A SEQUENCY DIVISION MULTIPLEX SYSTEM

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ABSTRACT

A sequency division multiplex (SDM) system using Walsh subcarriers was developed for the transmission of telemetry signals at our laboratory The basis of mathematics which can form a telemetry system is orthogonal function. It is the Walsh function that may form a new telemetry system.

At the first stage a baseband transmission system has been designed and tested. It shows that the results of experiments are quite good, and the new system works well. At a second stage FM is used as carrier transmission. Now the whole system can work property.

A proper choice of the subcarriers minimizes the crosstalk. Principles for the selection of Walsh subcarriers are deduced. It seems that the SDM system has great potentialies.

INTRODUCTION

Telemetry systems are widely used in industrial automation and space technology, particularly in aeronautics. It is necessary for us to measure various data. It is well known that two kinds of telemetry system are used up to mow: the frequency division mutiplex (FDM), and the time division multiplex (TDM). The basis of mathematics which can form a telemetry system is orthogonal function. As long as the crosstalk between the channels is minimal, the multiplex system can be formed. Expressing in mathematical terms, the conditions of orthogonality are

$$\int_{-T/2}^{T/2} f(k,\theta)\, f(j,\theta)\, d\theta = \begin{cases} 0 & k \neq j \\ 1 & k = j \end{cases}$$

where the function f( ) can be sine or cosine, and can also be other orthogonal functions. Walsh functions are orthogonal, normalized and complete. It is the Walsh functions that may form a new telemetry system. It is called sequency division multiplex.

OPERATION OF SM

A block diagram of SDM is shown in Figure 1, which is suitable for transmission of N signals, where N=16. At the transmitting terminal, the signals first pass through the sequency low pass filters TP. Then they arrive at modulators M, in fact, the modulators are multipliers. At the same,individual Walsh function is fed into M from Walsh function generator WG. Walsh function generator is triggered by pulse generator and controller CPC. The modulation is performed in multipliers. At last the amplitude modulated signals are added in a SUM stage, in which a combined signal is obtained. At the receiving termal, the desired signals should be separated. The channel separation is achieved by correlation. The combined signal arrives at all demodulators M and synchronization circuit S. The synchronization signal is firstly selected in S. Walsh function generator is triggered by the synchronization signal, so synchronism may be maintained between two Walsh function generators at the transmitting and the receiving terminals. Different Walsh functions are fed into multipliers M, in which the combined signal is respectively multiplied by the different Walsh functions. According to the orthogonality, the desired signal is separated.

A baseband transmission system with 16 channels has been designed and tested. It shows that the results of experiments are quite good, and the new system works well. In order to fulfill the radio transmission, the combined signal is applied to a conventional FM or AM transmitter. Naturally at the receiving terminal, a conventional FM or AM receiver is required. A FM system is here used as carrier transmission. The whole system can work properly: The crosstalk of the whole system is less than 5%, usually 1-3%o. The wave distortion is also less than 5%. It is acceptable in engineering applications.

SYNCHRONIZATION

The key factor for the SDM system using Walsh functions is the synchronization between the transmitter and the receiver. Generally speaking, the synchronization problem can be solved by using cross correlation functions of Walsh functions and phase locked loop.[7] Let Walsh cross correlation

$$F_{i,j}(t_\theta) = \int_0^T Wal(i,t)Wal(j,t-t_\theta)dt,$$

when $F_{i,j}(t_\theta) = 0$, it means that $t_\theta = 0$, the synchronization is achieved.

It is done not only by using digital PLL and correlation functions of Walsh functions, but also by using analog one. A conventional synchronization is also tested. But the discussion of these three methods must be postponed to a future paper.

