A TELEMETRY SYSTEM USING WALSH FUNCTIONS WITH IMPROVEMENTS IN ACCURACY

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ABSTRACT

A telemetry system based on Walsh functions has been developed since 1980.[1,2] The system is called sequency division multiplex, or SDM. A prototype of the system has been assembled and a lot of laboratory tests are also made in recent 2 or 3 years. Of course, in order to put this system into real use, some practical problems still remain to be solved.

In this paper the system design measures taken to improve the accuracy and some new synchronization methods we adopted are described. Since the choice of subcarriers is very important in designing a telemetry system, a table of recommended sequence values of the Walsh functions for subcarriers of the telemetry system is presented.

Since the vibration signal in high frequency band is produced in many cases, it is necessary to build a system which can measure this signal. The frequency response of each channel is 2000 Hz, it will have wide applications in industrial automation.

INTRODUCTION

According to the theory of orthogonal multiplexing, non-interference between channels can be guaranteed if the subcarrier waveforms are chosen from an orthogonal set [3] Orthogonal subcarrier waveforms can be selected in many ways, for example, block pulses are used as subcarriers in time division multiplex, sine and cosine waveforms are used as subcarriers in frequency division multiplex. There are some factors which should be considered, first in the choice of waveforms, they are: generation with ease, detectability, flexibility in engineering. The Walsh function waveforms are compatible with digital circuits. They can be easily generated. The experimental results show that Walsh waveforms are detectable and flexible. Synchronization is peculiar in SDM system, it can be realized not only by using phase locked loops and correlation functions of Walsh functions, but also by using conventional synchronization method.
SYSTEM DESIGN

A diagram of an improved Walsh telemetry system is shown in figure 1, which has 16 channels and each channel can be used for such variables as vibration, which change at a very high rate. In this system the Walsh function is only applied as subcarriers, the conventional sine wave is adopted as the main carrier. In other words, the Walsh subcarriers, modulated by signals to be measured, are added together to form the composite signal, then it must modulate a sine main carrier for radio transmission.

The main carrier is frequency-modulated, i.e. FM, on a standard VHF telemetry link, the peak frequency deviation is ± 150KHz. The sampling rate is 4.8KHz.

IMPROVED METHOD

Theoretically, Walsh waves, taking only two amplitude values +1 and -1, are jumping signals, which occupy unlimited bandwidth; the ideal sampling is the instantaneous one, which uses a impulse as sampling pulse; the reset time of an ideal integrator is zero.

However, practical Walsh subcarrier are the pulses with front and lagging edges: practical sampling will take certain time; and practical intergrator must have finite time to discharge. All of these will cause the orthogonal error of the Walsh subcarriers and reduce the accuracy of the system. In order to improve the performances of the system we introduce a new idea of orthogonal set, which is formed by “modified” Walsh functions and “original” Walsh functions. There are several ways of forming these functions, but from the view of the implementation by practical circuits, the simplest one is the “separated” Walsh functions, here we emphasize the orthogonality between the “saparated” Walsh function and “original” Walsh function. The 16 couples of these walsh function are shown in figure 2. SW(t) is a switch function needed to form the separated Walsh functions, and the switch is put on in the middle time $\frac{P_0}{2}$ of a clock pulse period $P_0$. It is obvious that

$$SW(t) = \frac{1}{2} \text{Wal}_0(t) - \frac{1}{2} \text{Wal}_{31}(t)$$

$$s\text{Wal}_i(t) = SW(t) \cdot \text{Wal}_i(t) \quad (i=0, 1, \ldots 15)$$

It is easily proved that

$$\frac{1}{T_0} \int_0^{T_0} s\text{Wal}_i(t) \text{Wal}_j(t) \, dt = \begin{cases} \frac{1}{2} & i = j \\ 0 & i \neq j \end{cases} \quad (i,j=0, 1, \ldots 15)$$
therefore, $sW_{al_i}$ and $Wal_i$ form a orthogonal set. In comparison with the original Walsh orthogonal set, the "separated" set is different only in the coefficient, it has reduced from 1 to 1/2, but it does not affect the performance of the system.

This new idea makes us easy to improve the construction and performance of the practical system. At the receiving terminal we have put a high-speed "separated" switch (see figure 1), which processes the composite signal of Walsh subcarriers, demodulated from the main carrier, and produces the "separated" Walsh functions. Then, upon the orthogonality of $sW_{al_i}$ and $Wal_i$, the signals to be measured of each channel are demodulated as before. In this way we have avoided the orthogonal errors usually caused by the practical Walsh wave’s edges.

Secondly, between two periods of "separated" Walsh functions there is a slot with duration $p_0/2$, which is sufficient for one to arrange the sampling pulse and the reset pulse of integrator and it does not destroy the orthogonality between $sW_{al_i}$ and $Wal_i$.

Simultaneously, in this slot a synchronous pulse can also be inserted, it provides another scheme of synchronization.

Finally, by means of "separated" processing, the edges of Walsh subcarriers can occupy the slot with duration $p_0/2$ it thus reduces the bandwidth of R F link of the system. Generally, the relationship between the rise time and the bandwidth is as follows

\[ f_v = 0.35 \sim 0.45/ t_r \]

where $t_r$ is rise time, $f_v$ is video bandwidth. According to our experience, it is taken as

\[ f_v = 4(0.35 \sim 0.45/ p_0/2) \]

and in our experiment $f_v = 240 \text{ KH}$.

