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BRAMBLE - AN AUTOMATIC PROCESSING SYSTEM FOR TELEMETRY DATA

by

E. S. Mallett

R. E. Perkins

H. W. P. Knapp

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JUN 14 1965

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SUMMARY

The processing of the large quantities of data associated with aircraft and missile trials can be eased by using automatic methods. An equipment is described which processes telemetry data recorded on magnetic tape giving a graphical record and digital outputs suitable for input to electronic computers.

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1 INTRODUCTION

"There was a man in our town,
And he was wondrous wise,
He jumped into a bramble bush
And scratched out both his eyes."

Most of the information presented in this report was prepared for a paper at the International Telemetry Conference held in London during 1963. The papers were printed before the sessions, but never published after the Conference in a final form with the usual appended record of discussions. Consequently it is thought necessary to publish the information in an R.A.E. Technical Report.

The paper attempted to give short descriptions of the telemetry systems in use in the United Kingdom in order to help an international audience understand the data processing problems. This information is repeated here as, although it is a useful summary, it does not warrant separate publication.

There are four main telemetry systems used in the United Kingdom and Australia for missile and aircraft instrumentation. Each system has some advantages over the others, and although there is some hope of a reduction to one or two systems in the future, this is unlikely to happen for some years. However there are some common features, for instance all of them use a similar method of time-multiplexing the data from 24 channels. As most of the telemetry data that can be analysed by a digital computer is transmitted by these time-multiplexed channels it is sensible to design a processing equipment for converting this data into a suitable digital form.

It became apparent during the initial stages of the design of the data processing equipment, that it could easily be made to cope with the digitisation of other forms of data recorded on magnetic tape; consequently the resulting product, nick-named BRAMBLE, is very versatile.

2 BRIEF DESCRIPTION OF THE TELEMETRY SYSTEMS

Since the last war a number of telemetry systems have been developed for aircraft and missiles. Some of these have fallen into disuse leaving one aircraft and three missile systems to cope with the majority of telemetry requirements.

2.1 Type 465 Telemetry

This is the most commonly used missile system, which has previously been known as R.A.F. sub-miniature 24-channel 465 kc/s telemetry^{1,2,3,4,5}.

It is a p.a.m./f.m./a.m. system with a mechanical switch rotating at about 100 revolutions/sec selecting 24 data channels in turn, one of them being allocated to a synchronizing signal. The data to be telemetered is converted to voltages by suitable transducers, time-multiplexed by the switch and then represented as a frequency deviation in the band 130 kc/s to 160 kc/s by a voltage-to-frequency converter; the synchronizing signal is outside the data band at 180 kc/s. The subcarrier signal modulates the amplitude of the u.h.f. carrier.

Some of the channels may be further time-multiplexed with synchronous 24-channel switches to give sub-multiplexed channels. There are facilities available for time-multiplexing inductive transducers to modulate the frequency of the subcarrier oscillator without going through the intermediate voltage stage.

A simplified representation of a telemetry sender is shown in Fig. 1. The waveform of the output signal is shown in Fig. 2.

The ground receiving equipment detects the radio frequency signal and shifts the subcarrier frequency by 95 kc/s to 35-65 kc/s with 85 kc/s for synchronization. This allows data to be recorded on a conventional magnetic tape recorder having a tape speed of 60 in/sec. The signals received from up to four senders, with timing, signal-strength and reference frequency signals are recorded by the seven channels of the tape machine.

The magnetic tape is played back at the missile range to give a quick-look record with the demultiplexed channels displayed as graphs against time on photographic film. This equipment is briefly described later.

2.2 Type 6 Telemetry

This is an f.m./a.m. system used in missiles. It was previously known as Bristol 6-channel high-frequency telemetry⁶. It has six subcarriers with frequencies spaced every 40 kc/s in the band 270 kc/s to 470 kc/s, the maximum deviation of each channel being ± 6 kc/s. The mixed subcarriers modulate the amplitude of a u.h.f. carrier. Each channel has a data bandwidth of 0 to 6 kc/s. Usually the two lower subcarriers are forfeited for one at 290 kc/s, which is modulated ± 15 kc/s, and fed with time-multiplexed data in a similar manner to the subcarrier of the 465 telemetry system.

The ground equipment records the data on magnetic tape and the time-multiplexed channels are separated and recorded by the 465 telemetry quick-look equipment.

2.3 Type 450 Telemetry

This is a p.a.m./f.m. or p.a.m./f.m./a.m. system depending on its missile application. It was previously known as S.R.D.E. (Signal Research and Development Establishment) Broadband Telemetry⁷. An 8-channel electronic switch is driven from a 64 kc/s source to give an 8 kc/s sampling rate. One channel is allocated to synchronization and calibration signals, the remaining 7 being used to telemeter data in the band 0 to 3.5 kc/s. The voltage output of the electronic switch either directly modulates the frequency of a v.h.f. or u.h.f. carrier, or modulates the frequency of a 1 Mc/s subcarrier by $\pm\frac{1}{2}$ Mc/s, which in turn modulates the amplitude of a u.h.f. carrier.

Each of the seven data channels may be further time-multiplexed by means of a mechanical switch. Unfortunately this switch is not synchronous with the electronic one and complicated electronic circuitry has to be used in the ground equipment to reconstitute the signal so that it can be recorded on magnetic tape and later processed by the 465 telemetry quick-look equipment. The seven data channels are demultiplexed and modulate the frequency of a subcarrier for recording on seven tracks of the tape machine. Playback of the magnetic tape into slow speed ($1\frac{1}{2}$ in/sec) and high speed (up to 500 in/sec) photographic recorders allows the visual analysis of the telemetry data.

