RECOVERY OF PCM TELEMETRY DATA IN THE PRESENCE OF INTERFERENCE SIGNALS

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ABSTRACT

PCM data is recorded on magnetic tape on-board the Space Shuttle during flight. After the vehicle has landed these tapes are played back into a laboratory tape recorder and copies or dubs are made. PCM data from the vehicle is also recorded during manufacture and pre-flight testing and dubs of these tapes are made. Signals from other electronic equipment at the recording site can be picked up and mixed with the PCM data. This can cause dropouts (loss of data) during playback. The low frequencies are easily removed by filtering but higher frequencies that lie in the same range as the data cannot be removed by filtering. Methods for dealing with this problem have been worked out with some success. The work has just started. Some of the results are described here.

INTRODUCTION

Although much of the data from the Space Shuttle is processed in real time, a great deal of it is also recorded on magnetic tape to be processed at a later date. These tapes provide a permanent record of the flight, of the pre-flight tests and of manufacturing tests. When anomalies occur, these tapes are played back and the processed data is examined for clues as to what actually happened. PCM data is processed by playing it back into a PCM Decommutation System whose internal clock must be synchronized to the bit rate of the data. A momentary loss of synchronization, referred to as a “dropout”, means that data is lost during the dropout. Interference signals that have become mixed with the PCM data can cause these dropouts. This paper describes how these signals are acquired and reports on efforts to remove them.

PROBLEMS IMPOSED BY INTERFERENCE

The history of electrical communications is also a history of how to deal with interference Great efforts have been made to understand the problem and to find solutions. Most electrical equipment manufactured today must meet EMI standards. Telemetry has its own set of problems in that electrical interference can have mechanical as well as electrical causes.

When a tape is received and it cannot be played back without an excessive number of dropouts, three courses of action are open:

1. Another dub can be requested, and it will be received in seven to ten days.
2. It can be requested that another dub be played into the KSC/Downey Data Link. The data can be recorded as it is received at Downey. This entire process (including coordination) takes 4 hours.
3. Techniques for drastically reducing the number of dropouts can be developed.

The first action takes too long. The second is possible only when the data link is not carrying data from a major test. The third course of action is the most desired, because delays are costly. During the design phase, each step taken may rest on the one taken before. The data is processed before the next test is started. When an anomaly is being looked into, any delay in getting started is intolerable.

Interference signals discussed in this paper fall into two groups:

1. Signals in the frequency range of D.C. to 1/10 PCM bit rate.
2. Signals in the range of 1/10 PCM bit rate to 4 times bit rate.

Those in group #1 are easily filtered out. Those in group #2 are difficult to deal with and most of this paper describes these efforts.

LOW FREQUENCY INTERFERENCE SOURCES

The introduction of low frequency interference signals can often be attributed to one of the following causes:

1. Worn out or poorly aligned mechanical components in the tape path.
2. Bent tape reels.
3. Stretched tape.
4. Improper tape tension.
5. Loose cable shields, poor grounds, etc.

REMOVAL OF LOW FREQUENCY INTERFERENCE

When PCM data that has become mixed with low frequency signals is viewed on an oscilloscope, it can be seen riding atop these signals. If the data is passed through a high pass filter before it enters the PCM Decommutation System, these signals are removed and dropouts should cease. If dropouts are not eliminated but merely reduced in number then the problem is more involved; perhaps high frequencies are also present.

HIGH FREQUENCY INTERFERENCE SOURCES

The sources of high frequency interference are of course computers and communications equipment that are located in the general area where the dubs are made. Block diagrams of the recording set-ups are shown in Figures #1, #2 and #3. All fourteen tracks are dubbed at the same time; every line in the block diagram between recorders represents fourteen coaxial cables. In Figure #3, 294 cables are involved and a loose shield on any one of them can result in the pick up of interference signals. Whether one dub or twenty are affected depends upon where the interference is introduced in the system. Twenty dubs may be made that have interference and twenty more that are free of interference because the offending equipments were turned off at the time.

THE REMOVAL OF HIGH FREQUENCY INTERFERENCE

A decision was made to develop a method of removing high frequency interference from PCM Telemetry Data. A test circuit was designed and built. A block diagram is shown in Figure #4. It consists of a mixer and a pulse shaper. An operational amplifier is used as a mixer and a zero crossing detector as a pulse shaper. A composite of any two signals can be observed at output port #1. A “reworked composite” is available at output port #2.

