Agilent
Improving the Performance of CDMA Transmission Systems by Predicting the Spreading Codes of Code Spurs

White Paper

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Table of Contents

1. Abstract

This paper describes a practical method for predicting the spreading codes of code spurs caused by non-linearities (e.g., compression or deliberate clipping) in the transmission path of a CDMA system. The value of predicting the spreading codes of code spurs is that it allows the code spurs to be positioned in the code domain so that they project primarily onto unused codes. Code spur prediction therefore allows for optimization of the modulation quality of the used codes on which the performance of the system depends. By using a code channel allocation algorithm based on code spur prediction, more aggressive signal clipping is possible, reducing the necessary headroom in the power amplifier without degrading system performance.

2. Introduction

Code division multiple access (CDMA) communications systems allow the transmission of multiple channels of information on the same frequency at the same time. Unlike in traditional communications systems where an information symbol is represented directly using some form of carrier modulation, in the CDMA system, each information symbol is modulated by a binary signaling (spreading) code. Each information channel is assigned a unique spreading code with known length such that the information symbol rate of each channel is converted or "spread" to a common higher modulation rate (chip rate) for the particular system. The individual channels can then be summed to create a composite signal, which is transmitted by the communication system. The spreading codes chosen for each channel are orthogonal, I.e. the dot product of any two time-aligned codes is zero. If the received composite signal is despread with one of the codes used in the spreading process and the result then demodulated, the output is the original symbol data that was spread by the transmitter using that specific code. The use of different length spreading codes (spreading factors) allows for channels with different symbol data rates to be spread up to the common system chip rate.

3. The Challenge of Managing High "Peak to Average Ratio" Signals

Although there are many benefits in the CDMA system, one of the challenges it presents is the highly time-varying power profile of the composite signal. The larger the number of channels that are combined, the more likely the instantaneous power of the signal will increase as compared to the average. It is typical of many composite CDMA signals to approximate gaussian noise. For example it is common for a composite signal to have peaks 10 dB above the average power although this may occur only 0.001% of the time. Dealing with such signals in practical transmission systems can be problematic since it is highly desirable to maintain a linear transmission path. Providing a linear transmitter for a signal that can have peaks 10 dB above the average power means the instantaneous power handling of the transmitter typically needs to be ten times greater than the average power of the signal. Allowing for such headroom is very costly.

If the composite signal is not linearly amplified, compression of the peaks of the signal can occur which inevitably leads to third order intermodulation products (spectral regrowth) in the adjacent channels. The capacity of any multi-frequency CDMA system is heavily dependent on controlling spectral regrowth since otherwise the capacity of the adjacent channels, and hence the system, can be severely reduced by the added noise. There are many techniques employed to ensure that excessive spectral regrowth does not occur. These include feed-forward and pre-distortion linearization techniques in amplifiers to try to extend the linear operating range. Another popular technique is the use of clipping which limits the peaks of the composite signal. This method can extend the operating range of a transmitter by several dB, which is highly valuable in either reducing spectral regrowth or allowing the use of lower cost amplifiers with less headroom.

4. Disadvantages of Using Clipping to Reduce Peak to Average Ratio (PAR)

Although clipping helps deal with adjacent channel spectral regrowth problems, its use inevitably leads to a degradation of the in-channel modulation quality. The extent to which a composite signal can be clipped is limited by the extent to which the composite signal can be despread and demodulated. Typical commercial CDMA systems such as the Third Generation Partnership Project Wideband CDMA (3GPP W-CDMA) system and the Telecommunications Industry Association Interim Standard 95 (TIA IS-95) system specify requirements for the modulation quality of the composite signal in the form of an Error Vector Magnitude (EVM) or likeness factor Rho. In addition, the 3GPP W-CDMA system specifies a limit on how much the modulation error vector projects onto any one code in the code domain at a specified spreading factor.

The most obvious impact of clipping a composite signal is that the modulation quality of the despread channel is degraded since some of the energy that should have been transmitted was lost. This degradation can lead to errors in the demodulation process, or a loss of margin in the channel with regard to other factors such as noise from interference sources. There is however a less obvious consequence of this lost energy which is how the energy is distributed in the code domain. If the error energy is random, it will project equally onto all codes in the code domain leading to a general but small loss of margin on any active code. But if the error energy happens to project onto only a few or even just one code, this would create a significant unwanted error signal (error vector) or code spur in the receiver on the codes in question. If the codes affected were not part of the codes chosen to transmit the original signal, then the impact on the quality of the active channels when despread would be minimal due to the orthogonality of the codes. However, if the error energy projects primarily on the used or active codes, the quality of the despread channels will degrade further as there is no orthogonality between the wanted signal and the error vector.

It can readily be seen in the code domain that the typical error vector generated by clipping the composite signal does not result in an even distribution of the error across the code domain. But in order to maximize system performance, it is desirable for the error energy to project onto unused codes so that the natural orthogonality of the CDMA system works to the benefit of the modulation quality of the despread channels. To this end it is beneficial to be able to predict how the error vector is projected into the code domain.

5. Using Vector Products to Calculate Spreading Codes of Code Spurs

The underlying principle behind the generation of code spurs in the code domain is not dissimilar to that which is well known in the frequency domain. When two sine waves at different frequencies f1 and f2 are added linearly, the frequency domain will only contain the original frequencies. If, however, the two signals are allowed to pass through a non-linear transformation such as an amplifier in compression, the signals will multiply together producing new frequency components, the most problematic usually being the generation of the third order intermodulation products at 2f1 – f2 and 2f2 – f1.

In an ideal CDMA transmitter, the generation of the composite signal is the result of a linear combination of spread channels. If however the transmitter is either compressed or has had deliberate distortion added such as signal clipping, similar intermodulation products will be generated. It has been generally assumed that the product of any two spreading codes of the same length multiply to create a new third code.

In the modulation domain, spreading codes are represented by the BPSK modulation values of +1 and -1. Consider the following set of Orthogonal Variable Spreading Factor (OVSF) codes taken from the 3GPP W-CDMA system (bit-reversed hadamard index numbering). The notation $C_n(X)$ denotes code number X from the set of nth order orthogonal spreading codes of length 2^n where X can vary from 0 to 2^n - 1. For example, the sixth code in the sequence below (1,-1,1,-1, -1,1,-1,1) can be denoted as $C_3(5)$.

