A PCM-PPK TELEMETRY SYSTEM

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ABSTRACT

PCM-PPK telemetry system is one of digitized PPM systems. The PCM-PPK Coverter, synchronous timing circuit and detection device are described. Besides, communication efficiency from viewpoint of information theory is calculated. We come to conclusion, minimum received energy required per bit of PPK system are lower than the PSK and FSK systems.

INTRODUCTION

Pulse position modulation possesses the following advantage: simple transmittors, large power margin, convenience for trasmitting brust information, etc., and has found certain application. For example, a PPM telemetering system with 2-KW power output has been used as the means for re-entry measurement in Sandia Laboratory, USA.[1]

However, general PPM system in essence are analog telemetering systems, in which two pulses (the marker pulse and the channel pulse) must be sent for transmitting each datum and the time interval between the pulses is continuously modulated by the measured voltage. For these systems it is difficult to transmit PCM data directly from digital transducers or storage and the measurement accuracies are low.

In the PCM-PPK (Pulse Code Xodulation-Pulse, Position Keying) system described in this paper, the position of a pulse to be sent is directly determined by the PCM data. Therefore, either in air or on the ground, interfacing with digital devices is very convenient. Besides, there is no need to send the marker pulses in such system and only one pulse is to be sent for each channel. For those channels where particularly high accuracies is demaded or the error-detecting capability is desired, two or more pulses can be arranged to be transmitted according to designer’s flexible considerations.

Let us first consider the case when only one pulse is sent (single pulse PPK). Assume M to be the word length of transmitted PCM data, q_0, q_1 , ... q_{M-1} . the status respectively. As shown in Fig. 1, before the arrival of the marker pulse the data are written in to register Q. At t=0, when the maker pulse arrives, the counter Q' is set to zero. Then the gate is started and the count pulses begin to enter the counter. At $t=k\Delta T$, the k-th pulse is entering the counter. At this moment the status of the counter Q' completely coincides with the status of the PCM data to be transmitted and the comparator gives a PPK pulse to key the transmitter to sent out a microwave pulse.

Obviously, the time position at which the PPK pulse appears is

$$t_k = k \Delta T \tag{1}$$

$$k = q_0 + 2q_1 + 4q_2 + \ldots + 2^{M-1} q_{M-1} \tag{2}$$

ΔT = quantizing time step

We confine the transmitter pulse width to be $\tau \leq \Delta T$. So PPK signals in essence constitute a 2^M -ary orthogonal series

$$\int a_j(t) \cdot a_k(t)\, dt = \begin{cases} 1 & \text{for } j=k \\ 0 & \text{for } j\neq k \end{cases} \tag{3}$$

As has been shown by the communication theory, orthogonal signals have the transmission potential very close to the Shannon's liMit.[2] In this paper a detection device for transforming the PPK signal back into the PCM data is proposed, the error probability in the case with noise is analysed and the energy necessary for transmitting each information bit is calculated.

DETECTION DEVICE

The basic task of the ground detection device is to transform the noisy detector output PPK singnals back to the PCM data (see fig. 2). The synchronous timing circuit provides two kind of timing pulse trains. One of them is the marker pulses (a), representing the starting points in succesive channels. The other is the counting pulses (b) whose period is equal to the quantizing step ΔT. When ever the marker pulse arrives, the gate is swithed on to allow the following counting pulses to enter the counter. The counting pulses also makes the sampling switch on for a short time to detemine whether the low-pass filther output uj exceeds the threshold level U_0 or not. If $U_k \geq U_0$ when $t\text{-}K\Delta T$, the gate will be switched off and no more counting pulses will enter the counter. In such way the counter will stop with binary status of k. Then the required PCM data can be obtained by serially or parallelly this status out. The key point in the design of PPK system is to strictly keep the on-board and the ground timing circuits in presise synchronization. For this purpose, all timing circuits are frequency stabilized by quartz and the timing circuits in the ground is continually "time checked" through the frame synchronization. To illustrate the work of timing circuit, we take the following example. Suppose a telemetering system has 64 main channels, sampling period T_i=9.6ms, quantizing step ΔT=1μs, word length of PCM data M=7, range of PPK pulse moving position t= 0 ~ 127μs. As shown f ig. 3, a temperature - controlled quartz crystal oscillator with for=20.00mc is used as the ground clock. It's frequency error $\Delta f/_f \leq 10^{-7}$. After dividing in frequency 20 times the counting pulse with intervals ΔT=1μs are obtained. Another frequency dividing by 150 times gives the marke pulses. Finally, through six cascades of binary deviders, the sequencing pulses which control the multiplexer are obtained.