The following procedure was followed:

1. The test circuit was connected as shown in Figure #5.
2. A 128 KHZ square wave was recorded at 30 inches per second for ten minutes.
3. The tape was rewound and then played back into input port #1 of the test circuit. No signal was applied to input port #2. Output ports #1 and #2 were monitored with an oscilloscope. The waveforms are shown in Figure #6. The square wave amplitude applied to input #1 was 3 volts peak to peak.
4. Tape was rewound and played back into input port #1 and a 1½ volt peak to peak sinewave of 50 HZ was applied to input port #2. The waveforms available at output ports #1 and #2 were observed as the sinewave frequency was varied from 50 HZ to 500 KHZ. Output waveforms are shown in Figure #7.

The plan was to determine if the pulse shaper could be used successfully in the playback of PCM data or whether new sophisticated circuits would have to be designed. A square wave was used because it is easier to observe on an oscilloscope than a 128 Kilobit Bi-level Manchester code.

When the waveforms from output port #1 in Figure #7 are observed, a resemblance to pulses engulfed in noise is perceived. In these cases the noise usually rides on top and bottom. It is removed by clipping the tops and the bottoms. This was the expectation when the zero crossing detector was selected. It does not clip waveshapes but produces square outputs whose tops and bottoms are flat. The waveform from output port #2, shown in Figure #7, is indeed flat on top and on bottom but the leading edge now has a considerable amount of jitter. If the sinewave amplitude is reduced, the width of the jitter is reduced, and the width is increased if the sinewave amplitude is increased. What has been accomplished? One form of distortion has been replaced by another but PCM Bit Synchronizers are able to accept PCM pulses with considerable jitter and put out a waveform virtually free of jitter. A decision was made to try out the pulse shaper on PCM data that had been mixed with sinewaves.

The equipment was set up as shown in Figure #8:

1. A 128 Kilobit Bi-level Manchester code was recorded at 15 inches/second for 6 minutes.
2. Six minute recordings were also made at speeds of 30, 60 and 120 inches/second.

Before the introduction of interference in the form of sinewaves, a decision had to be made about input amplitudes. The PCM input signal would remain at 3 volts peak to peak, but the sinewave amplitude would be determined for playback at each speed. The PCM Decommutation System was connected to output port #2. During playback the sinewave input was set to 5 KHZ and its amplitude was increased to a point where dropouts were numerous (one or two per second). Then the amplitude was decreased until there were no dropouts during an entire minute. This was the amplitude that was to be used during the playback. It was redetermined at each tape speed. The reason is simple; if the use of a pulse shaper reduces the number of dropouts from 100 to 15 per minute this may be unacceptable. The numbers involved would change as the sinewave amplitude changed. The desired result is zero dropouts. The maximum amplitude of the sinewave (at 5 KHZ) that would result in zero dropouts when output port #2 was used had to be determined.

The tape was played back for the first minute of each recording (15, 30, 60 and 120 IPS), into input port #1 and the sinewave generator was connected to input port #2. The PCM Decommutation System was connected to output port #1 and the number of dropouts for the minute of playback was written down for various sinewave frequencies. After each playback, the tape was rewound and played back at a different sinewave frequency.

The PCM Decommutation system was disconnected from output port #1 and connected to output port #2. The previous step was repeated.

The results are tabulated in Tables I, II, III and IV and will be discussed in the order in which the tests were made.

TABLE II RESULTS

The input frequency was extended down to 50 HZ even though such frequencies are easily removed by filtering. Perhaps a pulse shaper could remove high and low frequencies! The output bandwidths of the tape recorder are as follows:

Tape Speed	Bandwidth
15 IPS	400 HZ to 250 KHZ
30 IPS	400 HZ to 500 KHZ
60 IPS	400 HZ to 1 MHZ
120 IPS	400 HZ to 2 MHZ

A 50 HZ signal could be introduced by mechanical maladjustments in the tape path totally unaffected by the 400 HZ lower limit. It is easily observed that at 50 HZ and 100 HZ the pulse shaper is unnecessary. As the frequency is increased the dropouts increase when output port #1 serves as the input for the PCM Decommutation System. The results when output port #2 is used are consistently good, showing one or no dropouts at each frequency. At 50 KHZ, 350 KHZ and 500 KHZ the readings are high. These could probably be reduced to zero by decreasing the sinewave amplitude. It would seem that for the same amplitude, very high frequencies produce more dropouts.

