the Univac Scientific's scope display system, the programmer wishes to change the flow of his problem. If he has previously decided on the alternate course or courses he wishes to pursue due to scope display information, he need only press the interrupt button on the console to have the computer proceed on its new course. This avoids the stopping and resetting of the computer and the many errors that are inherent in trying to do this quickly.

Like many other new ideas in computer design it is expected that the stimulus of the needs of the many computing installations around the United States will father many other and exciting uses for the program interrupt. The program interrupt is confidently expected to be a feature of most digital computers in the future.

A Pulse-Duration-Modulated Data-Processing System

J. R. LOWE J. P. MIDDLEKAUFF

A COMMON engineering problem is that of measuring physical quantities which cannot be directly observed. In the case discussed here, these quantities exist in a missile during flight. Since it is not practical to mount recording instruments in the missile and recover them after the flight, the data must be recorded somewhere outside the missile so that they can be reduced to graphical or tabular form.

The usual solution to this type of problem is some form of telemetry. This paper considers one such form, namely, pulse duration modulation (PDM) telemetry, and describes a system for reducing data so obtained. The system represents a great improvement in speed, flexibility, and accuracy over previous reduction methods. Considering the time factor alone, the system described in this paper is a striking improvement. From 3 to 6 months were formerly required to obtain analyses of the data from a missile firing. Now, these can be provided in 2 or 3 days.

In the system described here, the data are transmitted by radio link from the missile and recorded in analogue form on magnetic tape at the ground station. This analogue tape is converted to digital tape which is processed by an IBM type *701* Electronic Data-Processing Machine. The *701* punches cards which are used to produce graphic presentations on an IBM type *407* Accounting Machine. The system provides for a "quick look" at the data, handles nonlinear calibration factors, plots only selected portions of the data, allows for many kinds of errors in the telemetry, permits subcommutation and supercommutation and numerous other exceptional circumstances. The reduced data are also left on magnetic tape ready to be used as input for other *701* programs.

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Brief Description of PDM Telemetry

This is a standard Applied Science Corporation of Princeton (ASCOP) system and will be described very briefly.

The missile carries transducers which measure such quantities as deflections, temperatures, pressures, and accelerations. All these quantities are developed as percentages of a battery voltage.

The transducers are sampled by a commutator (see Fig. 1). In the example shown here, the commutator has 30 contacts (can sample 30 transducers) and rotates 30 times per second, thus producing 900 samples per second. However, the system is entirely flexible in this regard, and other numbers of segments or commutation rates can be readily handled.

Square wave pulses whose durations are proportional to the sampled voltages are formed, and are differentiated twice. The resulting pulses frequency-modulate a radio wave which is transmitted to a ground station, where the pulses are demodulated and recorded on magnetic tape in analogue form. Simultaneously, a series of 0.01 second time pulses are recorded on a separate track of the magnetic tape. The data track is in the form of a series of groups of 30 "channels," each channel corresponding to a point of the commutator. Each group of 30 channels, corresponding to one revolution of the commutator, is called a "frame."

In practice, two adjacent segments of the commutator are not used. This produces two blank channels in every frame which are useful in identifying the frames. Also, two segments are used to measure the two sides of the battery called "ground" and "reference" voltages. If two batteries are used, as is frequently the case, there are two reference voltages and a common ground.

Fig. 2 is a sample telemetry record called a "lines record." This is a 35-millimeter film containing the same information, and produced by the same type of signal, as the analogue tape. Here the pulse widths are represented by line heights and the time marks by dots along the bottom of the film.

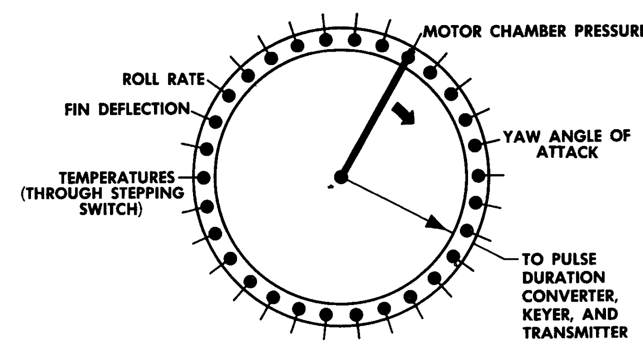


Fig. 1. Commutator

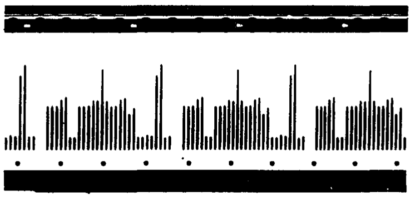


Fig. 2. Normal lines record. Pulse duration is represented by line height and time marks by dots above bottom edge

