

By using the new zoom procedure in the DM toolbox software [4] there is a considerable simplification in inputting any PSK measurement code. For a given signal, the zoomed PSK modulated version is obtained by replacing each a by  $(ab)^Z$  and each b by  $(ba)^Z$  in the original measurement code. Using the DM toolbox and the simplified approach in inputting the symbolic code from the keyboard, Figs 5, 6, 7 and 8 give the % power against harmonic number for Z=1, 2, 3 and 4. These figures clearly illustrate the shift of the narrowband dominants harmonics to higher harmonic numbers. The bandwidth about the same carrier frequency or % bandwidth with regard to the carrier harmonic number for

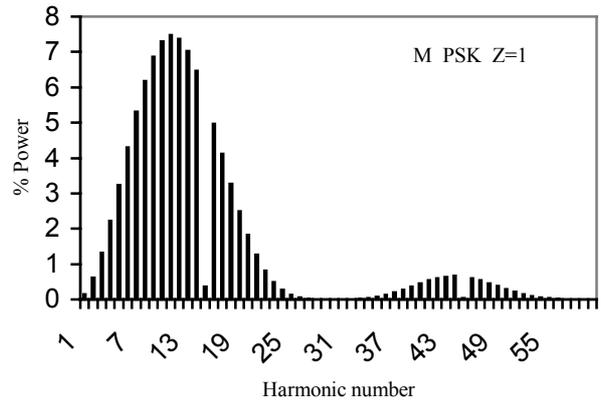


Fig. 5 – % power against harmonic number for 15 bit M PSK PRBS with Z=1

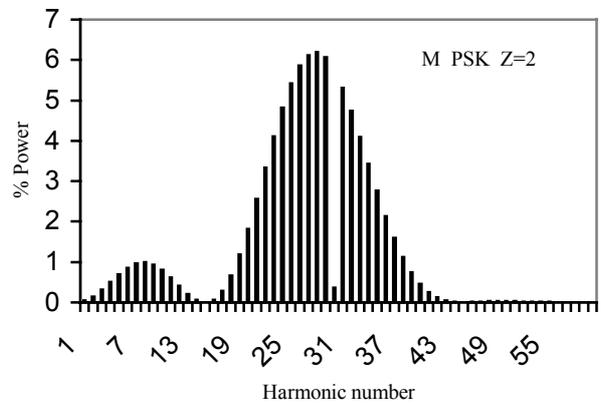


Fig. 6 – % power against harmonic number for 15 bit M PSK PRBS with Z=2

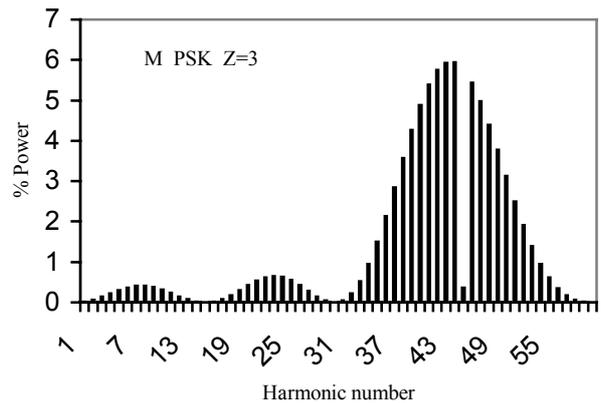


Fig. 7 – % power against harmonic number for 15 bit M PSK PRBS with Z=3

each zoom factor is reduced as the Z is increased. In all above figures there are 6 or 7 dominant harmonics making these new PSK PRBS test signals very suitable for measuring information over a narrow part of a frequency response.

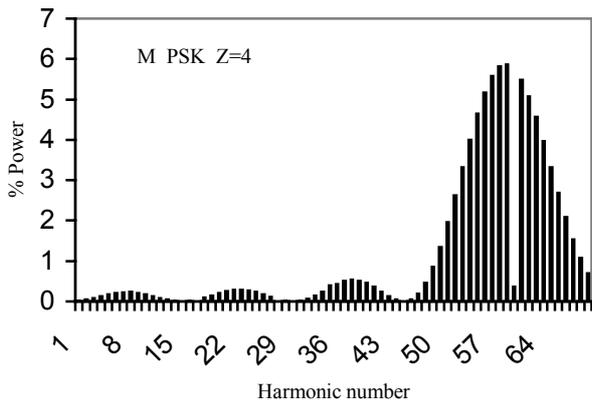


Fig. 8 – % power against harmonic number for 15 bit M PSK PRBS with Z=4

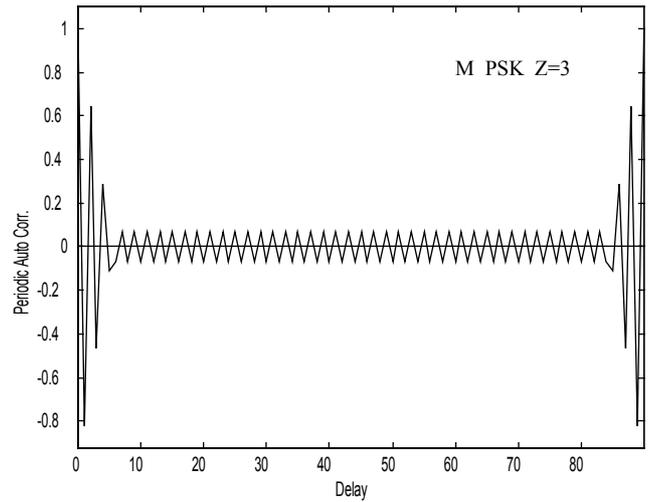


Fig. 11 – Periodic auto correlation function against delay for 15 bit M PSK PRBS With Z=3

