THE RECOVERY AND RESTORATION OF PCM DATA

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ABSTRACT

PCM data generated during pre-flight testing and during flight of the Space Shuttle is subject to contamination from many sources. Excessive noise and other interference can hamper attempts to process the data. A previous paper (The Recovery of PCM Telemetry Data in the Presence of Interference Signals, ITC ’82) discussed the sources of interference and the design of equipment to reduce it to acceptable levels. In the intervening period work has proceeded aimed at the total recovery of PCM data regardless of it’s condition. These efforts have been successful and data submerged in noise and previously unrecoverable has been easily processed. In addition, it has been determined that the time/phase relationships of different portions of a PCM wavetrain may be altered during transmission, dubbing, etc. This phenomena when it takes place makes it impossible to process the data without excessive dropouts. Equipment has been designed to correct this problem.

INTRODUCTION

This paper deals with efforts to process data recorded on tape at various test sites. This data is processed by playback into a PCM Decommutation System, where an internal clock is synchronized to the bit rate of the input data. If this synchronization is lost, decommutation ceases until it has been restored. This is referred to as a “drop-out”. Tapes received from test sites may have become contaminated with noise and other signals. This interference can produce dropouts. This paper describes efforts to remove this interference and reduce it to acceptable levels. This is a follow on to a previous paper. The work done in the interim has led to a better understanding of the problem. Technical progress is not always orderly and the solutions have sometimes preceded a full understanding.

PROBLEMS IMPOSED BY INTERFERENCE SIGNALS

Interference signals and noise can produce dropouts. When this happens, another tape is usually requested. Delivery takes about three weeks. Those who will analyze the data must wait. Multiply their salary by their number and the number of weeks and you arrive at a cost for the delay. This is the real problem caused by interference signals. In the case of an on-board anomaly hundreds of people may be involved. When the airborne tape is flawed, requesting another dub is useless. Clearly, finding a way to process PCM data regardless of it's condition is a worthwhile goal.

INTERFERENCE SOURCES

Interference may be spreadout over a wide range. It is convenient to divide these signals into three groups and devise separate techniques for dealing with each type.

LOW FREQUENCY RANGE - Signals from D.C. to 1/10 PCM bit rate.
INTERMEDIATE RANGE - 1/10 bit rate to 1½ times bit rate. Data range.
HIGH FREQUENCY RANGE - 1½ times bit rate and up.

LOW FREQUENCY SOURCES

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

Worn out mechanical components can produce amplitude or frequency modulation, often at the same time. Dirt build up on heads can produce sudden reductions in amplitude. A few millionths of an inch of dirt can produce a ten db drop in amplitude.

INTERMEDIATE AND HIGH FREQUENCY SOURCES

Many types of Digital and Communications equipment are located in the same general area as the tape recorders used for dubbing. Normally as many as twenty recorders are used to create twenty dubs at the same time. Over three hundred coaxial cables are involved. A loose shield on any one of them can allow extraneous signals to be picked up. Poor grounding is another source.

NOISE

Noise on PCM data tapes covers the whole frequency range, low, intermediate and high. The receipt of noisy tapes is usually the result of poor recording practices at the test site. There is a mistaken belief that the input voltage level is not important when recording PCM data on an analog taperecorder. This is not true.

Most analog recorders have a specified input voltage range of 0.15 v rms to 15.0 v rms. A dynamic range of 100 to 1. This is misleading. It means simply that the recorder may be calibrated to accept any signal in that range. Once calibrated, the level may not be allowed to vary very much. An increase creates harmonics while a decrease raises the noise level. A simple test may serve to illuminate the problem.

While recording a one volt rms PCM signal and playing back into a PCM Decommutation System, the output level may be varied slowly and as it is decreased to 0.1 v rms the PCM Decommutator will have remained locked up (synchronized). The AGC circuit in the Decommutator has worked perfectly.

Next, while recording a one volt rms PCM signal and playing back into a PCM Decommutator, the input level may be varied from one volt down to 0.1 volt. As it is decreased the output level also decreases and becomes noisy. As 0.7 v rms is reached, dropouts occur and at 0.3 v rms the dropout rate is about 100 per minute. When 0.1 v rms is reached, both MF and SF lamps on the Decommutator remain extinguished. No lockup for even an instant. THE AGC CIRCUIT IN THE DECOMMUTATOR DOES NOT WORK IN THE PRESENCE OF NOISE.

When recording PCM data on an analog tape recorder, the input level is crucial. It must not be allowed to vary more than plus or minus 2 db.

When PCM tapes from a test site are examined, often the level on each track is different. Obviously not enough care was exercised when the recording was made. This has been the major source of the problem.