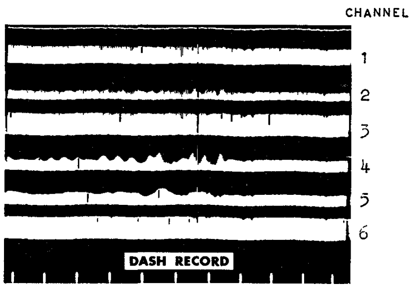


Fig. 3. Dash record. Vertical lines along bottom edge are time marks

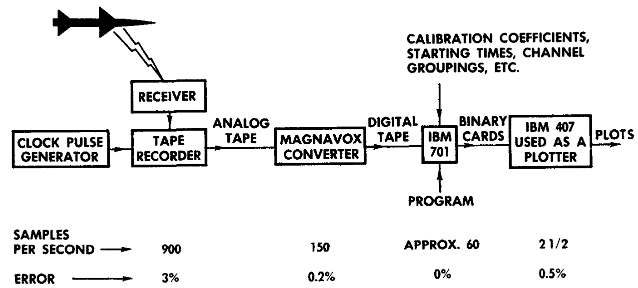


Fig. 4. System block diagram

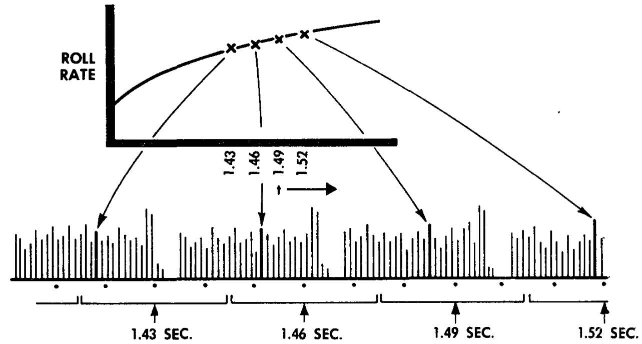


Fig. 5. Stripping

During the missile flight, a set of "dash records" (Fig. 3) are prepared and are available very soon after the flight. In these, the information is "decommutated" or "stripped" so that each channel appears separated from the others. Dash records are useful as qualitative "quick look" media and as an aid in determining how much of the total data should be reduced and plotted.

Outline of the System

Fig. 4 shows a block diagram of the system. The first step in processing the data is to convert the analogue tape to a digital form using a Magnavox Series *200* Data Converter which was specially built for the Douglas Aircraft Company. This will be described more fully in the following paper, "A PDM Converter" by Arsenault (pages 57–61). As will be developed in that paper, the design of the converter presented two basic problems: First, while the pulses on the analogue tape vary in their repetition rate due to variations of commutator speed in the missile and other factors, the recording density on the digital tape must be constant. This problem was solved by controlling the speed of the output tape unit by a phase-sensitive synchronizer.

Second, it was necessary to provide "inter-record gaps" or 1-inch spaces on the output tape after a predetermined number of samples, e.g., 1,500 samples. Since it was impractical to stop and start the input tape to provide these gaps, this problem was solved by using two intermediate tape recorders, recording blocks of data on them alternately, and finally playing them back alternately onto a composite tape in such a manner as to leave the required gaps. Incidentally, it is probably possible to solve this problem more elegantly using a more recent idea. This would involve inserting, after each block, a bit on an otherwise unused channel of the output tape which could be used to cause the *701* to stop reading the tape and back up to the marker.

The channels on the digital tape are in the form of *701* half words, or 18 binary digit groups. Ten binary digits are used for data, one is used to represent the time pulses, and seven are blank.

As noted in the introduction, this tape is then processed through the *701*, which punches binary cards. The cards are used to produce plots on the *407*. These two steps will be discussed in the following two sections.

The 701 Program

The raw data as transcribed by the Magnavox Converter must be processed in several ways in order to produce the desired final graphical output. One of the salient advantages of the system lies in the use of a general-purpose computer, already on hand, and a very flexible program.

