NASA TECHNICAL NOTE

NASA TN D-4161

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NASA TN D-4161

METHOD OF ANALYZING DYNAMIC DATA CHARACTERIZED BY A TIME-VARYING FREQUENCY SPECTRUM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1967

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SUMMARY

Many research areas are generating dynamic data whose frequency spectrum changes as a function of time, as is characterized by the data generated in the rocket-engine combustion instability program. From these data the instantaneous frequency spectrum at specific times during the test must be determined. Previous methods used in reducing these data were unsatisfactory; therefore, a different reduction method was required. A system was developed that produces a series of time history records from which the instantaneous frequency spectrum is determined.

INTRODUCTION

The need for reduction of dynamic data has increased greatly in recent years. With the required increase in size, reliability, and complexity of propulsion systems and space vehicles, a more thorough understanding of the dynamics of systems and system components is necessary. There are two general categories of frequency spectra that may be produced during an experiment. One is the stationary spectrum where the data frequencies and their amplitudes do not change during the experiment. Several types of commercial equipment are available to analyze this type of spectrum.

The second category is nonstationary in time and may have either or both the frequencies and their amplitudes changing during the test period. This report discusses a technique for the analysis of this type of dynamic data. The problems of data reduction for a rocket-engine combustion instability program prompted the initial investigation. In the study of rocket instability, recordings were made of the varying chamber pressure, and an instantaneous frequency spectrum at specific times during each test was required. This type of data analysis may be useful in studies of vibration analysis, accoustical engine noise, system dynamics, and jet-engine combustion instability.

Analysis of nonstationary data is more difficult for two reasons. First, the volume of data is much greater since the frequency-amplitude information must be continuously analyzed throughout the experiment. Second, data analysis is more difficult since great care must be taken to ensure that all the frequency-amplitude elements of each spectrum represent the same instant of time during the experiment.

Previous methods of reducing this type of data lacked accuracy in either amplitude or time definition of the frequency spectrum. It was, therefore, necessary to develop a method of reducing this time-varying frequency data in a manner that was not only rapid but also accurate in amplitude, frequency, and time definition. The system described herein automatically produces a record of the time history of selected frequencies so that an instantaneous frequency spectrum can be obtained at any specified time during the test.

CHARACTERISTICS OF DATA

A typical plot of the raw data produced in the rocket-engine combustion instability study (fig. 1) shows the chamber pressure variations plotted against time. The original data were recorded on analog magnetic tape using frequency modulation techniques at 60 inches per second (152.4 cm/sec) and were reproduced in real time (60 in./sec (152.4 cm/sec)) and plotted by a recording oscillograph with a paper speed of 4 inches per second (10.16 cm/sec). Because it is difficult to observe any of the detail in the raw data, expanded plots were made at intervals A, B, and C, as is shown in figure 2. In the expanded plots the tape-reproduce speed was reduced to $3\frac{3}{4}$ inches per second (9.525 cm/sec) and the recording oscillograph paper speed was increased to 80 inches per second (203.2 cm/sec), which gave a time multiplication factor of 320 times that of the plots in figure 1. As shown in the expanded plots of the raw data (fig. 2), frequency changes as a function of time and also some frequencies present in one plot are not present in another. These observations indicate that the general characteristic of the data is that the frequency spectrum changes as a function of time. The information required from the data is frequency, amplitude, and time. Because of the complex characteristic of the data and the difficulty and time required to develop the required information manually, it is obvious that the data must be reduced in an automatic and more meaningful manner.

While the data used as an example of characteristic data were those of the rocket-engine combustion instability study, other research areas, such as vibration analysis, system dynamics, etc., generate data of this nature (i.e., data whose frequency spectrum changes as a function of time).

OTHER METHODS OF REDUCING DATA

Various methods have been used and proposed for the reduction of this type of data; the results have not been completely satisfactory. Included in these methods are the use of a comb filter and the digitizing of the raw data with subsequent digital computer processing. These methods and their results are discussed separately.

