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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

NRC TELEMETRY GROUND STATION FACILITIES FOR MAKING PAPER RECORDS

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OTTAWA

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ABSTRACT

Facilities used by the Radio and Electrical Engineering Division of the National Research Council to process data from rocket firings are described. The capabilities of the various types of recording and data-processing equipment used are discussed and some sources of error in analog paper recorders are pointed out.

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- J.K. Pulfer -

INTRODUCTION

Data from rockets fired into the upper atmosphere are usually recorded on analog magnetic tape. Many Canadian rocket users do not have the facilities for processing data in this form. The Radio and Electrical Engineering Division of the National Research Council has been supplying users with paper charts on which a variety of data can be recorded in analog or digital form [1, 2].

The information stored on an analog magnetic tape for a particular firing usually includes the following three types of information.

1) Telemetered scientific and engineering quantities measured by transducers carried by the rocket vehicle or ejected packages, as well as pre-flight and in-flight calibration data.

2) Auxiliary data describing the performance of the rocket vehicle, as well as data from airborne and ground station equipment, which is not obtained from sensors in the vehicle. Typical examples are: telemetry signal-strength levels, vehicle trajectories obtained from ground radar, or by other means.

3) Time reference in various forms, such as a tape recorder speed servo reference, a wow and flutter compensation reference, and time-of-day in coded form.

Facilities are available in our laboratories for reproducing the information on the tape and converting it to electrical signals having the following forms:

1) Continuous outputs from fixed and tunable discriminators with voltage amplitude up to ± 90 volts, and frequency components up to 10,000 c/s.

2) Quasi-continuous outputs from a decommutator with amplitudes of 0 to 40 volts, and frequency components from d-c to an upper limit which can vary from 5 to 2000 c/s.

3) Subcommutated information with frequency components up to 0.25 c/s in multiplexed form from the decommutator.

4) Digital information in parallel three-channel staircase or 12-channel binary coded decimal form at sample rates from 0 to 8000 samples per second.

5) Range timing information in digital code with markers at 0.5 second intervals, on a 100 c/s carrier, or at 0.01 second intervals on a 1000 c/s carrier.

6) Decoded timing markers at 0.1 second, 1 second, and 1-minute intervals.

The electrical signals can then be passed on to further analog or digital data-processing equipment, or to paper chart recorders. Paper records can be made with as many as 36 parallel channels, but in most cases no more than 8 are recorded simultaneously.

ANALOG DATA-PROCESSING EQUIPMENT

Data in analog form can be processed in several ways to make the measured quantities more easily available to the user. The following equipment is available.

1) Variable electronic high-pass and low-pass filters, as follows:

   a) One Spencer Kennedy, Type 302, dual-section filter, each section high or low-pass, 20 c/s to 200 kc/s, with 18 db/octave roll-off.

   b) Two Spencer Kennedy, Type 308A, dual-section filters, each section high or low-pass, 0.2 c/s to 20 kc/s, with 24 db/octave roll-off.

   c) One EMR, Type 95F, variable low-pass filter, 3 c/s to 10 kc/s, with 36 db/octave roll-off.

2) Fixed narrow-band tuned amplifiers and detectors situated on IRIG Bands Nos. 1, 2, 3, 4, 5, and 6 (400 to 1700 c/s).

3) One Interstate Electronics Corporation, PL104, phase-lock tracking filter. This filter is a narrow-band automatic tracking filter, tunable over the range from 0 to 120 kc/s with tracking bandwidths from 2 to 100 c/s. Amplitude and phase-demodulated outputs are available with low-pass bandwidths from 3 to 60 kc/s. An internal memory allows automatic scanning and re-acquisition if phase-lock is lost.

4) A Racal receiver, Type RA17, with low-frequency converter, Type RA37B, and single-sideband adapter, Type 63B. This receiver is used as a general-purpose tunable narrow-band filter, a frequency shifter, and an AM detector, for manipulating signals in the range from a few kc/s to 30 mc/s. The principal frequency range used is from 5 kc/s to 120 kc/s to deal with signals recorded within the 100 kc/s passband of the tape recorder.