The same function from successive frames must first be selected and grouped together in a time sequence. This is referred to as "stripping." Also, a time must be associated with each sample. Since the plotter, the Type *407*, can give only uniform increments in time, the system selects, for each plot, the quantities which occur nearest the successive times defined by the successive abscissas or grid lines on the graph paper. These two steps are illustrated in Fig. 5.

Note that this method of ascribing times to the successive data points introduces some error, since the events do not occur at the precise times that the graph would indicate, but merely nearer to those times than to the adjacent times. However, experience indicates that this limitation introduces no objectionable error.

Defective data, in the form of missing pulses, overlong pulses, or broken pulses (see Fig. 6), are represented as zeros by the Magnavox converter. The program rejects these points, and inserts for each such point a signal which causes the *407* to space without printing (a space representing an advance in time). It is thus possible for the program to indicate time accurately over a long series of bad or missing data points.

Defective timing, either in the form of missing time marks or spurious time marks, is also occasionally encountered. Normally, time marks occur at the average rate of one every nine channels, ±10 per cent. Making use of this fact, the program deletes spurious time marks or supplies missing time marks as required.

The program next handles the problems

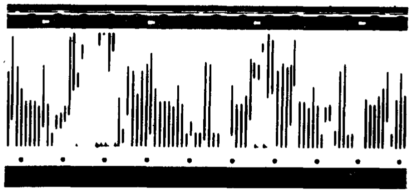


Fig. 6. Lines record showing defective data

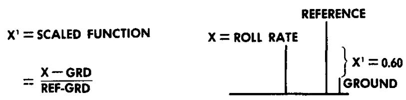
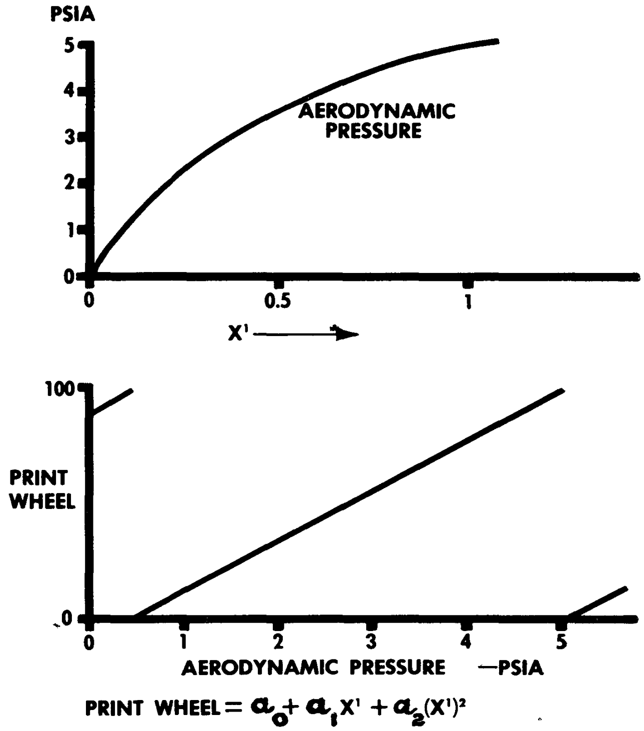


Fig. 7. Scaling

Fig. 8. Calibration



of scaling and calibration. For the purposes of telemetry, a quantity is represented as a percentage of the difference between a ground voltage and a reference voltage. With such a representation, it is not necessary for the voltages in the missile to be accurately regulated. Fortunately, any distortion of the data through the preparation of the digital tape is entirely harmless, so long as the distortion is no worse than linear. It is clear from the equation of Fig. 7 that any such linear distortion drops out in the scaling operation. The *701* program uses the ground and reference channels closest in time to a particular channel in the scaling of that channel.

The purpose of calibration is to convert the scaled quantities to physical units according to calibration curves determined for each of the transducers in the missile. These physical units are then converted to a *407* type-wheel location in such manner that the final graph will be on a convenient scale. This operation is illustrated by Fig. 8, where the 101 type wheels used for plotting are arbitrarily numbered 0 to 100. (Actually, the two steps of calibration and type-wheel determination are combined in one step by the computer.)