In Figure 1, the connections for playback into a PCM Decommutation System are shown, together with a test set-up to study the dropout problem. The dropout indicator has been described in a previous paper. Each time the MF and SF lamps blink on the Decommutator that fact is recorded on a counter and a discrete voltage is recorded on an oscillograph with a time code from the same tape. Three successive runs of the same portion of the tape may often reveal a random pattern, few of the dropouts repeat at the same times. This suggests excessive noise which can be reduced by filtering. In Figure 2, an example of an oscillograph record with a random pattern of dropouts is shown. Dropouts that do repeat are obviously not due to noise.

THE PCM SIGNAL CONDITIONER

The obvious solution is pre-conditioning; conditioning the data before it enters the PCM Decommutation System. A block diagram of such a device is shown in Figure 3. Both high and low frequency interference is removed by filters. The pulse shaper converts interference lying in the same frequency range as the data to leading edge jitter, a form easily handled by the PCM Decommutation System.

The concept of pre-conditioning widely used at Rockwell today, evolved slowly about three years ago. The background is interesting. As the first shuttle flight neared, the number of PCM tapes arriving from test sites increased and the number of these that couldn’t be processed because of excessive dropouts, also increased. The problem was tackled at once but with little success. The dropout indicator was hastily designed and it became apparent that the problem was excessive noise and that if it could be reduced, the number of dropouts would decrease. A little signal conditioning was needed. But what kind? A mental block arose. A PCM Decommutation System consists of a PCM Bit Synchronizer and a PCM Decommutator. The Bit Synchronizer conditions the data before it enters the Decommutator. Four circuits are used, an AGC circuit, a low pass filter to remove high frequency noise, a pulse shaper, and a phase locked loop to synchronize an internal clock to the bit rate of the input data. Loss of this synchronization is referred to as a dropout. Noisy distorted data may enter a PCM Bit Synchronizer, but what emerges is a PCM signal of correct amplitude, (5 volts) perfectly shaped and free of all noise and jitter. The Decommutator then easily extracts the measurements. What instrumentation engineer has not marveled when a PCM signal with jitter extending one third the width of a pulse enters the Bit synchronizer and comes out free of any jitter. An astonishing sight the first time it is witnessed. The present day PCM Bit Synchronizer is the result of thirty years of cooperation between private industry and government; an era that spanned vacuum tubes, transistors and integrated circuits, that saw bit rates climb from a few kilobits to one hundred megabits per second. Many people feel it is the finest signal conditioner conceived by man. Rockwell engineers hesitated briefly. What kind of conditioning could be better than that already contained in this unit? Nevertheless, a decision was made to reduce the noise level by filtering and a pulse shaper was included as an afterthought.

The results were extraordinary. Dropouts were eliminated. Where the rate had been 100 per minute, it was now zero. In cases where a tape had a few dropouts that couldn’t be eliminated it was determined that they were true dropouts, due to interruptions in transmission. A year later it was discovered that the pulse shaper contributed by converting interference in the data range to leading edge jitter and letting the PCM Bit

Synchronizer handle it. This had accounted for the great success a year before. This too was reported in a ITC paper. In the meantime, tapes have been created in the lab that are far worse than any encountered in real life and these have been easily processed.

NEW DEVELOPMENTS

The long sought after goal of being able to recover PCM data regardless of it's condition appeared to have been reached. A PCM data tape was received that could not be played back without excessive dropouts. This tape was free of all noise and jitter and the pulses were perfectly shaped. It was determined that the problem was due to a displacement of the trailing edge of the wide pulses in the Bi phase L PCM data. The source of this problem is unknown to this day. Speculation appeared to indicate that such a phenomena would produce, not numerous dropouts but one long one or failure to lock up at all. A means was found to deliberately create this condition. When this tape was played back, the dropouts were numerous. A circuit to correct the problem was designed and it was successful. Bi phase L PCM data appears in Figure 4 and a block diagram of the "phase corrector" is shown in Figure 5.

SUMMARY

Most of the interference signals that contaminate PCM tapes are either picked up at the test site from nearby equipment or are created during the dubbing process by poor recording techniques. Much of what has been discussed here was covered by previous ITC papers but the discussion of the creation of noise during dubbing and the PCM pulse edge displacement phenomena are new developments.

What has been learned at Rockwell is that, DIGITAL DATA IMMERSED IN NOISE CAN NOT BE PROCESSED BY DIGITAL CIRCUITS UNTIL MOST OF THE NOISE HAS BEEN REMOVED, WHICH CAN ONLY BE DONE BY ANALOG CIRCUITS. Up until now, the playback of PCM data from tapes has been discussed: PCM data received via an RF link might also require preconditioning. The work has revolved about PCM rates below 200 kilobits per second. Whether similar problems exist at the higher rates, 50 and 100 megabits is anybody's guess. The matter is being considered.