2.4 ANTAFF Telemetry

The aircraft narrow-band telemetry audio f.m./f.m. system⁸ has eight subcarriers having frequencies between 625 c/s and 14400 c/s, which are mixed to modulate the frequency of a v.h.f. or u.h.f. carrier. The two highest frequency subcarriers can be replaced by one time-multiplexed subcarrier at 12400 c/s, deviated ± 1700 c/s, having 24 channels, each selected 16 times/sec by means of a mechanical switch.

The ground equipment provides a real-time display of the telemetry data on dials and a graphical record on pen recorders. A magnetic tape recorder stores the data for subsequent playback and more detailed analysis.

3 EARLIER TELEMETRY DATA PROCESSING SYSTEMS

In the early days of missile telemetry all the data was recorded on photographic film. For instance, the 465 telemetry data was presented in two forms, a quick-look record which is still used for this purpose, and a "histogram" record which is now seldom used. Both these records are produced at the real-time speed of about 2400 data points/sec.

There are two types of equipment for providing a quick-look record, one¹⁰ shows 15 separate graphs of the demultiplexed data plotted against time on a

large photographic film 24 x 30 in, with the data from all the 23 channels obtained by arranging two or more channels to be plotted on the same graph. The other⁵ uses four 5½ in photographic film cameras, each recording four of the demultiplexed channels.

The "histogram" record, so-called from its appearance, was obtained by photographing on 35 mm film the waveform shown in Fig. 4(a) displayed on a cathode ray tube^{5,10}. This record is sometimes used for detailed accurate analysis but conversion of the data to recognizable form by manual or semi-automatic means is very time-consuming, about 200 hours for one minute's worth of original data.

One of the early (1957) automatic data processing equipments^{9,10} converted the histogram data recorded on 35 mm photographic film into a graphical or digital form. As the histogram recording camera and the multiplexing switch in the telemetry sender have poor speed stability, the length on the film corresponding to one switch cycle varies considerably. In order to simplify the design of the automatic data processing equipment, a special servo-controlled film printer was designed to give a positive from the original negative, with one switch cycle occupying a length on the film corresponding to four sprocket holes.

The automatic data processing equipment reads up to 6 data channels of the 23 in each switch cycle, moving automatically from one cycle to the next. A saw-tooth waveform on a cathode ray tube is optically projected on to the film. A photomultiplier behind the film gives a pulse of voltage as the image of the cathode ray tube spot sweeps in turn across the six chosen channels of the histogram film. Electronic circuitry combines the pulse and saw-tooth signals to give six output voltages proportional in amplitude to the six channels of the histogram. Subtle methods are used for correcting the non-linearities in the telemetry system. The output information is plotted as a graph and it can also be digitized to give data on punched cards for subsequent input to a digital computer. The output data rate is slow, only tens of data points/sec.

The equipment has not worked very satisfactorily, mainly due to imperfections in the film. This ingenious machine is hampered by using film as the playback medium, it is much easier to design a data processing equipment which accepts data as a voltage from magnetic tape.

Some of the telemetry systems described are used in missiles fired at the Woomera range in Australia. The responsible body, the Weapons Research

Establishment, began recording telemetry on magnetic tape in 1956. An automatic data processing equipment^{11,12,13,14} for playing back the telemetry data to give a digital output was developed by W.R.E. and began operation in the same year.

The telemetry data is recorded as a frequency modulation signal on a magnetic tape, known as the primary tape, and played back at one tenth real-time speed. The data is digitized and recorded as digits on magnetic tape, the secondary tape. The channels are not separated, so that a "digital histogram" is produced, coded timing data being inserted in place of the synchronizing channel. A digital computer accepts the secondary tape, corrects for non-linearities in the telemetry system, separates the channels, performs any other calculations necessary and then produces another digital tape, the tertiary tape. The tertiary tape is then fed into automatic graph plotters and printers for presentation of the processed data. The speed of the equipment which converts the data from the primary to the secondary tape is about 240 data points/sec.

The whole system relies on the use of one particular computer and neither the secondary nor the tertiary tape is in a form suitable for use by any user of the range on his own computer. To overcome this and other deficiencies the system is being replaced by a Mark II version which is similar in conception to BRAMBLE.

Another data processing equipment which converts the telemetry data on magnetic tape into a digital form on punched cards has been described¹⁵. The equipment employs a novel analogue-to-digital converter which corrects for non-linearities in the telemetry system. The buffer store used to assemble the data before feeding it to the card punch consists of relays, which limit the speed of operation to only 20 data points/sec.

Other data processing equipments which have been designed for the four telemetry systems could be described, but these are rather specialised and inappropriate to this paper.

4 DESCRIPTION OF BRAMBLE

4.1 Outline of system

The introduction of magnetic tape recording of telemetry helps the ranges operationally, as less complex equipment need be working during the firing of a missile. The use of magnetic tape also facilitates the playing back of the telemetry data into the BRAMBLE data processing equipment, which separates the

time-multiplexed channels to produce either a graphical record, or a digital output stored on punched cards or magnetic tape.

The telemetry data is recorded at the range as a frequency modulated signal on magnetic tape. A time code is also recorded so that the required parts of the magnetic tape can be automatically selected for data processing after perusal of the quick-look record. On replay the data processing equipment converts the frequency modulated signal into a voltage histogram (Fig.4(a)). Using the synchronizing channel for identification, any eight of the 23 data channels are demultiplexed to drive sample-and-hold circuits which give voltage outputs similar to those originally obtained from the appropriate eight transducers in the telemetry sender. A pen recorder produces a graphical record from any five of the eight being digitized, and so provides a convenient monitor on the performance of the equipment.

Each of the eight chosen data channels is digitized in turn and stored in a core store. The time of occurrence of each synchronizing channel is digitized and stored. The store empties into a card punch or a digital magnetic tape unit.

The analysis of the output of BRAMBLE is carried out by the user of the range on his own computer. Thus the output or outputs must be capable of input into many varieties of computers. Most users would be satisfied if cards and paper tape were provided but these are not particularly suitable media for the large quantity of data obtained from telemetry, magnetic tape can store far more data in a given volume.