Index	OVSF code							
0	1	1	1	1	1	1	1	1
1	1	1	1	1	-1	-1	-1	-1
2	1	1	-1	-1	1	1	-1	-1
3	1	1	-1	-1	-1	-1	1	1
4	1	-1	1	-1	1	-1	1	-1
5	1	-1	1	-1	-1	1	-1	1
6	1	-1	-1	1	1	-1	-1	1
7	1	-1	-1	1	-1	1	1	-1

Table 1. Length 8 OVSF codes

Therefore, it might be expected that if codes $C_3(3)$ and $C_3(5)$ were combined using a non-linear function e.g. clipping or compression, the code spur generated would be $C_3(3)$ x $C_3(5)$. This can be evaluated as the vector product of the two codes:

	1	1	-1	-1	-1	-1	1	1
x	1	-1	1	-1	-1	1	-1	1
=	1	-1	-1	1	1	-1	-1	1

From Table 1, it can be seen that the sequence 1, -1, -1, 1, 1, -1. -1, 1 matches the code shown at index 6.

As a mathematical convenience, it can be helpful to express the bipolar sequence 1, -1 using the binary notation 0,1 such that the multiplication operator can be replaced by the exclusive OR function ⊕:

	0	0	1	1	1	1	0	0
⊕	0	1	0	1	1	0	1	0
=	0	1	1	0	0	1	1	0

Using the binary to bipolar mapping, the binary sequence 0, 1, 1, 0, 0, 1, 1, 0, maps onto the bipolar sequence 1, -1, -1, 1, 1, -1. -1, 1 which is again the code shown at index 6 in Table 1.

In the first instance then it might be expected that in the presence of non-linear transmission, $C_3(3)$ x $C_3(5)$ will multiply to produce $C_3(6)$.

By using this generally accepted principle that any two codes at the same spreading factor will multiply in the presence of non-linearities in the transmission path it should be possible to develop algorithms that will predict for a set of active codes, where in the code domain the code spurs will exist. The remainder of this paper will explain that this simple assumption for code mixing is not in fact correct and cannot therefore be used to predict the position of code spurs in the code domain. An alternative method for code spur prediction is presented which can be used to develop algorithms for code channel allocation that will help optimize system performance.

6. Examples of Code Spur Generation

It can be readily shown using simple examples that two codes on their own in the code domain will not generate any additional codes when subject to typical clipping levels e.g. circular clipping | i+jq | to 50%. The following examples are based on the bit-reversed code numbering scheme of the hadamard spreading codes used in the 3GPP W-CDMA system. The principles however apply to any code numbering scheme.

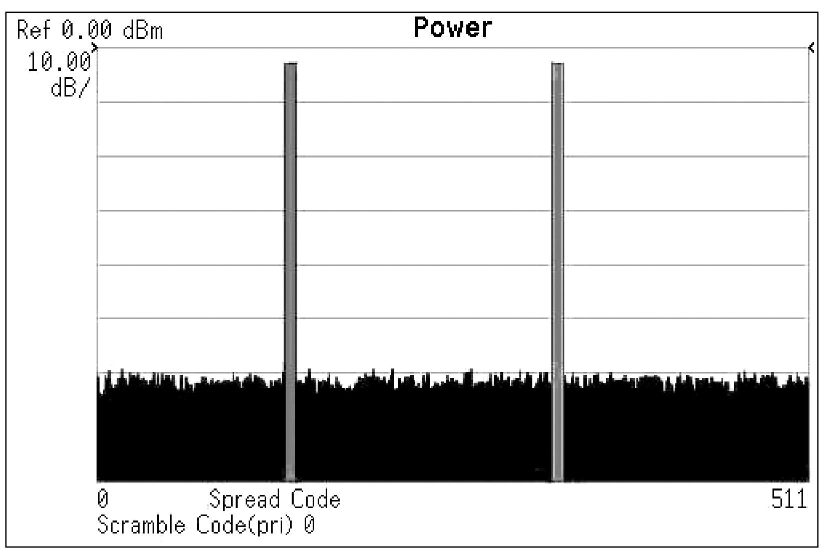

Figure 1. $C_6(17)$ and $C_6(41)$ with no clipping – no code spurs

Figure 1 shows two codes at spreading factor 64 in a linear environment i.e., no clipping or compression. As expected there are no other codes present as shown by the average code domain noise floor, which is below -60 dBc.

Figure 2 shows the same two codes but with 50% clipping added.

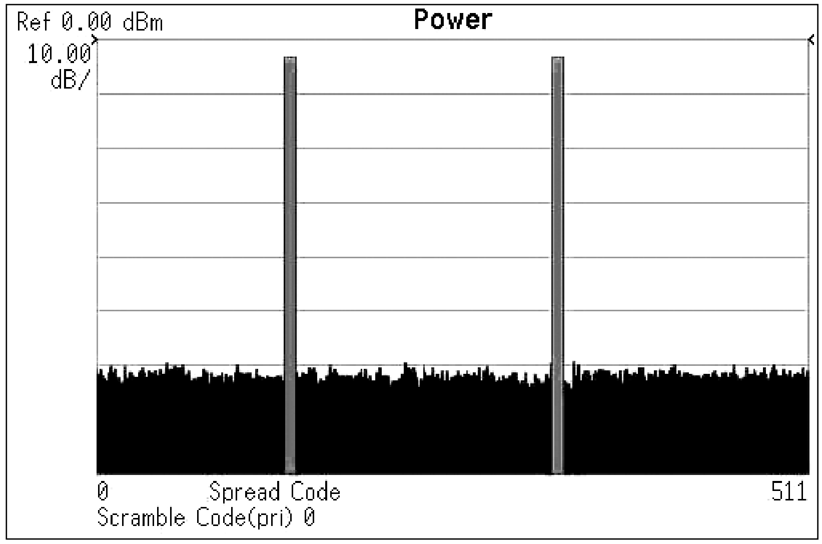

Figure 2. $C_6(17)$ and $C_6(41)$ with 50% clipping – no code spurs

Figure 2 shows the projection into the code domain of a highly nonlinear signal yet there is no evidence of any code spurs or even an increase in the average code domain noise floor. Such a two-code signal would never be used in a realistic CDMA communications system but it is shown here to disprove the generally held belief that two codes can multiply to produce a third code. The complete lack of code domain spurs when only two codes of the same spreading factor are clipped or otherwise compressed holds true for all channel numbers, any active channel symbol data and any active channel code domain power.