The calibration curves are first approximated by polynomials which are mostly linear but which may be of any degree up to five. The coefficients of these curves are supplied to the computer as part of the identifying and specifying information for a particular flight.

The normal commutation rate of 30 frames per second is not always high enough for the sampling of rapidly changing functions. This rate can be increased at the sacrifice of one or more channels by jumpering two or more commutator segments so as to sample a particular function two or more times per frame. This is called "supercommutation." On the other hand, it is frequently desired to sample more quantities than there are available commutator segments. This can be done by connecting several transducers to one segment through a stepping switch which steps once each frame. This is called "subcommutation." As is shown in Fig. 9, one of the quantities in the sampled group, called the reference voltage, is larger than the rest, and provides for the recognition of the sequence of functions with the group. Information regarding supercommutated and subcommutated channels is supplied to the *701* as part of the identifying information, and the machine selects and organizes the data appropriately.

The computer punches its output in the form of binary cards (binary rather than decimal to conserve *701* output time), one deck for each plot to be prepared. These decks must take cognizance of the number of curves to appear on each plot and this information is again supplied as part of the identifying information.

As another form of output, the scaled data are written on magnetic tape and are available for use by other programs. Examples of this use are the computation of Mach number, drag, and other aerodynamic forces.

In order to allow the operation of the program to be followed as it is being run, a table is printed showing the starting and ending times for each record and other relevant information (see Fig. 10).

It is worth emphasizing that these steps require only one reading of the input tape. Any number of plots, each with its own start time, end time, and time increment, may be prepared.

Plotting on the Type 407 Accounting Machine

The plots are printed on continuous rolls of vellum graph paper. Time is represented by the paper feed spacing, one space being equivalent to one time increment. Ordinate values are represented by printing from one of 101 typewheels. From one to five functions are put on one plot by using five different symbols selected from the 47 available.

Seven binary digits are necessary to specify a type wheel. Ten numbers are punched in each row of the card, and all 12 rows are so used. Thus, 120 points are punched in each card (see Fig. 11). The *407* reads each card 120 times, printing one symbol at each reading, and taking 48 seconds for each card. On each line, the machine prints the first symbol, then the second, and so on. When it has printed a number of symbols equal to the number of functions to be plotted (this number is also punched in the cards), it spaces and repeats the symbol printing cycle.

It is desirable for one abscissa grid line to represent a convenient time increment. This is achieved by choosing the proper combination of graph paper, carriage

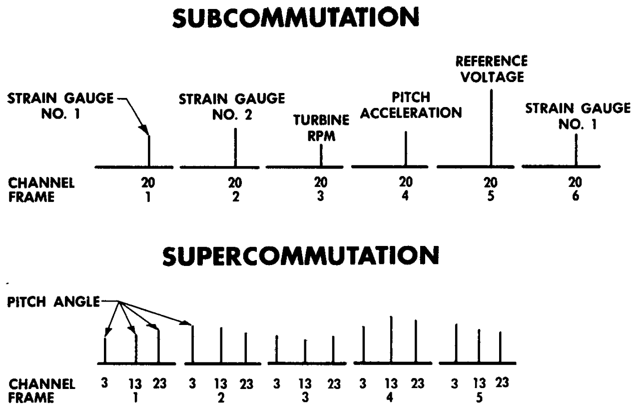


Fig. 9 (left). Subcommutation and supercommutation

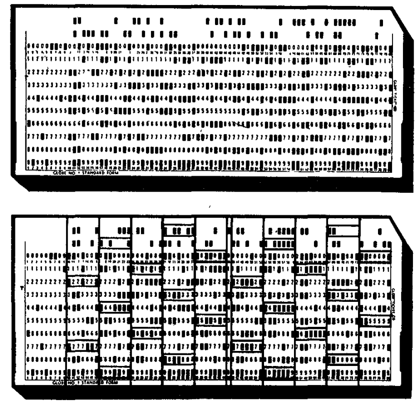


Fig. 11. Binary cards. The circled numbers represent successive values of one function