TABLES III AND IV RESULTS

In both of these cases the number of dropouts that result from playback using output port #1 are much higher than those shown in Table II, for all sinewave frequencies. There is no noticeable increase in dropouts as the frequency increases. The dropouts when output #2 is used are one or zero for the minute of playback. At 500 KHZ and others where this is exceeded, apparently a lower amplitude sinewave could be tolerated and results in zero dropouts.

TABLE I RESULTS

These results were obtained last for the following reasons: The recording of 128 Kilobit PCM data at 15 inches/second resulted in a PCM output that resembled a train of sinewaves. This was the result of the 250 KHZ upper band edge.

At 30 inches/second, the 500 KHZ upper band edge would allow the PCM data pulses to look more square. You can record for two hours at 15 inches/second, and only for one hour at 30 inches/second on a 9,200 foot reel of tape. PCM pulses that resembled sinewaves were always accepted by the PCM Decommutation System. When a noisy tape was received and dropouts were numerous, a zero crossing detector was sometimes used and dropouts ceased. Inasmuch as the output from the zero crossing detector was always a square pulse the conclusion was reached that PCM data recorded at higher tape speeds would be less vulnerable to dropouts because the pulse would be square.

The results in Table I were obtained last because it was felt that for data recorded at 15 inches/second not very much could be done. From the number of dropouts shown it would appear that the use of a “pulse shaper” results in no improvement but also no external device is needed. The PCM Decommutation System seems to respond well toPCM data that was recorded at 15 inches/second and that has become contaminated with sinewave interference signals.

SUMMARY

The effect of high frequency interference signals on PCM data has been demonstrated. It has been shown that the effect of this interference can be reduced or eliminated by the use of simple circuits. The interference signals that were used were sinewaves and only one signal at a time was used. Therefore the results are valid only for the introduction of single sinewave signals. In the near future the effects of other types of interference will be examined.

PCM data is routinely recorded at many installations and played back without difficulty every day. Most dubs received at the Rockwell plant in Downey, California, can be played back without difficulty. Occasionally a dub is received that requires special attention. The Instrumentation Engineer must anticipate problems and work out solutions in advance.

TABLE I

TAPE SPEED 15 IPS
ONE MINUTE RUN

SINEWAVE FREQUENCY	SINEWAVE AMPLITUDE	PCM AMPLITUDE	OUTPUT NO. 1 DROPOUTS		OUTPUT NO. 2 DROPOUTS	
			MF	SF	MF	SF
50 HZ	1.4 V p-p	3.0 V p-p	0	0	0	0
100			0	0	0	0
200			0	0	2	2
350			1	1	3	3
500 HZ			2	2	4	4
1 KHZ			2	2	0	0
2			0	0	0	0
3.5			2	2	0	0
5			0	0	0	0
10			2	3	3	3
20			1	2	2	2
30			1	2	1	1
50			2	2	2	2
100			3	3	1	1
200 KHZ	1.4 V p-p	3.0 V p-p	6	8	1	3

NOTE: MF refers to main frame dropouts
SF refers to sub frame dropouts
These are counted by the PCM Dropout Indicator shown in <u>Figure #8.</u>

TABLE II

TAPE SPEED 30 IPS
ONE MINUTE RUN

SINEWAVE FREQUENCY	SINEWAVE AMPLITUDE	PCM AMPLITUDE	OUTPUT NO. 1 DROPOUTS		OUTPUT NO. 2 DROPOUTS	
			MF	SF	MF	SF
50 HZ	1.2 V p-p	3 V p-p	0	0	0	0
100			0	0	1	1
200			2	1	0	0
350			9	9	0	3
500 HZ			6	12	1	1
1 KHZ			5	18	0	0
2			14	24	0	0
3.5			20	34	1	1
5			22	36	0	0
10			32	54	1	1
20			25	60	1	1
35			30	48	0	0
50			45	92	2	4
100			80	158	1	3
200			135	208	1	1
350			202	330	4	3
500 KHZ	1.2 V p-p	3 V p-p	380	590	9	13