But as will be seen later, the lack of code domain spurs does not mean the signal is free from distortion. In this special case, all the distortion energy projects onto the two used codes only.

Now consider the situation in Figure 3 when a third code is added to the already clipped signal.

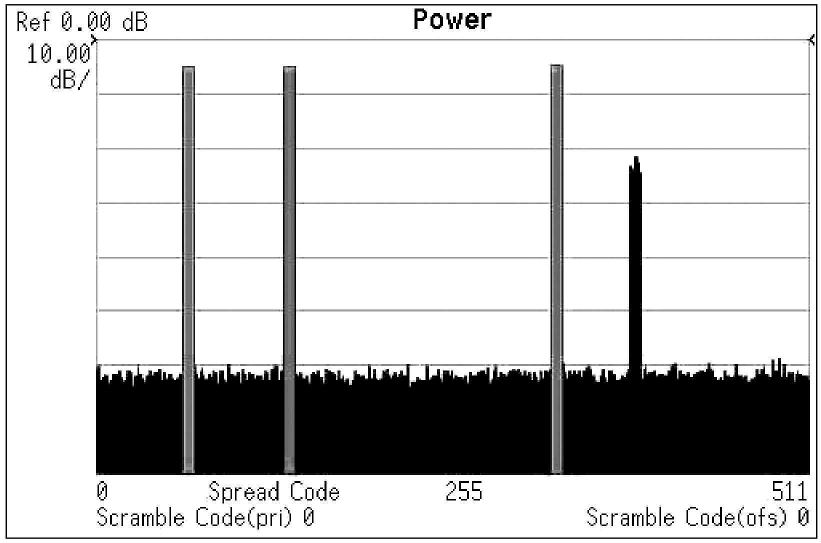

Figure 3. $C_6(8)$, $C_6(17)$ and $C_6(41)$ with 50% clipping – one code spur at $C_6(48)$

The addition of $C_6(8)$ to the other two channels has produced a large single code spur on $C_6(48)$, which was not part of the original signal.

Figure 4 below then shows what happens when the clipping is removed from the composite signal.

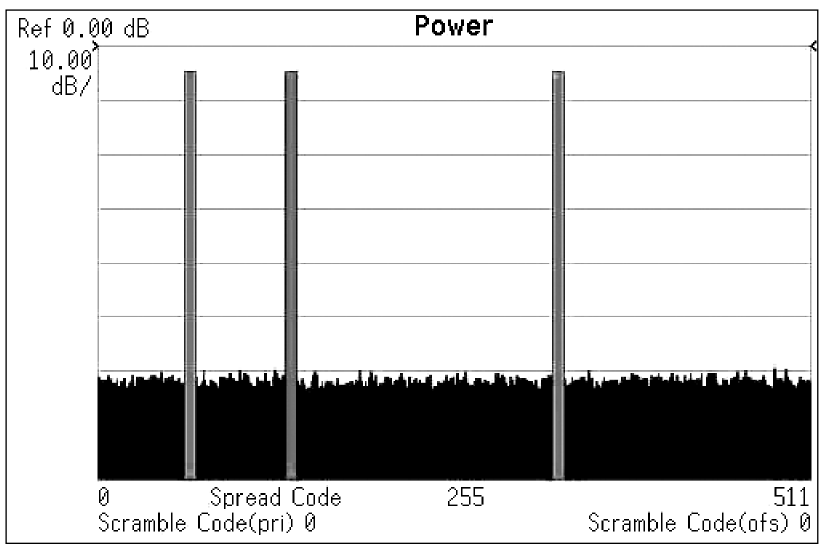

Figure 4. $C_6(8)$, $C_6(17)$ and $C_6(41)$ with no clipping – no code spurs

Now that now the non-linearity has been removed, the code spur at $C_6(48)$ has completely disappeared.

The above examples are far less complex than the signals that are required to operate a CDMA communications system. But they are used here to illustrate a previously undocumented principle that at least three codes in any orthogonal set (i.e. at the same spreading factor) have to be present in a composite signal before the addition of clipping (or other non-linearities such as amplifier compression) can create a spur in the code domain.

Building on this assertion consider the following four-code example:

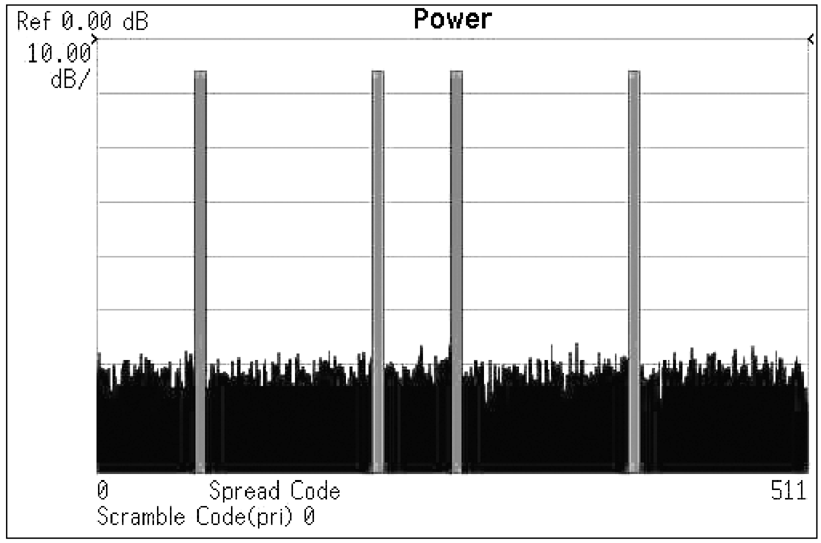

Figure 5. $C_6(9)$, $C_6(25)$, $C_6(32)$ and $C_6(48)$ with 50% clipping – no code spurs

Figure 5 shows the code domain display for a four code composite signal with 50% clipping applied. The most obvious observation is that now with a four-code signal and clipping there are no code spurs. However, Figure 6 shows an alternative set of four codes which does demonstrate code spurs.