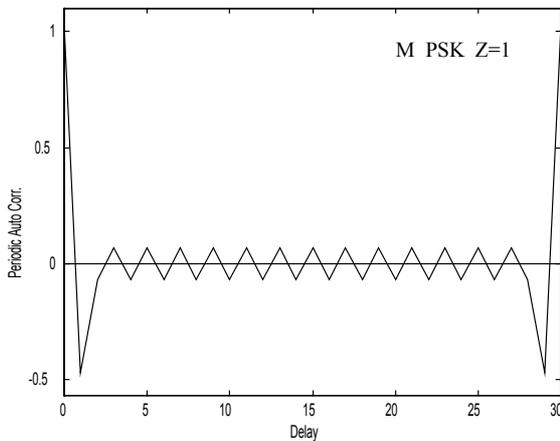


Fig. 9 – Periodic auto correlation function against delay for 15 bit M PSK PRBS with Z=1

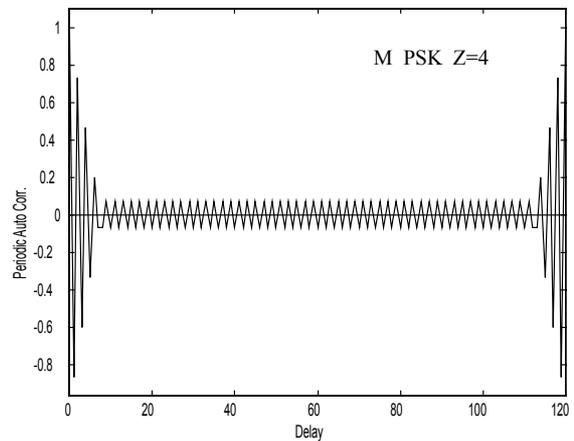


Fig. 12 – Periodic auto correlation function against delay for 15 bit M PSK PRBS with Z=4

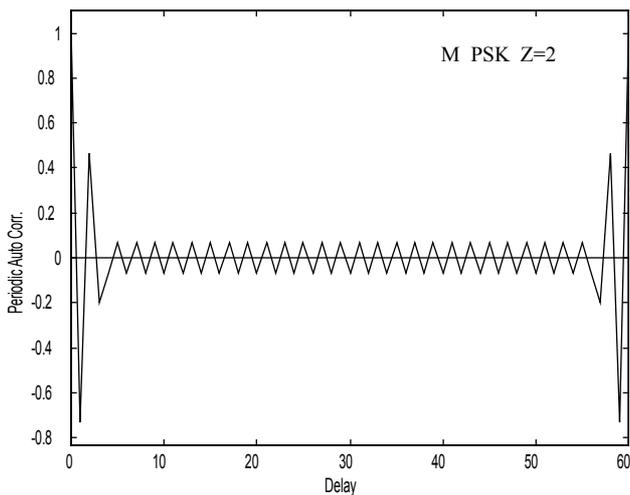


Fig. 10 – Periodic auto correlation function against delay for 15 bit M PSK PRBS with Z=2

Figs 9, 10, 11, and 12 give the periodic autocorrelation function against delay for Z=1, 2, 3 and 4 respectively. An entirely new set of PRBS is obtained due to the PSK

modulation of the M PRBS signals. For all values of Z, these give band limited impulse responses. Band limited PRBS test signals are obtained when M PRBS signals are modulated by a squarewave carrier in digital phase shift keyed (PSK) modulation. This will allow a band limited identification with an impulse response in the time domain or narrowband multifrequency estimates in the frequency domain. There is a need for a digital signal, which will concentrate the binary energy in frequency arrays with a small number of harmonic numbers. This is of particular interest in the impulse testing of band pass filters or the auto tuning of control systems using an estimate of the frequency at the phase crossover [14,15].

## 5. CONCLUSIONS

The identification coding theorems and their associated signal engineering concepts have been successfully extended to PRBS. Descriptive languages, symbolic codes, phase shift keyed symbols have been shown to make an important contribution in the design of a new set of PRBS signals as

the pseudo random nature of the signals is unaltered by PSK modulation. These digital measurement concepts are still evolving with the aid of the source and channel coding theorems, which include the premise of capturing information from a measurement channel.

Any design based on coding theory ensures that a signal, which is described by the minimum number of symbols, concentrates its energy on the aspect of the channel frequency response information that is required. These new shift keyed signals can allow an immediate and accurate evaluation of the frequency response information during the first period [16] of the signal. Strathclyde compact digital signals are robust in the presence of noise. They add powerful new interrogation signals for the on-line microcomputer evaluation of frequency response estimates.

This paper has provided an improvement in the software design of PSK signals and the successful extension of the design philosophy to PRBS test signals. This will provide further opportunities for intelligent on-line action by a measurement system in a wide variety of applications.

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