Unfortunately there is no common magnetic tape format; each computer manufacturer defines queer standards which are particular to his own computer. We have attempted to solve this difficulty by using a digital magnetic tape which has a format similar to that of 5-hole paper tape. As most computers can accept paper tape or can easily be modified to accept paper tape, and the chosen magnetic tape unit is comparatively cheap compared with those usually associated with computers, this solution is practicable although not ideal.

4.2 Input magnetic tape standard

The subcarrier frequency of 465 telemetry varies between 130 kc/s and 180 kc/s. In order to reduce the tape speed necessary for recording the telemetry data, it is sensible to transpose the frequency band by 95 kc/s to give 35 kc/s to 85 kc/s. The lowest frequency is sufficiently far away from the upper limit of the data band and the highest frequency low enough to use a practicable recording speed of 60 in/sec. It was found essential to use staggered recording heads in order to reduce the cross-talk between tracks to

an acceptable value of 50 dB. The design of the data processing equipment was made easier by using servo-control of the tape on playback. The best possible transport mechanism was used in order to reduce the flutter of the tape speed to a minimum. In fact the machines are so good that electronic flutter compensation is seldom used, except at very low replay speeds.

The required specification for the tape recorder approached very closely to that proposed by the Inter-Range Instrumentation Group of the U.S.A., so their standard was adopted. The same standard is used at the Woomera range in Australia.

The allocation of the seven tracks on the $\frac{1}{2}$ -inch tape allows the recording of the data from four 465 telemetry senders, it is:

Head Stack 1

Track 1	System performance channel	(frequency modulation recording)
Track 3	Data channel B	(frequency modulation recording)
Track 5	50 kc/s reference frequency, composite timing and event signal	(frequency modulation and direct recording)
Track 7	Data channel D	(frequency modulation recording)

Head Stack 2

Track 2	Data channel A	(frequency modulation recording)
Track 4	50 kc/s reference frequency, speech, coded timing	(frequency modulation and linear recording)
Track 6	Data Channel C	(frequency modulation recording)

The magnetic tape is played back at different speeds depending on the nature of the data output medium. Usual speeds are real-time speed (60 in/sec) and one-eighth real-time speed ($7\frac{1}{2}$ in/sec).

4.3 Frequency-to-voltage converter

A block diagram of the equipment is shown in Fig. 3.

The frequency of the subcarrier obtained from one of the data tracks of the tape recorder is converted to a proportional voltage to give a "histogram" (Fig. 4(a)). Although it is possible to convert the frequency modulation data directly into a digital form by electronic counting of a reference frequency for a chosen number of data subcarrier cycles, and indeed this method is used in the W.R.E. telemetry converter^{11,14}, the apparently less accurate method of converting the data first to a voltage form and then to a digital form has been chosen for this equipment because of the disadvantages of direct conversion

from frequency to digits, which are:

- (a) No voltage output is available for the analogue recorder.
- (b) Period rather than frequency is measured, so the digital output is not directly related to the voltage input.
- (c) The cycles of the subcarrier that are chosen for controlling the reference frequency counter must be carefully arranged so that they do not include the transients caused by the telemetry switch moving from one multiplexed channel to the next. This imposes difficult requirements on the strobe pulses used to identify the channels.
- (d) The correction for the flutter of the magnetic tape is complicated by the need to multiply the frequency of the reference signal by at least 64 times, which tends to eliminate the flutter frequency components, with consequent inefficient compensation.

The replay tape speed is servo-controlled by comparing the 50 kc/s reference frequency recorded on tape with the 50 kc/s crystal oscillator in the simulator. This ensures that the replayed frequencies are correct and permits the 50 kc/s signal from that simulator to be used for setting up the equipment.

The signal from the magnetic tape is filtered by a bandpass filter, which at real-time speed has a bandwidth of 30 kc/s to 70 kc/s. The frequency-to-voltage converter is a pulse-averaging type, pulses of constant voltage "height" and time "widths", synchronous with the incoming frequency, being passed into a low-pass filter to give a voltage proportional to the input frequency. Both positive-and-negative-going cross-overs of the subcarrier signal gives pulses in order to obtain the minimum residual subcarrier output from the low-pass filter. The error due to the variation of amplitude of the input signal due to tape imperfections is reduced to a negligible quantity by a limiter having a dynamic range of 60 dB. The mean value of the pulse output is obtained by means of a filter with an approximation to a Gaussian response, to give the best compromise between output signal/noise ratio and response time. The output of the filter is amplified and off-set to give a voltage output of 0 to +50 V, equivalent to the input of 65 kc/s to 35 kc/s. The synchronizing channel frequency is off-scale, the synchronizing pulse being selected by other circuits. The frequency-to-voltage converters can be switched to cope with all required tape replay speeds.

The reference frequency recorded on the magnetic tape can be played back into a frequency-to-voltage converter to give an output proportional to the

flutter of the tape. This could be used to correct for flutter by the conventional subtractive or multiplicative methods. Simple subtractive compensation gives a slight improvement in accuracy at one-eighth replay speed, especially when servo-control of tape speed is used, and so has now been added as a routine feature.

4.4 Synchronizing selector and strobe generators

The synchronizing channel is separated from the data channels by a resonant circuit tuned to the synchronizing frequency. This method has the advantage over the more straightforward amplitude selection from the voltage histogram that it enables a narrower bandpass filter to be used prior to demodulation and so improves the threshold level. The synchronizing channel selector incorporates circuits for minimizing the production of false synchronizing pulses by data channels wandering outside their allocated band.