The frame synchronization code consists of a series of pulses with specific intervals between them. The last on of those pulses occurs just at the position of the marker pulse belongine to first channel. Therefore, pulse from ground synchronization separator are coincides with first channel marker pulse. By resetting all cascades of deviders with this pulse, so-called "time check" can be performed, so that the synchronization between the starting points of the air and ground timing signals is guaranteed. The synchronism is keep by the guartz crystal oscillators until the next synchronization pulse is separated. The relative frequency difference between the on-board and ground crystal can be made very small by pairing method. And in quite a long period timing signals replicated on the ground can have the time error much smaller than the quantizing step ΔT. Thus, not only the marker pulses can be dispense with, but also the various correct timing pulses can be supplied on the ground even though due to the weakness of signal the frame synchronization interruption occurs. Therefore in such a synchronization system are note any troubles with the "pull-in time" as in phase - locked loops.

ERROR PROBABILITY

There are two kinds of possible errors in detection device of fig. 2: (1) one or more samples $u_j \geq 0$ before $t=t_j <$ tk, i.e. the noise is mistaken for signal. The probability of such errore is called false-alarm probability P_x ; (2) the sampled value at $t=t_k$, u_k Uo, i.e. the signal is mistaken fo noise. The probability of such errors is called miss probability P_x . Whichever of the kinds of errors happens will introduce a error in to the data tranmitted by the PPX system.

It is well known that the output voltage u of a linear detector is subordinated to the Reyleigh distribution when the signal is absent. Hence, the probability of encountering a false-alarm for each sampling of u_n is

$$= \int_0^\infty u/\sigma^2 \cdot e^{-u^2/2\sigma^2}\, du = e^{-x^2/2} \qquad (4)$$

where

σ^2 — mean square value of noise voltage

$X = U_0/\sigma$, relative threshold level

In order to avoid the first kind errors all k samplings must be without any flase-alarms. When the status of the transmitted data is k, i.e.

$$P_{I,K} = 1 - (1 - P_w)^K \tag{5}$$

Asume that the status of the measured data k is equally probable from 0 to (2^M-1) for the average value and substituting it, we obtain the average value of the false-alarm probability

$$P_I = \frac{2^M - 1}{2} e^{-X^2/2} \tag{6}$$

Now let us look at the miss probability. At t=tk, the object to be sampled is the mixture of signal and noise U_{S+N} subordinated to the Rice distribution. Therefore

$$\begin{aligned} P_{II} &= P(U_{s+N} < U_0) \\ &= \int_0^{U_0} \frac{u}{\sigma^2} I_0\left[\frac{Au}{\sigma^2}\right] e^{-\frac{u^2+A^2}{2\sigma^2}} du \end{aligned} \tag{7}$$

where

A --- peak voltage of IF signal

I_0 —Bessel fuction of zero order

In real PPK systems the signal to noise power ratio ($^S/_N$)

$$(^S/_N) = A^2/2\sigma^2 \tag{8}$$

always exceeds 10, under this codition it may be proved that formula (7) can be approximitted to

$$P_{II} = \frac{1}{2}\left[1 - \operatorname{erf}(Y/\sqrt{2})\right] \tag{9}$$

where

$$y = A/\sigma - X = \sqrt{2(S/N)} - X \tag{10}$$

If y > 3, P_x can be further simplified to

$$P_{II} = \frac{1}{\sqrt{2\pi}\, y} e^{-y^2/2} \tag{11}$$

In fig. 4 the relation between P_x and y has be drawn. The dashed curve is related to the approximate formula (11). Obvimisly, when $Y \geq 3$, the error in approximation is neglectable.