**SYNCHRONIZATION METHOD**

There are following features for the Synchronization.

1) For SDM system, it is needed to maintain the synchronization both in period and in phase, but the both can be fulfilled together.
2) Synchronization is probably the most critical part of SDM. Once the synchronization could not be maintained, the whole system can not work.
3) Any deviation of synchronization will cause a serious error of the system. Thus a more accurate synchronization circuit must be applied.

4) The composite signal of Walsh subcarriers is a step-shaped signal, its amplitude distribution is random. It is neither sine-type nor pulse-type. This introduces the difficulty to detect the synchronous signal.

Therefore, detection of synchronous signal is the first step of the implementation of synchronization, and is also the most important step. By careful analysis we suggest two schemes for the detection of synchronous signal. One of them utilizes the cross-correlation function $F_{1,2}(t)$ between $Wal_1(t)$ and $Wal_2(t)$ as an error signal to control the phase locked loop. When the error approaches to zero, synchronism is established. $F_{1,2}(t)$ is a triangular waveform shown in figure 3.

The other one is just mentioned in the previous section. In the slot between two periods of the “separated” Walsh subcarrier a sync. pulse is placed. At the receiving terminal a special circuit may be used to detect the sync. pulse whenever it occurs, then a sync. signal forms, which will trigger the local clock generator and in such way a synchronization between both transmitter and receiver ends is kept.

A practical sync. pulse and its detecting circuit is shown in figure 4,5. This is an open loop system without any feedback.

Upon this basis, we can use also the error between the sync. pulse and local clock pulse to control the PLL to fulfill synchronization, this is called closed loop system, which is effective to improve the noise immunity. The diagram upon this principle is shown in figure 6.

THE CHOICE OF SUBCARRIERS

The principles for the selection of Walsh subcarriers was discussed in 1981. It will be summarized here only briefly.

a) Odd normalized sequences should be avoided, at most not more than one odd normalized sequence could be used.

b) Even normalized sequences with values $2^{P_i}$ should be preferred over any other even normalized sequences. $P_i=2$, 3, 4, ... .

c) One of same sequency, say sal(i, $\theta$), is first used, then the other of different sequency, say sal(j, $\theta$), may be used. When proper sequency is used up, another of same sequency, say cal(i, $\theta$), may be used.
The selection of subcarriers according to these rules is shown in Table 1 for 2-17 channels or subcarriers out of a total of 32 available subcarriers.

**Table 1 Recommended Selection of Subcarriers**

<table>
<thead>
<tr>
<th>required number</th>
<th>Number of Walsh functions</th>
<th>Channels</th>
<th>Recommended order number of Walsh functions</th>
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<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>3, 1,</td>
<td></td>
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<tr>
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<td></td>
</tr>
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</tr>
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<td></td>
<td>17</td>
<td>31, 28, 27, 24, 23, 20, 19, 16, 15, 12, 11, 8, 7, 4, 3, 2, 1,</td>
<td></td>
</tr>
</tbody>
</table>

**TEST RESULTS**

Each channel may be used for vibration signal, which changes at a very high rate. The number of channels in this system is 16. Total capacity of the system is 32KH\text{z}. Sampling rate at 4.8KH\text{z} is used. The experimental model may be arranged in different ways.

<table>
<thead>
<tr>
<th>Number of Channels</th>
<th>Sampling Rate</th>
<th>Maximum Response of a channel</th>
<th>Total Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2400/sec</td>
<td>1000 H\text{z}</td>
<td>8000 H\text{z}</td>
</tr>
<tr>
<td>16</td>
<td>2400/sec</td>
<td>1000 H\text{z}</td>
<td>16000 H\text{z}</td>
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<tr>
<td>8</td>
<td>1800/sec</td>
<td>2000 H\text{z}</td>
<td>16000 H\text{z}</td>
</tr>
<tr>
<td>16</td>
<td>4800/sec</td>
<td>2000 H\text{z}</td>
<td>32000 H\text{z}</td>
</tr>
</tbody>
</table>
Generally, it is difficulty to build a system with high rate and large capacity. This kind of system mentioned above can meet the needs for industry. It may have wide applications in industrial atomation.

CONCLUSION

A prototype with 16 channels has been built. The whole system works well, total capacity of the system is 32 kHz. The accuracy of the SDM system is quite good. The principles for selection of Walsh subcarriers was theoretically discussed. The improved method is useful in engineering. The synchronization problem can be properly solved. The experimental results show that the SDM system may have great potentialities.

ACKNOWLEDGMENTS

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REFERENCES

Figure 1. BLOCK DIAGRAM OF WALSH TELEMETRY SYSTEM

TP - Sequence Filter.
M - Multiplier of Walsh Function.
S - Adder.
SW - Separated Switch.

CP - Control Pulse Generator.
WG - Walsh Function Generator.
FMT - FM Transmitter.
FMR - FM Receiver.
SC - Synchronization Circuit.
LPF - Low Pass Filter.
Figure 2. THE ORIGINAL AND SEPARATED WALSH FUNCTIONS
Figure 3: THE CROSS-CORRELATION FUNCTION $F_{1,2}(t)$

Figure 4: A PRACTICAL SYNC. PULSE

Figure 5: A PRACTICAL SYNC. PULSE DETECTOR

Figure 6: BLOCK DIAGRAM OF SYNCHRONIZATION SCHEME WITH PLL.