The synchronizing pulse is used to generate strobe pulses for demultiplexing the data channels. It triggers a linear time-base whose peak amplitude is remembered throughout the following switch cycle and is known as the reference voltage (Figs. 4(b) and 4(c)). Each channel strobe pulse (Figs. 4(d) and 4(e)) is generated by feeding the time-base and a proportion of the reference voltage to a separate voltage comparator for each channel. Individual potentiometers are used to select the appropriate proportions of the reference voltage so that each strobe is set to the middle of the flat top portion of the required channel. This method of strobe pulse generation compensates for moderate changes in the telemetry sender mechanical switch speed, as the reference voltage is equal to the peak amplitude of the previous switch cycle. There are advantages in this method over the conventional ring-counter method, because it is more tolerant of the variable positions of the samples caused by the mechanical nature of the switch, as each strobe can be set individually to the optimum position. Also it has a short recovery time of only one complete cycle in the event of a synchronizing failure, e.g. due to a radio frequency fade. The main disadvantage is that, if the full 23 strobes are required, then each has to be set individually, thus requiring a skilled and conscientious operator. Recent improvements in mechanical switch manufacture may make it worth considering a semi-automatic method for producing the strobes.

4.5 Sample-and-hold circuits

The eight sample-and-hold circuits are operated by the strobe pulses and each consists of a bi-directional diode gate which charges or discharges a

capacitor to the voltage level of the required channel (Figs. 4(d) to 4(g)). The capacitor is connected to a high input impedance (10000 M Ω) unity gain directly-coupled amplifier whose output is then fed to the digital equipment or to the analogue recorder. Each sample-and-hold circuit is adjusted so that gain and voltage offset error together are less than $\pm 0.05\%$ of the full scale of 50 V. Apart from the analogue recorder requirement, the advantage of separating the eight channels is that it allows the digital equipment to space these channels evenly over the whole switch cycle irrespective of their original positions, thus reducing the rate at which the voltage-to-digital converter must function.

4.6 Calibration correction circuits

The equipment was originally designed to correct for drift and sensitivity variations in the telemetry system if zero (0%) and full-scale (100%) calibration levels are transmitted by the telemetry sender. The two levels are separated by two of the eight sample-and-hold circuits and their difference is compared with a 50-V reference, the error is then used to control the gain of the frequency-to-voltage converter by varying the pulse "area". Drift is corrected by comparing the 0% channel with zero voltage level and the error added in antiphase to the histogram signal before demultiplexing. This method of correction has the disadvantage that the noise of the calibration channels is added to that of the data channels so that considerable filtering of the calibration channel outputs is necessary before being used for correction. Consequently the circuit does not recover quickly after a radio frequency transmission fade; matters are even worse if the calibration channel data is transmitted on submultiplexed channels. Because of this it is advisable to use digital methods of correction in the computer if possible.

As there has been little demand for the calibrated analogue records (see below) and in view of the above, these units will not be incorporated in the engineered version of the equipment.

4.7 Analogue recorders

In the original concept the analogue output was to have been a rather sophisticated graph with accurate scale lines and was to be immediately visible using xerographic techniques. It was hoped that a record of this type, with corrections for non-linearities and scale lines, would reduce the need for data to be processed in a computer. Unfortunately the cost of a xerographic recorder was prohibitive for this application, so a photographic recorder was made to check the system. A 16-channel electronic switch is used to multiplex,

at a rate of 10 kc/s, up to 11 horizontal scale lines and the telemetry data. The scale lines are sampled once, but the telemetry data is sampled five times, to give a heavier trace on the graph. Timing information is given by vertical scale lines, which are produced by timing pulses actuating on electronic change-over switch that causes the cathode ray tube spot to sweep across the tube in 3 msec. The cathode ray tube is brilliance modulated in order to prevent the switching transients being recorded and to increase the brilliance of the timing lines. The scale lines are set by means of 11 potentiometers fed from a 50 V source and can be placed anywhere between zero and 50 V so that non-linear scale lines can be recorded. The 50 V can be obtained from a fixed reference source or from the output of the sample-and-hold circuits driven from the zero and full-scale telemetry sender calibration signals. The latter method has the advantage that errors are reduced, but the disadvantage that a radio frequency fade in the telemetry link distorts the scale lines. Consequently the former method is usually used; the error is not appreciable with automatic calibration correction. Up to five information traces could be recorded on the same graph at the expense of reducing the contrast between the information traces and the scale lines; of course the scale lines would have to be common to all traces. The photographic recorder only gives a visible record after the delay of photographic processing. As no xerographic recorder is available, it is hoped that users will not require this graphical record and that the quick-look record or the digital output will satisfy them. There has been little demand for this record and so this form of output will not be provided in the engineered version.

Useful checking of telemetry tape is obtained by the use of a 5-channel pen recorder with a frequency response up to 25 c/s. The effective frequency response can be increased by replaying the magnetic tape at reduced speed.

A cathode ray tube monitor is provided, primarily for examining the histogram waveform and setting the strobos on their correct channels, but also for checking other parts of the equipment.

4.8 Replay speeds

Replay may be required at any speed from the real-time recording speed of 60 in/sec down to $1\frac{1}{2}$ in/sec, in binary steps, depending upon the output medium, the output format, and the telemetry sampling rate. The filters and some components in the frequency-to-voltage converters must be changed in order to cope with the different tape speeds. A relay-operated change-over system allows quick change between any two selected speeds. The filters and components

for these two speeds are made as plug-in units. This arrangement gives a reasonable compromise between the complexity of switching for all speeds and the time delay of changing plug-in units. The usual replay speeds are 60 in/sec for analogue records and $7\frac{1}{2}$ in/sec for digital outputs.

4.9 48 channel switch

For some applications more than 24 channels are required at a higher sampling rate than can be provided by the normal method of sub-commutation. To meet this requirement a 48 channel switch, rotating at a nominal 40 c/s is used; i.e. the total number of samples per second, and the channel width, is the same as for the 24 channel, 80 c/s switch. So that existing ground equipment can demultiplex and record the data, two synchronizing channels (numbers 1 and 25) are transmitted per switch cycle. In order to identify each half of the switch, channel 2 transmits the 35 kc/s calibration level and channel 26 the 65 kc/s calibration level.

