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THE MUSE SYSTEM: DESCRIPTION AND
MANUAL FOR OPERATION

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DECEMBER 1965

A. W. Slawson

OFFICE OF SCIENTIFIC AND TECHNICAL INFORMATION
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



Project 1700

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-2390

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FOREWORD

Robert Curtis, Edward Bensley, and Ferrell Sandy all contributed important ideas during the planning and programming of the MUSE Program. James Valentine and Augustine Kish designed and built the digital-to-analog converter. Professor K. N. Stevens of MIT provided very helpful criticism and the use of his sound spectrograph. Drs. F. S. Cooper and A. M. Liberman of Haskins Laboratory lent encouragement and valuable critiques. The author is much in debt to these and many other individuals.

ABSTRACT

The MUSE system, an IBM 7090 computer program and associated conversion equipment, has been designed for use as a sound synthesizer. Concise descriptions of complex sounds including human speech are converted by the MUSE system into sound pressure waveforms. The inputs to the MUSE system are specifications of the changing resonance frequencies of multiple acoustic filter networks and of the changing frequencies and amplitudes of the sources of acoustic energy that excite those networks. The output of the MUSE system is a sampled waveform calculated for each resonance by the solution of a second-order difference equation. The results are summed over a single system of resonances and then the resonance systems are also added together. The resulting string of sampled waveform ordinates is written in digital form on magnetic tape. Conversion to a voltage waveform is accomplished by use of the standard IBM 729 IV tape transport unit and a simple digital-to-analog converter. Although the quality of the sound is somewhat degraded by tape wow and flutter, acceptable and highly intelligible speech has been synthesized.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

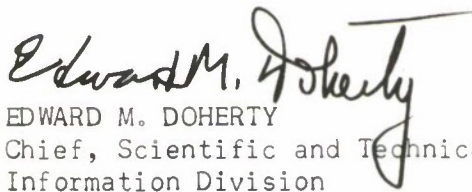

EDWARD M. DOHERTY
Chief, Scientific and Technical
Information Division

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SECTION I

INTRODUCTION

A phonetician, wishing to test his model of speech production, often describes some speech utterance in terms dictated by his model and then uses this description to control a speech synthesizer. Provided the speech synthesizer is a good one, the quality of the resulting speech is a good indication of the sufficiency of his model. The model may be too complicated or may not be limited by physiological constraints, but if high quality speech can be synthesized according to the model, it commands attention as a possible means of gaining insight into that most complicated and refined biological system — the human vocal apparatus.

The MUSE system is a computer simulation of a class of sound synthesizers that have been used with success in testing theories of speech production. In spite of some loss of fidelity, the computer simulation can be used in place of this class of sound synthesizers. MUSE, consisting of an IBM 7090 computer program and simple digital-to-analog conversion equipment, translates concise descriptions of a large class of complex sounds, including human speech, into the corresponding analog waveform. This signal can be recorded for later playback or it can be used to drive a loudspeaker for immediate presentation of the sound.

Sound synthesizers can also be used to present information in the form of spoken messages to the human operators of a computer-centered, real-time control system.^[1] In such an application, these messages would be stored in computer memory in concise digital form. The main program for the control system would select some appropriate message and send it to a sound synthesizer that would then expand the concise form of the message into the corresponding wide-bandwidth speech signal and present it to the operator in real time. The MUSE system, by simulating the output of various alternative

synthesizers, could aid in designing the simplest adequate device for each application.

The MUSE system is itself a weak theory of speech production. MUSE is a weak theory because it leaves unspecified the manner in which the sounds are produced and because, subject to a limited bandwidth, it can reproduce the output of a large class of acoustical devices. The limitations that make it a theory at all are mainly practical ones. MUSE couldn't be used in practice to simulate a symphony orchestra because a single chord could require thousands of statements in the input language. General statements about these limitations are impossible but they will be made explicit by the detailed description of the input language and the operation of MUSE both of which follow.

SECTION II

EQUIPMENT NECESSARY AND OVER-ALL SCHEME

EQUIPMENT NECESSARY

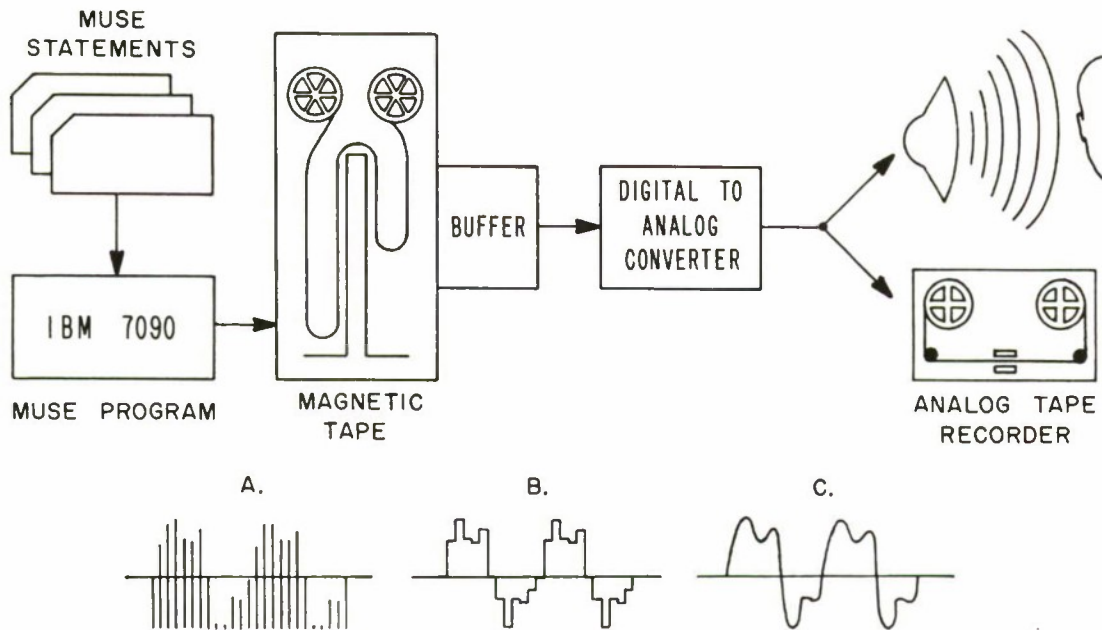
The equipment needed for running the MUSE program consists of a standard IBM 7090 EDPM with at least two data channels and at least one 729 IV tape transport unit, a special purpose digital-to-analog converter, a variable bandpass filter, and any electro-acoustic transduction system or, preferably, a good quality magnetic tape recorder.

OVER-ALL SCHEME

In general, the operation of the MUSE system consists of a translation or calculation phase and a subsequent digital-to-analog conversion phase. In the first phase, the data cards containing the sound specifications are read in as needed and the ordinates of the specified waveform are calculated. These numbers representing the instantaneous pressure of the specified waveform at successive small intervals of time are stored in blocks on magnetic tapes. When calculation is completed for the sound sample or utterance being synthesized, the waveform ordinates are read from the magnetic tape storage into the computer for normalization. These data are then written onto a new tape in which the inter-record gaps between the blocks of numbers are eliminated.

In the conversion phase the tape unit, an IBM 729 IV tape transport unit on which the final output has been written, is disconnected from the data channel and connected to the digital-to-analog conversion device. This device then reads the six-bit (64 levels) waveform ordinates off the magnetic tape, sets them in a buffer register, and converts them to a voltage waveform

smoothed by a low-pass filter. The resulting signal can be transduced by a standard loudspeaker system or recorded on magnetic tape as shown in Figure 1.



1. MUSE Statements on IBM cards are read into the computer.
2. The computed waveform ordinates (A) are written onto magnetic tape.
3. The waveform ordinates are converted into a step function (B) representing voltage levels.
4. A low-pass filter smooths the step-function into an analog waveform (C).
5. The output of the digital-to-analog converter is a varying voltage which drives a loudspeaker or tape recorder.

