Standard Electronic Units Interconnect to Provide Flexible Digital Recording

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● THE PURPOSE of this paper is to introduce those familiar with analogue recording techniques to some of the Standard Electronic Units which may be combined to form Flexible Digital Recording Systems.

The Bureau of Public Roads has been digitally recording traffic survey data since 1946 when O.K. Normann had special solenoids mounted on standard adding machines after trying in vain to find a similar piece of commercially available equipment. In 1956, because of a need to use 14 bank adding machines, it was still necessary for the Bureau of Public Roads to provide its own solenoids when this equipment was improved and expanded. Today, only three years later, the manufacturers of adding machines provide for the remote electrical actuation of nearly all models and, almost all, either provide for a direct output to a motorized tape punch or have an auxiliary unit to provide this output. And this rapid trend toward the remote or automatic handling of data by office machines is only mildly indicative of the advances being made in electronic computer print-outs or recorders designed for digital systems.

These newer recorders are briefly discussed and a few typical systems are shown that can be used individually or in combination to produce direct printed records of measures of physical quantities.

It is difficult to observe any digital system without becoming fascinated by the regularity and positiveness with which the data are printed and to admire the complex mechanism which so faithfully transfers electrical intelligence into numerals. In fact, the effect is to often overweight the importance of the recorder which may mask a much more complicated system of data collection. So, because of the straightforward design of these recorders, it is possible for the purpose of this paper to consider only a few external features that are pertinent to any digital system and then consider in more detail such systems and possible alternates.

The selection of one's first digital recorder will probably be dictated by the output of the system that has determined its need. Therefore, it will be only necessary to refer to recorders in terms of "staircase," "10-line," or "binary code," as the features of accepting and storing digits to be printed on command are common to all.

By a "staircase" input, (Fig. 1) is meant that each digit in each column is represented by some particular voltage with respect to a zero level. A typical example is the use of +138V to represent "0," +54V to represent "9," and the other digits represented by voltages equally separated between these two. The "10-line" recorder provides a common terminal for a battery connection and 10 digit terminals for each column. A digit is stored in such a recorder by simply completing the circuit from the other terminal of the battery to the proper digit terminal. A "binary code" input is such as its name implies. In this system, the sum of the code units is the decimal equivalent of the binary number produced by the electronic system. Because of electronic expediency, code values of 1-2-2-4 are usual although recorders with a 1-2-4-8 input are available.

Physically, digital recorders are about 20 in. long by 12 in. high by 15 in. deep and may be obtained in individual cabinets or with panels for relay rack mounting. They normally operate from 120V 60 cycle power with a demand of the order of 150 watts. Models are commonly available to print from 6 to 12 digits as rapidly as 5 times per second with some special computer print-outs capable of much higher recording rates.

In considering in some detail the systems that will collect and prepare the data to be

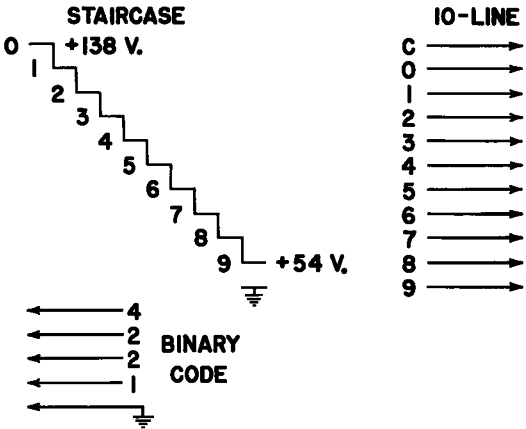

Figure 1. Standard recorder inputs.

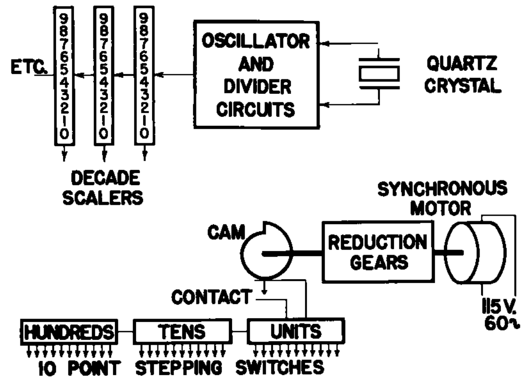

Figure 2. Time bases.