Comb-Filter Method

Previously data were reduced by the use of a commercial comb filter, whose specifications are listed in appendix A. This filter consisted of a series of contiguous narrow bandwidth filters mounted around a commutator stator. The input signal was applied simultaneously to all the filters, and the motor-driven commutator rotor then sampled the output of the filters sequentially. The sampled filter outputs, along with a synchronization pulse, were then amplified and made available for recording by an external readout device. This unit, because of its fixed sampling rates and fixed number of filters and filter bandwidths, did not provide an acceptable system. Because of the cost of modification and the inflexibility, it was decided to abandon this approach.

Digital Computer Method

Digitizing of the raw data with subsequent digital computer processing was contemplated, and an investigation was made to determine the feasibility of this method. It was decided that because of the required sampling rate, the total number of samples, the complexity of the computer program, and the anticipated computer load, which would be excessive, this method would be too time consuming and costly and, therefore, could not be justified.

DESCRIPTION OF NEW METHOD

Because of the disadvantages associated with the methods described, it was decided to develop a system that would satisfy the requirements of being inexpensive, reasonably rapid, and capable of producing the required quantitative results.

Frequently, as previously mentioned, the information required from the raw data is the instantaneous frequency spectrum at specific times during a test. Therefore, it was decided to generate an amplitude time history of selected frequencies and, in this manner, to produce a series of records from which the instantaneous frequency spectrum could be determined. A time history plot is a record with the amplitude of one frequency component plotted against time. A typical time history plot for a single frequency is shown in figure 3. The top trace is the raw data, which is plotted for reference purposes; the middle trace is the amplitude record of the selected frequency component; and the bottom trace is the time, originally recorded along with the raw data, which is plotted for time correlation purposes. A complete time history consists of a number of individual records of the selected frequency components. The instantaneous frequency spectrum can be determined for any desired time by examining each record of the complete time history at a specific time and then plotting the corresponding amplitude against frequency. An example of this method is shown in figure 4, where the traces (fig. 4(a)) are a time history of the raw data, contained in the frequency range of 3.0 to 3.7 kilohertz. (The raw data and time plot usually plotted on each time history record have been eliminated here for clarity.) Figure 4(b) shows the instantaneous discrete frequency spectrum determined at times A, B, and C from the time history records.

The method used to generate the time history record is to pass the raw data through a bandpass filter at the selected frequency and record the filter output along with the other necessary information. A complete time history consists of a number of such individually generated records whose selected frequencies are separated by the bandpass of the filter through which the data are passed.

DESCRIPTION OF SYSTEM

The system developed to generate the complete time history automatically (see fig. 5) consists of an analog loop tape handler, a tape search unit, conditioning amplifiers, a recording oscillograph, a frequency-tuned bandpass filter, an externally controlled oscillator, and a control logic unit. The analog loop tape handler, the tape search unit, the conditioning amplifiers, and the recording oscillograph are standard data-processing devices that are used to process analog data.

The frequency-tuned bandpass filter is a commerically available device. The manner in which it is used is the unique feature of this system. It was originally designed to be used as a sweep-frequency analyzer; however, in this application, it is used as a stepped-frequency analyzer and is tuned in discrete frequency steps for each pass of the tape loop. Features that led to the selection of this unit include its use of plug-in crystal filters with sharp bandpass characteristics, that it is electronically tuned (rather than mechanically), its built-in calibration unit, and that it was readily available at minimal cost. A detailed list of specifications of the frequency-tuned bandpass filter and a description of the operation of the unit are given in appendix B.

The oscillator is also a commercially available device and was selected because it is very stable (0.01 percent short-term drift), is capable of having the desired frequency selected remotely, and produces the selected frequency within 2 milliseconds after command. The last two features were essential because they made the device readily adaptable to being integrated into an automatic system, which was necessary because of manpower and time considerations.

The control logic unit was designed and fabricated at Lewis and performs all the necessary control functions required in the generation of a complete time history. The operating controls include start frequency, stop frequency, incremental frequency, and start and stop. Also included are reset and load controls and a readout that displays the particular frequency component being analyzed. The system was calibrated by processing data of known characteristics, and the overall accuracy is within 2 percent.