Figure 1. Functional Diagram of the MUSE System

SECTION III

SOUND SPECIFICATION LANGUAGE AND FORMATS

INTRODUCTION

Since the common denominator of all sound synthesis systems is an output waveform, the important differences between these systems lies in the method of specifying the desired sound and in the faithfulness with which these specifications are embodied in the output waveform. The level of sophistication or, in other terms, the degree of bandwidth compression of the system is more or less fixed by the specification language. The MUSE system's specification language consists of statements describing the changing acoustic spectra of the desired sound. Representing the instantaneous frequency response of independent resonating systems at given points in time, these statements contain the resonance frequencies and bandwidths of the several variable resonators that make up these systems.

SOUND SPECIFICATIONS: DATA CARDS

In the description of sound for MUSE, resonators are grouped so that several of them can be excited by the same energy source. These groups are called Spectra. A specification of the states of the resonators in a Spectrum and the excitation function for those resonators at some point in time is called a Statement. Whenever "Spectrum" and "Statement" are used below in this technical sense, they will be capitalized.

Spectrum Specification

The experimenter describes the instantaneous frequency response of a particular Spectrum by supplying the resonance frequency and bandwidth in cycles per second of each resonance contributing to that Spectrum. More explicitly, the resonance frequency refers to the frequency of a pole in a

passive electrical network which is analogous to the acoustical system to be simulated. The bandwidth of the resonance controls the real component or the attenuation of that particular pole. The value of a resonance bandwidth is the difference between the two frequencies at which the attenuation of the resonant network is 3 db greater than at the pole frequency under the assumption that the network has only this single resonance.

Excitation Source Specification

Supplying the states of resonances, as described above, can specify an acoustic resonating system at a fixed point in time. If enough points are picked, or if points of inflection are chosen and the program is designed to interpolate between them, a fairly complete description of the continuing response of say the human vocal tract, uttering speech can be made. To excite the resonant system, however, some provision must be made for an excitation source.

In the MUSE language, energy is supplied to the resonant system in the form of a train of shaped pulses. The pulses, whose response characteristics are fixed at the beginning of the run, can excite the system at periodic or pseudo-random intervals. The mode of excitation, buzz or noise, is specified in each Statement. The fundamental frequency of the buzz source and its amplitude are also specified. When the noise option is used, the repetition rate must also be supplied since the pulses are shaped in terms of decibels per octave above the fundamental frequency. The fundamental frequency is given in cycles per second. The amplitude multiplier is a two-digit number specifying the relative amplitude of the source pulse (it is not a logarithmic quantity).

Timing Specification

Having specified the Spectra and their excitations for single points in time, these points must be fixed at particular times by entering in each

Statement the time in hundredths of a second since the beginning of the sound sample.

It has been mentioned above that sparse specification of the variation of a Spectrum through time would suffice if some kind of interpolation is assumed. The translation phase of the MUSE program assumes that all variables in a Statement (except specifications of time and mode of excitation) change linearly between Statements. The values of each variable in successive Statements and the time interval between these Statements determines the rate of this change. If a variable has the same value in successive Statements, that particular variable remains constant throughout the interval between those two Statements.

Sorting the Specification Cards

In the process of running the program, each Statement is read in as needed. Since interpolation between Statements is called for, it is necessary that as the calculations reach the "time" value of one Statement, the next Statement in each Spectrum must be read into the computer. The Spectra are independent of each other so ordering the Statements when specifying multiple Spectra can be fairly involved.

Although it is not necessary for running the system, it is recommended that a sorting field, not read by the computer, be included in the data cards. This sorting field contains in order a single-digit field that is zero ("0") for the first card in a Spectrum and a one ("1") for all other cards, the time value from the previous statement in the Spectrum, and the Spectrum number.

Data Card Formats

The format of the data cards whose fields have been described above are as given in Table I.

TABLE I
FORMAT OF A SOUND SPECIFICATION DATA CARD

<u>Field or Variable Name</u>	<u>Column</u>
Mode of excitation and card type identification: "0" = periodic excitation; "1" = noise excitation	1
Number of Spectra ("1" through "9")	2
Time (in the form XXXX.XX sec)	3-8
Amplitude Multiplier (XX arbitrary units)	9-10
Fundamental Frequency (XXXXXX cps)	11-15
Resonance Specifications for Resonance Number i (i = 1, 2 ..., 8), where bandwidth = b_i (XXX cps), frequency = f_i (XXXXX cps):	
b_1	16-18
f_1	19-22
b_2	23-25
f_2	26-29
b_3	30-32
f_3	33-36
b_4	37-39
f_4	40-43
b_5	44-46
f_5	47-50
b_6	51-53
f_6	54-57
b_7	58-60
f_7	61-64
b_8	65-67
f_8	68-71
<u>Sorting Field</u>	
"0" for first card in Spectrum, "1" for all others	73
Time from Previous Card in this Spectrum	74-78
Spectrum Number	79

Any resonances that are not used can be left blank.

At this time, a MUSE Statement is presented in its entirety on a single card. Possible future expansions of the input language to multiple cards justify the use of "Statement" as a special term.

CONTROL CARDS

There are three control cards that must be used in the operation of the MUSE program. These are not acoustic data but serve to set up parameters and options for the processing of the sound specifications.

Parameter Control Card

The first control card is identified by a "2" punched in Column 1. This card specifies for the entire set of data which follows it, the number of spectra, the number of resonances in each of these spectra, the response characteristics of the source function, the sampling period of the output waveform and a field controlling program options.

The number of spectra depends upon the number of independently excited resonant systems desired (for speech synthesis the question of number of Spectra is discussed under "Selection of Spectrum Parameters"). In the present version of the program, all spectra have the same number of resonances, hence, only one entry is necessary in the "2" control card. The response characteristics of the source functions in all Spectra are the same and are specified in terms of the slope of their frequency response in db per octave above the fundamental. The sampling period is usually fixed at 44×10^{-6} seconds, the program option field at "00."

The format of the first control card is as given in Table II.

Table II

Format of MUSE Control Card, Type "2"

<u>Field or Variable Name</u>	<u>Column</u>
Identification Field (contains a "2")	1
Number of Spectra ("1" to "9")	2
Sampling Period (in secs x 10^{-6} , usually "000044")	3-7
Number of Resonances ("01 to "08")	8-9
Source Characteristic (in db per octave x 10^{-1} ; for instance, "060" is 6db per octave)	10-12
Program Option (usually "00")	13-14

End Cards

There are two kinds of control cards which signal the end of a set of data. Any card with a "4" in Column 1 signals the program that there are no more Statements in this sound segment and that the run is over. A "5" in Column 1 indicates the end of this sound segment and, in addition, sets up the program to accept the specifications for another sound segment preceded by its initial control card. When either of these end cards is read, the program begins processing the computed samples for the conversion phase. About one second of silence is automatically included on the end of each sound segment to erase a section of the output digital tape. The silent interval prevents spurious bits immediately following the waveform samples on the output tape from ruining the synthesized sound segment during the conversion process.

SECTION IV

SPEECH SYNTHESIS WITH THE MUSE SYSTEM: AN EXAMPLE

INTRODUCTION

Although implicit in the description given in Section III, the process of using MUSE for synthesizing sound is best clarified by presenting an example. A complex example, the speech utterance "All's well that ends well," has been chosen so that all features of MUSE can be demonstrated.

This example represents approximately 2 seconds of speech. It took approximately 200 seconds of computer time to synthesize this example.

The first steps in the synthesis procedure are common to all so-called "terminal analog" synthesizers.^[2,3,4] First the utterance is recorded and sound spectrograms are made.^[5] Amplitude sections, displays of the Spectrum of the speech during some selected short interval of time, can be made to clear up ambiguous areas on the time-frequency-amplitude graph. An additional useful datum is an oscillograph of the utterance with the time scale such that the period of the fundamental and the over-all amplitude can be measured throughout the utterance. These data for the sample "All's well that ends well," from which an analysis of the utterance can be made, are presented in Figure 2.