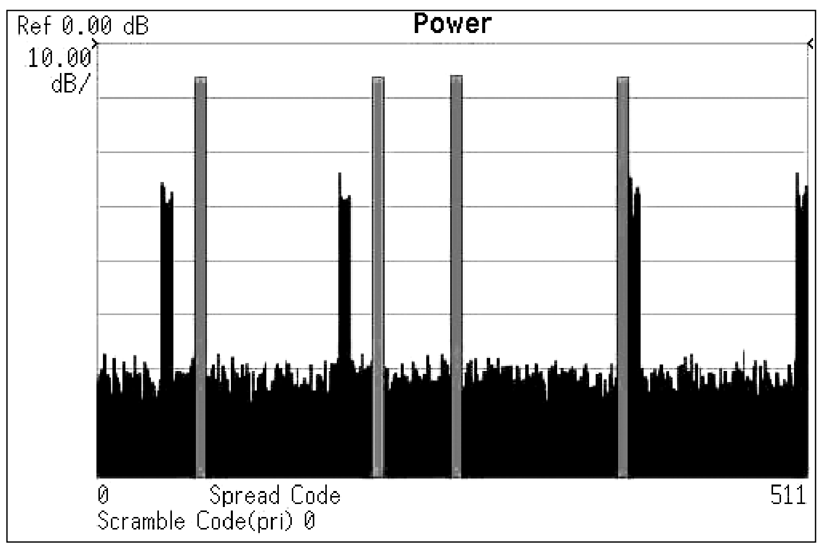

Figure 6. $C_6(9)$, $C_6(25)$, $C_6(32)$ and $C_6(47)$ with 50% clipping – plus four C_6 code spurs

The only difference between Figure 5 and Figure 6 is that $C_6(48)$ was changed to be $C_6(47)$. The effect of this is to apparently generate four code spurs on channels $C_6(6)$, $C_6(22)$, $C_6(48)$ and $C_6(63)$. The lack of code spurs in Figure 5 is another example of a signal where the error energy projects onto the used codes only.

The next two figures show examples of five and six code composite signals with 50% clipping.

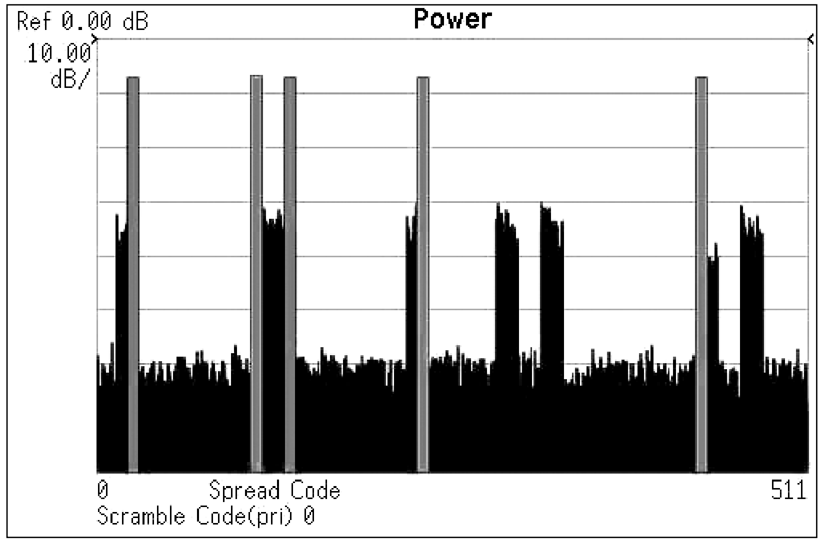

Figure 7. C_6(3), C_6(14), C_6(17), C_6(29) and C_6(54) with 50% clipping – plus eleven C_6 code spurs

Figure 7 shows the five code composite signal comprising C_6(3), C_6(14), C_6(17), C_6(29) and C_6(54). In the presence of 50% clipping there are eleven clearly visible code spurs at C_6(2), C_6(15), C_6(16), C_6(28), C_6(36), C_6(37), C_6(40), C_6(41), C_6(55), C_6(58) and C_6(59).

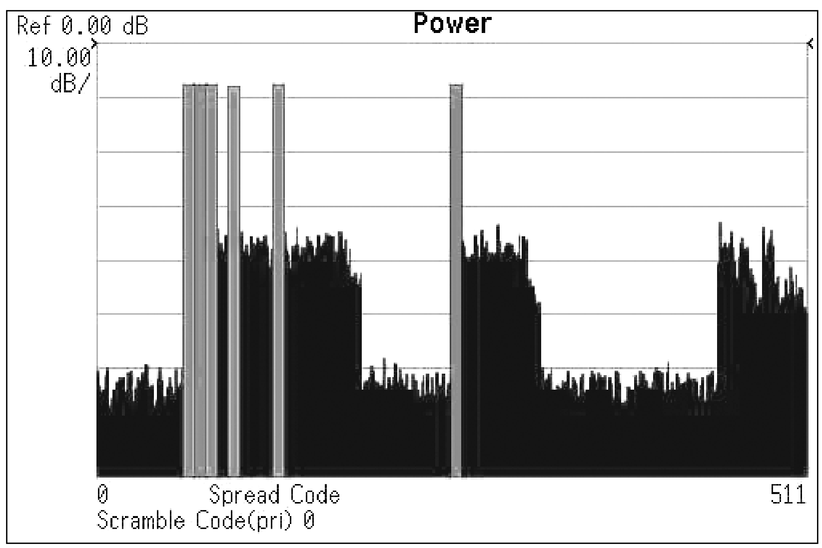

Figure 8. C_6(8), C_6(9), C_6(10), C_6(12), C_6(16) and C_6(32) with 50% clipping – plus 26 C_6 code spurs

Figure 8 shows a six code composite signal comprising C_6(8), C_6(9), C_6(10), C_6(12), C_6(16) and C_6(32) with a further 26 C_6 code spurs on indices 11, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 33, 34, 35, 36, 37, 38, 39, 56, 57, 58, 59, 60, 61, 62 and 63.