Procedure

The procedure for generating the complete time history is to place the tape loop on the tape handler, select the start time (time on tape when the frequency is to be incremented) on the tape search unit, select the start frequency, stop frequency, and incremental frequency in the control logic unit, and then start the system. The tape search unit generates a coincidence signal when the time recorded on tape equals the start time. The amplitude of the first frequency component for the full period of the tape loop is recorded by the recording oscillograph, which was started at the same time. Each time the coincidence pulse is generated the oscillator is increased by the incremental frequency value, and the new frequency component is analyzed. This operation continues until the stop frequency component is reached, after which the tape handler and the recording oscillograph stop. In this manner, the complete time history is generated automatically with a minimum of operator intervention.

System Output

As previously explained, the system output is a series of records from which the instantaneous frequency spectrum is determined. This satisfies the requirement of being able to determine the instantaneous frequency spectrum; however, the output requires manual time correlation.

This requirement can be eliminated by digitizing the individual time history records and having the time correlation performed by a digital computer which could then produce a plot of the instantaneous frequency spectrum. The required sampling rate, the amount of computer memory, and the complexity of the computer program for this operation is greatly reduced from that required for the complete processing of raw data.

CONCLUDING REMARKS

A means of determining the instantaneous frequency spectrum at specific times during a test of data whose frequency spectrum changes as a function of time was required. The method decided on was to generate a series of amplitude time history records of the frequency components, from which the required information could be determined. A system was then developed to generate the amplitude time history records. The system is automatic and accurate, produces quantitative results, and consists of standard data-processing devices with the exception of the control logic unit which was designed and fabricated at Lewis.

The system is capable of reducing any data whose frequency spectrum changes as a function of time, even though the example used in discussing the characteristic data was from a specific test program. The output, if digitzed, can be reduced and plotted in its final form by a digital computer.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 20, 1967
124-09-05-03-22.

APPENDIX A

SPECIFICATIONS OF COMB FILTER

The specifications of the commercial comb filter described in this report are given in the following listing:

Frequency ranges, depending on frequency of translating oscillator, Hz	20 - 3372; 3372 - 6724; [a]6724 - 10 076
Frequency response over operating frequency band, db	±3
Dynamic range, db	40
Linearity, db	±1.5
Sensitivity for best operation, mV	0.25 to 250
External oscillator voltage, V (rms)	7
Output, V (peak)	40
Filter bandwidth, Hz	10
Filter frequency range, Hz	84 700 to 88 052
Filter spacing, Hz	8
Filters, total number	420
Commutator speed;	
rpm	1800 or 3600
scans/sec	30 or 60
Commutator direction	low to high frequencies

[a]Any 3352-Hz band between 20 and 20 000 Hz with an external oscillator.

APPENDIX B

THEORY OF OPERATION OF FREQUENCY-TUNED BANDPASS FILTER

A block diagram used in describing the basic operation of the frequency-tuned bandpass filter is shown in figure 6. The output frequency f_t of an external oscillator, used for tuning the unit, is mixed with the output freqeuncy (100 kHz) of the internal oscillator in a carrier converter. The carrier converter produces an output frequency that is the sum of the tuning frequency and the reference oscillator frequency, 100 kilohertz + f_t. This frequency is then heterodyned with the input signal in a balanced modulator. The output frequency of the balanced modulator is (100 kHz + f_t) $\pm f_s$, which is applied to the input of the crystal lattice filter. The center frequency of the crystal filter is exactly equal to the reference frequency, 100 kilohertz. Thus, when a frequency component of the input signal f_s is equal to the tuning frequency f_t, one of the output frequencies of the balanced modulator will be equal to 100 kilohertz. This 100-kilohertz signal, which is directly proportional to the amplitude of the frequency component that is equal to the tuning frequency, is then passed through the crystal filter. The output of the crystal filter is rectified and filtered and results in an analog representation of the amplitude of the frequency component that is equal to the tuning frequency. Varying the tuning frequency f_t has the apparent effect of varying the center frequency of the crystal filter. In this manner, the frequency-tuned bandpass filter is electronically tuned.

