parameters can easily be found using frequency dependent functions that contain parameters dependent on strip width only. These strip-width dependent parameters can be developed in polynomial functions where the strip width varies in a chosen interval. Only slight correction is needed to achieve high accuracy.

S. TEDJINI 29th March 1989
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BANDWIDTH-POWER PERFORMANCE ANALYSIS OF MULTI-*h* PHASE-CODED MODULATIONS WITH ASYMMETRIC MODULATION INDICES

Indexing terms: Modulation, Telecommunications, Signal processing, Errors

Multi-*h* phase-coded modulation (MHPM) with asymmetric modulation indices has recently been proposed and found to be a bandwidth-efficient modulation scheme with attractive improvements in error probability performance. This letter analyses in detail the bandwidth-power performance of such new schemes using the minimum Euclidean distances and the averaged modulation index for three phase pulse functions.

Introduction: Continuous phase modulation (CPM) schemes provide a means of achieving narrower transmission bandwidth than phase shift-keying (PSK) or similar formats. Multi-*h* phase-coded modulation[1] (MHPM) schemes form a special class of CPM which offers ways of coding without explicit redundancy. In conventional MHPM schemes, the modulation indices for the bipolar data +1 and −1 are always identical. In a recent paper,[2] it was proposed that the modulation indices for the bipolar data +1 and −1 do not have to be equal and it was found that for linear phase pulse functions such asymmetric modulation indices can provide further improvements in the error probability performance over conventional MHPM with essentially no bandwidth expansion. In this letter, comparisons of the error probability performance as well as estimated bandwidth are made for such asymmetric MHPM schemes with linear phase (LP), raised-cosine (RC) and half-cycle sinusoid (HCS) phase pulse functions. Preliminary results show that a full range of bandwidth-power efficiency trade-offs are available for designers in system optimisation.

System description: The information-carrying phase function of a binary MHPM signal is

$$\phi(t, \alpha) = 2\pi \sum_{i=-\infty}^{\infty} a_i h_i q[t - (i-1)T] \qquad -\infty \le t \le \infty \quad (1)$$

where $\alpha = \{\ldots, a_{-2}, a_{-1}, a_0, a_1, a_2, \ldots\}$ is the transmitted data sequence and $q(t)$ is a phase pulse function. The modulation index used in the ith symbol time interval is h_i. In practice, the modulation indices are multiples of $1/q$, where q is an integer. These modulation indices are used cyclically with period K. In this letter only full response schemes are considered, and the phase pulse functions used are LP, RC and HCS functions:

$$q(t) = \begin{cases} 0 & t \le 0;\ \text{LP, RC, HCS} \\ t/2T & 0 \le t \le T;\ \text{LP} \\ [1 - \cos(\pi t/T)]/4 & 0 \le t \le T;\ \text{HCS} \\ [(t/T) - \sin(2\pi t/T)/2\pi]/2 & 0 \le t \le T;\ \text{RC} \\ 1/2 & t \ge T;\ \text{LP, RC, HCS} \end{cases} \quad (2)$$

With proper choice of the modulation indices, no pair of distinct phase paths will merge before v intervals, and v is the constraint length of the phase code. In general, MHPM schemes cannot have constraint length longer than $K + 1$.[1]

In this letter, the recently proposed concept of asymmetric modulation indices for MHPM is analysed, i.e., the modulation indices h_{+i} for the ith data being +1 and h_{-i} for the ith data being −1 are not necessarily equal. Since $q(h_{+i} + h_{-i})$ does not have to be an even number, this new asymmetric MHPM concept can provide the designer better flexibilities in choosing indices for system optimisation.

Bandwidth-power performance analysis using minimum Euclidean distances and averaged modulation indices: In this letter, the minimum Euclidean distances will be used as an indicator for the power efficiency of MHPM schemes. On the other hand, the averaged modulation index $\bar{h}$ approach[3] will be used to estimate the bandwidth of MHPM signal, where

$$\bar{h} = \frac{1}{2K} \sum_{i=1}^{K} (h_{+i} + h_{-i}) \quad (3)$$

Since the bandwidth of a constant-h signal is proportional to its modulation index h, $\bar{h}$ can be taken as an estimate for the bandwidth of an asymmetric MHPM signal. In this letter, $\bar{h}$s are rounded to 0·01 for comparison.