The existing ground equipment at the ranges cannot separate the two halves of the switch cycle, e.g. if channel 2 is recorded on tube 3, of the 24 in x 30 in recorder, then so is channel 26 and similarly for the other channels; this fact should be taken into account when working out the sender channel allocations.

This limitation does not apply to BRAIBBLE - the strobe pulse, common to channels 2 and 26, operates a sample-and-hold circuit whose output consists of a square-wave with a level of approximately +50 volts for channels 2 to 25 and zero volts for channels 26 to 1. The square-wave, after passing through a Schmitt trigger to produce a waveform of fixed amplitude, is used to gate the outputs of the 24 strobe generators thus providing a total of 48 separate strobes at the input to the patch panel.

4.10 Timing data

The time code and the reference frequency signals played back from the magnetic tape are used to provide time data every telemetry synchronizing pulse for the digital output. Timing pulses having a frequency of 10 kc/s are derived from the 50 kc/s reference frequency signal and these, or 1 kc/s pulses from the time decoders, drive a counter which can be programmed to give a pure binary or a binary-coded decimal output. The latter output can give "seconds", or "minutes and seconds". The time counter can be set to any initial value and programmed to start counting when a signal is received from the time decoder.

At the first timing pulse succeeding a telemetry synchronizing pulse the time counter transfers the value of the time into a shift register to enable

any part of the number to be selected for transfer to a buffer store. The number can also be reversed, so that the most significant or the least significant bit emerges first from the shift register. A separate time difference counter is provided which is set to zero by each telemetry synchronizing pulse. This is a useful facility as time differences between successive telemetry synchronizing pulses can be recorded instead of the cumulative value, thus giving more economical recording of data on the digital output medium. When the digital data is subsequently analysed in a computer these time differences are added together to give the cumulative time. The time difference counter is arranged so that no cumulative error in time is produced.

The capacity of the time counter is 32 bits (with the least significant digit being one-tenth of a millisecond) or 28 bits (with the least significant digit one millisecond).

4.11 Voltage-to-digital conversion

Up to eight of the outputs from the sample-and-hold circuits are time-multiplexed by means of high speed relays to drive a voltage-to-digital converter. This is of conventional design, working by the subtraction of successive weighted voltages and detection of the resulting polarity. It has a maximum digitizing rate of 1000 data points/sec and provides a 10 bit pure binary output or a 12 bit 8-4-2-1 binary-coded decimal output.

In the engineered version, the internal logic rate will be such that a sample-and-hold value can be digitized in the period between strobes so that no multiplexer will be necessary, then any number of channels may be dealt with by a single sample-and-hold circuit, the upper limit being set by the core store capacity.

The digital output of the voltage-to-digital converter is transferred into a shift register before it is transferred to the buffer store. As with the time shift register, parts of the number may be selected or the number reversed. Another facility provided by this register is the subtraction of the offset for scale 3 in Table 1 below.

The output from the voltage-to-digital converter can be programmed to give three different types of scale:

Scale	Analogue input	Digital output
1	Negative	0
	0%	0
	+100%	500
2	-20%	0
	0%	100
	+100%	600
3	-20%	-100
	0%	0
	+100%	+500

Note that Scale 1 has the disadvantage of ignoring negative data and Scale 3 requires an extra bit of storage capacity for the sign. So far, users have only used Scale 2, and only Scales 1 and 2 will be provided in the engineered version.

4.12 Core store

The mean rate of flow of data from the telemetry magnetic tape is fixed once the playback speed and the number of data channels to be processed has been chosen. The maximum recording digit rate of the digital unit must of course be sufficiently fast to accept this mean input rate. With this proviso the digitized data could be recorded directly on a digital magnetic tape unit, but the spacing of the digital data along the tape would be variable, with consequent uneconomical storage on the tape and subsequent uneconomical use of the computer time. If the digitized data is being recorded on cards, a whole card's worth of data must be assembled before beginning the punching of a card, due to the construction of the card punch. Both of these facts indicate the need for a buffer store to allow the assembly of input digital data which is then transferred to the output units in bursts.

A magnetic core store has been chosen for this function as it is reliable and allows easy access to the stored data. It is divided into two equal blocks, each capable of storing 1080 bits (9 planes of 10 x 12 cores). This size of store was originally chosen to store one 80-column card's worth of information with one plane for parity check bits, although the store has not actually been used this way. Conventional methods of control of the store are used with a bit rate of 10 kc/s.

The store accepts the digital data from the telemetry and time-shift registers and also from the program to provide spaces on the punched cards where required. However, in the case of data for the magnetic tape unit,

computer control characters are inserted when the store empties into the unit in order to make the best use of the available storage capacity.

4.13 Loss of synchronizing signal

Occasionally the telemetry signal is lost due to a radio frequency fade, and there is no synchronizing pulse. This loss of synchronism is detected by the time difference counter which is programmed to produce a dummy synchronizing pulse at a time difference count of about $1\frac{1}{2}$ times the period of the telemetry mechanical switch. This pulse can be programmed to set the digitized telemetry data to an "impossible" value, or special characters can be inserted, so that the loss of synchronism can be detected subsequently by the computer. Even when synchronism is regained, normal functioning of the circuit is not resumed until at least two synchronizing pulses have been received, in order to allow the analogue circuits time to settle down.

This facility also prevents the time difference counter overflowing, as the dummy synchronizing pulse sets the counter to zero; this prevents errors in the subsequent cumulative time calculation in the computer.

4.14 Program and control

The program can be changed rapidly by means of two detachable plug-boards; spare boards being plugged to the required programs. These control the number representation of the telemetry and time data, the arrangement of the data on the card or magnetic tape, the position and type of computer control characters, and other similar functions.