The specifications of the frequency-tuned bandpass filter are presented in the following listing:

Frequency range, Hz . . . . 2 to 25 000
Useful frequency range, Hz . . . . 1 to 30 000
Frequency response, db:
  From 1/2 bandwidth to 10 kHz . . . . ±0.25
  At 25 000 Hz . . . . -1
Dynamic range, db 60
Linearity, db . . . . ±0.25
Sensitivity, full scale, V . . . . 0.001 to 1000
Input impedance, mΩ 1
Minimum tuning signal required (sinusoidal with less than
  5 percent distortion), V (rms) 0.2
Selectivity
  Standard bandwidths, Hz . . . . 2, 5, 10, 20, 50, and 100
  Nominal shape factor (60 db/3 db bandwidth) . . . . 4 to 1 (or 30 db/bandwidth octave)
Calibration reference . . . . Internal
Maximum output (adjustable), V (rms) . . . . 10 V into 10 kΩ load

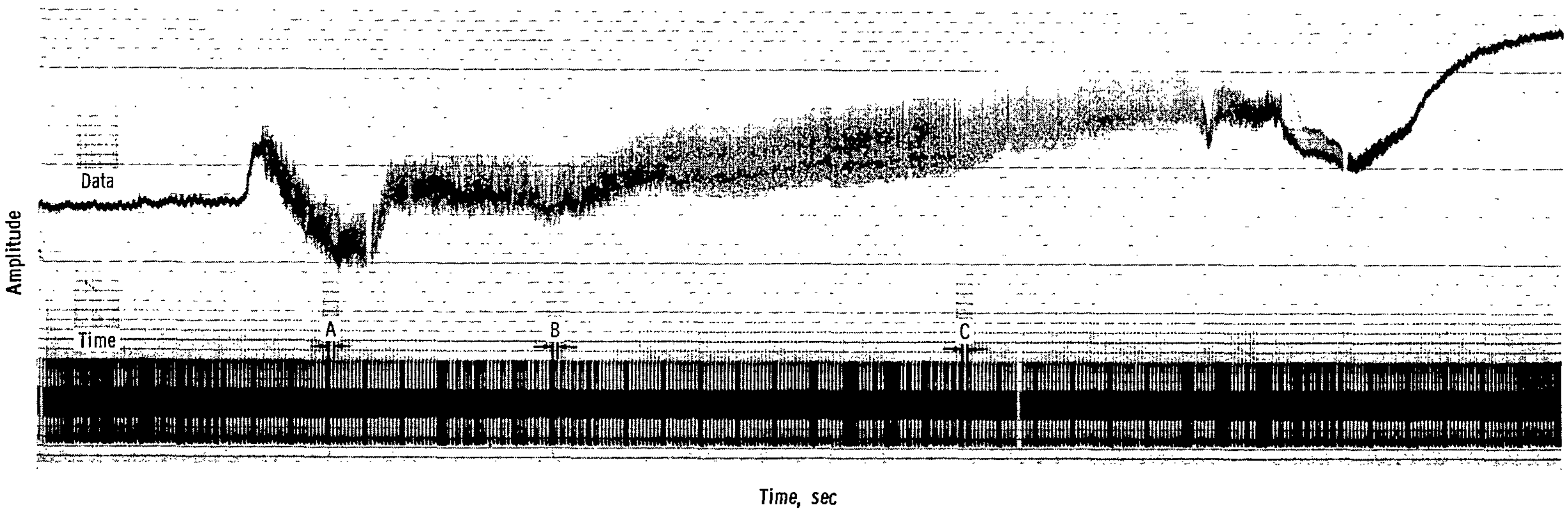
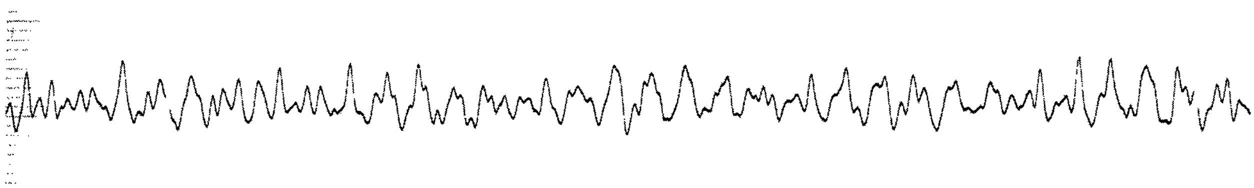
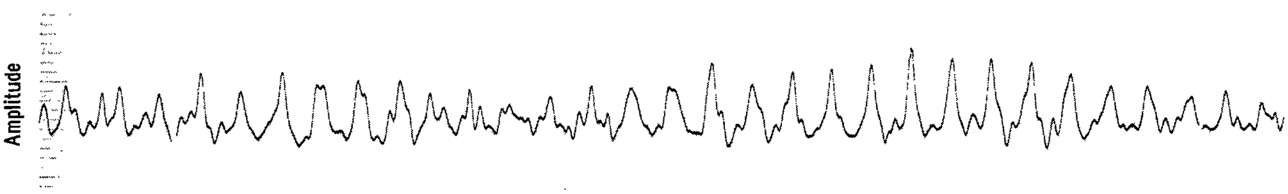


