Obviously, the choice of the most appropriate configuration is fully dependent on the specific application of the antenna, and the cross-polar requirements the design has to meet.

4. CONCLUSIONS

This paper has presented an analysis of the sequential rotation technique applied to linear arrays. An array of eight elements has been used as an example to illustrate how different distributions of the sequential phase arrangement affect the cross-polar cancellation and the angular location of the cross-polar lobes. It has been shown that these cross-polar lobes can be reduced using these alternative arrangements, maintaining the cross-polar cancellation performances in the main beam.

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COCHANNEL INTERFERENCE CANCELLATION VIA EMPLOYING A REFERENCE CORRELATOR FOR SYNCHRONOUS OPTICAL CDMA SYSTEMS

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ABSTRACT: Interference cancellation using a reference correlator for synchronous optical CDMA systems is investigated. We employ a padded modified prime sequence to achieve a “unique” cross-correlation value of “1” among all signature sequences. This scheme requires only one reference correlator to effectively suppress the interfering signals. © 2000 John Wiley & Sons, Inc. *Microwave Opt Technol Lett* 25: 390–392, 2000.

Key words: interference cancellation; optical CDMA systems; optical communications

1. INTRODUCTION

It has been discussed that synchronous optical CDMA systems can provide a greater number of simultaneous users than asynchronous systems [1]. However, multiple-access interference can cause a degradation of system performance. Conventionally, such interference-limited systems cannot eff-

ectively alleviate the adverse impact of multiple-access interference via increasing optical power.

Using an interference canceller is an effective method to eliminate the error floor [2, 5]. In [2], a cancellation scheme with PPM signaling is presented; nevertheless, system complexity, power splitting loss, and a longer signature sequence (because of PPM signaling) are the major costs of improving system performance.

In [5], a parallel cancellation scheme utilizing a reference correlator is proposed to suppress the multiple-access interference. However, such a scheme wastes some correlators; thus, it will reduce the cardinality of the spreading code. In this letter, we use the padding method to make the entire spreading sequence family have a unique cross-correlation value of “1”; therefore such a scheme requires only one reference correlator.

2. SYSTEM DESCRIPTION

A prime sequence [1], whose length is p^2 , can be constructed from the modulo- p multiplication of the Galois field $GF(p) = \{0, 1, \dots, p-1\}$, where p is a prime number. To improve the characteristics of cross correlation of the prime code, padding $(p-1)$ zeros in each subblock of the codeword has been discussed [4].

Prime sequences with time-shifted versions (i.e., a modified prime code) can be applied to synchronous systems [1], which can provide more simultaneous active users. The modified prime code has p groups, and each has p mutually orthogonal code sequences. Each code sequence has p^2 chips (i.e., code length $= p^2$) with weight p . Sequences between any different groups have a unique cross-correlation value of “1.”

We pad the same subsequence of length p in each group of the modified prime sequence. Table 1 illustrates the padded modified prime sequences for $p = 5$. This padded spreading code has the same cardinality as the original one, but the code weight and spreading length become $w = (p+1)$ and $F = p^2 + p$, respectively.

The interference cancellation scheme using a reference correlator is shown in Figure 1. The reference correlator is a decoder chosen from the spreading code family. Any receiver uses the same reference correlator; hence, the full load subscriber is $p^2 - 1$. As the cross-correlation value between any two signature sequences is “1,” for N simultaneous active users, the cancellation output Z is

$$Z = \frac{1}{p+1} \left\{ \left[S_i \cdot (p+1) + \sum_{j=1; j \neq i}^N S_j \right] - \left[S_i + \sum_{j=1; j \neq i}^N S_j \right] \right\} \\ = \frac{S_i \cdot p}{p+1} \quad (1)$$

where S_i , S_j represent the desired signal and interfering signal, respectively, and the scaling factor $1/(p+1)$ is the power splitting loss due to the optical tapped delay-line decoder.

3. PERFORMANCE EVALUATION

In this section, we analyze the side effects of thermal noise, APD noise, and interference. The APD output can be modeled approximately as a Gaussian distribution [3]. The received optical signal intensity over a chip interval T_c is modeled as a Poisson point process. The average number of