4.15 Card punch

The cards are punched on an I.C.T. 80-column gang punch. The usual decimal punching of one hole per column is not used as this would seriously limit the speed of data processing. Binary or binary-coded decimal numbers are punched along rows or columns, a 12-bit binary-coded decimal number fitting conveniently into one column. Spaces may be inserted where required, provided not more than eight groups of spaces are required per row. When time differences are used, the cumulative time can be punched once on each card in order to give a means of identification of the card, or to allow the computer to detect any error in its calculation of cumulative time from the differences.

The maximum punching rate is 100 cards/min which limits the data rate to 75 telemetry data points per second, which is equivalent to a telemetry magnetic tape replay speed of $7\frac{1}{2}$ in/sec (one eighth real-time speed).

4.16 Digital magnetic tape unit

There is no doubt that magnetic tape is more economical than punched cards or paper tape for storing the large quantity of data associated with telemetry. The difficulty of finding a magnetic tape format which could be used with the majority of computers has already been mentioned. The final choice of the Honeywell magnetic tape unit is not ideal, for instance it limits the data processing rate, but at least it provides a tape format which allows input to almost any computer with simple modification.

The digital magnetic tape unit records digits with a packing density of 100 bits/in on eight tracks of the $\frac{1}{2}$ -in magnetic tape at a maximum speed of 10 in/sec. Five tracks record input data and the other three record two check bits and a parity bit. The tape unit has a reading head adjacent to the recording head; the former plays back and compares this data with the input data, and if it is correct, the next character (group of 5 bits) is recorded; if it is incorrect the check bits change from ones to zeros and another attempt is made at recording the character. On replay, the tape unit rejects the incorrect characters and only transfers the correctly recorded data to the computer. The parity bit gives a check on the replay of data.

Binary-coded decimal data is usually recorded with one decimal digit on four tracks, the fifth track recording:

- (a) all ones or all zeros,
- (b) either ones or zeros, the change taking place at nominated places with a maximum of eight changes per block of data (time and telemetry data can be identified by this method),
- (c) an odd or even parity bit.

Binary information can be recorded on four tracks with the fifth track providing the same facilities as for the binary-coded decimal numbers, or it may be recorded on five tracks with one telemetry data point conveniently filling two characters.

The core store limits a block to 1080 bits of time and telemetry data. Computer control characters are provided external to the store; four different such characters may be inserted in each block of data, indicating, for example, the start of a switch cycle or the start or end of a block. Between each block of data on the magnetic tape, occupying about 2 in, there is a gap of blank tape of about 0.15 in, being sufficient to allow the tape transport mechanism to stop and start without losing data on replay.

5 FLEXIBILITY

Obviously BRAMBLE can be used for the time-multiplexed data of the telemetry systems already described. However the equipment has flexibility, and the input data need not be time-multiplexed. For instance a continuous signal can be digitized at a constant rate up to a limit determined by the voltage-to-digital converter (1000 samples/sec) or the output digital unit (500 samples/sec for magnetic tape, 100 samples/sec for punched cards). The effective rate can be increased by playing back the analogue data at a speed lower than that at which it was recorded.

Frequency modulation signals recorded on magnetic tape can be processed provided the centre frequency is between 1 kc/s and 75 kc/s, and the maximum frequency deviation is between $\pm 10\%$ and $\pm 50\%$.

The input signal may be time-multiplexed provided an electrical pulse is available, or can be derived, to trigger the time-base circuits. The input is not limited to 24 time-multiplexed channels, any number between 1 and 48 can be processed.

It would be unwise to assume the capability of BRAMBLE from the short description given here, it is vitally important to discuss any processing problem with the designer or operator of the machine.

6 PERFORMANCE

The accuracy of the data processing equipment does not degrade appreciably the overall telemetry system accuracy of 1% rms of full-scale. The accuracy without the magnetic tape replay unit is about $\pm 0.2\%$ peak; with tape replay this becomes about $\pm 0.5\%$ peak, say 0.2% rms.

The analogue part of the equipment mainly uses valves, as some of the circuits are based on previous designs, and moreover valves have advantages in high impedance circuits such as the sample-and-hold. It is possible that transistors could now replace the valves. The digital part of the equipment uses transistors throughout.

The BRAMBLE equipment has successfully processed considerable telemetry data in the past few years. The reliability has been reasonably good but the breadboard construction leaves something to be desired; the equipment is now being engineered using conventional bought-in logical elements.

7 CONCLUSIONS

The development of a telemetry data processing equipment has been completed successfully. Not only has the equipment done good service operationally, but its development has been excellent training for scientists who have since applied their knowledge to other similar problems.

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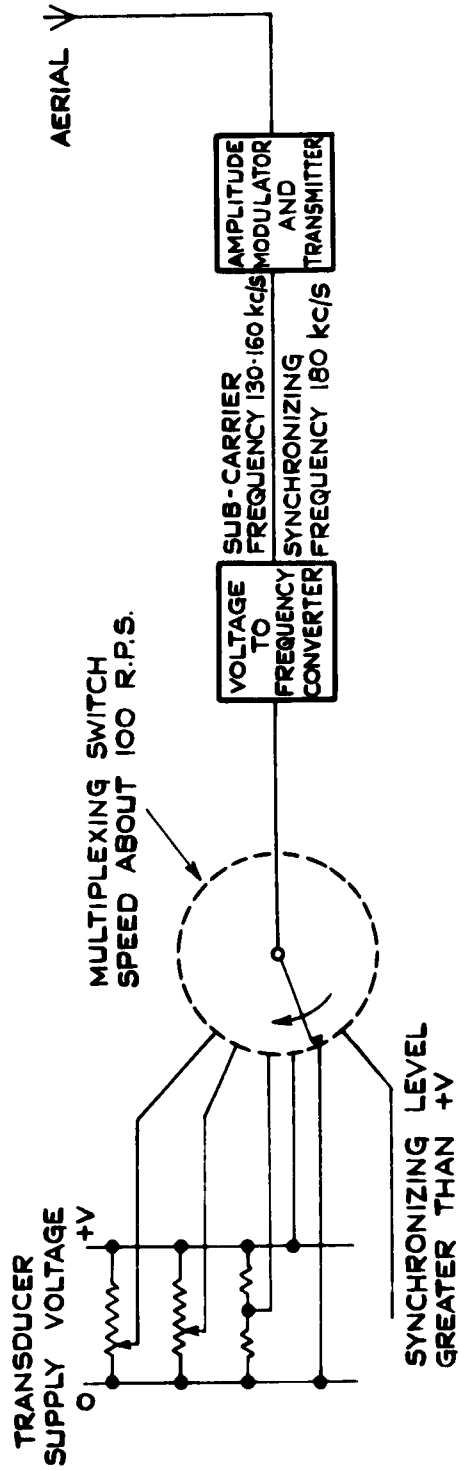