The minimum Euclidean distances for the best combinations of modulation indices with $K = 2$, 3, and 4 have been calculated for full response asymmetric MHPM schemes with different phase pulse functions. The maximum value of all the minimum Euclidean distances with the same $\bar{h}$ but for all possible values of q being considered is taken as a measure of the power efficiency. This minimum Euclidean distance against the average of modulation indices $\bar{h}$ is plotted in Figs. 1–3 for $K = 2$, 3 and 4, respectively.

From Fig. 1, we can find that for $2-h$ schemes the minimum distances of the RC phase pulse function are larger than those of LP and HCS functions when $\bar{h}$ is smaller than 0·6. Note that the minimum distances form a deep notch with the minimum value less than 4·0 when $\bar{h} = 0{\cdot}5$ for all the three phase functions considered. This is because for $2-h$ schemes the modulation index sets with $\bar{h} = 0{\cdot}5$ are weak index sets, i.e. the constraint length will be only 2, instead of $K + 1 = 3$ for these cases. We can also see that the highest power efficiency will be achieved at a minimum distance of 7·81 with $\bar{h} = 0{\cdot}52$

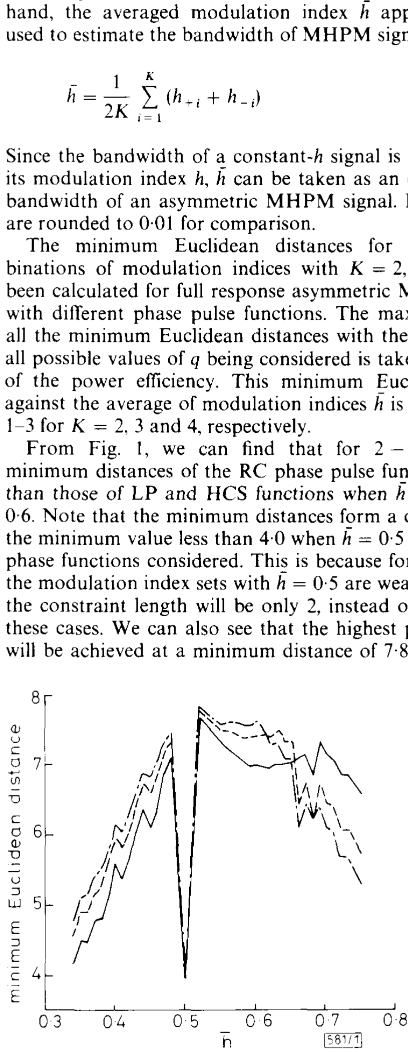

Fig. 1 *Minimum Euclidean distances against averaged modulation index $\bar{h}$ for asymmetric MHPM with K = 2*

—— LP —·—· RC ---- HCS

when the RC phase pulse function is used, which seems to be a very attractive design.

In Fig. 2, it can be seen that for $3 - h$ schemes although the RC phase pulse function seems to be the most power efficient when $\bar{h}$ is less than 0·6, the LP phase pulse function will be the best choice when $\bar{h}$ is allowed to exceed 0·65. In other words, LP can be used to achieve better error probability performance but at the price of a slight bandwidth expansion. It can also be seen that for $3 - h$ schemes the modulation index sets with $\bar{h} = 0{\cdot}67$ will limit the constraint length to 3, and this is why the distances form another deep notch there.

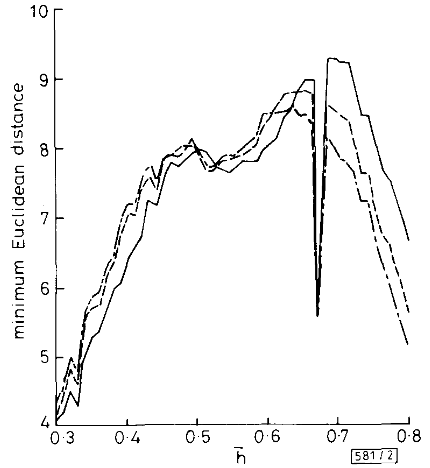

Fig. 2 *Minimum Euclidean distances against averaged modulation index $\bar{h}$ for asymmetric MHPM with K = 3*