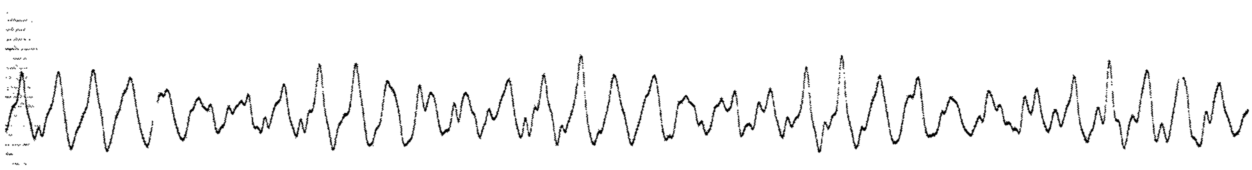
Figure 1. - Typical data plot. Recording speed, 60 inches per second (152.4 cm/sec); reproducing speed, 60 inches per second (152.4 cm/sec); recording oscillograph speed, 4 inches per second (10.16 cm/sec).



(a) Time, 38.79 seconds (interval A).



(b) Time, 39.39 seconds (interval B).



(c) Time, 40.49 seconds (interval C).

Time, sec

Figure 2. - Expansion of typical data plot at intervals A, B, and C. Recording speed, 60 inches per second (152.4 cm/sec); reproducing speed, 3-3/4 inches per second (9.525 cm/sec); recording oscillograph speed, 80 inches per second (203.2 cm/sec). Time elapsed approximately 1/100 second.