5) A Raytheon Rayspan spectrum analyzer. This analyzer operates by commutating the outputs of 100 narrow-band filters covering a 300 c/s frequency range. A converter ahead of the filters allows the operator to monitor any 300 c/s portion of the band from 0 to 10 kc/s. The filters are scanned at a fixed rate of 30 scans per second. Bandwidths of individual filters are 3 c/s.

These analog data-processing facilities may be combined with the variable speed feature of the playback tape recorder and tunable discriminators to handle a large variety of signal types and bandwidths.

DIGITAL DATA-PROCESSING EQUIPMENT

Equipment is under construction which is designed to manipulate the digital data obtained from the analog-to-digital converter, change its format, interleave time and other auxiliary information, and punch out the result on 8-channel paper tape. More detail on the capabilities of the digital processing equipment will be available in a later report.

PAPER RECORDING FACILITIES

The following paper recorders are available:

Consolidated Electrodynamics

Recording Oscillograph, Type 5-119

This recorder uses optical galvanometers and photographic paper 12 inches wide. Facilities are available for developing and fixing the paper in lengths up to 400 feet. The recorder is capable of handling up to 36 parallel channels, but ground station facilities can make use of only 19 channels, except in unusual circumstances. The following paper speeds are possible: 0.16, 0.25, 0.40, 0.64, 1.0, 1.6, 2.5, 4.0, 6.4, 10.0, 16.0, 25.0, 40.0, 64.0, 100 and 160 inches per second . Galvanometers are available with frequency response up to 3000 c/s. For deflections less than ±2 inches, the linearity of the recorded trace deflection is better than 1%.

Sanborn Direct-Writing Optical

Oscillograph, Model 650

This recorder operates on the same principle as the Consolidated Electrodynamics recorder described above. Paper width is 8 inches, and continuous records up to 350 feet long can be made. Either quick-look temporary or developed and fixed records can be made. Galvanometers are available with frequency response up to 3000 c/s.

The recorder is capable of handling up to 18 parallel channels, but paper width and ground station facilities make the use of more than 7 or 8 undesirable.

Recording speed can be rapidly adjusted to the following values: 0.25, 0.5, 1.0, 2.5, 5.0, 10.0, 25.0, 50.0, and 100.0 inches per second.

Sanborn Recorder, Model 154-5470

This instrument is a relatively slow-speed recorder. It produces a rectilinear trace by using a hot-wire pen to burn the paper as it is drawn over a knife edge. Frequency response is flat from d-c to 30 c/s, so it is adequate for commutated data, or for single-channel records from subcarrier channels which have been divided down in frequency by lowering the tape speed. Two pens and a locally generated timing signal are available. Paper speed is adjustable from 0.25 to 100 mm/sec or approximately 0.01 to 4 inches/sec.

Offner Dynograph Recorder, Model 504A

This recorder provides eight parallel channels of low-accuracy low-speed data. It is ideal for most of the decommutated information. Frequency response of each channel is approximately 0 - 140 c/s, and deflection of the pens is such that quantities can be scaled to an accuracy of approximately ±2%. Paper speeds from 1 to 250 mm/sec are available. Finished records are on heat-sensitive paper.

ACCURACY

As the quantity to be telemetered passes through each stage between the measurement in the vehicle and the paper record on the ground, errors are introduced in various ways. A discussion of the sources of error and their magnitudes for a typical FM-FM system is given in NRC Report ERB-653.

Errors arise in chart recorders owing to two principal causes:

1) The displacement of the trace on the paper is only a quasi-linear function of the applied voltage or current.

2) A filtering error is introduced because of the inability of the recorder to respond to rapid changes in signal.

Nonlinearity arises for various reasons. In the optical recorders, trace displacement is proportional to the tangent of the angle of rotation of a galvanometer, which, in turn, is approximately linearly proportional to the current through it. Error is introduced therefore because the approximation $\tan \theta = \theta$ breaks down for large values of θ. Most "knife edge and stylus" recorders have the same source of error.

Table I gives the results of some linearity measurements on optical recorders. It is only in the case of the relatively large deflections obtainable from the optical recorders that the nonlinearity of the deflection is large enough to be measured easily by scaling.