Selection of Spectrum Parameters

The next step in the analysis procedure is to decide how many Spectra will be necessary to specify the sound sample to be synthesized. Perhaps the most important factor in making this decision for synthesizing speech is a heuristic one; i. e., how many Spectra will best fit the experimenter's view of the speech process? For the example presented here, three spectra are used. Each corresponds to a different mode of operation of the vocal apparatus. The

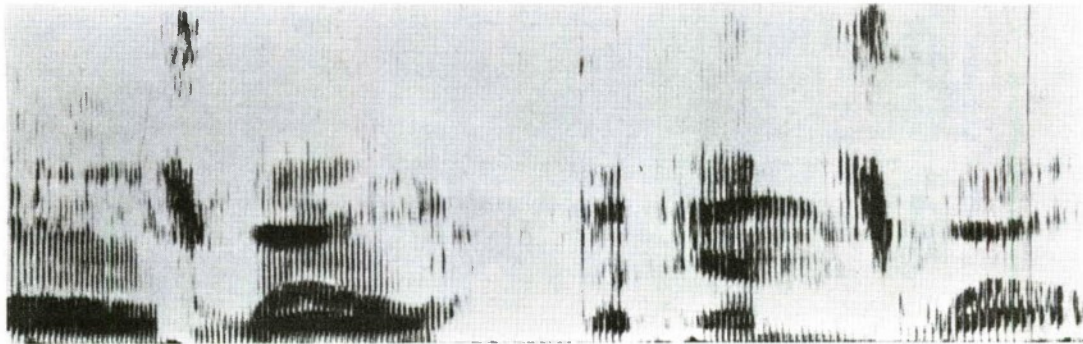


Figure 2a. Sonogram of the Utterance

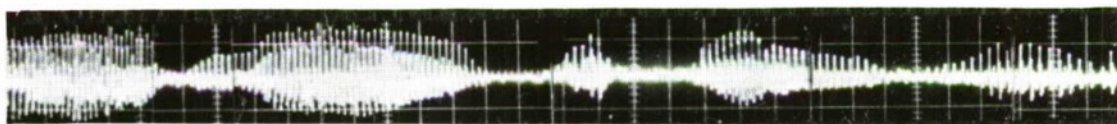


Figure 2b. Oscillogram of the Utterance

Figure 2. Spectrum of the Utterance, "All's well that ends well," Spoken by a Native American.

first spectrum corresponds to the mouth and throat excited by periodic laryngeal pulses. In other words, it is used for all voiced sounds. The second spectrum corresponds to any excitation of the vocal apparatus by noisy sources. Fricatives, aspirates, and some stops call for the use of this spectrum. The third Spectrum represents the contribution of the nasal cavities to nasalized vowels and consonants.

A similar division of the speech process into three more or less independent spectra is implied in the synthesizers built by Fant and K. N. Stevens.* A more concise description of speech utterances can be accomplished using only a single Spectrum with a corresponding degradation in the quality of the synthetic speech.

The other important decision to be made at this point in the analysis involves the number of resonances in the Spectra. Three resonances are a minimum number for intelligible speech. Higher frequency resonances contribute to the realism of the speech and may be important in realizing a particular speaker's voice. Since calculation of these extra resonances takes computer time, some restraint is to be exercised. In the present example, four resonances per Spectrum are specified. The resulting speech is highly intelligible but the speakers are generally not identifiable.

The slope of the power spectrum of the excitation source must be decided upon at this point also. Certain theoretical considerations by Fant^[6] give 6 db per octave attenuation as a good empirical approximation to the over-all spectrum slope.

*These synthesizers are discussed in References [3] and [4].

The values chosen for the number of Spectra, the number of resonances per Spectrum, and the slope of the source spectrum are entered into the "2" type control card as specified under "Parameter Control Card," page 9.

SEGMENTATION

Since MUSE interpolates between parameter values on successive statements, it is necessary to select times for the Statements between which the Spectrum parameters change only linearly. This is done by close examination of the spectrograms and oscillograms of the speech utterance. The segmentation is entirely acoustic and has little to do with phonetic divisions. An easy way to place the Statements and find parameter values is to plot the resonance frequencies for each Spectrum as a function of time. Figure 3 contains these plots for the example being considered here. The resonance values can be left constant or can be changed linearly when the amplitude multiplier is zero. (For example, see times 0.00 to 0.06, 1.98 to 0.20 in Figure 3.)

It can be seen from Figure 3 that the Spectra are time-independent; that is, the time segments in difference Spectra do not necessarily coincide. The values of the various parameters can be read from these graphs at the points corresponding in time to the Statements. The parameter values are then entered into a coding form and punched onto IBM cards in the format described under "Data Card Formats," page 7. After sorting the cards on the sorting field, the specification data are only ready for calculation. A printout data for these cards is given in Table III for the sample utterance.

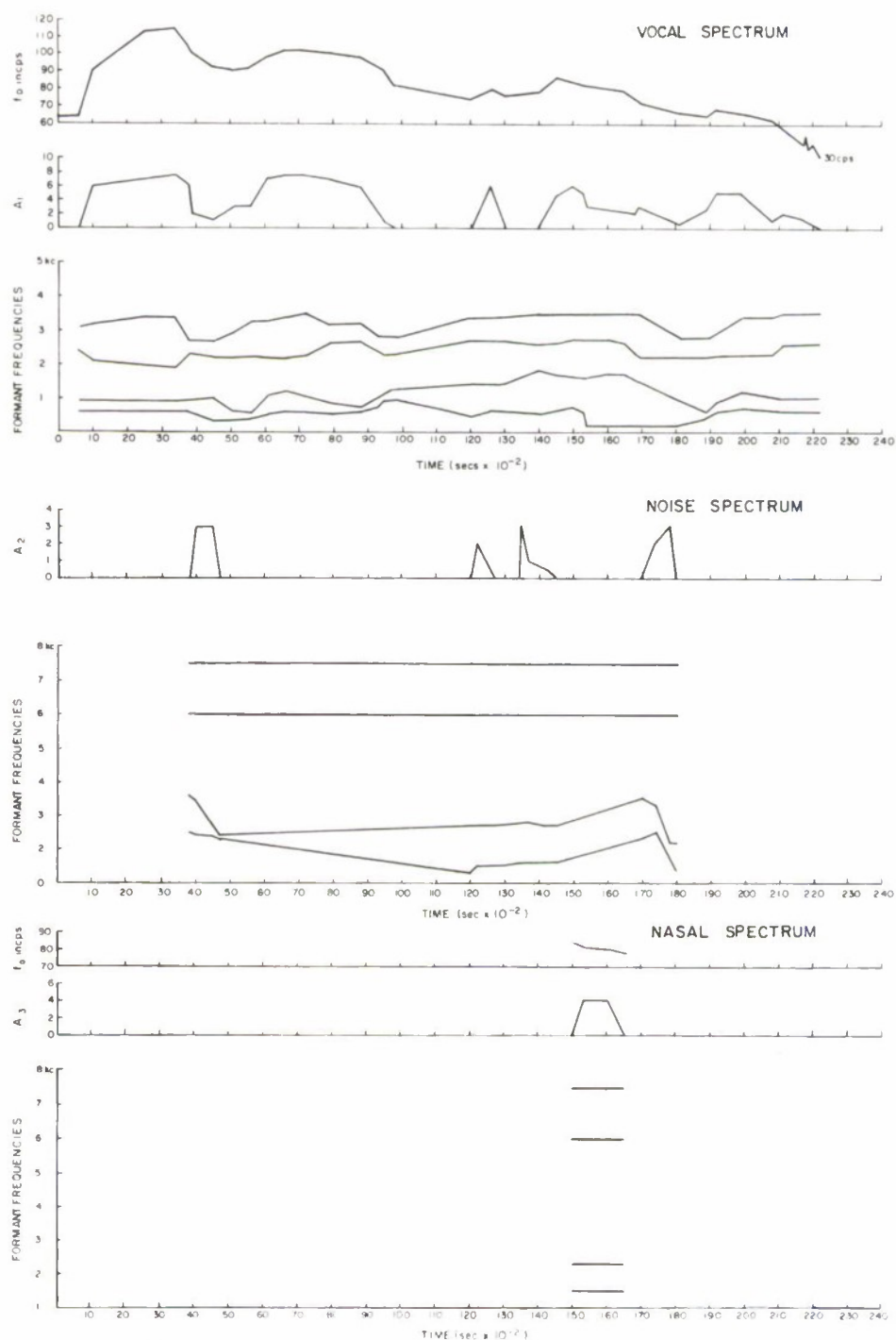


Figure 3. Tracings of the Sonograms (Figure 2a) from which the Input Data to MUSE are Copied. (The Vocal Spectrum Number is "1," the Noise Spectrum is "2," and the Nasal Spectrum is "3.")