PRINCIPLES FOR THE SELECTION OF WALSH SUBCARRIERS

The Walsh functions are used as subcarriers in the SDM system. A proper choice of the subcarriers minimizes the crosstalk. This may be inferred from Table 1. The results of the calculation are obtained with a computer. The following rules apply:

a) The cross correlation functions of Walsh functions with odd normalized sequencies are not identically zero.
b) The cross correlation functions of Walsh functions with even and odd normalized sequencies are identically zero.
c) The cross correlation functions of Walsh functions with even normalized sequencies are identically zero, if the sum of the two sequencies is not equal to 2^{pi}, where pi = 2,3,4,....
d) The cross correlation function of a Walsh function with normalized sequency 2^{pi} and another with an even normalized sequency smaller than 2^{pi} is identically zero.

The principles for the selection of Walsh subcarriers may thus be summarized as follows:

a) Odd normalized sequencies should be avoided. At most one odd normalized sequency should be used.
b) Even normalized sequencies with values 2^{pi} should be preferred over any other even normalized sequencies.
c) One of some sequency, say sal(iθ), is first used, then the other of different sequency, say sal(j,θ), may be used. When proper sequency is used up, another of same sequency, say cal(i,θ), may be used.

The selection of subcarrier according to those rules is shown in Table 2.

DESIGN OF WALSH FUNCTION GENERATOR

For the development of the SDM system it was necessary to design a Walsh function generator that produces almost pure Walsh functions, just as a generator for almost pure sinusoidal functions is needed for a frequency division multiplex system. Several Walsh function generators have been developed. A number of different designs are known. Harmuth was first to introduce a design based on the definition of Walsh functions by products of Rademacher functions. Besslich introduced a design that is minimal in orthogonal error. We discuss first the relation between the symbol function S_t^n and the dyadic increment d(t) of Gray code. A method for design of a Walsh function generator based on the symbol function S_t^n is presented. This method has been used for the design of Walsh function generator with normalized sequency up to n = 64.

CONCLUSION

A prototype with 16 channels has been built. The baseband transmission is well solved, and radio transmission is also solved properly. The accuracy of the SDM system is quite good. Each channel can transfer the signal with frequency 1 kHz, so the capacity of the whole system is 16 kHz. Our experiment not only demonstrates the feasibility of SDM, which is regarded as the third method other than FDM and TDM, but also shows that it may be put into effect.

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REFERENCES

1. Walsh.J.L. A Closed get of Normal Orthogonal Functions, American Journal of Math. Vol. 45, 1923
2. Harmuth.F.F. Application of ‘Walsh Function in Communications, IEEE Spectrum, Vol. 6, No. 11, 1969
3. Hubner.H. Analog and Digital Multiplexing by Means of Walsh Functions, WFS 1970 pp.238-247
4. Harmuth F.F. Transmission of Information by Orthogonal Functions, 2nd ed. Springer-verlag New York Inc. New York, 1972, pp.191-198
5. Harmuth F.F. Sequency Theory Foundations and Applications, Acapemic Press, Inc. New York, 1977, pp. 122-147
6. Besslich P.W. Walsh Function Generators for Minimum Orthogonality Error, IEEE trans. Electromagn. Compat. EMC-15, pp.177-180
7. Zhang Qishan Telemetry System Based on Walsh Functions Proceedings of ITC, 1980, pp. 617-623