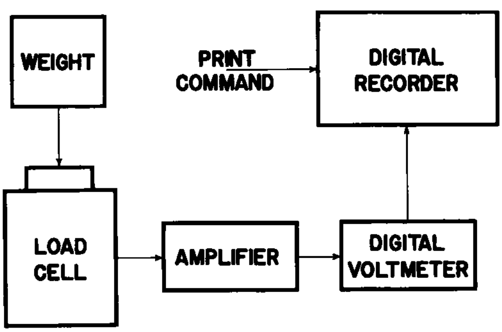

Figure 3. Weight recording.

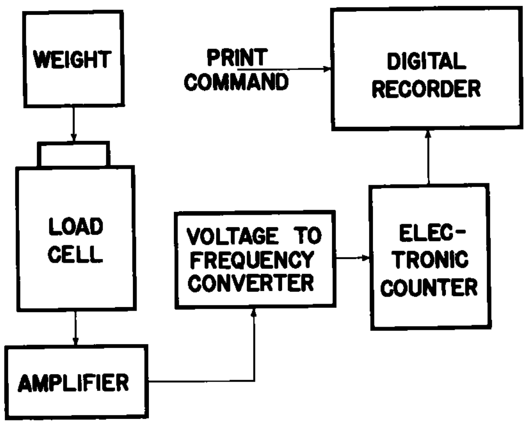

Figure 4. Weight recording.

recorded, the measurement of time should probably be considered first — time being the abscissa of almost all of the common analogue records. Unit time in the analogue is unit length and its measure is dramatically illustrated by the bulk of the recorded chart.

In a digital system, time, like all other quantities, must be recorded in its numerical value. An exception to this would be a situation which permitted the recorder print command to be controlled by time units. Each record would then indicate the passage of one time unit and elapsed time could be determined in the data reduction process by totaling the individual recordings.

In the general case, however, a time base generator or digital clock must be included as a part of the data collection system and its significant figures recorded. Two typical time bases are shown in Figure 2. A quartz crystal oscillator (usually 100 kc) is connected to suitable electronic frequency divider circuits to produce the time unit required. These time units are counted by an electronic decade scaler with an output for each count of ten carried over to another similar scaler. As many as necessary of these decades may be interconnected and the output of each (staircase or binary code) is always available for transfer to a proper digital recorder.

A second practical, and somewhat more mechanical system would utilize a synchronous motor, proper reduction gears, and an electrical contact closed by the driver cam. Ten contact, spring-driven stepping switches would then be used in each decade and a 10-line output to a digital recorder would be available.

As circumstances might require, the stepping switches could be actuated by the crystal oscillator and divider circuits or the electronic decade scalers could count the contact point closures. Other suitable time base circuits make use of capacitor discharge time, tuning forks, direct counting of the power line frequency, etc.

Weight can be directly detected by load cells. These and the necessary oscillator-amplifier systems for their use in conjunction with direct writing oscillographs are commonly used in many highway research laboratories. Two alternative methods of converting this typical laboratory analogue system to digital recording are possible. Both are equally accurate and the choice will be dictated by future utilization of the equipment which is to be procured.

A direct substitution approach (Fig. 3) is simply to replace the direct writing oscillograph with a digital voltmenter. For a minimum of data collection, the weight values can be manually recorded from the digital indication on the voltmeter. However, because it is assumed that large quantities of data are to be collected and that a digital recorder has also been obtained, the digital voltmeter will be directly connected to a compatible digital recorder and automatic data collection will be accomplished on each print command.

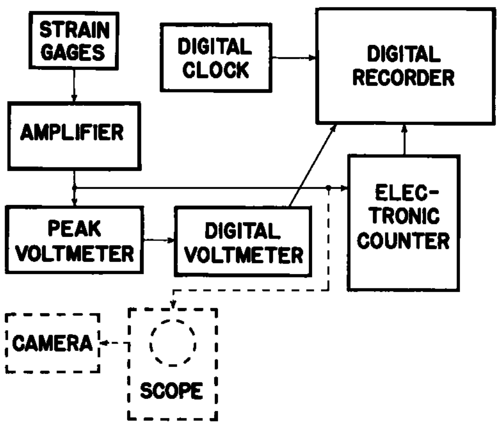

Figure 5. Digital recording of vibration or dynamic strains.