Table III
Input Data For The Utterance "All's Well That Ends Well"

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b_1	f_1	b_2	f_2	b_3	f_3	b_4	f_4
0	1	0	0	64	50	600	50	900	70	2400	120	3100
1	2	0	0	100	100	2500	60	3600	100	6000	100	7500
0	3	0	0	84	100	1500	90	2300	300	6000	400	7500
0	1	6	0	64	50	600	50	900	70	2400	120	3100
1	2	38	0	100	100	2500	60	3600	100	6000	100	7500
0	3	150	0	84	100	1500	90	2300	300	6000	400	7500
0	1	10	60	90	50	600	50	900	70	2100	120	3200
0	1	25	70	112	50	600	50	900	70	2000	120	3400
0	1	34	75	114	50	600	50	900	70	1900	120	3400
0	1	38	60	104	100	600	100	900	100	2300	200	2700
0	1	39	20	100	100	500	100	900	100	2300	200	2700
1	2	40	40	100	100	2400	60	3400	100	6000	100	7500
0	1	45	10	92	100	300	100	1000	100	2200	200	2700
1	2	45	40	100	100	2400	60	2700	100	6000	100	7500
0	1	51	30	90	70	300	80	600	100	2200	200	2900
1	2	47	0	100	60	2300	60	2400	100	6000	100	7500
1	2	120	0	100	80	1300	80	2700	150	6000	150	7500
0	1	56	30	92	60	400	70	500	100	2200	200	3300
0	1	61	70	98	40	500	50	1100	70	2200	100	3300
0	1	66	75	102	50	600	50	1200	70	2200	100	3400
0	1	72	75	102	50	600	50	1000	100	2300	150	3500
0	1	79	70	100	50	500	50	800	120	2600	200	3200
0	1	88	60	98	60	600	60	700	120	2700	120	3200
0	1	93	30	94	70	700	80	1000	100	2400	100	2800

Table III (cont'd)

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b_1	f_1	b_2	f_2	b_3	f_3	b_4	f_4
0	1	95	10	90	70	900	150	1100	100	2300	100	2800
0	1	98	0	82	100	900	150	1200	100	2300	100	2800
0	1	120	0	74	100	500	150	1400	150	2700	150	3400
0	1	126	60	80	50	600	70	1400	90	2700	100	3400
1	2	122	20	100	80	1500	80	2700	150	6000	150	7500
1	2	127	0	100	80	1500	80	2700	150	6000	150	7500
0	1	128	35	78	50	600	70	1400	90	2700	100	3400
1	2	134	0	100	80	1600	80	2800	150	6000	150	7500
0	1	130	0	76	50	600	70	1400	90	2700	100	3400
0	1	140	0	78	50	500	70	1800	90	2600	100	3500
1	2	135	40	100	80	1600	80	2800	150	6000	150	7500
1	2	137	10	100	80	1600	80	2800	150	6000	150	7500
1	2	141	30	100	80	1600	80	2700	150	6000	150	7500
0	1	145	45	86	50	600	50	1700	90	2600	100	3500
1	2	145	0	100	80	1600	80	2700	150	6000	150	7500
0	1	150	60	84	50	700	50	1600	90	2700	100	3500
1	2	170	0	100	60	2300	50	3500	100	6000	100	7500
0	1	153	50	82	60	500	60	1600	90	2700	100	3500
0	3	153	40	82	100	1500	90	2300	300	6000	400	7500
0	1	154	30	82	90	200	100	1600	120	2700	150	3500
0	3	160	40	80	100	1500	90	2300	300	6000	400	7500
0	1	160	25	80	90	200	100	1700	120	2700	150	3500
0	1	165	25	78	90	200	100	1700	120	2600	150	3500
0	3	165	0	78	100	1500	90	2300	300	6000	400	7500
0	1	168	20	74	90	200	100	1600	120	2300	150	3500
0	3	222	0	78	100	1500	90	2300	300	6000	400	7500

Table III (Concl'd)

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b ₁	f ₁	b ₂	f ₂	b ₃	f ₃	b ₄	f ₄
0	1	169	30	72	90	200	100	1500	120	2200	150	3500
0	1	181	5	66	90	200	100	1000	120	2200	150	2800
1	2	174	40	100	50	2500	50	3300	100	6000	100	7500
1	2	178	50	100	50	1700	50	2200	100	6000	100	7500
1	2	180	0	100	50	1400	50	2200	100	6000	100	7500
1	2	222	0	100	50	1400	50	2200	100	6000	100	7500
0	1	189	25	64	90	400	100	600	120	2200	150	2800
0	1	192	50	68	50	600	50	900	90	2300	100	3000
0	1	199	50	66	50	700	50	1200	90	2300	100	3400
0	1	208	10	62	50	600	50	1000	90	2300	100	3400
0	1	211	20	56	50	600	50	1000	90	2600	100	3500
0	1	216	15	50	50	600	50	1000	90	2600	100	3500
0	1	222	0	30	50	600	50	1000	90	2600	100	3500

EVALUATION

The resulting synthetic speech is highly intelligible if somewhat artificial sounding. Recordings have been rather widely demonstrated, with almost total comprehension of the utterances reported by the audience. A spectrogram and oscillogram of the original and synthesized versions of the utterance "All's well that ends well" are given in Figure 4.

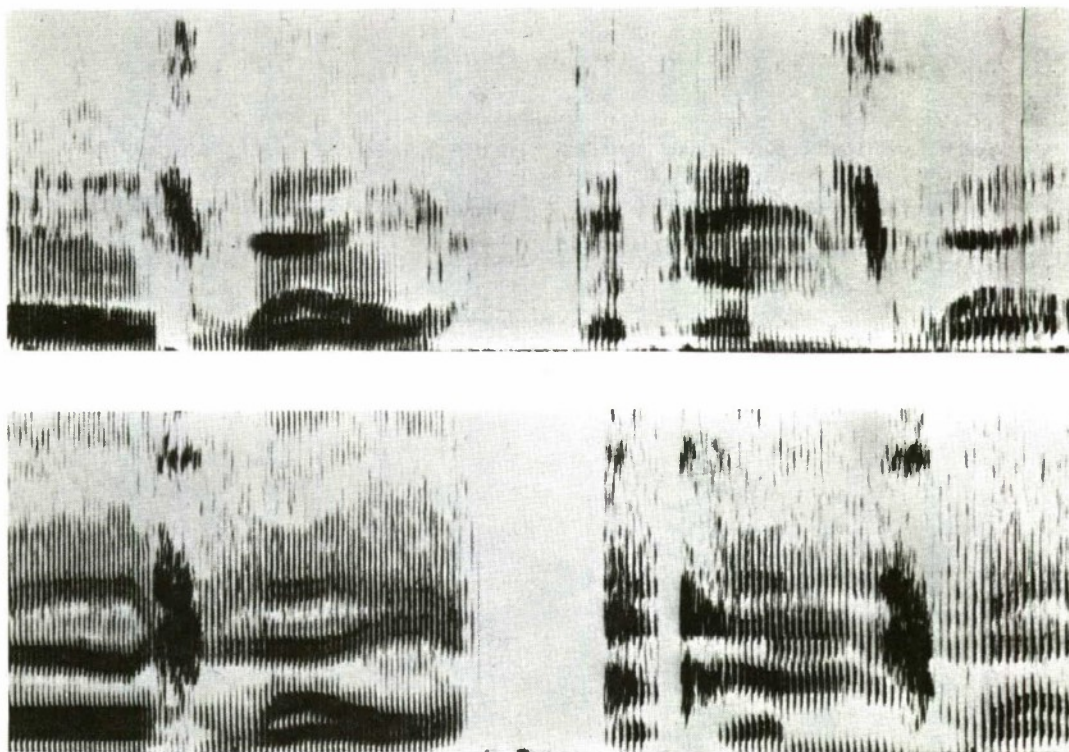


Figure 4a. Sonograms of the Original (Top) and Synthesized (Bottom) Versions of the Utterance