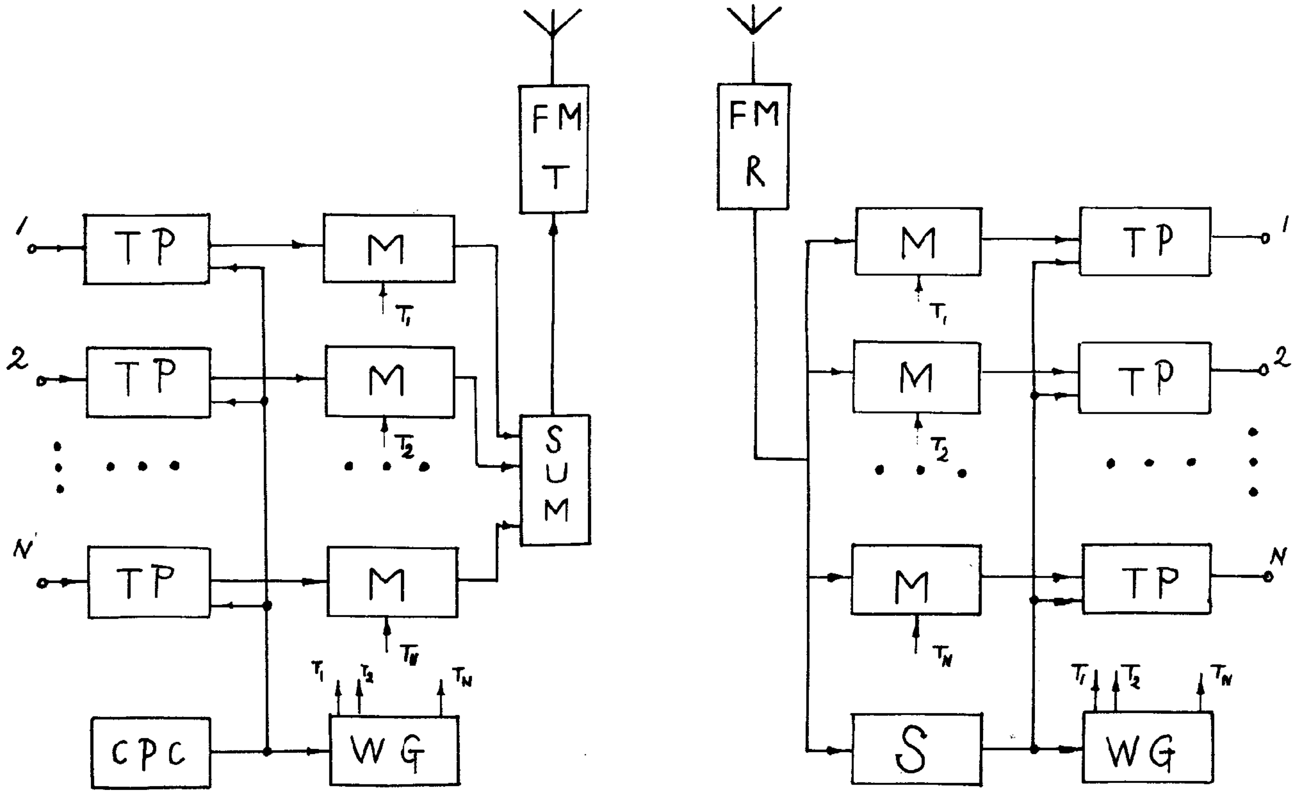

Figure 1 block diagram of SDM

Table 1 Correlation Function for Periodic Walsh Function

Sn \ Sm		0	1		2		3		4		5		6		7		8
	n \ m	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0																
1	1		-1	-1			-1	-1			-1	-1			-1	-1	
	2		1	-1			-1	1			1	-1			-1	1	
2	3				-2	-2							-2	-2			
	4				2	-2							-2	2			
3	5		-1	1			-3	-1			-1	-3			1	-1	
	6		1	1			1	-3			-3	1			1	1	
4	7								-4	-4							
	8								4	-4							
5	9		-1	-1			-1	3			-5	-1			-1	-1	
	10		1	-1			3	1			1	-5			-1	1	
6	11				-2	2							-6	-2			
	12				2	2							2	-6			
7	13		-1	1			1	-1			-1	1			-7	-1	
	14		1	1			1	1			1	1			1	-7	
8	15																-8

Table 2 Recommended Selection of Subcarriers

Number of Channels	
2	15 and any one of (1-4) or (7,8) or (11,12)
3	15 7 3 1 any three of them
4	15 7 3 1
5	15 7 3 2 1
6	15 7 4 3 2 1
7	15 8 7 4 3 2 1
8	15 11 8 7 4 3 2 1
9	15 12 11 8 7 4 3 2 1