FIG.1 SIMPLIFIED TYPE 465 TELEMETRY SENDER

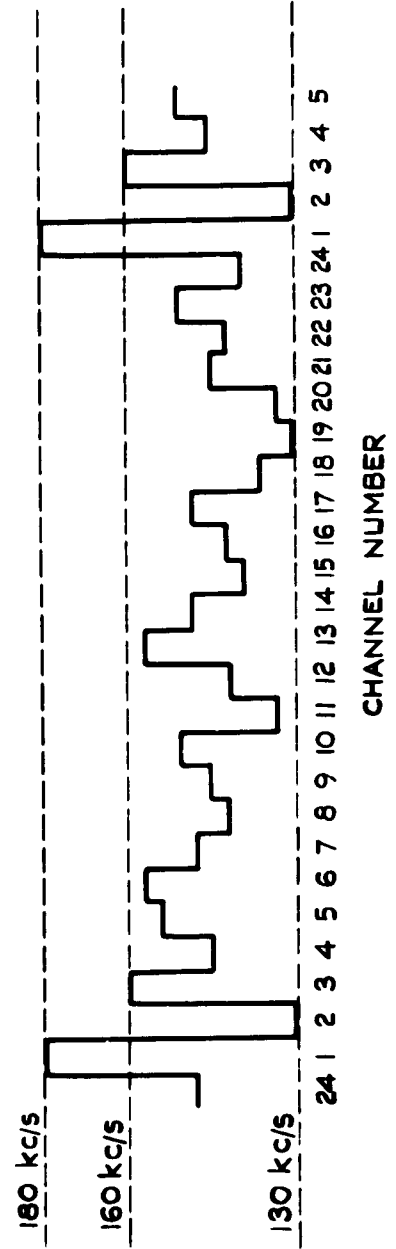


FIG.2 TYPICAL HISTOGRAM WAVEFORM

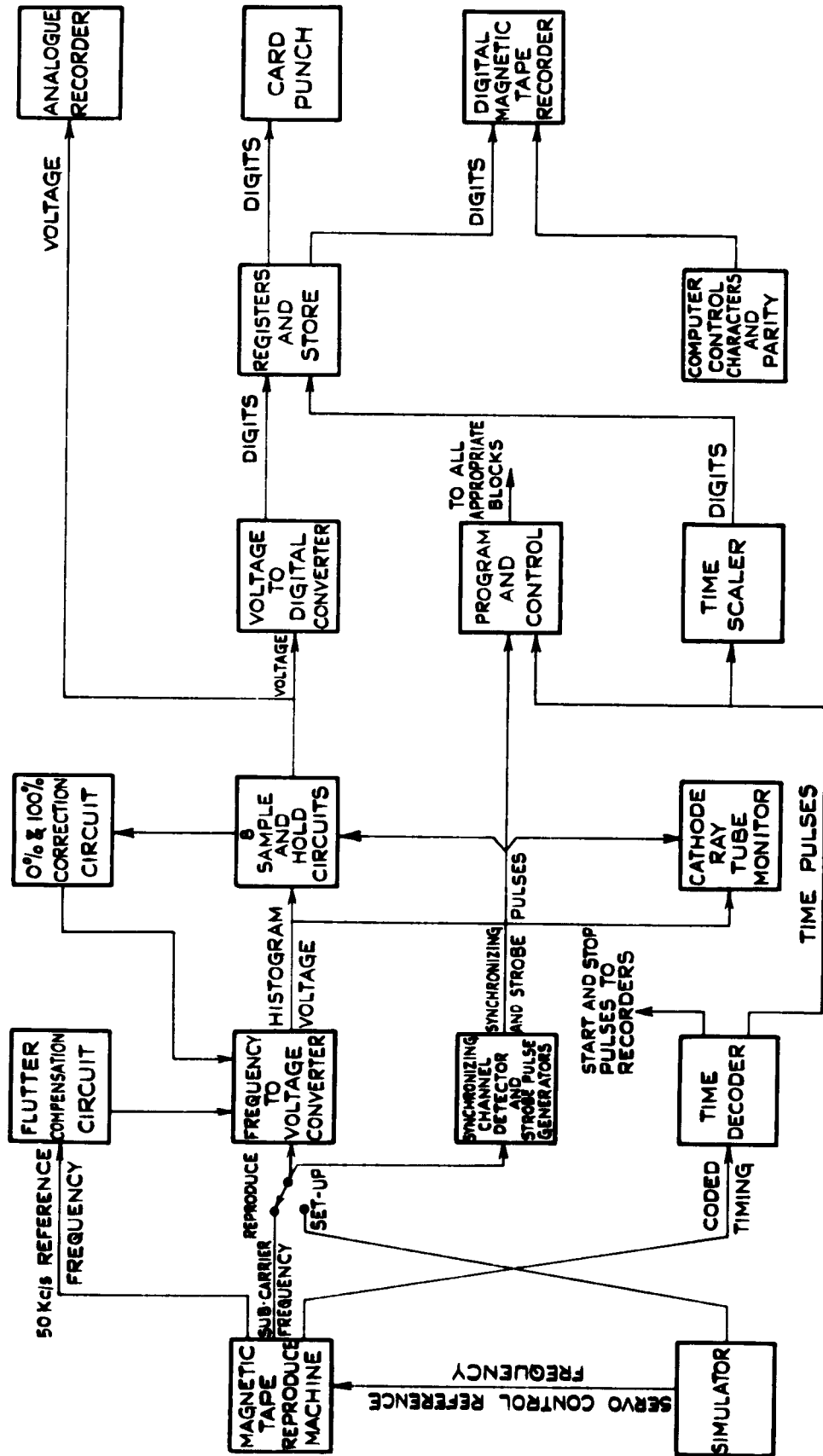
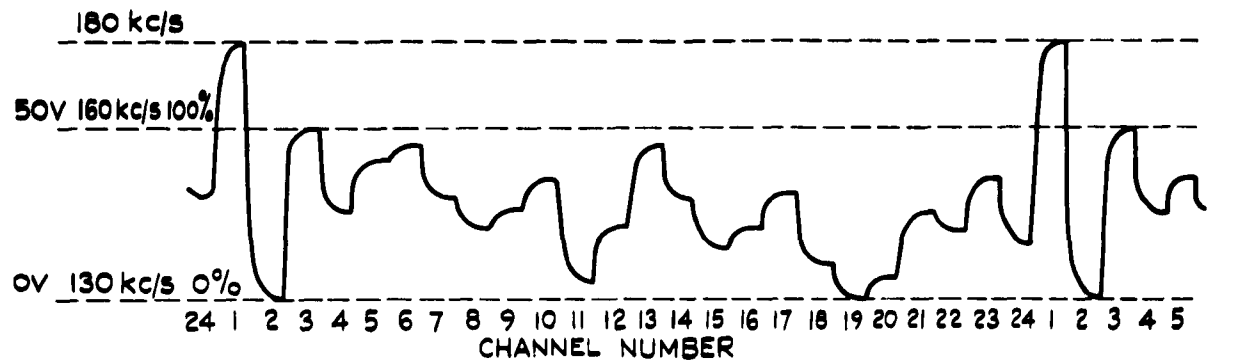