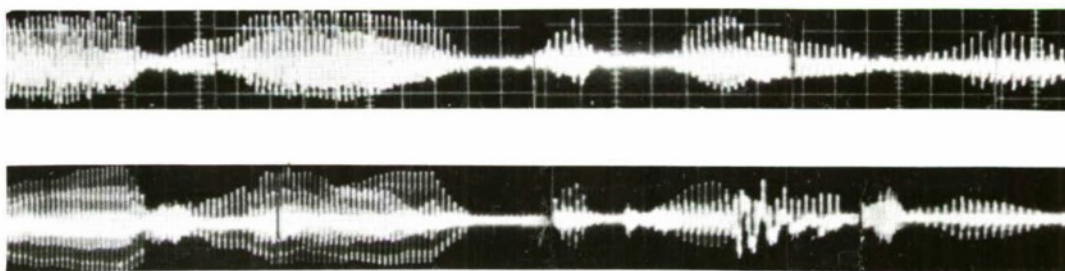


Figure 4b. Oscillograms of the Original (Top) and Synthesized (Bottom) Versions of the Utterance

Figure 4. Comparison of Sonograms and Oscillations of Original and Synthesized Utterance, "All's well that ends well."

SECTION V

FLOW OF THE PROGRAM

INPUT PROCESSING

In order to avoid a "hardware" limitation on the number of data cards or number of spectra, the data cards are read into the computer as needed by an input subroutine. When a new card is read, spectrum parameters are set up and an interpolation increment for each Spectrum parameter is calculated. These increments are added after each period of the excitation pulse. Although "continuous" interpolation (i. e., after each waveform ordinate) would more closely approximate the smooth changes in the vocal tract, substantial savings in computation time accrue if the interpolation is lumped in coordination with the source periods.

CALCULATION PHASE

The two (momentarily) constant coefficients of the following second-order difference equation are the recipients of the interpolation increments:

$$x_t = Ax_{t-\Delta t} + Bx_{t-2\Delta t} + S ,$$

where

$$A = \begin{bmatrix} -2\pi b_{ij}\Delta t \\ 2e^{\cos(2\pi f_{ij}\Delta t)} \end{bmatrix} ,$$

$$B = -\begin{bmatrix} -4\pi b_{ij}\Delta t \\ e \end{bmatrix} ;$$

and where

- b_{ij} = bandwidth of the i^{th} resonance in the j^{th} spectrum,
- f_{ij} = frequency of that resonance,
- Δt = sampling period,

x_t = amplitude at time, t , and
 S = relative amplitude of the source function.

Evaluation of this difference equation for successive sampling periods results in a series of ordinates of the waveform of a single resonance excited by a pulse of amplitude, S , once per period of the source function. At each sampling point, t , the ordinates of each resonance are summed, and these sums are added over all Spectra. The resulting over-all ordinate is

$$x_t = \sum_{j=1}^{\ell} \sum_{i=1}^K X_{ijt} ,$$

where

i = resonance index,
 j = spectra index, and
 ℓ and K = upper limits of the indices (the number of spectra and resonances given in the "2" control card).

As the calculation proceeds, the waveform ordinates are stored temporarily in blocks of 12,000 on a magnetic tape.

OUTPUT PROCESSING

When one of the final control cards (with either a "4" or "5" in Column 1) is encountered, the final output routine is begun. The blocks of waveform ordinates stored temporarily on tapes are read into the computer, scaled, packed and converted to a steady stream of six-bit numbers written as a single record in low density on the output tape. If the final control card is a "4," the program is finished and control is returned to the monitor system. If the "5"

control card terminates the utterance, the program clears storage space and begins reading in the control and data cards for the next utterance.

SECTION VI

RUNNING THE PROGRAM AND CONVERTING THE OUTPUT DATA

INTRODUCTION

This section describes the preparation of the input deck for computation, the running of the program itself, and the operation of the digital-to-analog converter.

RUNNING THE PROGRAM

The data cards, after sorting on the field described under "Sorting the Specification Cards" on page 7, are preceded by the "2" control card, followed by the "4" or "5" control card and inserted behind the "*DATA" card following the MUSE program binary deck.

Tapes needed in running the program are B5 and B6 and A10. The B-channel tapes provide temporary storage while the final output is written on an A10. Under ordinary operation there are no stops in the program. Any on-line printouts are used by an observer only to keep track of the program's operation. They do not require action from the computer operators.

OUTPUT CONVERSION PROCESS

While the program's operation is quite routine, the output conversion process definitely is not (see Figure 1 for an over-all schematic of the conversion system). It is advisable to make the connections between the converter and the tape drive under the supervision of IBM customer engineers. Computer time is conserved if the tape drive containing the digital output tape is disconnected from the computer during a routine halt between two runs. An extra "terminator" for the detached tape drive must be attached to the converter. The bandpass filter on the output of the converter should be set at a nominal low-pass cutoff of about 10,000 cps.

The tape recorder should be started before the tape drive. A switch on the converter supplies the signals necessary for starting the digital tape drive. The conversion process then continues in real time. When conversion is finished, the digital tape can be stored for later use and the tape drive can be re-attached to the computer.

DIGITAL-TO-ANALOG CONVERSION EQUIPMENT

The digital-to-analog converter that was used in the MUSE system is only one of several circuits that would serve as a conversion device.

An IBM cable attachment plug is part of the converter used. The input to the read amplifiers comes from this plug. The equipment is most conveniently mounted on an ordinary rack with space provided for the bandpass filter used to smooth the output of the converter.

REFERENCES

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5. Potter, Kopp, and Green, Visible Speech, New York, Van Nostrand, 1947.
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APPENDIX A PROGRAM LISTING

Following is the FORTRAN program listing of the MUSE Program. [7]

```

W. SLAWSON      MUSE2, A SOUND SYNTHESIZER                                4/10/63

C      *****
C
COMMON  FREQ, FANC, SREQ, SAND, DCOA, DCOB, VAL, TOT, STORE, PUTIN, FMIS,  MU200300
XSMIS, CMIS, FCCA, FCCB, FORCE, PERIOD, IIN                                MU200400
X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME, IRESN, L, IMS2, NAR,
XGREAT, SAMPER
X, STOR
X, CCTL
X, PULSE, CPULSE, DP
X, PERTY
X, OPTICN
DIMENSION FREQ( 8, 10), FANC( 8, 10), SREQ( 8, 10), SAND( 8, MU200500
X 10), DCOA( 8, 10), DCOB( 8, 10), VAL( 2, 8, 10), TOT( 10),  MU200600
X STOR( 100), PUTIN( 21), FMIS( 4, 10), SMIS( 4, 10 ),  MU200700
XCMIS(2,10), FCCA(8,10), FCCB(8,10), FORCE(8,10) ,
X PERIOD ( 10 ) , IIN(2)  MU200900
X, STOR(12000)
X, CCTL(2000)
X, PULSF(8,10), CPULSE(8,10)
X, PERTY(10)
EQUIVALENCE ( STOR, STOR )

C      *****
C      MUSEKEEP AND READ CONTROL CARD.                                MU201100
C      *****
C
100 READ INPUT TAPE 5,10,IIN(1), ISPEC, SAMPER, IRESN, DB, OPTICN
10  FORMAT (2I1,F5.0,12,F3.1 , F2.0 )
   IF ( OPTICN - 2. ) 25,15,15
15  PRINT 11
11  FORMAT ( 1F1 )
   PRINT 12,IIN(1),ISPEC,SAMPER,IRESN, DB, OPTION
12  FORMAT (1F 12, 13, E15.7, 13,2E15.7)
25  WRITE OUTPLT TAPE 6, 11
   WRITE OUTPLT TAPE 6, 12, IIN(1), ISPEC, SAMPER, IRESN, DB,OPTION
   SAMPER = SAMPER * 10. **(-6 )
   LCCUNT = 0                                MU201300
   SMALL = 0.                                MU201500
   GREAT=0.
   REWIND 8
   L = 1                                MU201600
   ISW2 = 2                                MU201700
   NAR = 12000
   IF ( OPTICN - 5. ) 45, 50, 60
45  IF ( OPTICN - 4. ) 60,57,60
50  NAR = 999
   GOTO 60
57  NAR=100
60  DO 110 J=1,ISPEC
   DO 112 I=1,IRESN                                MU202000
   VAL(1,I,J) = 0.                                MU202100
112 VAL(2,I,J) = 0.                                MU202200
   PERTY(J) = 0.
110 TCT(J) = 0.                                MU202300
   DO 55 I=1,NAR