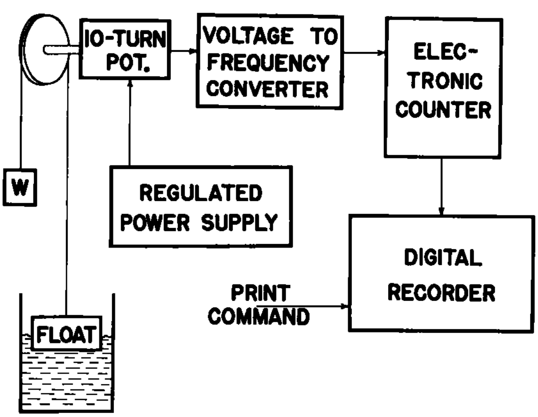

Figure 6. Height recording.

The less direct, but in some respects more desirable method (Fig. 4) is to substitute a voltage to frequency converter for the oscillograph. An additional unit of the electronic counter type is then used to measure the output frequency and transfer the weight data to the digital recorder. Although requiring an additional unit, this method is favored because the counter unit will have many more laboratory applications than a digital voltmeter and the extra original expense will result in later economies. Furthermore, the two units will always combine for a direct measurement of voltage.

Vibration or dynamic strain investigations have encouraged the purchase of much of the electronic equipment now used in highway and structural laboratories. Again, the usual system is standard carrier-amplifier equipment with either a direct writing or galvanometer-type oscillograph output. The digital system for these data recording (Fig. 5) requires a direct measurement of two values, amplitude and frequency. The amplitude is detected by a peak voltmeter for measurement by a standard digital voltmeter and the frequency is directly determined by one of the standard electronic counters. Both amplitude and frequency can then be recorded as desired and the time saved can be best appreciated by those who have counted cycles on analogue charts to determine frequency. The addition of a cathode ray oscilloscope will permit the observation of wave form and a camera will provide the few necessary illustrations for technical reports.

Liquid levels, large displacements in operating mechanisms, etc., can be measured and recorded by the system shown in Figure 6. A precision, ten turn potentio-

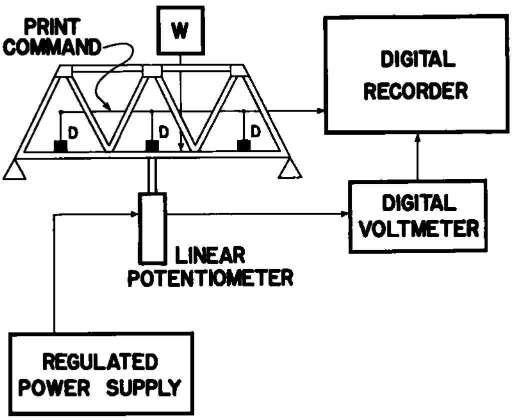

Figure 7. Deflection recording.

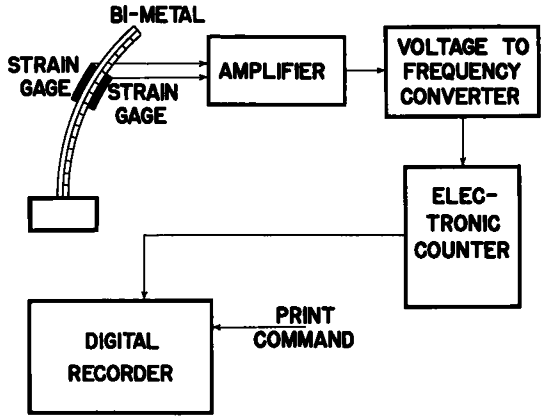

Figure 8. Temperature recording.

meter divides the voltage output of the regulated power supply in direct ratio to the level being measured. The print command would usually be controlled by some digital clock and a direct printed record is the result.

Figure 7 shows a similar system that is more practical for small displacements or deflections. In this case a linear precision potentiometer, or an LVDT (linear variable differential transformer) in a carrier-amplifier system provides a direct reading of movement. The print command in this instance could be controlled by position detectors "D" to provide a deflection record of a structural member.

Any system of temperature detection with an electrical output can be adapted for digital recording. Figure 8 shows one typical system in which strain gages are attached to a bi-metal strip. A standard bridge-amplifier couples such a detector to a digital voltmeter for transfer to the recorder at any desired time. Other detectors, such as thermistors or thermocouples, can be as easily accommodated.