As both kinds we have ust discussed are little probability events, we can straitway add (6) and (11) together to obtain the error probability of PCM data transmission in PPK systems P_{ew}

$$P_{ew} = P_I + P_{II} \tag{12}$$

Commonly, in binary system the bit error probability $_{\mathrm{Peb}}$ is used to valuate the quality of transmission, while what the formula (12) gives is the data “word” error probability; and this causes inconvenience in comparison. Considering that in binary systems the data “word” can have no errors only provided all of the M bit are free of any errors, we conclude that the equivalent bit error probability for PPK systems P_{eb} must satisfy following equality

$$(1-P_{eb})^M = 1-P_{ew} \tag{13}$$

If P_{ew} is small enough, then

$$P_{eb} = 1 - \sqrt[M]{1-P_{ew}} \simeq P_{ew}/M \tag{14}$$

Substitute (6) (11) (12) into (14) and obtain

$$\begin{aligned} P_{eb} &= P_I/M + P_{II}/M \\ &= \frac{2^M-1}{2M} e^{-x^2/2} + \frac{1}{\sqrt{2\pi}\, My} e^{-y^2/2} \end{aligned} \tag{15}$$

In the following, we are going to discuss how to determine the requirement in signal to noise ratio by the given tolerable error probability P_{eb}. We equally assign the P_{eb} to the term of the right side in the above formula

$$P_{eb}/2 = P_I/M = P_{II}/M \tag{16}$$

Then substitute then into (6) and obtain

$$X = \sqrt{-2 \ln \left[{}^{M P_{eb}}/_{2^M - 1} \right]} \qquad (17)$$

By the same reason, we can find aut the value for y directly from fig.4 by the value

$$P_{II} = \frac{M}{2} P_{eb} \qquad (18)$$

According to (10), we can write the relation between x,y and the signal to noise ratio as

$$(S/N) = (x+y)^2/2 \qquad (19)$$

COMMUNICATION EFFICIENCY

As early as 20 years ago, R.S. Sander already proposed to use a coefficient to evaluate the quality of various telemetering systems [3]

$$\beta = E_b/N_o \qquad (20)$$

where, Eb --- minimum received energy required per bit under the condition of given tolerable error probability
N_o --- noise spectral power density

Obviously, small β mean that the communication efficiency is high and the system is advanced.

In single pulse PPK systems only one pulse is sent in each channel slot T, and the information included consists of M bits. So the information rate is equal to

$$H = M/T \qquad (21)$$

The energy spent on every bit

$$E_b = E_w/M = P_s \tau/M \qquad (22)$$

where, E_w --- energy in the recieved signal pulse
P_s --- pulse power of recieved signal
τ --- pulse width

Because the noise density N_o is the noise power in the unit bandwidth, so

$$N_o = {}^{P_N}\!/_{\Delta f} \tag{23}$$

where, P_N --- noise power
Δf --- bandwidth

Substitute (22 (23) into (20) and obtain

$$\beta = ({}^{P_s}\!/_{P_N})\ \Delta f \cdot \tau / M \tag{24}$$

the ratio $({}^{P_s}\!/_{P_N})$ in the above formula really is the signal to noise ratio $({}^{S}\!/_{N})$

expressed in (19), thus

$$\beta = [{}^{(X+Y)^2}\!/_{2M}]\ \Delta f \cdot \tau \tag{25}$$

As mentioned in the above section, X and Y are determined by error probability Peb. In the following table the values β of various PPK telemetering system with $P_{eb} = 10^{-3} \sim 10^{-6}$ are given. In the calculation assumed to be $\Delta f\tau=1$ with the consideration that the matched filters had been applied in recievers.

Table 1. Values β for some digital telemetering systems

system Peb β	PCM——PPK				PCM—FSK	PCM—PSK
	M=8 (256-ary)	M=7 (128-ary)	M=6 (64-ary)	M=5 (32-ary)		
10^{-3}	3.25	3.66	4.17	6.07	12.43	4.81
10^{-4}	4.36	4.95	5.85	8.28	17.03	7.30
10^{-5}	5.55	6.15	7.19	10.55	21.64	9.84
10^{-6}	6.70	7.56	8.70	12.82	26.24	11.20

In the above table the values β for the FSK and PSK system also have been tabulated[4]. When M = 8, Peb = 10^{-6} , the values β of PPK are lower by 40% than that of PSK. If the microwave transmitter is equipped with high efficient TRAPATT diods[4] the effects of saving the on-board energy in PPK system will be even more remarkable.

