

Application of Walsh Functions to an FM Stereo Demodulator*

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In the conventional FM stereo demodulator, interference from adjacent channels is demodulated by the harmonics of a square-wave switching signal resulting in a high-pitched whistle-type noise. In this new demodulator no such noise is generated because the switching square waves are derived from Walsh functions. The low-pass filter can therefore be eliminated, producing a phase-linear composite signal characteristic with high separation and low distortion.

0 INTRODUCTION

Most modern FM stereo decoders are the square-wave switching type, and they make use of a phase-locked loop (PLL). The left and right audio channels are obtained by switching the composite signal with a 38-kHz square wave produced in the PLL circuit. A simple double-balanced mixer is employed for this purpose. While the decoder itself is not subject to harmonic distortion or deterioration in signal-to-noise ratio, it suffers from "beat" problems. The switching square wave contains not only the fundamental frequency but also its harmonics. Usually the composite signal contains frequencies close to the harmonics of the switching signal due to interference from adjacent channels. These adjacent channel frequencies, when decoded, deteriorate the signal-to-noise ratio and cause beat interference, making listening extremely unpleasant. In order to avoid such a phenomenon, a low-pass filter, often referred to as an "antibirdie" filter, is used to filter out the unwanted high-frequency components in the composite signal before demodulation. The use of this low-pass filter, however, creates phase errors between the main channel and the subchannels, which degrades stereo separation.

Various demodulation methods have been developed to avoid such degradation. One method is to use a sinusoidal wave instead of a square wave as the switching signal. Such a decoder demodulates only the desired

frequency range, thus no beat-interference problem is encountered. Drawbacks of this method are that it requires an analog multiplier, making the decoder expensive. This technique still falls short of performance in total harmonic distortion, signal-to-noise ratio, and dynamic range because of analog processing. We are yet to see a commercial application of this demodulation method.

Another demodulation method is to eliminate the antibirdie filter by canceling beat frequency components. The composite signal is separately switched by the third-order harmonic of 38-kHz, or 114-kHz, while it is demodulated by the 38-kHz switching signal [1]. This method is good for cancellation of the beat frequency at 114-kHz, but no other frequencies are canceled.

Yet another method known to us is to generate a 38-kHz sinusoidal wave from a composite signal derived from a pulse-counting-type FM detector. Demodulation is accomplished by switching the sine wave by the output pulses of the pulse counter [2]. This is a very effective method of eliminating the beat problems and avoids performance degradation of a tuner. One drawback, however, is that the detector and the decoder have to be combined, making its application rather limited.

In this report we describe a new demodulation system which does not produce the birdie noise found in conventional processing. Our technique still uses square waves as switching signals, but multiples of different width pulses are derived from Walsh functions. Two

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switching circuits are employed where the composite signal is switched by two different square waves based on Walsh functions, resulting in virtually no harmonics up to the 6th order of the 38 kHz. In practice, this is equivalent to a composite signal multiplied by a sinusoidal wave, but we still retain the advantages of digital processing. This new demodulation system makes receivers immune to interference from adjacent channels up to 228 kHz apart, including the most harmful harmonic at 114 kHz. Unlike the demodulation method referenced above, the new demodulator can be used independently of the detector.

1 "BIRDIE" NOISE GENERATION MECHANISM

Due to the harmonics of the switching square wave, conventional demodulators suffer "birdie" noise. The noise is generated as follows. Fig. 1(a) shows a frequency spectrum of an FM-detected composite signal when a desired and adjacent channels are FM modulated. Suppose that the adjacent channel is located 200 kHz away from the desired station and is deviated by ± 75 kHz. The desired station is also deviated by ± 75 kHz. The relative frequency deviation between the two channels becomes ± 150 kHz, making a wide frequency range of the detector output subject to beat problems. In practice, the high-frequency area is attenuated by the IF filter, and the frequencies in the range of about 50–200 kHz in Fig. 1(a) (shaded area) become the beat components. These frequencies are outside the audible range, and an ideal stereo demodulator does not cause any problem. The switching square wave, however, poses problems here. The odd harmonics of the square wave demodulate the ultrasonic beat components [Fig. 1(b)], making them audible. Fig. 1(c) shows spectra that are converted to the audible frequencies. The spectrum around 38 kHz is necessary for stereo demodulation, but those around 114 and 190 kHz cause unnecessary noise. Such noise varies with the amount of frequency deviation between the desired and the adjacent channels and resembles the twittering of birds. Thus the name birdie noise.