```



```

55  STCR(I) = C.
    TIME      = 0.
C                                     MU202400
C .....
C                                     END OF HOUSEKEEPING. SET
C                                     UP INITIAL CONDITIONS.
C .....
C
115  DO 130 J=1, ISPEC
      J=J
      CALL SUB2( IMS2 )
130  CALL SUB3
      DO 147 J=1, ISPEC
      J=J
      CALL SUB2( IMS2 )
      CALL SUB4
147  CALL SUB5
      IF (OPTICN) 150, 150, 149
149  PRINT 4020
      WRITE OUTPUT TAPE 6, 4020
4020  FORMAT ( 12F BEFORE 150.
      CALL WDUMP
C .....
C  BEGIN MAIN FLW
C                                     MU202600
C .....
C
150  J      = 1
155  TCT(J)      = 0.0
600  DO 620 I=1, IRESCN
      TEMP      = (FCCA(I,J) * VAL(1,I,J)) - FCCB(I,J)
      X* VAL(2,I,J) + FORCE(I,J)
      FORCE(I,J) = C.C
      VAL(2,I,J) = VAL(1,I,J)
      VAL(1,I,J) = TEMP
820  TCT(J)      = TCT(J) + TEMP
1553  IF (SMIS(1,J) - TIME) 163, 163, 1552
1552  IF (PERTY(J) - TIME) 160, 160, 157
157  IF (ISPEC - J) 159, 159, 158
158  J      = J+1
      GC TO 155
C                                     MU206100
C                                     MU206200
C
159  TEMP      = 0.0
      DO 820 J=1, ISPEC
820  TEMP      = TCT(J) + TEMP
      STCR(L) = TEMP
      TIME     = TIME + 1.
      L = L+1
      IF (NAR - L) 1591, 150, 150
C
1591  CALL SUB7
1595  L=1
      GC TO 150
C                                     MU206800
C                                     MU206900
C .....
C                                     PERIOD OF THE FUNDAMENTAL
C

```

```

C                                     IS OVER. INCREMENT PARAMET-
C                                     ERS AND START A NEW PERIOD.
C .....
160 DC 920      I=1, IRESON
    PULSE(I,J) = PULSE(I,J) + OPULSE(I,J) * PERIOD(J)
    FCCA(I,J) = FCCA(I,J) + DCCA( I,J )      *PERIOD(J)      MU226400
120 FCCB(I,J) = FCCB(I,J) + DCCB( I,J )      *PERIOD(J)      MU226500
    FMIS(2,J) = FMIS(2,J) + OMIS(1,J)        *PERIOD(J)      MU226600
    FMIS(3,J) = FMIS(3,J) + CMIS(2,J)        *PERIOD(J)      MU226700
161 CALL SUB5                                     MU207200
    GC TO 157                                     MU207300
C .....
C                                     PROCESS A NEW CARD
C .....
163 CALL SUB3                                     MU207500
164 CALL SUB2( IMS2 )                             MU207600
    IF ( IMS2 - 1 ) 167, 166, 165                 MU207700
167 CALL SUB4                                     MU208300
    GC TO 1552
C .....
C                                     END CARD HAS BEEN REACHED.
C                                     START FINAL PROCESSING.
C .....
165 DC1653 IX = L,NAR
1653 STCR (IX) = 0.C
    CALL SUB7
    IF (OPTICN -4. ) 175,1651,1651
175 DC 1751 IX = 1,NAR
1751 STCR(IX) = 0.C
    LCCUNT = LCCUNT + 6
    DC 1752 IX=1,6
1752 CALL RITE(STCR)
    REWIND 8
    REWIND 10
    DC 185 IX = 1,LCCUNT
180 CALL REED(STCR)
5002 FORMAT ( 1F E19.7, 5E20.7 )                19M9290
185 CALL SUB10 (SMALL,GREAT,NAR,STOR,OUTL)
    ENDFILC 10
170 CALL SUB11                                     19M9290
1651 PRINT 4016
    WRITE CUIPUT TAPE 6, 4016
4016 FORMAT (12F END OF JOB. )
    CALL WCUMP
1652 IF(IMS2-2) 192,192,191
191 GC TO 100
192 CALL EXIT
C .....
C ERRCR RCLTINES
C .....
C

```

W. SLAWSON MUSE2, A SOUND SYNTHESIZER

```
166 PRINT 4017
    WRITE OUTPLT TAPE 6, 4017
4017 FORMAT ( 41F DATA CARD OUT OF ORDER. STOP EXECUTION. )
    CALL WCUMP
    CALL EXIT
    ENCL(1,1,0,0,C,0,C,0,0,0,0,0,0,C,0)
```

SLH2, READ DATA CARD INTO S(J) REGIONS.

4/10/63

```

SUBROUTINE SUP2(IIRS2 )
COMMON FREQ,FANC,SREF,SAND,DCCA,DCOH,VAL,TOT,STORE,PUTIN,FMIS,
XSMIS,FMIS,FCCA,FCCB,FORCE,PERIOD , IIN
X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESO, L, IMS2, NAR,
XGREAT, SAMPER
X , STOR
X,CUTL
X,PLUSE,CPULSE,DB
X,PERTY
X, OPTICN
DIMENSION FREQ( 8, 10), FAND( 8, 10), SREF( 8, 10), SAND( 8,
X 10), DCCA( 8, 10), DCOH( 8, 10), VAL( 2, 8, 10), TOT( 10),
X STORE( 100), PUTIN( 21), FMIS( 4, 10), SM(S( 4, 10 ),
XCMIS(2,10), FCCA(8,10), FCCB(8,10), FORCE(8,10)
X PERIOD ( 10 ) , IIN(2)
X,STCR(12000)
X,CUTL(2000)
X,PLUSE(8,10),CPULSE(8,10)
X,PERTY(10)
EQUIVALENCE ( STORE, STOR )
200 READ INPUT TAPE 5, 2000, IIN(1), IIN(2), (PUTIN(M), M=1,19 )
IF ( OPTICN- 2. ) 260, 250, 250
250 PRINT 2001, IIN(1), IIN(2), (PUTIN(M), M=1,19)
2001 FORMAT (1PC212, F7., F4., F8., 8(F5.,F6.))
260 WRITE OUTPUT TAPE 6, 2001, IIN(1), IIN(2), ( PUTIN(M), M=1,19)
201 IF ( IIN(1) - 2 ) 210, 202, 205
202 PRINT 2002
WRITE OUTPUT TAPE 6,2002
2002 FORMAT (24F MISPLACED CONTROL CARD. )
CALL WCUMP
CALL EXIT
205 IF ( IIN(1) -3 ) 206, 207, 245
206 CALL WCUMP
CALL EXIT
207 PRINT 2003
WRITE OUTPUT TAPE 6, 2003
2003 FORMAT (50F CHANGE IN NUMBER OF RESONANCES. TO BE PROGRAMMED. )
CALL WCUMP
CALL EXIT
245 IF(IIN(1)-4) 208,208,240
208 IIRS2 = 2
209 RETURN
C
END CARD.
210 IF ( IIN(2) - J ) 215, 220, 215
215 IIRS2 = 1
PRINT 4003
WRITE OUTPUT TAPE 6, 4003
4003 FORMAT ( 48F DATA CARDS FROM WRONG SPECTRUM. STOP EXECUTION. )
CALL WCUMP
CALL CUMP
220 SMIS(2,J) = PUTIN(2)
225 SMIS(3, J) = 1. / ( PUTIN(3) * SAMPER )
SMIS(1,J) = PUTIN(1) / (100. * SAMPER)
SMIS(4,J) = IIN(1)
I'=4