DOUBLE PULSE PPK SYSTEMS

While designing telemetering systems, one often faces with the cases when the most of the parameters are required with not very high accuracies, but some of objects to be measured are required with particularly high accuracies. In PPK systems there is a method to meet the requirements of these channels without improving the whole system accuracy requirement, i.e. the method of sending one pulse more.

For example, in a PPK system with word length M=7 bits for transmission of a datum with 11 bits accuracy (q_0 , q_1 , q_2 ..... q_{10}), we disjoint it into two parts: the group consisting of q_o , q_1 ,.....q_6 (altogether 7 bits) is called light-weighed datum k_1 ; the group cons q_7 , ...q_{10} (altogether 4 bits) is call havy-weighed datum k_2 :

$$k_1 = q_0 + 2q_1 + \ldots\ldots\ldots +64\, q_6 \tag{26}$$

$$k_2 = q_7 + 2q_8 \ldots\ldots\ldots\ldots +8\, q_{10} \tag{27}$$

$$k_3 = k_1 + 128k_2 \tag{28}$$

As shown in fig. 5, the transmitter sends pulses I and II separately at $t=k_1\,\Delta T$ and $t= (k_1 + k_2)\,\Delta T$. On the ground there are two counters in the detection device. The gate of the first counter starts at the marker pulse and stop the counting by the pulse I, then this counter is stopped with the status k_1. The second counter sterts at I and stops at II, then remains in the status k_2 . The results of these two counters read out serially form the 11 bit word length PCM data to be sent.

Provided that the time slot T each channel occupies and the quantizing step ΔT are keep constant, there exist various methods to increase the word length by sending extra pulses. The method described above is just the simplest one. For example, one can further divide 128 ΔT into two halves, each transmitted pulse representing 6 bits, and two pulses representing 12 bits. Further more, it is possible to transmit a 16 bit PCM datum by sending three pulses in $(128+16)\Delta T$. Apparently, it is also possible to form signals with error-detecting capability, utilizing the redundance provided by multi-pulse PPK links.

In summary, the design of PPK systems will be diversified and flexible.

CONCLUSIONS

PCM-PPK telemetering system is one of digitized PPM systems. From the standpoint of communication theory it has low values β and very high communication efficiency. From the engineering point of view it is very easy to interface with digital transducers and storages. Besides, the equipment is simple and the design is flexible. The main shortcoming of PPK systems consists in the need occupying larger bandwidths.