Those Rockwell personnel who worked on this problem back in 1980 put in long hours after work, when other work had been completed. They didn't have the time or the money to pursue this problem, but they found the answers anyway.

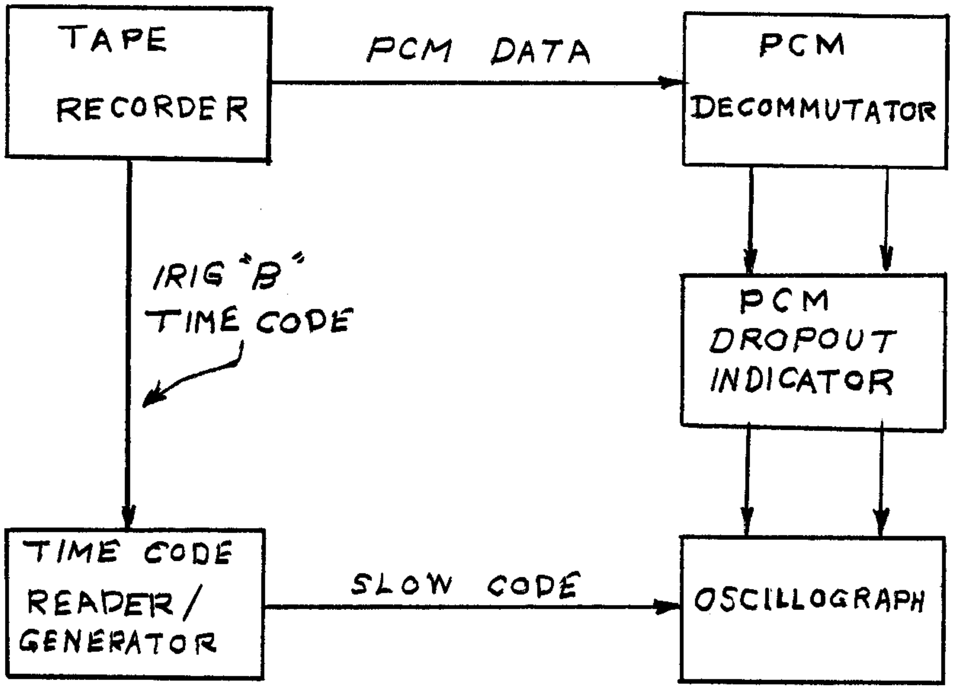