7. A Method for Predicting Spreading Codes of Code Spurs

Most practical CDMA composite signals contain many more than six or seven codes and include the added complication of different spreading factors and code domain powers. It is therefore not at all obvious how to predict where code spurs will occur and at what power. Clearly from the above examples there is a strong relationship between the number of active codes and the number of spurs but otherwise there is no intuitive way to predict the exact number and position of code spurs.

However, in all of the above examples and in the general case (the mathematics of which is not presented here) it can be shown that there is in fact a simple but non-intuitive relationship between the active codes and the code spurs that are generated due to non-linearities.

The general rule for code spur generation can be stated as:

> **General Rule:** Code spurs will be generated in a CDMA communications system whenever a composite signal containing energy in three or more codes from the same orthogonal set (i.e. at the same spreading factor) is passed through a non-linear function such as amplitude clipping or amplifier compression. One code spur will be generated for each and every permutation comprising an odd number of at least three active codes that can be chosen at the same spreading factor from the composite signal. Furthermore, the spreading code of the code spur will be the vector product (assuming bipolar notation) of all the spreading codes in each permutation and will have the same spreading factor as the codes in each permutation.

In addition, two special cases need to be stated:

> **Special case 1:** If the vector product of an odd number of at least three spreading codes at the same spreading factor results in a code of all ones (i.e. predicting $C_n(0)$ where 2^n is the spreading factor) then for that permutation, no discrete code spur will be produced.

> **Special case 2:** If the composite signal contains spreading codes from more than one orthogonal set (i.e. multiple spreading factors) it is necessary to substitute the lower order active codes by the higher order codes that occupy the same space in the code domain. This substitution needs to be carried out at all orders of orthogonal code sets present in the composite signal at which active codes exist. For each order of orthogonal code sets represented in the composite signal it is then possible to calculate the code spurs for that order using the general rule and special case 1.

Note in Figure 6 and Figure 8 examples where permutations of an even number of codes do not multiply to produce spurs on other codes. In Figure 6, codes $C_6(9)$, $C_6(25)$, $C_6(32)$ and $C_6(47)$ multiply to predict $C_6(31)$, but it is clear that no such spur exists. Similarly for the six-code case of Figure 8, the six-code vector product is $C_6(55)$, and again, no such spur exists. This is an important principle that is essential if correct algorithms are to be developed to predict the spreading codes of code spurs.

8. Predicting the Number of Code Spurs

The number of permutations of size r that can be drawn from a number of active channels n is given by:

$$\frac{n!}{(n-r)!\ r!}$$

This applies even in the trivial case where n = r since 0! = 1.

Examples of the numbers of code spurs for different numbers of codes in the same orthogonal set is given in Table 2 below:

Number of active codes	Permutations of 3 codes	Permutations of 5 codes	Permutations of 7 codes	Permutations of 9 codes	Total number of code spurs	Total number of codes
1	0	0	0	0	0	1
2	0	0	0	0	0	2
3	1	0	0	0	1	4
4	4	0	0	0	4	8
5	10	1	0	0	11	16
6	20	6	0	0	26	32
7	35	21	1	0	57	64
8	56	56	8	0	120	128
9	84	126	36	1	247	256
10	120	252	120	10	502	512

Table 2. Permutations of codes that create code spurs

Note that the total number of codes is always equal to 2^n - 1 where n is the number of active codes. However, in most circumstances, the code spurs will fall on used codes or other code spurs and therefore the total number of code spurs visible in the code domain will usually be less than the number indicated in Table 2.

9. The Use of 'Exclusive OR' as an Alternative to Calculating Vector Products

There is a convenient way for calculating the code spur spreading codes that does not require calculating vector products of lengthy spreading codes. In the above examples it can be shown that performing an exclusive OR operation on the binary representation of the code indices of any one orthogonal set will generate the index number in that set of the vector product of the OVSF codes. This relationship holds for both the Hadamard numbering of the Walsh codes in IS-95 and CDMA2000 as well as the bit-reversed hadamard code numbering used in the 3GPP W-CDMA system. For example, the index of the code spur produced from the codes $C_n(x)$, $C_n(y)$ and $C_n(z)$ is given by $x \oplus y \oplus z$. Note that when using the exclusive OR index method, special case 1 applies when the predicted index is zero (i.e. the spreading code is all ones).

Using this convenient property of indices, it is easy to verify that the examples shown in Figures 1 to 8 can be explained by application of the general rule and special case 1.

For example, consider the signal in Figure 6. The active channels are $C_6(9)$, $C_6(25)$, $C_6(32)$ and $C_6(47)$. If we apply the general rule we see from Table 2 that with 4 active codes, there are four permutations of three codes that will multiply to predict code spurs. The four permutations of three active codes are:

$C_6(9)$, $C_6(25)$, $C_6(32)$
$C_6(9)$, $C_6(25)$, $C_6(47)$
$C_6(9)$, $C_6(32)$, $C_6(47)$
$C_6(25)$, $C_6(32)$, $C_6(47)$

By using the rule that the code spur code index can be calculated by performing an exclusive OR operation on the indices of the codes in each set we can predict the code spurs as follows:

$$9 \oplus 25 \oplus 32 = 48$$
$$9 \oplus 25 \oplus 47 = 63$$
$$9 \oplus 32 \oplus 47 = 6$$
$$25 \oplus 32 \oplus 47 = 22$$

This matches the code spurs shown in the code domain display of Figure 6.

10. Predicting the Power Level of Code Domain Spurs

The power level of code spurs is firstly a function of the number of codes in the permutation. The code spurs with the highest code domain power are generated by permutations of three active codes. The next most powerful code spurs are generated from permutations of five active codes. Higher orders of permutations produce code spurs whose power is likely to be insignificant in practical systems. An example of the difference between a five-code permutation spur and three-code permutation spur can be seen in Figure 7 above. The typical code spur level of the ten spurs generated from the 10 sets of three codes is seen to be about 10 dB higher than the code spur generated at $C_6(55)$ which is the only spur to be created by the presence of a permutation of five codes.

The power level of a code spur is also a function of the code domain power of the active codes that were used to generate it. The details are not elaborated here but the level of the code spur obviously drops with the level of the active codes. Since any real CDMA system will employ real-time power control, the instantaneous calculation of the power of a particular code spur is going to vary with the proximity of the mobile phones to the base station and the respective channel conditions. With the power control rate for W-CDMA being as high as 1500 Hz, attempting to predict instantaneous code spur levels is unlikely to be a worthwhile exercise. It is probably sufficient to base spreading code allocation algorithms on the assumption that over time, the level of active channels at the same spreading factor will be equal.