JOB 5569 TELEMETRY DATA REDUCTION RUN 475

INITIAL REFS	CHANNEL 25	CHANNEL 26	CHANNEL 27	CHANNEL 28
	679.00	694.00	118.00	123.00

RECORD NO.	FIRST T	LAST T	NO. FRAMES	EMPTY FRAMES	TAPE ERRORS
1	1.43–	.15	50		1
2	.16	1.74	50		
3	1.75	3.33	50		1
4	3.34	4.93	50		
5	4.94	6.52	50		
6	6.53	8.11	50		
7	8.12	9.70	50		
8	9.71	11.29	50		
9	11.30	12.88	50		
10	12.89	14.47	50		
11	14.48	16.06	50		
12	16.07	17.66	50		
13	17.67	19.25	50		
14	19.26	20.84	50		
15	20.85	22.43	50		
16	22.44	24.02	50		
17	24.03	25.62	50		
18	25.63	27.21	50		
19	27.22	28.80	50		
20	28.81	30.40	50		

Fig. 10. Printed output

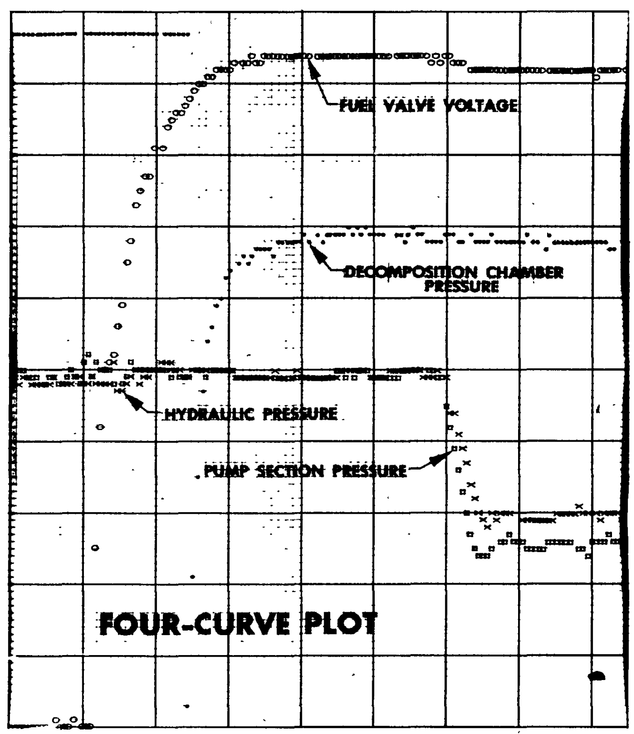


Fig. 12. Output of 407

spacing, and time interval between successive lines of printing.

A portion of a plot is shown in Fig. 12. Note that the plot is rotated 90 degrees from its position in the *407*. The symbols "X", "□", "0", and "." are used here to denote four curves. Because of the *407* spacing employed for this plot (one space equals 0.06 inch), the symbols overlap somewhat. The time increment in this example is 0.03 second, and the resulting scale is 1/2 second per inch.

The vertical range is covered by the 101 type wheels. If the result of calibrating a point is a number lying outside the range 0 to 100, the type wheel represented by the difference between 100 and the absolute indicated value is selected instead (Fig. 8). Thus 103 is represented by type wheel 3 and −7 by type wheel 93. The curve labeled "Decomposition Chamber Pressure" in Fig. 12 is an illustration of this.

Summary

A system has been described for reducing data from standard ASCOP PDM telemetry. This system has certain advantages and certain disadvantages.

One of the design criteria for the system was that special-purpose hardware be kept to a minimum. The only device especially constructed was the Magnavox Series *200* Converter, which actually is not particularly special-purpose, since it will handle almost any form of PDM magnetic tape. This was a necessity since the system was designed to handle telemetry data from widely different missiles and from other sources such as static tests and wind tunnels. There were so many different circumstances and such a variety of possible errors in the data that special-purpose devices to handle them all would be very expensive. It was decided to relegate as much as possible of the work to the *701*, where a flexible program could easily take care of unusual circumstances.

An outstanding advantage of the system is the fact that the reduced data are automatically available to the *701* on magnetic tape for use in performing further calculations. Sometimes these data are correlated with other data from the same flight, such as radar tracking data.

The error introduced in the data by the reduction system is considerably less than that introduced by the telemetry system. This point is illustrated by Fig. 4.

The system provides for a preliminary look at qualitative information and for reducing only the regions of interest.

The speeds of the system, as illustrated by Fig. 4, are entirely adequate for handling data from missiles, whose flights last no more than a few minutes. However, where data are being taken for very much longer periods of time, as would be the case in aircraft flight testing, several improvements are indicated, the most important being increased plotting speed.