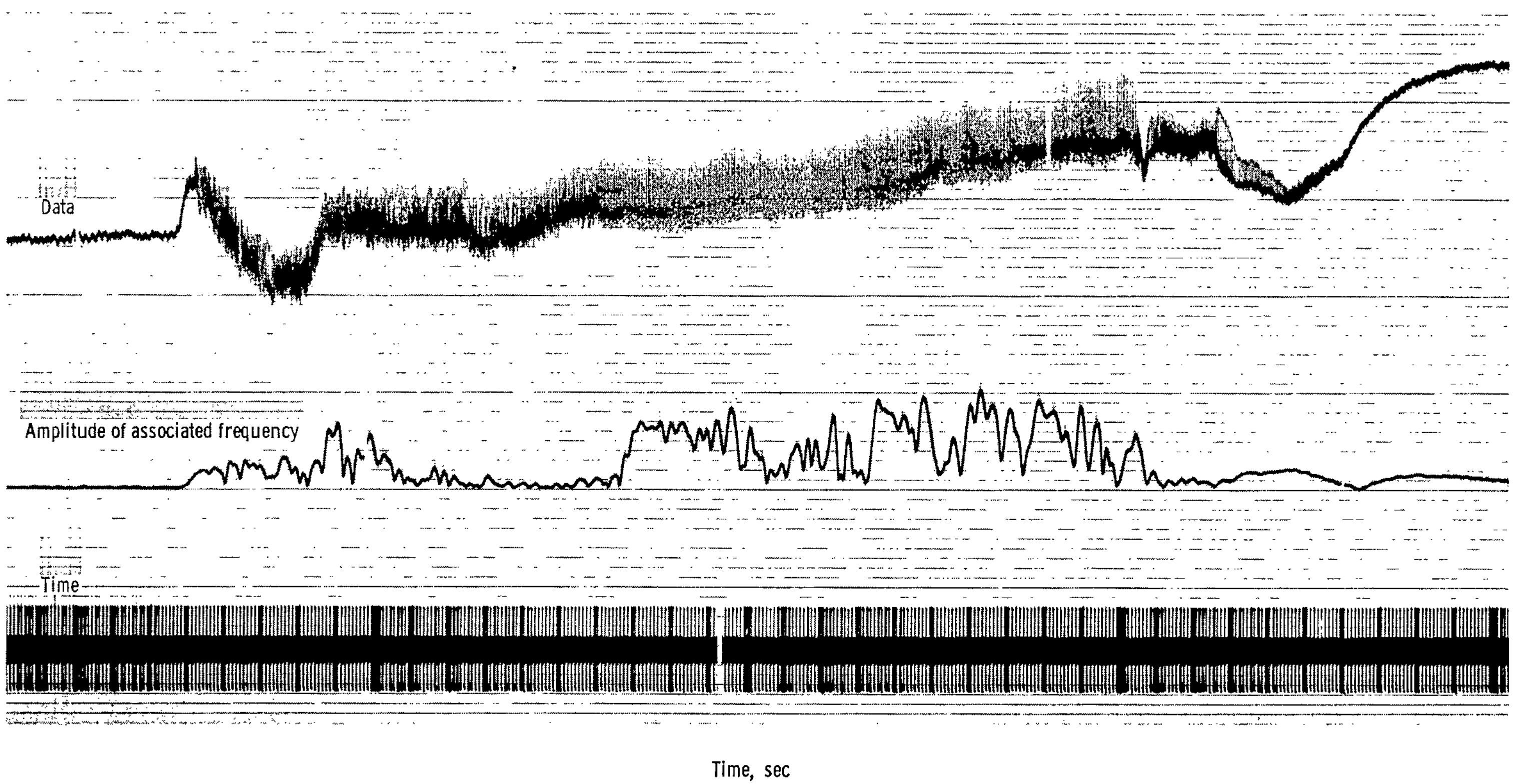
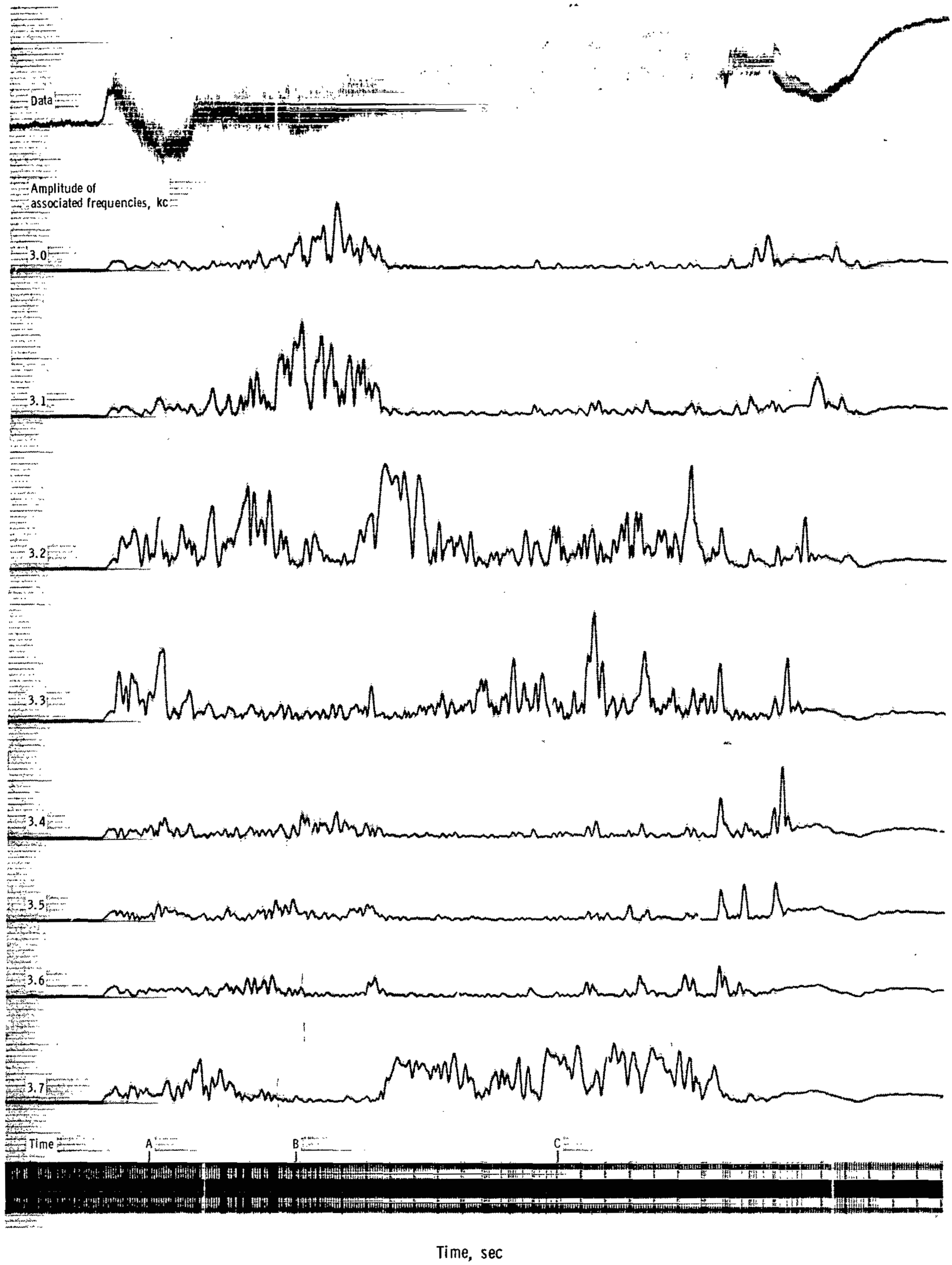