Finally, the level of the code spur will vary according to the nature and level of the non-linearity e.g. the clipping or compression level. The higher the distortion, the higher will be the code spur power.

11. Example Using a Signal Containing Different Spreading Factors

In cases where we are dealing with more than one set of orthogonal codes (i.e., more than one spreading factor) we need to apply special case 2. To illustrate this consider the example below in Figure 9.

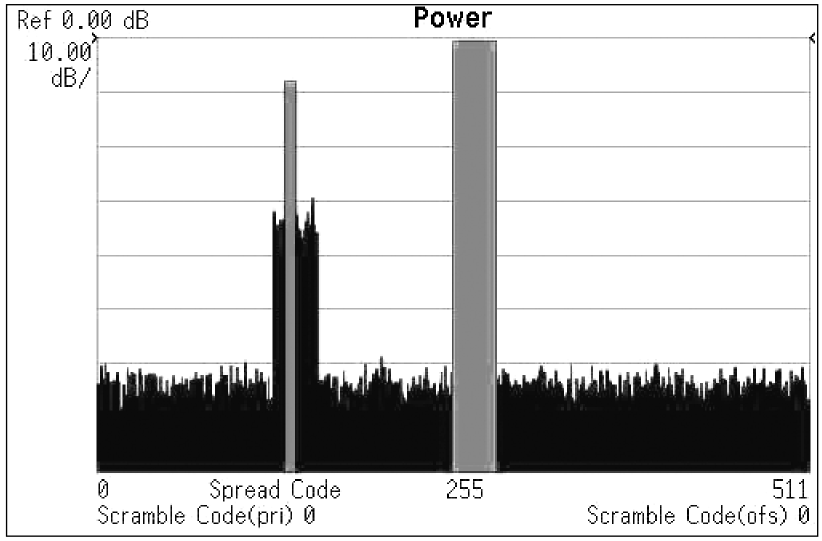

Figure 9. $C_6(17)$ and $C_4(9)$ with 50% clipping ñ plus 3 C_6 code spurs

Although Figure 9 shows only two active codes in the composite signal it is clear that several code spurs have been generated. This is very different from Figure 2, which also had two active codes but no code spurs. The difference is because the signal shown in Figure 9 contains codes of differing spreading factors, i.e. more than one set of active orthogonal codes. In order to calculate the spurs we have to apply special case 2.

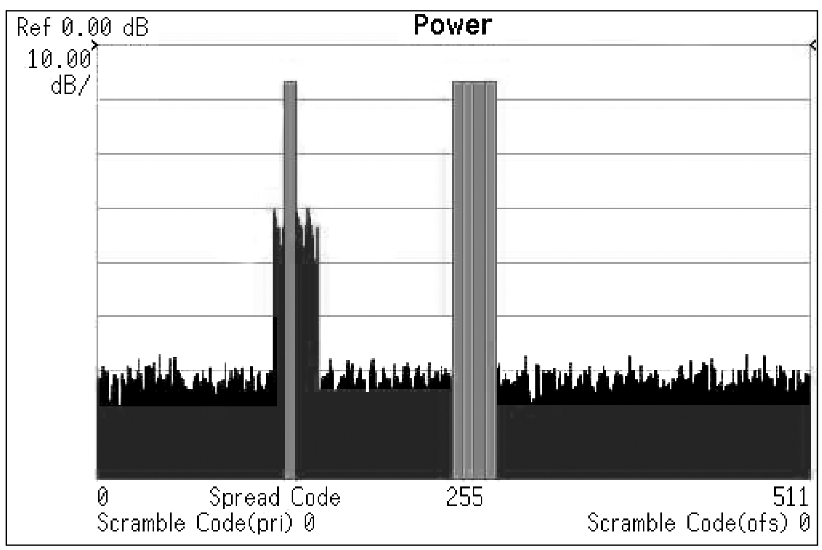

Figure 10. $C_6(17)$, $C_6(32)$, $C_6(33)$, $C_6(34)$ and $C_6(35)$ with 50% clipping – plus 3 C_6 code spurs

Figure 10 shows $C_4(9)$ substituted by the four spreading codes that occupy the same code space using codes from the same orthogonal set C_6 as the active code at $C_6(17)$. In other words, the code domain of the composite signal has been represented using codes from only one orthogonal set, in this case spreading factor 2^6 or 64. (Note that the code powers of the C_6 channels are 6 dB lower than the original C_4 channel, this is so that the integrated power of the four C_6 channels adds up to the same as the power of the original C_4 channel.) It is now possible to apply the general rule to calculate the position of the C_6 code spurs. This predicts that there will be eleven C_6 code spurs that will project onto the C_6 code indices 16, 17, 18, 19, 32, 33, 34, and 35 (codes 17, 18, and 19 are predicted twice). And, since five of these predicted codes are already used, only three new C_6 code spurs can be seen.

In cases where there are three or more different spreading factors represented in the composite signal, it is necessary to substitute the lower order codes at all levels where active codes exist. For example, consider a composite signal containing one active code at spreading factor 8, two codes at spreading factor 32 and three codes at spreading factor 64. Since there is only one code at spreading factor 8, the general rule predicts that there will be no code spurs at this level. Next it is necessary to substitute the spreading factor 8 code by the codes that occupy the same space in the code domain at the next level down where an active code exists, in this case that would be four substitute codes at spreading factor 32 . We now have six codes at spreading factor 32, two being active codes, the other four being substitute codes. The general rule and special case 1 are then applied at spreading factor 32, which according to table 2, will yield 26 code spurs. The process is then repeated whereby the six codes at spreading factor 32 are substituted at the next layer down, which in this case produces 12 substitute codes at spreading factor 64. These are added to the three active codes at this level and the general rule and special case 1 are again applied.

The code spurs generated at one level could be considered as “active” and substituted at lower levels but they are likely to be low enough in power to be effectively ignored.