TABLE III

TAPE SPEED 60 IPS
ONE MINUTE RUN

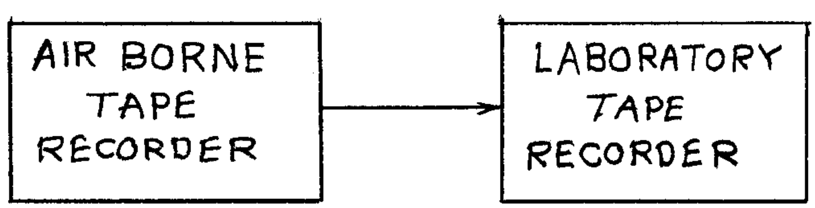
SINEWAVE FREQUENCY	SINEWAVE AMPLITUDE	PCM AMPLITUDE	OUTPUT NO. 1 DROPOUTS		OUTPUT NO. 2 DROPOUTS	
			MF	SF	MF	SF
50 HZ	1.2 V p-p	3.0 V p-p	55	92	0	0
100			165	219	0	0
200			193	280	0	0
350			302	408	0	0
500 HZ			230	360	0	0
1 KHZ			275	400	0	0
2			400	640	0	0
3.5			390	640	0	0
5			370	580	2	2
10			320	480	0	0
20			360	542	0	0
35			370	522	1	1
50			372	543	0	0
100			347	526	1	2
200			409	613	0	0
350			608	855	4	4
500 KHZ	1.2 V p-p	3.0 V p-p	791	1080	10	18

TABLE IV

TAPE SPEED 120 IPS
ONE MINUTE RUN

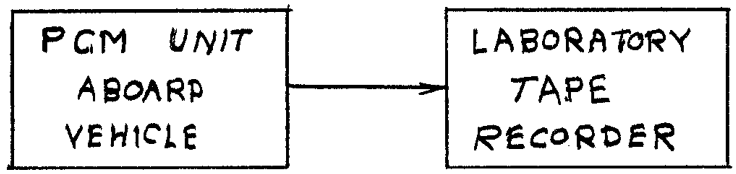
SINEWAVE FREQUENCY	SINEWAVE AMPLITUDE	PCM AMPLITUDE	OUTPUT NO. 1 DROPOUTS		OUTPUT NO. 2 DROPOUTS	
			MF	SF	MF	SF
50 HZ	1.4 V p-p	3.0 V p-p	332	436	0	0
100			231	265	0	0
200			355	407	0	0
350			273	564	2	2
500 HZ			606	710	0	0
1 KHZ			1116	1316	0	0
2			267	432	2	4
3.5			296	992	1	1
5			870	683	1	1
10			842	631	1	1
20			709	604	0	0
35			784	637	2	2
50			619	480	0	0
100			829	691	1	1
200			*	*	0	0
350			*	*	1	1
500 KHZ	1.4 V p-p	3.0 V p-p	*	*	17	34

*Lamps on PCM Decommutator are not even lit.
Count is meaningless.