2 NEW DEMODULATION SYSTEM

Our objective was to develop a demodulator that is basically a square-wave switching type, but with beat rejection capability equivalent to the sinusoidal wave

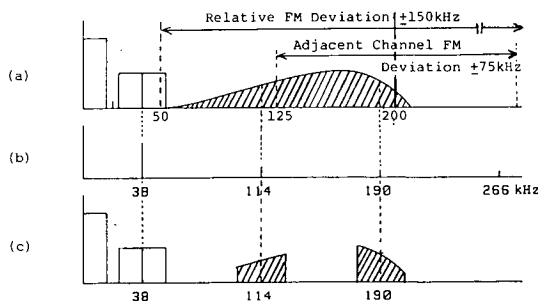


Fig. 1. Birdie noise generation.

demodulator. This is achieved by applying the Walsh functions to the conversion of a sine wave into square waves for switching.

2.1 Walsh Transform of a Sinusoidal Wave

Since an arbitrary waveform can be resolved into multiples of sinusoidal waves by the Fourier transform, the Walsh transform makes it possible for such waveforms to be resolved into multiples of square waves (Walsh waves). This means that the original sinusoidal waveform can be reconstructed by composing the Walsh waves after adjusting their amplitude. The Walsh waves are composed of positive and negative binary values, and they can be generated by a simple digital circuit. They are suitable for use as switching signals of a demodulator. Table 1 shows two examples of a sine wave transformed by the Walsh functions.

2.2 Fourier Transform of a Walsh Wave

Let us now confirm how closely the results of the Walsh transform in Table 1 approximate a sinusoidal wave. Fig. 2 shows the Walsh waves of W_1 , W_7 , and $0.65W_1 - 0.27W_7$ shown in the first example in Table 1. Fourier transform of the $0.65W_1 - 0.27W_7$ reveals how accurately a sine wave is approximated. The same method is applied to the second example. From Fig. 3(a) it is clear that with the 8th-order Walsh transform, the 7th-order harmonic of 38 kHz, or 266 kHz, is the lowest harmonic component and there are no other harmonics lower than that frequency. With the 16th-order Walsh transform [Fig. 3(b)] the 15th-order harmonic, or 570 kHz, is the lowest harmonic component that exists.

3 CIRCUIT CONFIGURATION

For practical applications of the Walsh functions to the decoder we assumed that the 8th-order Walsh transform is sufficient. With this transform beat frequencies above 266 kHz are demodulated, but interfering frequencies higher than that from adjacent channels are attenuated by the IF filter. Those frequencies

Table 1. Walsh transformations of a sine wave

	8th-Order Transform	16th-Order Transform
W_0	0	0
W_1	0.65	1.00
W_2	0	0
W_3	0	0
W_4	0	0
W_5	0	0
W_6	0	0
W_7	-0.27	-0.41
W_8	—	0
W_9	—	0
W_{10}	—	0
W_{11}	—	-0.20
W_{12}	—	0
W_{13}	—	0.08
W_{14}	—	0
W_{15}	—	0

are further reduced in level at the FM demodulation stage, or when they are turned to a composite signal, and if necessary, a simple filter can be added for further attenuation.