TABLE I

ERRORS DUE TO NONLINEAR DEFLECTION IN OSCILLOGRAPH RECORDERS

	Peak-to-Peak Deflection (inches)	Error (%)
Type 5-119 Oscillograph (12" paper)		
a) 350 c/s Galvanometer	3	±0.5
	5	±1.5
	9	±2.5
b) 600 c/s Galvanometer	6	±0.3
	8	±1.8
	10	±3.6
c) 1200 c/s Galvanometer	2	±0.6
	4	±0.8
Type 650 Oscillograph (8" paper)		
a) 300 c/s Galvanometer	4	±0.1
	8	±0.5

The second form of error is that due to pen response time. Most galvanometers are damped by either electrical or mechanical means, so that the response to a step function input can be adjusted to a minimum of overshoot without seriously affecting the high-frequency response. Fig. 1 shows the frequency of response of some of the galvanometers used in the Sanborn optical oscillograph.

A complete set of curves showing step responses for various galvanometers, with and without damping, driven from low-pass filters of various telemetry bandwidths is available in the form of a file at the ground station. The effect of any given galvanometer on a waveform can then be easily estimated.

The effects of pen response and nonlinearity can be completely removed by converting the analog signals to decimal staircase digital form, and recording the resulting waveforms on paper charts. New errors are introduced, however, by the sampling process and, in addition, the pen response must be quite high relative to the rate of change of the signal in order that it can follow the staircase waveform unambiguously.

Recording the staircase waveforms on pen recorders is satisfactory for relatively slowly changing signals. For rapid signals, however, it is necessary to slow down the data, either in digital or analog form, before making records.

USER REQUESTS FOR RECORDS

In order to keep a record of the number and type of paper charts supplied to the various users, a standard request form has been drawn up. This form satisfies the dual function of supplying the ground station operator with all the information needed to make the record, and of keeping a file of requests. A replica of the form is shown in Fig. 2.

RADAR DATA

In addition to the data on analog magnetic tape, the Range also supplies radar data in the form of a copy of the plotting table sheet which gives the position of the rocket in terms of height and range by a succession of points at regular time intervals.

A computer program has been written which enables this information to be reduced to a more usable form. The individual plots are read from the chart with a Benson-Lehner Oscar reader which automatically punches IBM cards with time, height, and range.

The program used to process this data computes an average position at regular intervals and from these values, the horizontal and vertical velocities