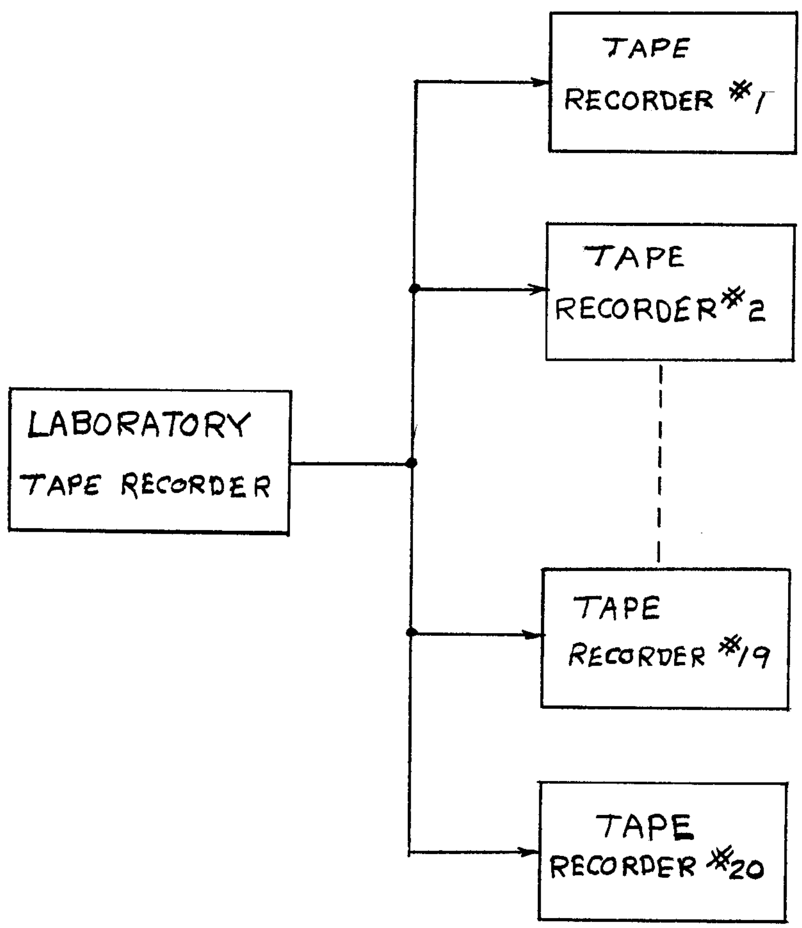
MAKING A DUB AFTER LANDING

FIGURE #1



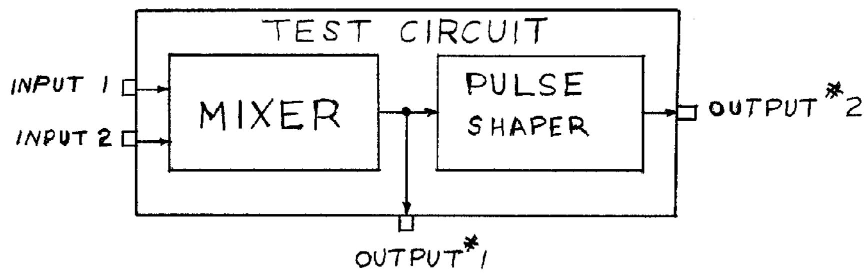
RECORDING A TEST ON GROUND

FIGURE #2



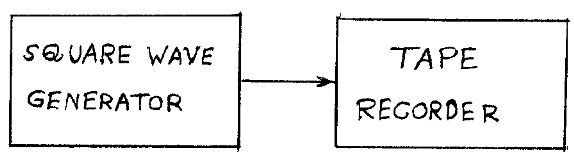
MULTIPLE RECORDING OF DUBS

FIGURE #3

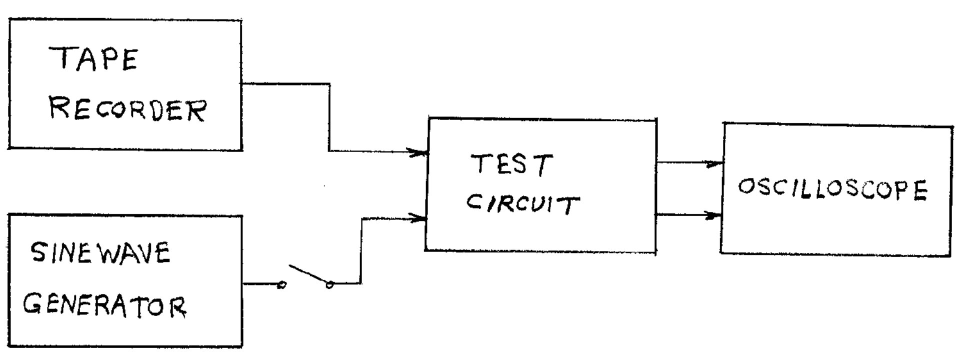


TEST CIRCUIT

FIGURE #4.