3.1 Walsh Functions and Hardware Realization

A 3-bit counter and EXOR circuit generate the Walsh waves of the 8th-order Walsh transform (Fig. 2). Fig. 4 shows its diagram and Fig. 5 its timing chart. The input clock frequency for the counter is 8 times the fundamental W_1 , and it is successively divided to obtain $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ the clock frequency. They are denoted as W_4 , W_2 , and W_1 , respectively, and the following relationship is established: $W_6 = W_4 \oplus W_2$, $W_7 = W_6 \oplus W_1$ and also $W_3 = W_1 \oplus W_2$. Thus W_1 to W_7 waveforms can all be expressed by the combination of the three divided frequencies. The \oplus indicates EXOR between the signals. When a 4-bit counter is used, Walsh waves of up to the 16th-order Walsh transform are generated, and with a 5-bit counter up to the 32nd order. W_0 represents the dc component in the Walsh functions.

3.2 Actual Circuit

With the switching-type demodulator, the composite signal is multiplied by a demodulation carrier. There are two different ways for separating the left and right channels, one is called a switching method and the other a matrix method. With the former the left and right channels are obtained directly by switching, and with the latter a difference signal is first demodulated by switching before it is fed to a matrix circuit to obtain the necessary separation. The new demodulation system we have developed can be applied to either type of demodulation, and the following explanation refers to the matrix method.

In Fig. 6, DBM1 and DBM2 are double balanced mixers, ATT is an attenuator, ADD is an adder, and MTX is a matrix circuit. The composite signal is fed to one of the inputs of DBM1 and DBM2, while their other inputs are fed with W_1 and \bar{W}_7 signals that are derived from the Walsh functions (Fig. 5). The output of DBM2 is multiplied by $1/(1 + \sqrt{2})$ by ATT, its output is summed by ADD, and the difference signal $L - R$ is obtained. The difference signal and the sum signal of the composite are matrixed, and the left and right

separation is achieved. Although it appears that the above function is smaller to the conventional switching demodulator, the result of demodulation is equivalent to multiplying the composite signal by a sinusoidal wave which does not contain the 2nd- to 6th-order harmonics [Fig. 2(c)], and therefore no birdie noise is generated. Fig. 7 shows a block diagram of the complete demodulator.

3.3 Performance

The new demodulator is compared with a conventional square-wave switching demodulator for its ability to cancel birdie noise. Fig. 8 shows the measured results.

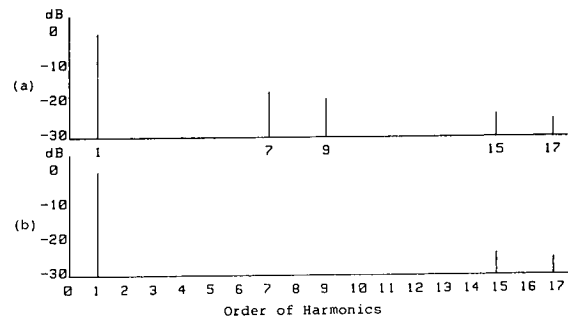


Fig. 3. Fourier transforms of Walsh waves.

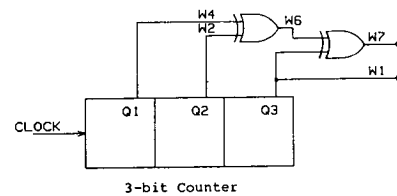


Fig. 4. Walsh wave generator.

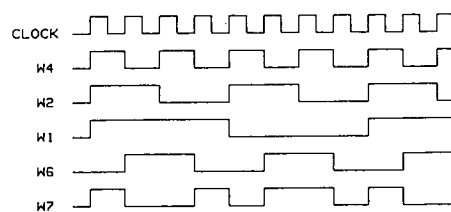


Fig. 5. Timing chart of Walsh waves.