In this simple example it can easily be seen that when low spreading factor codes are present along with high spreading factor codes, the substitution process quickly multiplies the number of codes to the point where the number of predicted spurs grows exponentially. A limit is obviously reached when the entire code domain is occupied by active codes and code spurs, however, it is not anticipated that practical systems will ever be fully loaded. As long as the code domain has some unallocated space there will be an allocation of spreading codes that optimizes the active code quality.

12. Applying code spur spreading code prediction to improve CDMA system performance

An example of the advantage of being able to predict the position of code spurs is given below.

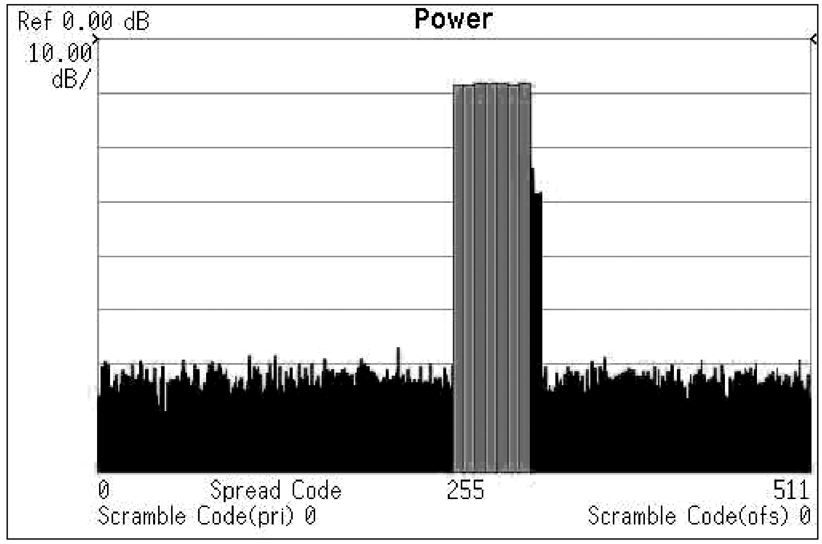

Figure 11. C_6(32), C_6(33), C_6(34), C_6(35), C_6(36), C_6(37) and C_6(38) with 50% clipping

Figure 11 shows a seven-code signal with 50% clipping. The only visible code spur is seen at C_6(39). We will call this the "adjacent channel" allocation.

Consider now an alternative spreading code allocation.

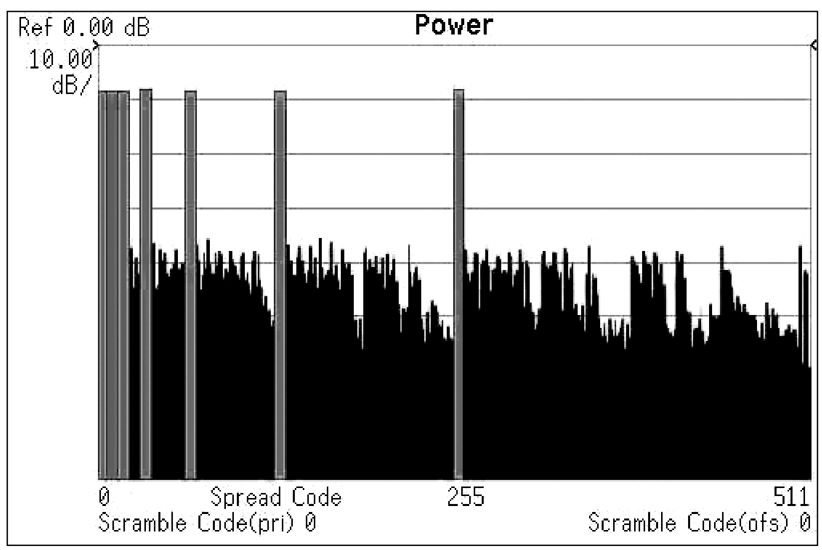

Figure 12. C_6(0), C_6(1), C_6(2), C_6(4), C_6(8), C_6(16) and C_6(32) with 50% clipping

Figure 12 shows an "alternative channel" allocation of the spreading codes for the seven C_6 channels. On first inspection by considering only the code domain power analysis, the adjacent allocation in Figure 11 seems to be much better in terms of code spurs. However, if we look further at these two composite signals and consider the Error Vector Magnitude we see a very different picture.

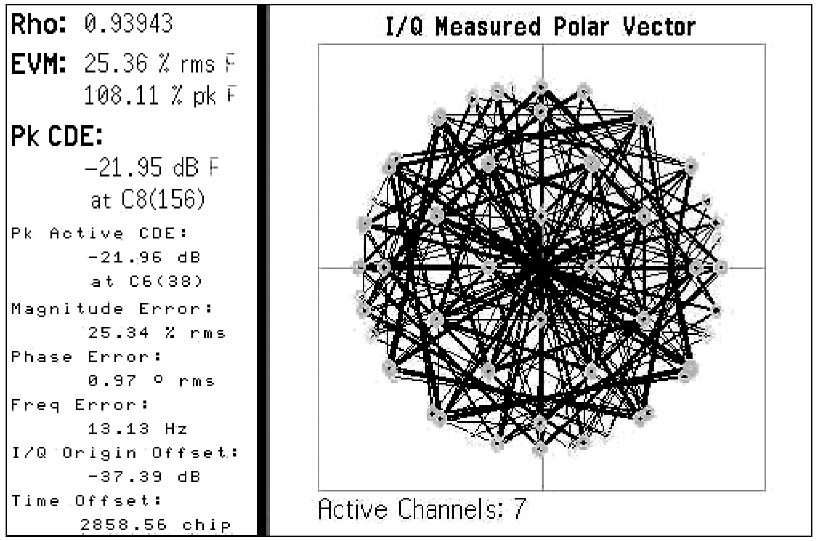

Figure 13. EVM for $C_6(32)$, $C_6(33)$, $C_6(34)$, $C_6(35)$, $C_6(36)$, $C_6(37)$ and $C_6(38)$ with 50% clipping

Figure 13 shows the composite EVM and peak code domain error (PCDE) of the signal with the adjacent codes. Despite there being only one code spur visible at $C_6(39)$ the signal is severely distorted with an EVM of 25.36% against a system specification of 17.5%, and the PCDE is –21.95 dB compared to a requirement of less than –33 dB. Looking at the measurements on the alternative codes shows a very different result.