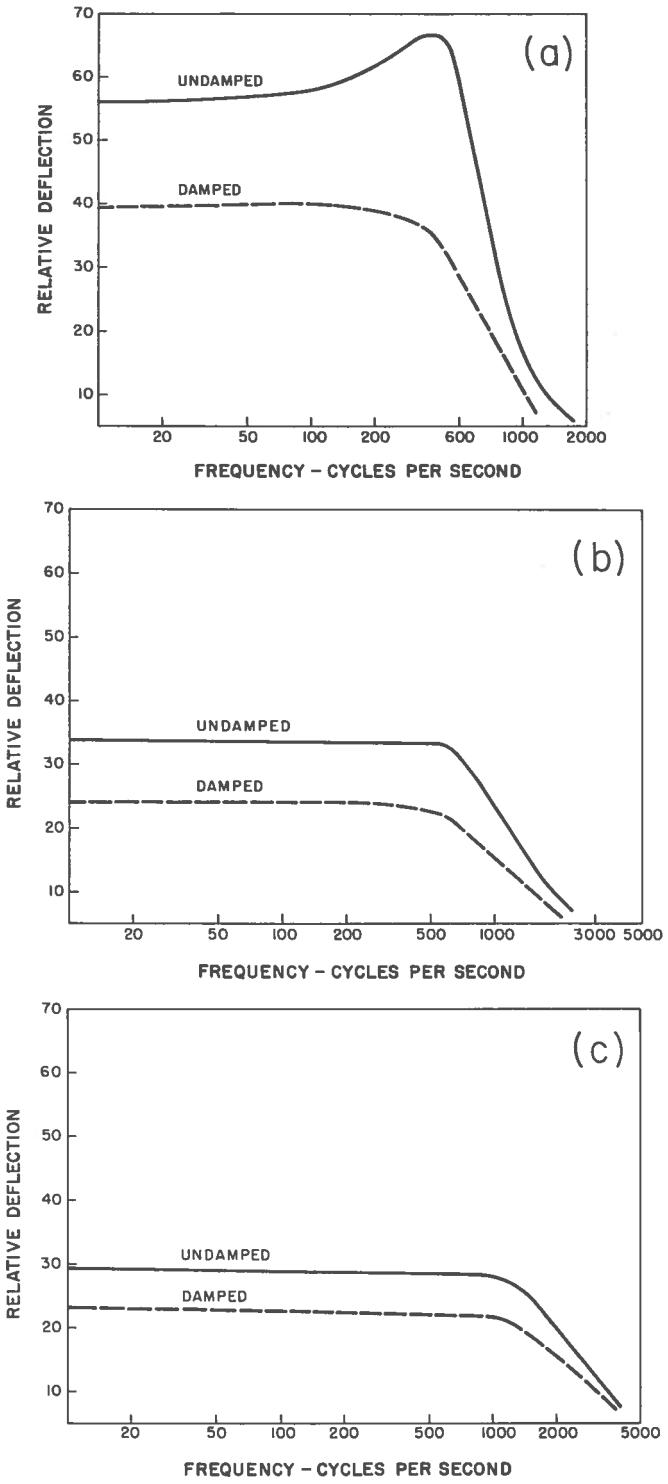

Fig. 1 Frequency response of typical galvanometers in the Sanborn optical oscillograph: (a) 350 c/s galvanometer, (b) 600 c/s galvanometer, and (c) 1200 c/s galvanometer

REQUEST FOR ANALOG PAPER RECORDS

A request form should be filled out for each paper record required. The following information is necessary:

(1) Rocket Number . . . . . .

(2) Source of Magnetic Tape Record (main telemetry, back-up, etc.) . . . . . .

(3) Paper Speed. . . . . .

A range of paper speeds from approximately 0.1"/sec. to 100"/sec. is available.

Please specify desired times for starting and ending the paper record, as well as any speed changes during the flight if desirable . . . . . .

. . . . . .

. . . . . .

TIMING INFORMATION

Specify which of the following are required:

- ☐ Slow range time - two pulses per second.
- ☐ Fast range time - 100 pulses per second.
- ☐ Timing markers - non-synchronous with range time.
- ☐ Timing grid - non-synchronous with range time.

DATA

The following information is required for each channel on the paper record. The tracks on the paper will be placed in the order shown below. A maximum of nine parallel records (including timing) is possible.

PEN	SUBCARRIER FREQUENCY	COMMUTATOR CHANNEL	PEAK-TO-PEAK GALVANOMETER DEFLECTION
1			
2			
3			
4			
5			
6			
7			
8			
9			

NAME & LOCATION OF PERSON REQUESTING RECORD: _____

_____

DATE: _____ _____

FIG. 2

from point to point. In addition, a best-fit parabola is determined for the data above 200,000-foot altitude (essentially free-fall conditions) and the computed positions for 5-second intervals are listed. To date this amount of reduction appears to be all that is required, but the program could be extended should demand warrant.

This information is also used to draw a trajectory plot showing the height-range relationship and giving the time of the rocket at 40,000-foot intervals and at apogee. These plots are distributed to all experimenters.

CONCLUSIONS

This report has described the facilities available at the Radio and Electrical Engineering Division of the National Research Council, which are presently being used for processing data from rocket and balloon flights. Particular emphasis has been placed on the portion of the facility which handles data in analog form, and the equipment used to produce paper chart recordings. Other equipment from within the Radio and Electrical Engineering Division is used from time to time as required.

Facilities for processing rocket telemetry data are also utilized by a number of other government, military, and university laboratories in Canada, in addition to the excellent ground station at the Churchill Research Range. Our data-reduction equipment has been chosen to complement these other facilities wherever possible, in addition to meeting the basic requirements of a telemetry ground station.

ACKNOWLEDGMENT

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REFERENCES

1. Payload Preparation for Research Rockets, NRC Report ERB-680, p. 1, July 1964
2. Ibid, pp. 21-26