```

MU208800

MU208900

MU209000

MU209100

MU209200

MU209300

MU209500

MU209700

MU210400

MU210600

MU210700

MU210800

MU211400

MU211500

SUB2, READ DATA CARD INTO S(J) REGIONS.		4/10/63
	N=5	MU211600
	TWCPI = 2. * 3.14159265	
	CC 230 I=1, (RESCN	MU211700
	SREQ(I,J) = PUTIN(N) * TWUPI	MU211900
	SAND(I,J) = PUTIN(M) * TWUPI	MU211800
	N=N+2	MU212000
230	M=M+2	MU212100
	IRRS2 = 0	MU212200
	GOTO 204	
C	NORMAL RETURN.	MU212400
240	IRRS2= 3	
	GOTO 204	
2000	FORMAT (2 I1 , F5.0 , F2.0 , F6.0 , 8(F3.0,F4.0))	MU212500
	END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)	

SUB3, MOVE S(J) TO F(J) REGIONS.		4/10/63
SUBROUTINE SLR3		MU212900
COMMON FREQ,FAND,SREQ,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,		MU213000
XSMIS,FMIS,FCCA,FCCB,FORCE,PERIOD,IIN		MU213100
X, (SW2, J, SMALL, ISPEC, LCOUNT, TIME, (RESON, L, IMS2, NAR,		
XGREAT, SAMPER		
X, STOR		
X,CLTL		
X,PULSE,CPULSE,CH		
X,PERTY		
X, CPTICN		
DIMENSION FREQ(8, 10), FAND(8, 10), SREQ(8, 10), SAND(8,		MU213200
X 10), DCOA(8, 10), DCOB(8, 10), VAL(2, 8, 10), TOT(10),		MU213300
X STOR(100), PUTIN(21), FMIS(4, 10), SMIS(4, 10),		MU213400
XFMIS(2,10), FCCA(8,10), FCCB(8,10), FORCE(8,10)		
X PERIOD(10) , IIN(2)		MU200900
X,STOR(1200)		
X,CLTL(2000)		
X,PULSE(8,10),CPULSE(8,10)		
X,PERTY(10)		
EQUIVALENCE (STORE, STOR)		
300	ISW =1	MU213700
	CC 310 M=1,4	
310	FMIS(M,J) = SMIS(M, J)	MU213900
	CC 320 I=1, (RESCN	MU214000
	FAND(I,J) = SAND(I, J)	MU214100
320	FREQ(I,J) = SREQ(I, J)	MU214200
	RETURN	MU214300
	END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)	

SLB 4 COMPUTE COEFFICIENT INCREMENTS

```

SUBROUTINE SUB4
C   MY END IS MY BEGINNING. FIDOLE WITH THE MIDDLE COEFFICIENTS. MU214700
COMMON FREQ,FANO,SREQ,SANC,CCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS, MU214900
XSMIS,DMIS,FCCA,FCOB,FORCE,PERIOD,IIN MU215000
X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME, IRESO, L, IMS2, NAR,
XGREAT, SAMPER
X, STOR
X, CLTL
X, PULSE, DPULSE, DB
X, PERTY
X, CPTICN
  DIMENSION FREQ( 8, 10), FAND( 8, 10), SREQ( 8, 10), SANO( 8, MU215100
X 10), CCOA( 8, 10), DCOB( 8, 10), VAL( 2, 8, 10), TCT( 10), MU215200
X STCR( 100), PUTIN( 21), FMIS( 4, 10), SMIS( 4, 10 ), MU215300
XDMIS(2,10), FCOA(8,10), FCOB(8,10), FORCE(8,10)
X PERIOD( 10 ), IIN(2)
X, STCR(12000)
X, CLTL(2000)
X, PULSE(8,10), CPULSE(8,10)
X, PERTY(10)
  EQUIVALENCE ( STCR, STOR )
400 DTIME = SMIS(1,J) - FMIS(1,J) MU215600
  E = 2.7182818
  DO 410 I=1, IRESO MU215700
    PULSE(I,J) = FMIS(2,J) * SIN( FREQ(1,J) * SAMPER )
X *(( FREQ(1,J) * ( FMIS(3,J) * SAMPER ) / 6.2831853)) ** (-DB *
X .166096 )
    CPULSE(I,J) = ( ( SMIS(2,J) * SIN( SREQ(1,J) * SAMPER )
X *(( SREQ(1,J) * ( SMIS(3,J) * SAMPER ) / 6.2831853)) ** (-DB *
X .166096 ) ) - PULSE(I,J) ) / DTIME
    FCCA(I,J) = (2.0 * E ** (-FAND(I,J) * SAMPER)) * COS( FREQ MU215800
X(I,J) * SAMPER ) MU215900
    DCCA(I,J) = ((2.0 * E ** (-SANC (1,J) * SAMPER) * COS( SREQ MU216000
X(I,J) * SAMPER)) - FCOA(I,J)) / DTIME MU216100
    FCCB(I,J) = E ** (-2.0 * FANO (1,J) * SAMPER) MU216200
410 DCCB(1,J) = ( E ** (-2.0 * SANO(1,J) * SAMPER) - FCOB(1,J)) MU216300
X / DTIME MU216400
  DO 420 I=1,2 MU216500
420 DMIS(1,J) = (SMIS(I+1,J) - FMIS (I+1 , J) ) / DTIME MU216600
  RETURN MU216700
  ENCL(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0)

```

SLB5, SET PERIOD AND FORCING FUNCTION

4/10/63

```

SUBROUTINE SUB5
COMMON  FREQ,FANC,SREQ,SAND,DCOA,CCOB,VAL,TOT,STORE,PUTIN,FMIS, MU217200
XSMIS,CMIS,FCCA,FCCB,FORCE,PERIOD,IIN MU217300
X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME, IRESN, L, IMS2, NAR,
XGREAT, SAMPER
X, STCR
X, CLTL
X, PULSE, CPULSE, DB
X, PERTY
X, CPTICN
DIMENSION FREQ( 8, 10), FANC( 8, 10), SREQ( 8, 10), SAND( 8, MU217400
X 10), CCOA( 8, 10), CCOB( 8, 10), VAL( 2, 8, 10), TCT( 10), MU217500
X STORE( 10), PUTIN( 21), FMIS( 4, 10), SMIS( 4, 10 ), MU217600
XCMIS(2,10), FCOA(8,10), FCCB(8,10), FORCE(8,10)
X PERIOD( 10 ), IIN(2)
X, STCR(12000)
X, CLTL(2000)
X, PULSE(8,10), CPULSE(8,10)
X, PERTY(10)
EQUIVALENCE ( STORE, STCR )
IF ( FMIS(4,J) - 1.) 500, 510, 500 MU217900
500 PERIOD(J) = FMIS(3,J)
GO TO 520 MU218100
510 CEWRAN = RCUN(DUMMY)
CEWRAN= (CEWRAN*(1./((1000.*SAMPER)))+(1./ ( 5000.*SAMPER))
517 PERIOD(J) = CEWRAN
520 PERTY(J) = PERTY(J) + PERIOD(J)
DO 530 I=1, IRESN
530 FORCE(I,J) = PULSE(I,J)
RETURN MU218500
END(1,1,0,0,C,0,0,0,0,0,0,0,0,C,0)