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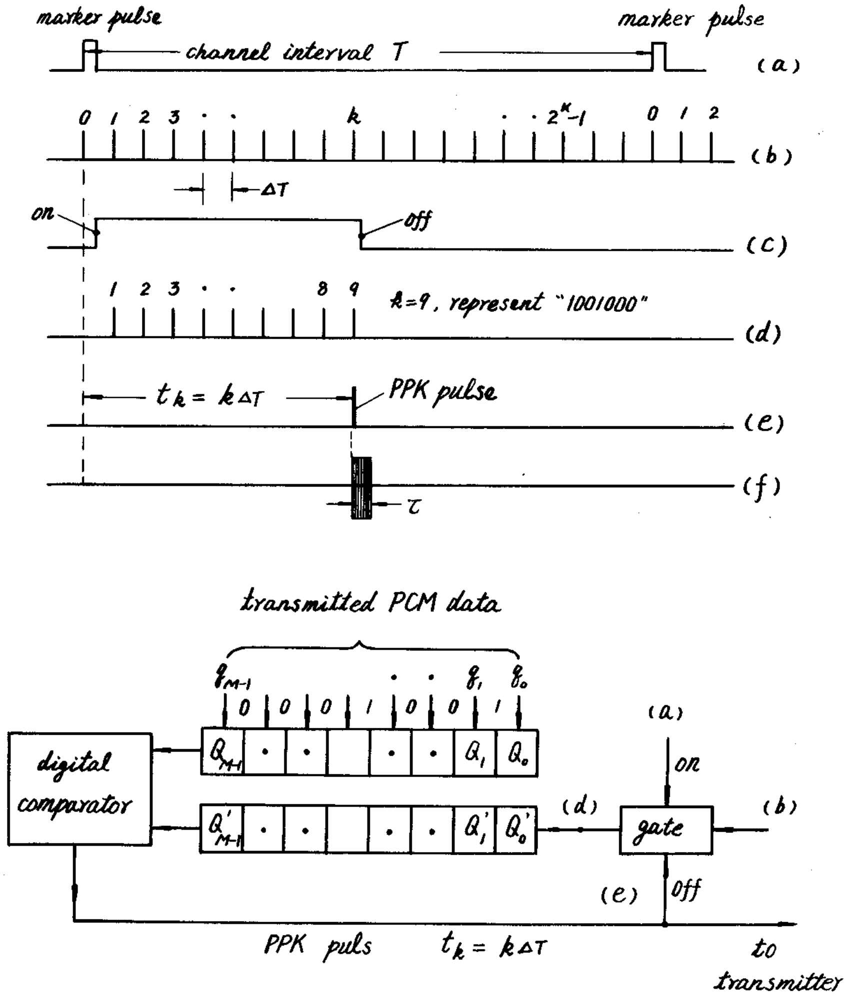

Fig. 1 The formation of PPK pulse

(a) marker pulse (b) count pulses (c) gate pulse
(d) the pulse which entering the counter (e) PPK pulse
(f) sending pulse