There seem to be two paths that this development can follow. First, put the output on magnetic tape, instead of binary cards, in a form suitable for a tape-driven high-speed line printer. This would enable the printer to print all the characters for one line in one machine cycle, and also take advantage of the higher printing speed of the new printers. The second way would be to use a cathode-ray oscilloscope output for the *701*. This would reduce *701* output time, and leave as the only subsequent step the development and reproduction of the film. This method would have the further advantage of reducing the error presently introduced because of fixed time interval in the plotting.

In general, the system has been very satisfactory and has adequately fulfilled a definite need.

A PDM Converter

W. R. ARSENAULT

DIGITIZING Pulse Duration Modulated (PDM) data at a rapid rate and presenting it in a suitable form for data reduction has been a problem of data reduction centers for some time. The Magnavox Series *200* Converter is designed to accept PDM data recorded on magnetic tape, automatically digitize it, and record the digital information on the magnetic tape in a form suitable for input to a digital computer or other data reduction equipment.

The original PDM data are obtained by recording telemetered or ground data in the usual way during test runs. Using two intermediate tape units, the converter produces appropriate gaps in the digital output tape, making it compatible with such formats as that used by the International Business Machines Corporation (IBM) *701*. A data-tracking servo is incorporated in order to keep the digital output tape at constant density regardless of variations in the sample rate of the input tape. The servo also acts as a noise filter, producing a recording continuity on the final digital tape during periods of sporadic noise or long intervals of interrupted telemetered data.

Introduction

Pulse Duration Modulation has been used for some time now as an information carrier in telemetry systems. The method is to sample various analogue types of signals, usually appearing as a direct voltage, and converting this into a pulse, the duration of which is a function of the magnitude of the signal. This same result may also be realized by having a pulse, say positive, indicate the start of the duration and a second pulse, negative, indicate the end of the duration.

The system for which the Magnavox Series *200*, model *201* converter was designed, transmitted these pulses via a frequency-modulation system and eventually recorded the data on tape. Fig. 1 shows how these data appear on tape. The original sampling system contains a commutator that sequentially switches various direct voltages into a unit that generates the PDM data. This unit is called a keyer. The output from the keyer is a sequence of pulses, spaced equally in time but of varying duration. This shows up in Fig. 1 as pulses with equal intervals. In the particular system described the commutator has 30 segments. Of these 30, 28 contain data and two are left blank.

There are various ways of reducing these data to a usable form. Analogue methods have been used to scale and calibrate the samples and plot them directly. Digitizing the data allows processing by a digital computer. The general subject of processing these PDM data in a computer is covered by Lowe and Middlekauff.[1]

Conversion Problem Defined

The major design problems encountered were those in making the output tape compatible with the tape units and format of the computer with which it is being used. Specifications on both the input and output tapes will be discussed before discussing these problems further.

As pointed out in the "Introduction," the information recorded on the input tape originated in an air-borne keying system. In this sampling equipment, a commutator with 30 segments revolves at 30 revolutions per second providing 900 samples per second. The commutator scans sequentially the various instrument channels and provides the inputs to the keyer. The output eventually appears on a frequency-modulated carrier, telemetered to a ground station. On the ground it is converted to a pulse form and recorded on magnetic tape.

The ground recorder is an Ampex Model *309*. This recorder uses a 1/4-inch tape and two recording channels are provided, one for PDM data and one for frequency-modulated (FM) recording. In this instance, the major data are on the PDM channel with the FM channel used for timing markers.

During recording on the ground the tape runs at 60 inches per second. A pictorial view of the information as it is recorded at the ground station is shown in Fig. 1. The pulse interval from leading edge to leading edge is shown to be constant (within the specified tolerances) and corresponds to the interval from one segment to the next on the commutator. The pulse duration is a function of the parameter being measured at that time. There are 28 pulses of varying width on this tape corresponding to the sampling of 28 different parameters by the commutator. Two segments are left blank in order to define a single frame or commutator rotation. Timing in Fig. 1 is for playback at 15 inches per second.

This magnetic tape now becomes the input tape to the converter. Specifications as they apply to a single pulse are shown in Fig. 2. The nominal pulse interval of 0.067 inch is derived from 900 samples per second being recorded at 60 inches per second. This interval may

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