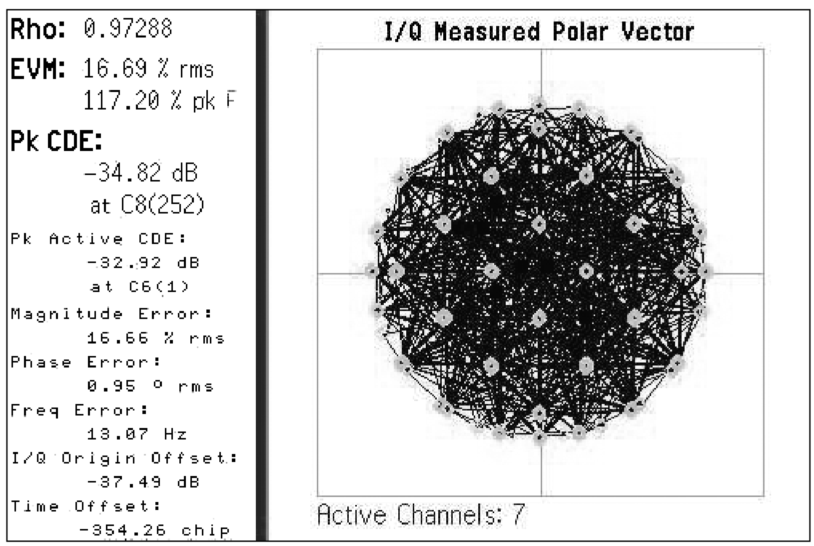

Figure 14. EVM for $C_6(0)$, $C_6(1)$, $C_6(2)$, $C_6(4)$, $C_6(8)$, $C_6(16)$ and $C_6(32)$ with 50% clipping

Figure 14 shows a much better situation for the signal with the non-adjacent codes. The EVM at 16.69% and the PCDE at –34.82 dB are both inside the 3GPP W-CDMA system's specifications. This composite analysis of the quality of the two signals shows some degradation of EVM for the adjacent channel allocation. This is mainly explained by a secondary effect due to the adjacent channel signal having a higher peak to average ratio compared with the alternative code allocation as shown in the CCDF plot of Figure 15.

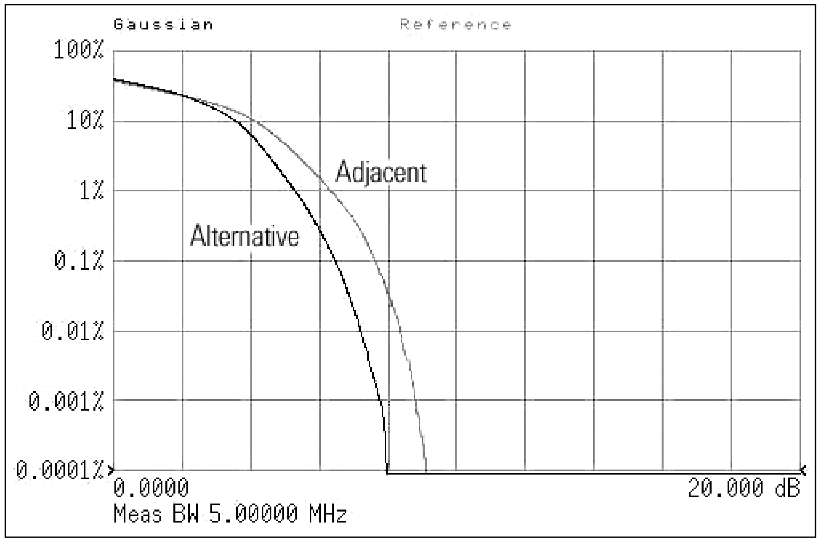

Figure 15. CCDF showing 1 dB higher PAR for the adjacent code allocation

Figure 15 shows that the adjacent code allocation has about a 1 dB worse PAR than the alternative code allocation so the effect of the 50% clipping is more severe making the composite EVM worse.

But the real difference between the two signals and hence the advantage of the code spur prediction algorithm can only be seen when considering the EVM of the individual code channels at the symbol level. A summary of the average symbol EVM on each code for the two signals is shown below:

	Composite EVM %	PCDE	Code number	Symbol EVM %
Adjacent code allocation	25.36	-21.95	32	20.9
			33	20.2
			34	21.2
			35	20.6
			36	20.8
			37	20.6
			38	21.4
Alternative code allocation	16.69	-34.82	0	5.5
			1	6.1
			2	5.2
			4	5.7
			8	5.5
			16	5.4
			32	5.6

Table 3. Comparison of modulation quality

The reason the worse looking signal in the code domain is actually the better signal for communication is due to the position of the code spurs. In the adjacent channel case, all of the code spurs can be shown to fall on $C_6(32)$, $C_6(33)$, $C_6(34)$, $C_6(35)$, $C_6(36)$, $C_6(37)$, $C_6(38)$ and $C_6(39)$. But since seven of these codes are already active, the code spurs cannot be seen in the code domain display. It is only when the modulation quality of the active codes is measured that the consequence of the code spurs projecting on active codes can be seen.

In the case of the alternative code channel assignment, it can be predicted using the general rule that all 57 C_6 code spurs are seen not to project onto ANY of the active codes. In fact the code spurs exactly occupy all the non-active code space. The effect is to better maintain the modulation quality of the active codes such that the EVM of the active codes is an average of 5.5% compared to over 20% for the adjacent allocation.

A further application of the code spur prediction technique is also evident from this example since although the composite EVM of the alternative code allocation is just inside the system spec of 17.5%, the quality of the active channels on which demodulation of information data must be performed, is significantly better at around 5.5%. This would indicate that a higher level of clipping could be tolerated (i.e. less amplifier headroom required) without the active codes exceeding 17.5% symbol EVM.

Provided the position of code spurs is predictable, the system can likely be operated successfully at composite EVM and PCDE figures significantly worse than the system specification. Put another way, when the majority of the error energy due to clipping can be made to project onto unused codes, the fundamental orthogonality provided by the system between different codes in the same cell will protect the system from itself.

In summary, by evaluating the signal using symbol EVM, the composite EVM and PCDE requirements can effectively be ignored, allowing the system to be operated in conditions previously considered to be unacceptable due to the unpredictability of the code spurs.

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