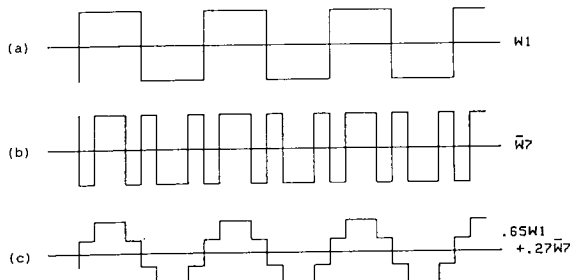


Fig. 2. Walsh waves.

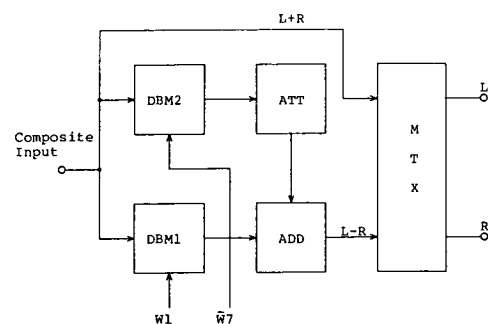


Fig. 6. Decoding block.

The frequency response, separation, and total harmonic distortion of the new demodulator are shown in Fig. 9.

4 CONCLUSION

Modern FM receivers are required to be free from beat problems. This becomes particularly important when coping with the additional channel allocations being considered, new Subsidiary Communications

Authorization (SCA) uses, or FM discrete quadraphonic transmissions which require wide bandwidth. It is our belief that the new demodulation system based on the Walsh functions will demonstrate its advantages more than ever. The birdie noise level caused by the 3rd- and 5th-order harmonics of the switching signal is reduced by more than 40-dB compared with that of a conventional square-wave switching demodulator. We have confirmed that the harmonics higher than the 7th order do not appear in the composite signal when the

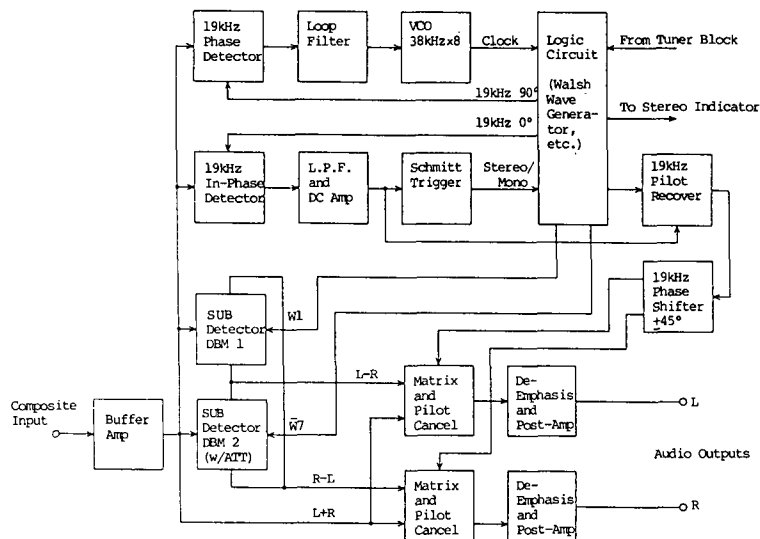


Fig. 7. Demodulator block diagram.