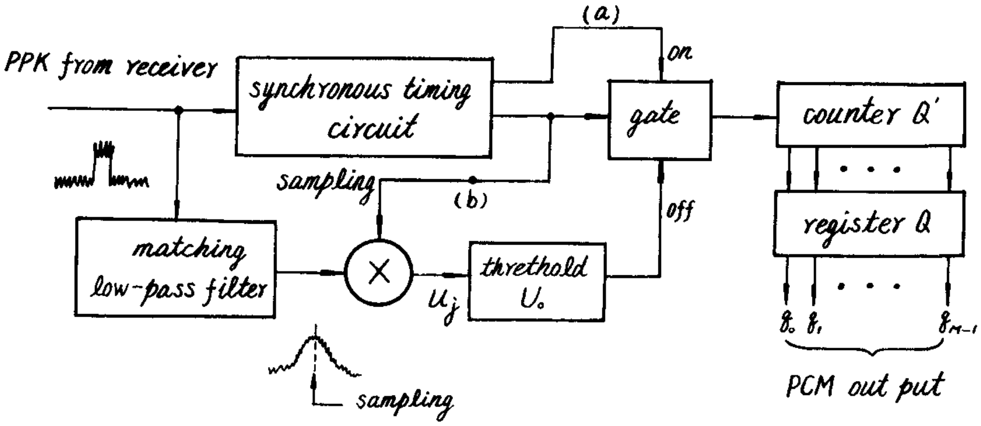

Fig.2 Detection device

(a) marker pulse (b) count pulse

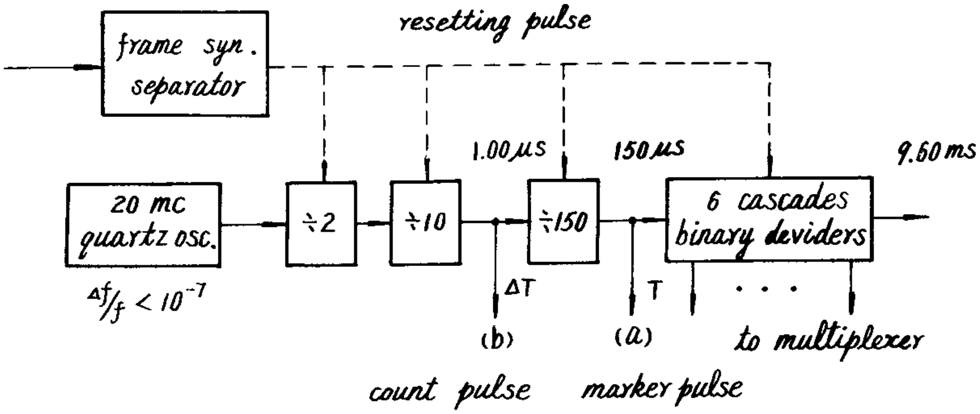

Fig.3 Synchronous timing circuit

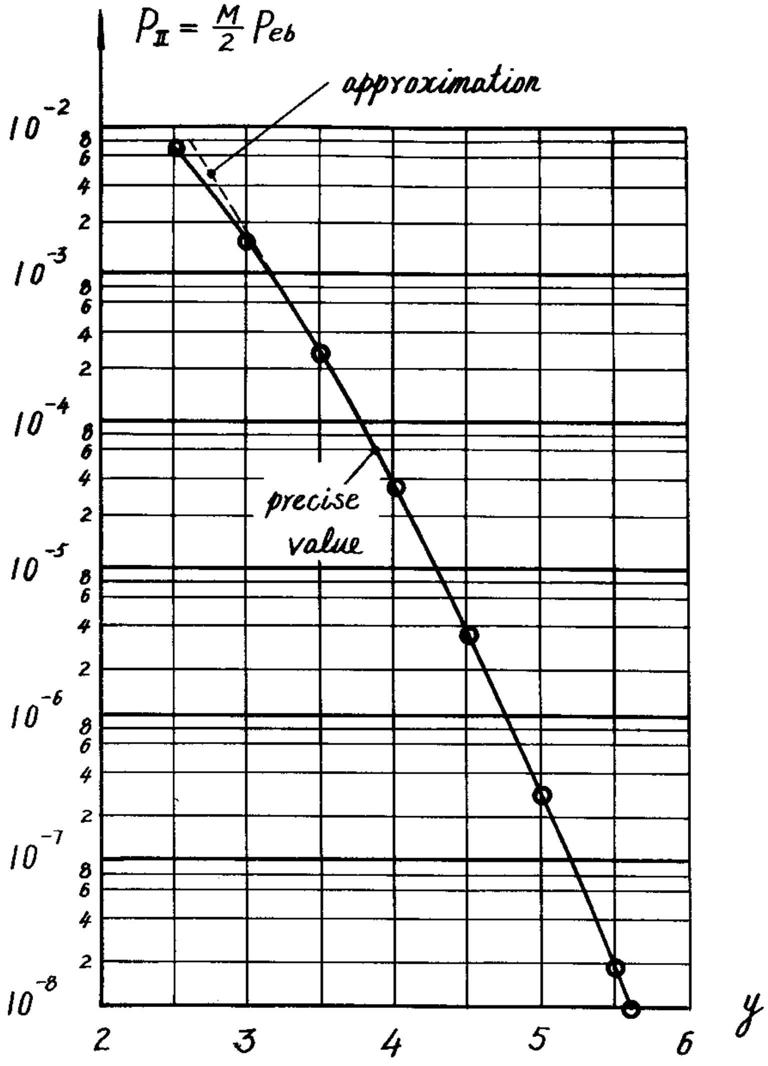

Fig. 4 Relation between P_{II} and y

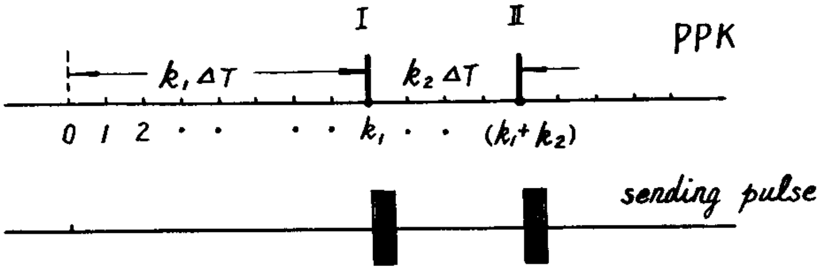

Fig. 5 Double pulse PPK