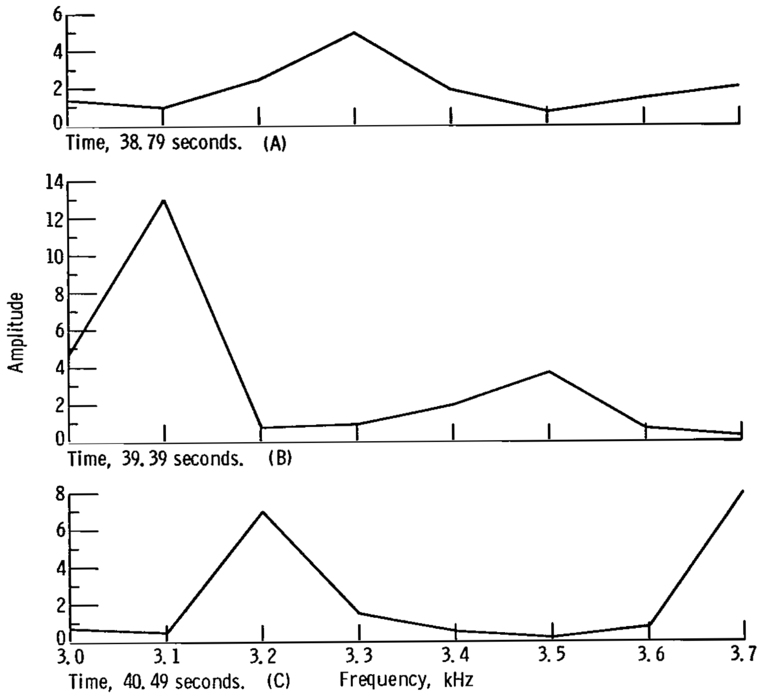