Shaft speeds are detected by a tachometer as in analogue systems. However, for digital recording it is generally more convenient to use a digital tachometer rather than converting an analogue output. The tachometer generator, which is more familiar, produces an increasing voltage with increasing shaft speed; the digital tachometer produces one or more pulses per revolution of the shaft. The digital recording system is completed by connecting a digital tachometer to an electronic counter which has a time base and gating circuits to count pulses per unit of time. The shaft speed then becomes direct reading for transfer to the printing recorder. A typical system is shown in Figure 9.

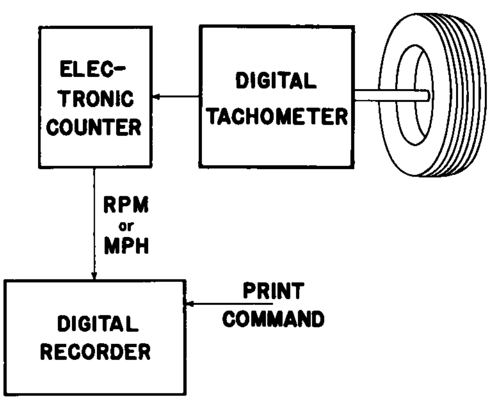

Figure 9. Speed recording.

Notations, which must be entered by hand on an analogue chart, can usually be more conveniently handled in a digital system by entering numerical codes directly in the recorder. This can always be done by providing decades of push buttons connected to produce the proper digital code for the type of recorder used as shown in Figure 10.

It is a rare occasion when a physical investigation requires the recording of but a single channel of information. More likely the capacity of any given recorder will be strained and some complicated system for programming the data entries will become desirable. However, most problems can be reasonably limited to the capacity of the 11 or 12 digit recorders available.

An example of several data being simultaneously entered on a digital recorder is provided in the Traffic Impedance Analyzer developed by the Bureau of Public Roads for speed and delay or operating economy studies. This digital data collecting and recording system is mounted in a vehicle (Fig. 11) and at one-second intervals prints the vehicle speed in miles per hour, accumulated mileage in three significant figures, two decades of manual code, time in seconds for a sequence check, and three significant figures of fuel consumption. These data are shown in a typical recording sample (Fig. 12).

Figure 13 reverts to a block diagram presentation of this instrument and will simplify the explanation of its operation. As both speed and delay, and operating economy studies would require speed and distance to be recorded as a part of the data, primary consideration was given to recording these quantities. The speedometer cable of American cars is designed to make 1,000 revolutions per mile. On this basis a special digital tachometer was designed that would provide direct speed and distance outputs. For the measurement of speed, a disc with 36 holes near its outer edge was rotated by a shaft input. With a light source on one side of the disc and a photoelectric cell on the other, electronic pulses in direct representation of speed in miles per hour could be generated each $1/10$ second with a shaft input rate of 1,000 revolutions per mile. The first disc was coupled to a second disc with one hold near its outer edge by a 10:1 gear reduction unit. A second photoelectric cell on the outer side of the second disc therefore generated an electronic pulse for each $1/100$ of a mile of vehicle travel. The shaft input of this digital tachometer was coupled to the regular speedometer cable of the vehicle by a 1:1 geared "T" at the speedometer head.

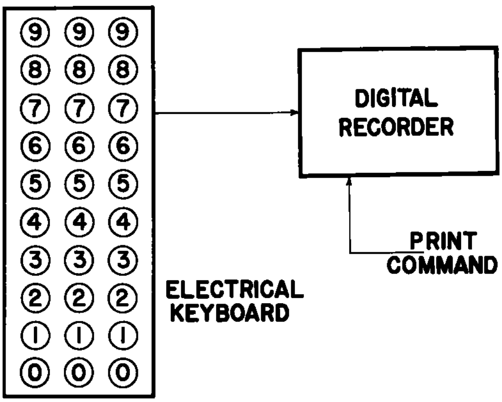

Figure 10. Manual coding.

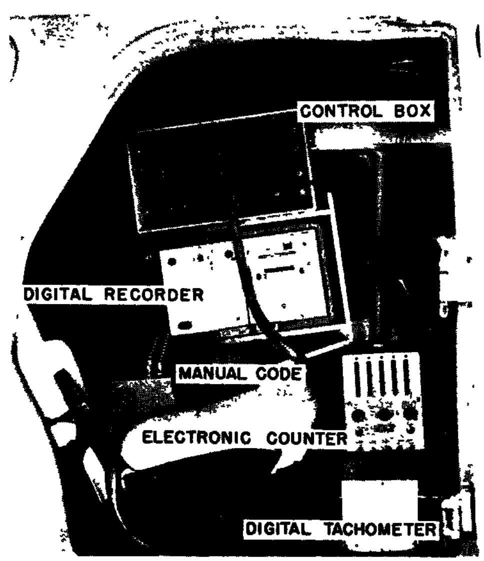

Figure 11. Traffic impedance analyzer.