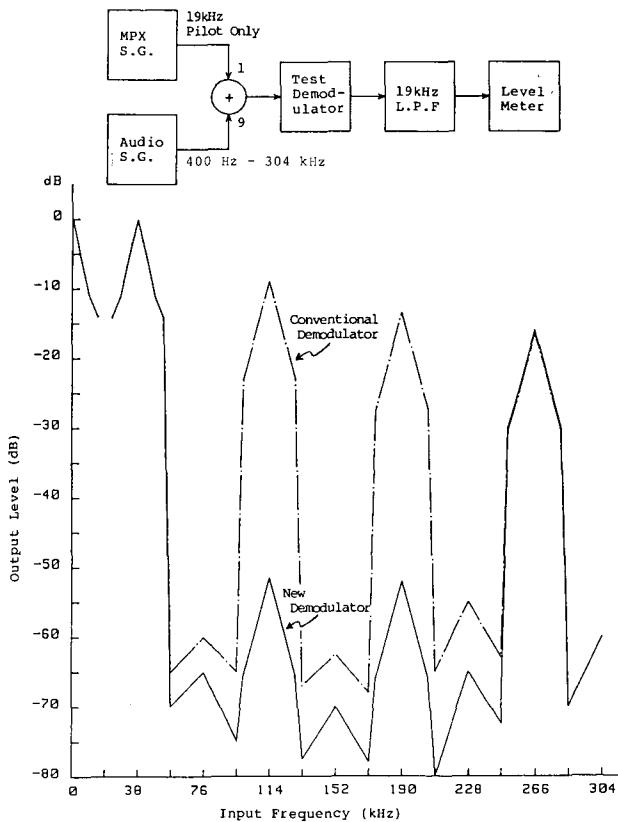


Fig. 8. Comparison of birdie noise cancellation.

demodulator is combined with an FM tuner. The demodulator is similar in its construction to the conventional PLL-type multiplex demodulator and no special circuit is required other than an additional double-balanced mixer and a change in the oscillation frequency of the voltage-controlled oscillator to 304 kHz. The new demodulator is quite suitable for IC integration.

5 ACKNOWLEDGMENT

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6 REFERENCES

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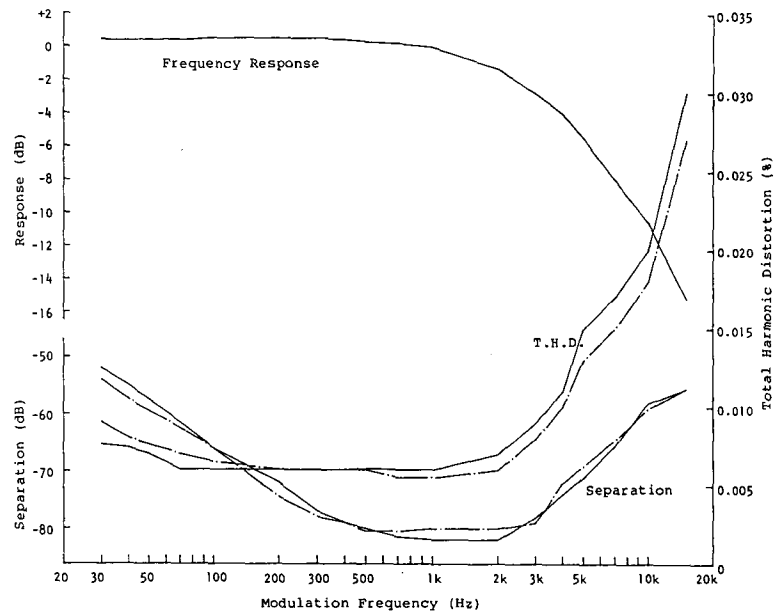
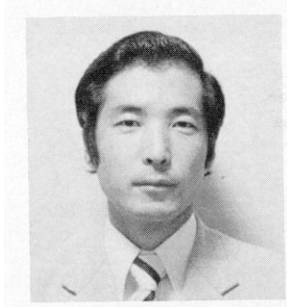


Fig. 9. Performance of the new demodulator.

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Susumu Takahashi was born in Tokyo, Japan, in 1938. He received a bachelor's degree in electrical engineering from Keio University in 1962. Prior to joining Sansui Electric Co., Ltd., in 1967, he worked on multichannel transmitters at Mitsubishi Electric Company. At Sansui he was first responsible for the development of four-channel systems, including FM discrete four-channel transmission systems, and then AM stereo systems. He has presented various papers at the AES conventions covering amplifier designs, measuring methods, tonearms, and loudspeakers. He is now actively involved in the development of digital audio and video systems, and is a general manager of



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