Figure 3. - Typical time history plot for single frequency component. Recording speed, 60 inches per second (152.4 cm/sec); reproducing speed, 60 inches per second (152.4 cm/sec); recording oscillograph speed, 4 inches per second (10.16 cm/sec).



(a) Time history of data.

Figure 4. - Method of determining instantaneous frequency spectrum. Recording speed, 60 inches per second (152.4 cm/sec); reproducing speed, 60 inches per second (152.4 cm/sec); recording oscillograph speed, 4 inches per second (10.16 cm/sec).



(b) Instantaneous discrete frequency spectrum determined from time history record.

Figure 4. - Concluded.

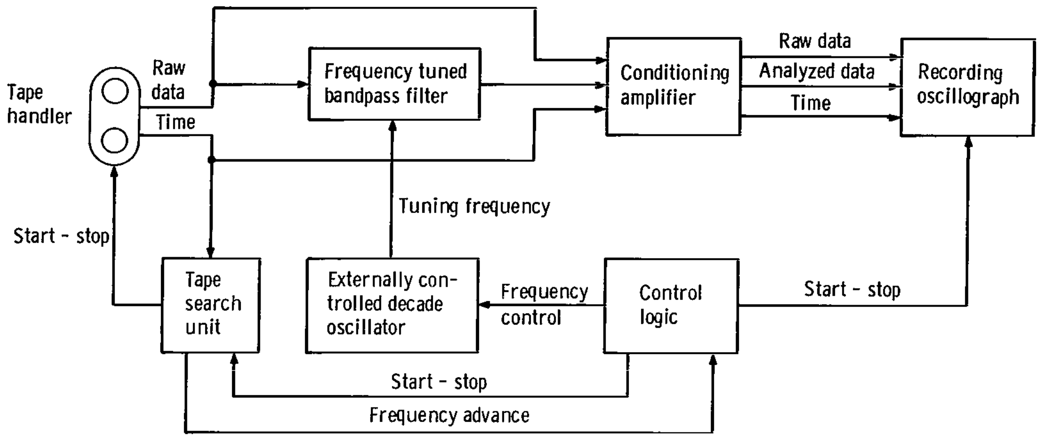


Figure 5. - Block diagram of system used to generate complete time history automatically.

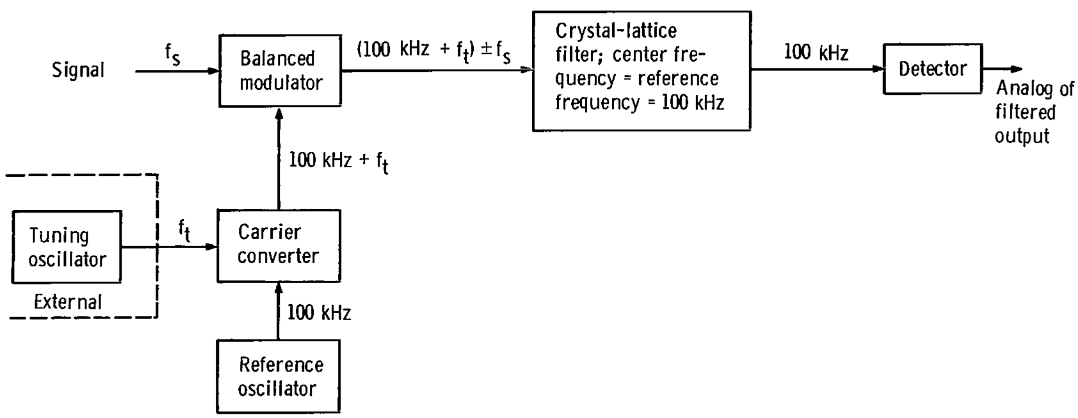


Figure 6. - Block diagram of basic operation of frequency-tuned bandpass filter.

NASA-Langley, 1967 —— 8 E-3502

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