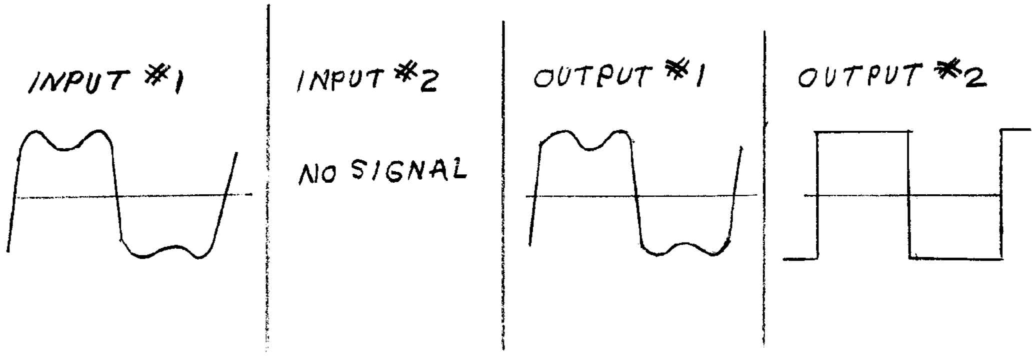


RECORDING OF SQUARE WAVE



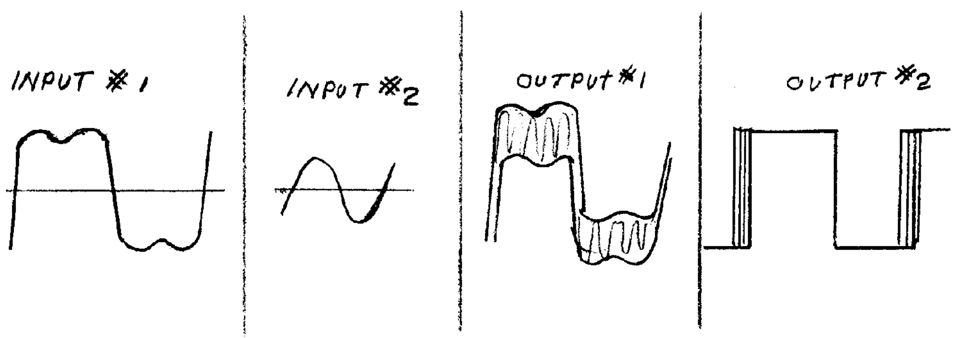
PLAYBACK OF RECORDED SQUAREWAVE

FIGURE #5



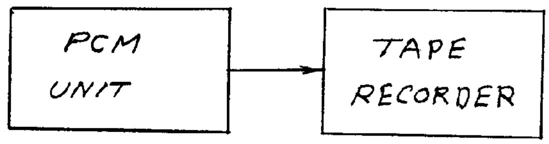
WAVEFORMS - SQUARE WAVE PLAYBACK
NO INTERFERENCE

FIGURE #6

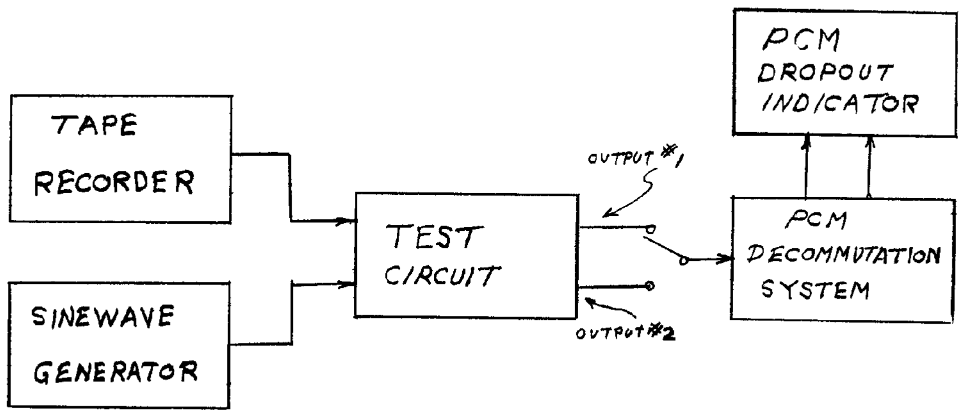


WAVEFORMS - SQUAREWAVE PLAYBACK
WITH INTERFERENCE

FIGURE #7



RECORDING PCM DATA



PLAYBACK OF PCM DATA CONTAMINATED
WITH SINEWAVE INTERFERENCE SIGNALS

FIGURE #8