—— LP —·—· RC ---- HCS

For $4 - h$ schemes in Fig. 3, it is clear that the minimum Euclidean distances for LP have two peaks of 10·01 and 10·39 for $\bar{h} = 0{\cdot}53$ and $\bar{h} = 0{\cdot}66$, respectively. However, because the coding gain difference is only 0·16 dB between these two peaks but the bandwidth for $\bar{h} = 0{\cdot}53$ is apparently much smaller, the LP function with modulation index set with $\bar{h} = 0{\cdot}53$ seems to be a very attractive choice when considering both the bandwidth and power efficiencies.

From Figs. 1–3 it is quite clear that the RC phase pulse function is the best choice when $\bar{h}$ is required to be less than 0·5. Furthermore, a comparison of Figs. 2 and 3 indicates that the distance of $4 - h$ schemes with $\bar{h} = 0{\cdot}53$ can be larger than that of $3 - h$ schemes with $\bar{h} = 0{\cdot}68$, which means that with $4 - h$ schemes better error probability performance can be achieved than with the best $3 - h$ schemes even with significantly less bandwidth, inevitably at the price of increased complexity. It is thus quite clear that there exist many asymmetric MHPM schemes which can be chosen in system design when the trade-offs among bandwidth and power efficiencies and system complexity are considered.

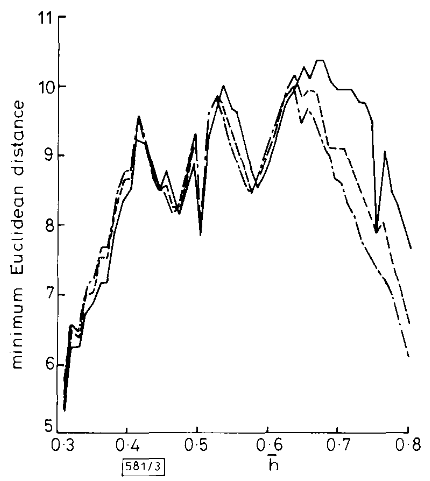

Fig. 3 *Minimum Euclidean distances against averaged modulation index $\bar{h}$ for asymmetric MHPM with K = 4*

—— LP —·—· RC ---- HCS

Conclusion: In this letter the minimum Euclidean distances of full response asymmetric MHPM schemes with LP, RC and HCS phase pulse functions have been calculated and discussed, and $\bar{h}$ is taken as a measure of bandwidth. It is shown that a full range of design trade-offs among bandwidth and power efficiencies and complexity are available for system optimisation when the new concept of asymmetric MHPM is considered.

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CAPACITY OF *T*-USER COLLABORATIVE CODING MULTIPLE-ACCESS SCHEME OPERATING OVER NOISY CHANNEL

Indexing terms: Data transmission, Telecommunications, Codes, Noise

The collaborative coding multiple-access (CCMA) technique potentially permits efficient simultaneous transmission by several users sharing a common channel, without subdivision in time or frequency. The capacity of a *T*-user binary adder multiple-access channel is calculated for additive white Gaussian noise (AWGN) conditions. The capacity in bits/channel use for different numbers of users is derived by simulation for the baseband antipodal and bandpass on-off keying systems with coherent and noncoherent combining. It is shown that in principle *T*-user CCMA permits higher transmission rates than time-division multiple-access (TDMA) employing the same signal alphabet.

Introduction: In Fig. 1, data from the source *i*, U_i, where $i = 1, 2, \ldots, T$, are encoded by encoder *i* according to a uniquely assigned code C_i. The resulting codeword vector X_i is then

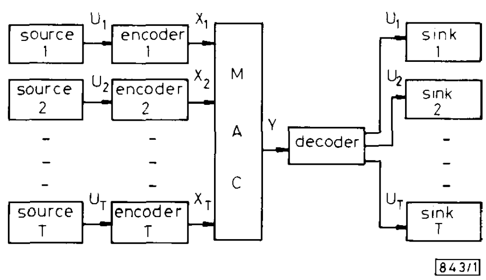

Fig. 1 *T-user multiple-access channel*