FIG. 3 BLOCK DIAGRAM



(a) OUTPUT OF FREQUENCY - TO - VOLTAGE CONVERTER



(b) OUTPUT OF SYNCHRONIZING CHANNEL DETECTOR



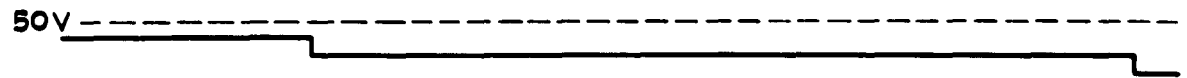
(c) TIME BASE AND REFERENCE VOLTAGE



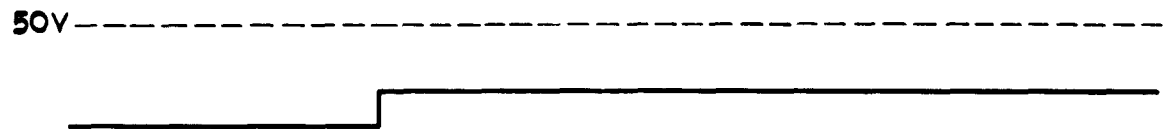
(d) CHANNEL 5 STROBE PULSE



(e) CHANNEL 7 STROBE PULSE



(f) CHANNEL 5 SAMPLE - AND - HOLD OUTPUT



(g) CHANNEL 7 SAMPLE - AND - HOLD OUTPUT

FIG. 4 (a - g) PRINCIPAL WAVEFORMS

<p>Mallett, E.S. Perkins, R.E. Knapp, H.W.P.</p> <p>BRANBLE - AN AUTOMATIC PROCESSING SYSTEM FOR TELEMETRY DATA.</p> <p>Royal Aircraft Establishment Technical Report 65053</p> <p>March 1965</p> <p>The processing of the large quantities of data associated with aircraft and missile trials can be eased by using automatic methods. An equipment is described which processes telemetry data recorded on magnetic tape giving a graphical record and digital outputs suitable for input to electronic computers.</p>	<p>629.19.097.1</p> <p>Mallett, E.S. Perkins, R.E. Knapp, H.W.P.</p> <p>BRANBLE - AN AUTOMATIC PROCESSING SYSTEM FOR TELEMETRY DATA.</p> <p>Royal Aircraft Establishment Technical Report 65053</p> <p>March 1965</p> <p>The processing of the large quantities of data associated with aircraft and missile trials can be eased by using automatic methods. An equipment is described which processes telemetry data recorded on magnetic tape giving a graphical record and digital outputs suitable for input to electronic computers.</p>
<p>Mallett, E.S. Perkins, R.E. Knapp, H.W.P.</p> <p>BRANBLE - AN AUTOMATIC PROCESSING SYSTEM FOR TELEMETRY DATA.</p> <p>Royal Aircraft Establishment Technical Report 65053</p> <p>March 1965</p> <p>The processing of the large quantities of data associated with aircraft and missile trials can be eased by using automatic methods. An equipment is described which processes telemetry data recorded on magnetic tape giving a graphical record and digital outputs suitable for input to electronic computers.</p>	<p>629.19.097.1</p> <p>Mallett, E.S. Perkins, R.E. Knapp, H.W.P.</p> <p>BRANBLE - AN AUTOMATIC PROCESSING SYSTEM FOR TELEMETRY DATA.</p> <p>Royal Aircraft Establishment Technical Report 65053</p> <p>March 1965</p> <p>The processing of the large quantities of data associated with aircraft and missile trials can be eased by using automatic methods. An equipment is described which processes telemetry data recorded on magnetic tape giving a graphical record and digital outputs suitable for input to electronic computers.</p>