FIGURE 1. DATA PLAYBACK

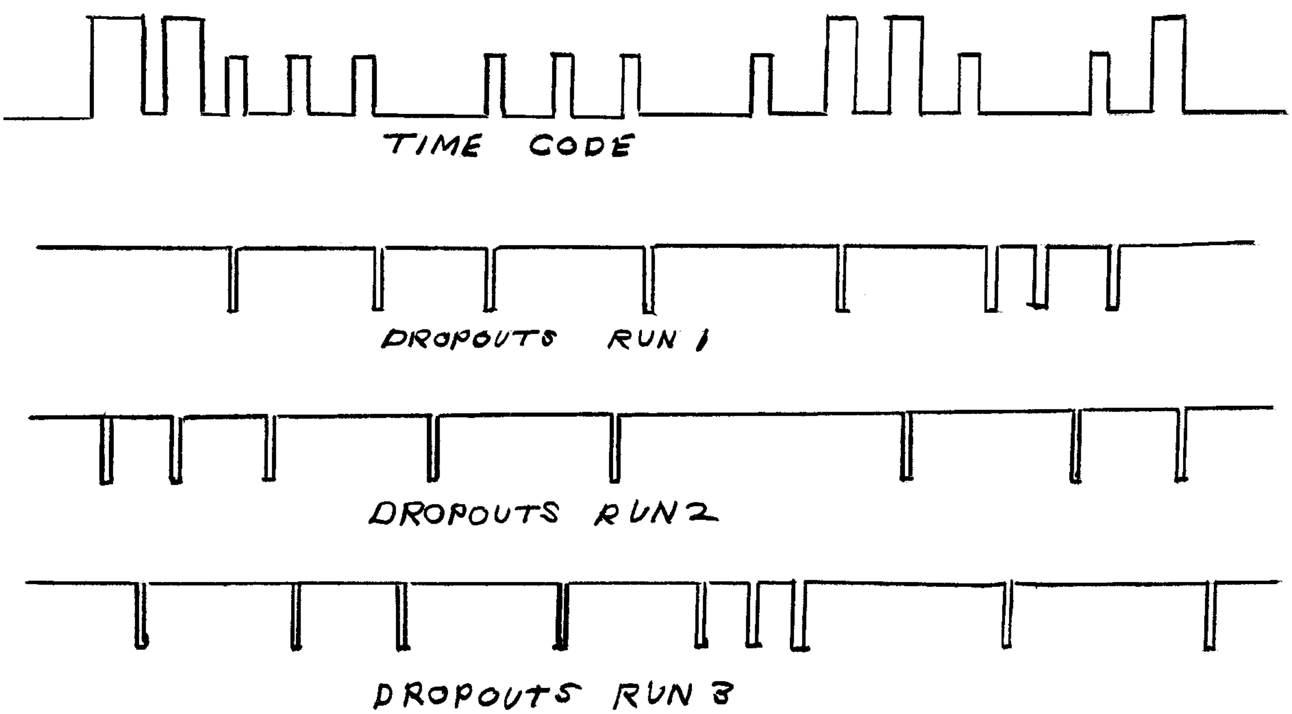

FIGURE 2 RANDON PATTERN DROPOUTS

FIGURE 3. PCM SIGNAL CONDITIONER

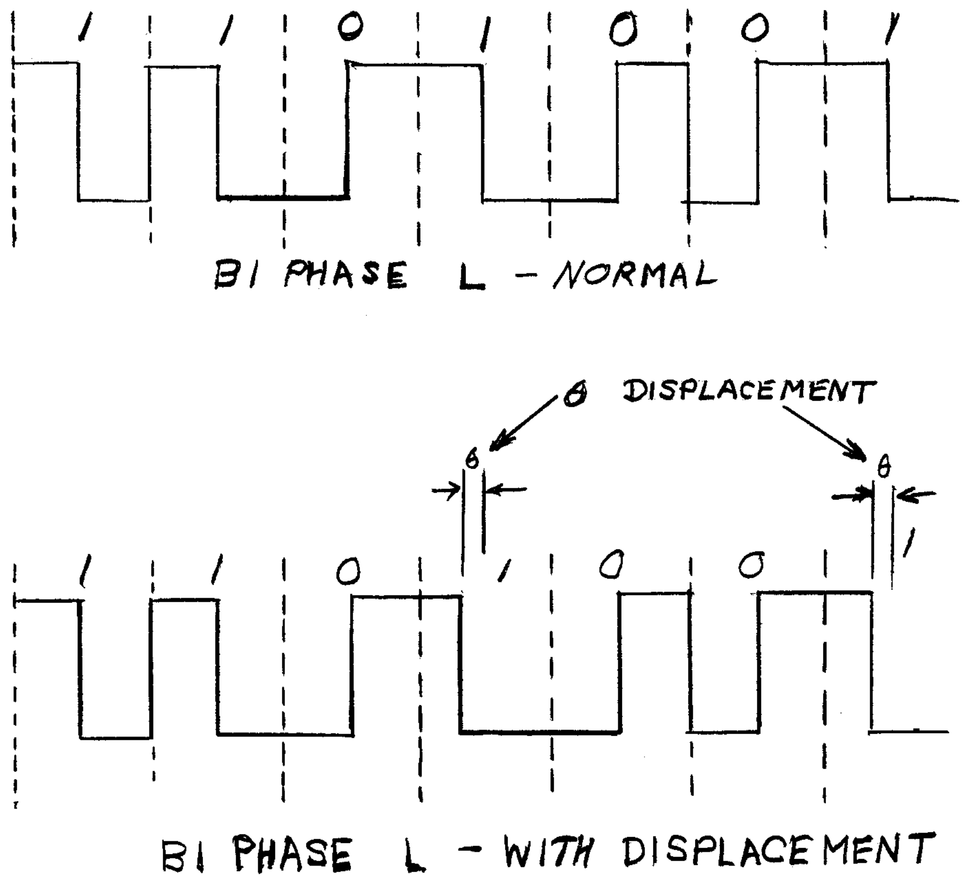

FIGURE 4 EDGE DISPLACEMENT

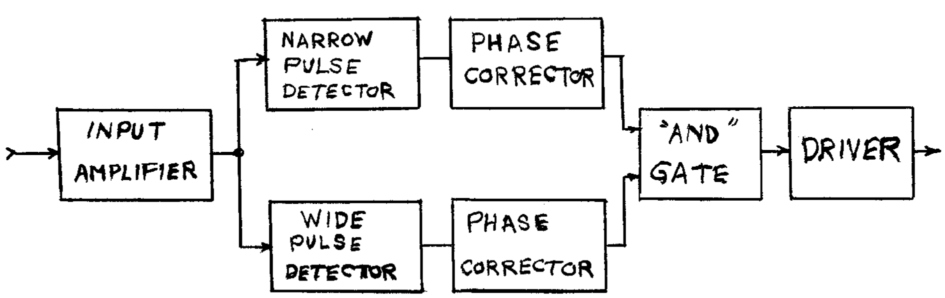

FIGURE 5 DIGITAL PHASE CORRECTOR