TABLE 1 Padded Modified Prime Sequence Code for $p = 5$

Group	Code Sequences					
0	$C_{0,0} = 10000$	10000	10000	10000	10000	10000
	$C_{0,1} = 00001$	00001	00001	00001	00001	10000
	$C_{0,2} = 00010$	00010	00010	00010	00010	10000
	$C_{0,3} = 00100$	00100	00100	00100	00100	10000
	$C_{0,4} = 01000$	01000	01000	01000	01000	10000
1	$C_{1,0} = 10000$	01000	00100	00010	00001	01000
	$C_{1,1} = 01000$	00100	00010	00001	10000	01000
	$C_{1,2} = 00100$	00010	00001	10000	01000	01000
	$C_{1,3} = 00010$	00001	10000	01000	00100	01000
	$C_{1,4} = 00001$	10000	01000	00100	00010	01000
2	$C_{2,0} = 10000$	00100	00001	01000	00010	00100
	$C_{2,1} = 00100$	00001	01000	00010	10000	00100
	$C_{2,2} = 00001$	01000	00010	10000	00100	00100
	$C_{2,3} = 01000$	00010	10000	00100	00001	00100
	$C_{2,4} = 00010$	10000	00100	00001	01000	00100
3	$C_{3,0} = 10000$	00010	01000	00001	00100	00010
	$C_{3,1} = 00010$	01000	00001	00100	10000	00010
	$C_{3,2} = 01000$	00001	00100	10000	00010	00010
	$C_{3,3} = 00001$	00100	10000	00010	01000	00010
	$C_{3,4} = 00100$	10000	00010	01000	00001	00010
4	$C_{4,0} = 10000$	00001	00010	00100	01000	00001
	$C_{4,1} = 00001$	00010	00100	01000	10000	00001
	$C_{4,2} = 00010$	00100	01000	10000	00001	00001
	$C_{4,3} = 00100$	01000	10000	00001	00010	00001
	$C_{4,4} = 01000$	10000	00001	00010	00100	00001

↑
padded subsequence

Figure 1 Receiver using parallel cancellation scheme with reference correlator

absorbed photons is $\lambda_s T_c$, where λ_s is the arrival rate of incident photons due to chip “1” transmission, which can be represented as $\lambda_s = \eta P_w / hf$. Here, P_w is the optical power incident upon APD, η is the APD quantum efficiency, h is Planck’s constant ($6.624 \times 10^{-34} \text{ W} \cdot \text{s}^2$), and f is the optical carrier frequency.

We use two Gaussian random variables X and Y (they are independent because photons are incident upon the APD independently) to represent APD outputs for the upper arm and lower arm, respectively, and their mean and variance are given as

$$\mu_x = GT_c[P_{wx} \cdot \lambda_s + I_b/e] + T_c \cdot I_s/e \quad (2)$$

$$\sigma_x^2 = G^2 F_e T_c [P_{wx} \cdot \lambda_s + I_b/e] + T_c \cdot I_s/e + \sigma_{th}^2 \quad (3)$$

$$\mu_y = GT_c[P_{wy} \cdot \lambda_s + I_b/e] + T_c \cdot I_s/e \quad (4)$$

$$\sigma_y^2 = G^2 F_e T_c [P_{wy} \cdot \lambda_s + I_b/e] + T_c \cdot I_s/e + \sigma_{th}^2 \quad (5)$$

where G is the average APD gain, I_s is the APD surface leakage current, I_b is the APD bulk leakage current, e is the electron charge, P_{wx} and P_{wy} represent the optical power incident upon the APD for upper and lower arms, respectively, and F_e is the excess noise factor given by

$$F_e = K_{eff} G + (2 - 1/G)(1 - K_{eff}) \quad (6)$$

where K_{eff} is the APD effective ionization ratio, and σ_{th}^2 is the variance of thermal noise given by

$$\sigma_{th}^2 = 2K_B T_r T_c / (e^2 R_L) \quad (7)$$

where T_r is the receiver noise temperature, K_B is Boltzmann's constant, and R_L is the receiver load resistance.

After cancellation, the decision variable $Z = X - Y$ is also Gaussian (since X and Y are independent), with mean and variance given as

$$\mu_z = \mu_x - \mu_y \quad (8)$$

$$\sigma_z^2 = \sigma_x^2 + \sigma_y^2. \quad (9)$$

Assuming that transmitted data are equally likely, the conditional probability density function of a k user transmitting bit "0" or "1" is $\Pr[k/N - 1] = \binom{N-1}{k} \cdot 2^{-(N-1)}$.

Therefore, the bit-error probability can be represented as

$$\begin{aligned} P_e &= \frac{1}{2} [\Pr(Z > \theta/S_i = 0, N-1) \\ &\quad + \Pr(Z \leq \theta/S_i = 1, N-1)] \\ &= \frac{1}{2} \sum_{k=0}^{N-1} \{\Pr(Z > \theta/S_i = 0, k, N-1) \\ &\quad + \Pr(Z \leq \theta/S_i = 1, k, N-1) \cdot \Pr[k/N - 1]\} \quad (10) \end{aligned}$$

where θ is the OOK decision threshold, and we set the threshold to be half of the mean of the decision variable Z .

4. NUMERICAL RESULT AND DISCUSSION

The link parameters are the same as those in [3]. Figure 2 illustrates the bit-error probability versus received optical power [power of $r(t)$] in the case of full load subscribers ($p^2 - 1$) for $p = 5, 7$, and 11 , respectively. It can be seen

that this scheme can completely suppress the multiple-access interference, hence eliminating the error floor. To avoid reducing the cardinality of the spreading code, using a padded modified prime sequence is a superior approach. The aggregate capacity is proportional to $(p^2 - 1)$. To achieve a larger aggregate capacity, we should take the costs of increasing optical power and using a larger prime number p .

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Figure 2 Bit-error probability versus received optical power for $p = 5, 7, 11$ in the case of a full load