The electronic pulses from the speed detecting photoelectric cell were connected to the input of an electronic counter. This counter included a quartz crystal time base and generated usable pulses at $1/10$-, 1-, and 10-sec intervals. The $1/10$-sec pulses were used internally to operate the "count" and "stop" gates so that the number of "speed" pulses for any $1/10$-sec period could be accurately counted. The 1-sec pulses were connected to the control box and used to initiate a recording period. Therefore, at the beginning of each second the electronic counter was reset and the "count" gate opened to accumulate "speed" pulses. One-tenth sec later the "count" gate was closed and a print command recorded the speed of the vehicle and all other data which were available at the recorder inputs.

The electronic pulses from the distance detecting photoelectric cell were connected to 3 decades of electronic counting in the control box where they were accumulated. This distance accumulation was continually available for recording.

The traffic, geometric, control, weather, and other pertinent data could be coded by 2 decades of push buttons which would transfer like digits to the recorder at any printing cycle.

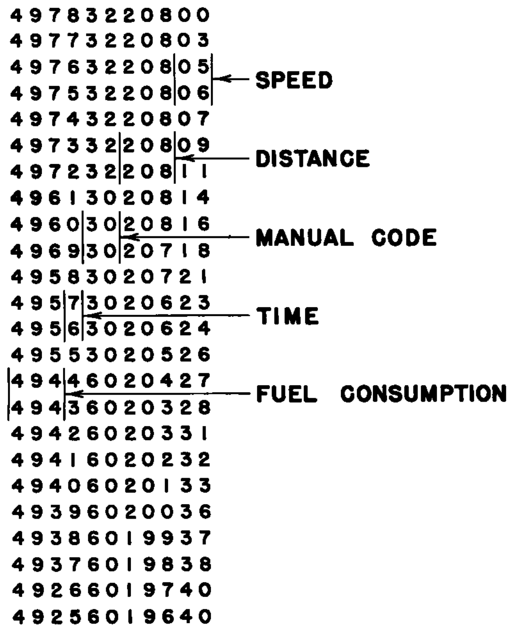

Figure 12. Typical recording.

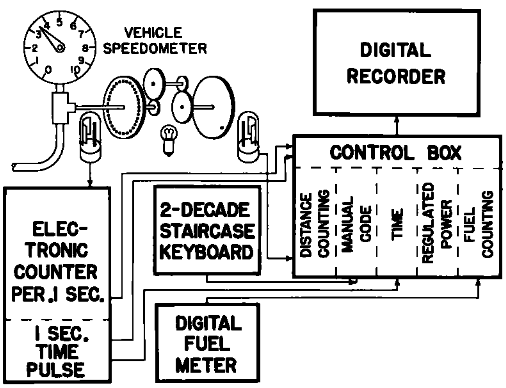

Figure 13. Traffic impedance analyzer.

One decade of time counting was provided in the control box as a printing sequence check. The circuitry also provided for this to be extended to 4 decades as an alternative to fuel recording when it was more convenient, for field observation, to have elapsed time recorded during speed and delay studies.

A digital fuel meter was mounted between the fuel pump and carburetor. The particular one used in this instance produced an electrical pulse for each $1/2000$ gallon of gasoline passing through it. These pulses were accumulated in 3 decades of electronic counters in the control box so that a total of fuel consumption was available for transfer to the recorder at each print command.

The complete equipment was powered by a 1250-watt gasoline-driven generator weighing 85 lb which was carried on a standard roof mount luggage rack. This self-contained unit well illustrates the advantages of digital recording and the possibilities of adapting a few standard electronic instruments to the myriad data-collecting problems encountered by the highway research engineer.

Fully automatic data reduction can, of course, be realized by adding standard tape punch units to the digital recorders shown here. The punched tape then may be used as a computer input or its data may be automatically transferred to magnetic tape or punch cards as individual cases require. The equipments to accomplish these processes are available to those who may wish to extend their systems to include them; but, for the purpose of this paper, it was felt that a simple introduction to digital recording would better serve the greater number of highway engineers.