```

SUBROUTINE 7, WRITE BUFFER AREA

4/10/63

```

SUBROUTINE SUB7
COMMON FREQ,FANC,SREQ,SAND,CCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,
XSMIS,DMIS,FCCA,FCOB,FORCE,PERIOD,IIN
X,ISW2,J,SMALL,ISPEC,LCOUNT,TIME,IRFSON,L,IMS2,NAR,
XCREAT,SAMPER
X,STCR
X,CUTL
X,PULSE,CPULSE,DB
X,PERTY
X,CPTICN
DIMENSION FREQ( 8, 10), FANC( 8, 10), SREQ( 8, 10), SAND( 8, MU221300
X 10), CCOA( 8, 10), DCOB( 8, 10), VAL( 2, 8, 10), TOT( 10), MU221400
X STCR( 100), PUTIN( 21), FMIS( 4, 10), SMIS( 4, 10 ), MU221500
XDMIS(2,10), FCOA(8,10), FCOB(8,10), FORCE(8,10)
X PERIOD ( 10 ) , IIN(2)
X,STOR(12000)
X,ISTOR(12000)
X,CUTL(2000)
X,PULSE(8,10),CPULSE(8,10)
X,PERTY(10)
EQUIVALENCE ( STCR, STOR )
X,(STOR,ISTCR)
700 LCOUNT = LCOUNT + 1 MU221800
IF ( OPTICN - 4. ) 705, 707, 707
705 CALL RITE(STCR)
GOTO 725
707 IF ( CPTICN - 6. ) 720, 710, 720
710 PRINT 5001
PRINT 5002, STCR
720 WRITE OUTPUT TAPE 6, 5001
5001 FORMAT ( 36+ NAREA CONSECUTIVE WORDS OF OUTPUT. )
WRITE OUTPUT TAPE 6, 5002, STORE
5002 FORMAT ( 1H E19.7, 5E20.7 )
725 DO 730 L=1, NAR
IF ( GREAT - STCR(L) ) 740, 750, 750
740 GREAT = STCR(L) MU222300
GOTO 730
750 IF( SMALL - STOR(L) ) 730, 730, 760
760 SMALL = STCR(L) MU222600
730 CONTINUE
770 IF(SENSE SWITCH 5 ) 775,790
775 DIFF = GREAT - SMALL
DO 780 L=1,NAR
780 ISTORE(L) = ((( STOR(L) - SMALL ) / DIFF ) * 512.) + 256.
PRINT 7001
7001 FORMAT(120H THERE IS A REPEATING DISPLAY ON THE CRT. TO STOP IT,
XPUT SWITCH 5 UP. AFTER HALT, SW5 UP TO STOP TV, DOWN TO SEE MORE.)
790 RETURN
END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0)

```

SUBROUTINE WCLMP

4/10/63

```

SUBROUTINE WCLMP
COMMON  FREQ,FANC,SREQ,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,
XSMIS,DMIS,FCCA,FCCB,FORCE,PERIOD,IIN
X,ISW2,J,SMALL,ISPEC,LCOUNT,TIME,IRESN,I,IMS2,NAR,
XGREAT,SAMPER
X,STCR
X,CLTL
X,PULSE,CPULSE,DB
X,PERTY
X,CPTICN
DIMENSION FREQ( 8,10),FAND( 8,10),SREQ( 8,10),SAND( 8,
X10),FCCA( 8,10),FCCB( 8,10),VAL( 2, 8,10),TOT(10),
XSTORE(100),PUTIN(21),FMIS( 4,10),SMIS( 4,10),
XFMIS(2,10),FCCA(8,10),FCCB(8,10),FORCE(8,10),
XPERIOD(10),IIN(2)
X,STOR(12000)
X,CLTL(2000)
X,PULSE(8,10),CPULSE(8,10)
X,PERTY(10)
EQUIVALENCE ( STORE, STOR )
WRITE OUTPUT TAPE 6, 3001
3001 FORMAT (11H- J L IRESN)
X CPTICN ISPEC LCOUNT IRESN)
WRITE OUTPUT TAPE 6, 3002, ( J,L,OPTION, ISPEC,LCOUNT,IRESN )
3002 FORMAT(1H 119, I20, F19.7, 3I20 )
WRITE OUTPUT TAPE 6,3021
3021 FORMAT (11H- IMS2 NAR DB )
X TIME SMALL GREAT DB )
WRITE OUTPUT TAPE 6,3022, (IMS2, NAR, TIME, SMALL, GREAT,DB )
3022 FORMAT (1H 119,I20,4E20.7 )
WRITE OUTPUT TAPE 6, 3025
3025 FORMAT (11H IIN(X,J) )
WRITE OUTPUT TAPE 6, 3026, IIN
3026 FORMAT ( 1H 119, I20 )
WRITE OUTPUT TAPE 6, 3013
3013 FORMAT (11H PUTIN(X) )
WRITE OUTPUT TAPE 6, 3004, PUTIN
3004 FORMAT ( 1H F19.7,5E20.7 )
WRITE OUTPUT TAPE 6, 3003
3003 FORMAT (11H FREQ(I,J) )
WRITE OUTPUT TAPE 6, 3004, FREQ
WRITE OUTPUT TAPE 6, 3005
3005 FORMAT (11H FANC(I,J) )
WRITE OUTPUT TAPE 6, 3004, FAND
WRITE OUTPUT TAPE 6, 3006
3006 FORMAT (11H SREQ(I,J) )
WRITE OUTPUT TAPE 6, 3004, SREQ
WRITE OUTPUT TAPE 6, 3007
3007 FORMAT (11H SAND(I,J) )
WRITE OUTPUT TAPE 6, 3004, SAND
WRITE OUTPUT TAPE 6, 3014
3014 FORMAT (11H FMIS(I,J) )
WRITE OUTPUT TAPE 6, 3004, FMIS
WRITE OUTPUT TAPE 6, 3015
3015 FORMAT (11H SMIS(I,J) )
WRITE OUTPUT TAPE 6, 3004, SMIS

```

SUBROUTINE WCUMP

4/10/63

```
      WRITE OUTPUT TAPE 6, 3016
3016 FCRMAT (11F CMIS(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      DMIS
      WRITE OUTPUT TAPE 6, 3017
3017 FCRMAT (11F FCCA(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      FCOA
      WRITE OUTPUT TAPE 6, 3018
3018 FCRMAT (11F FCCB(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      FCOB
      WRITE OUTPUT TAPE 6, 3008
3008 FCRMAT (11F CCOA(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      DCOA
      WRITE OUTPUT TAPE 6, 3009
3009 FCRMAT (11F CCOB(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      DCOB
      WRITE OUTPUT TAPE 6, 3010
3010 FCRMAT (11F VAL(X,I,J) )
      WRITE OUTPUT TAPE 6, 3004,      VAL
      WRITE OUTPUT TAPE 6, 3011
3011 FCRMAT (11F TOT(J) )
      WRITE OUTPUT TAPE 6, 3004,      TOT
      WRITE OUTPUT TAPE 6, 3012
3012 FCRMAT (11F STORE(L) )
      WRITE OUTPUT TAPE 6, 3004,      STORE
      WRITE OUTPUT TAPE 6, 3019
3019 FCRMAT (11F FORCE(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      FORCE
      WRITE OUTPUT TAPE 6, 3020
3020 FCRMAT (11F PERIOD(J) )
      WRITE OUTPUT TAPE 6, 3004,      PERIOD
      WRITE OUTPUT TAPE 6, 3023
3023 FCRMAT (15F DPULSE(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      DPULSE
      WRITE OUTPUT TAPE 6, 3024
3024 FCRMAT (15F PULSE(I,J) )
      WRITE OUTPUT TAPE 6, 3004,      PULSE
      WRITE OUTPUT TAPE 6, 3027
3027 FCRMAT ( 15F PERTY(J) )
      WRITE OUTPUT TAPE 6, 3004,      PERTY
      RETURN
      ENCL(1,0,0,0,C,0,0,0,0,0,0,0,0,0,0)
```


SUBROUTINE IC SCALING AND PACKING ROUTINE

		SCALING AND PACKING SUBROUTINE			
	CCCC2	ENTRY	SUB10		
LINKAGE DIRECTOR					
00000	CCCC0000CCCC				
00001	62642201006C				
00002	0634 00 4 C0060	SUB10	SXA	XSAVE,4	
00003	0634 00 2 C0061		SXA	XSAVE+1,2	
00004	0634 00 1 C0062		SXA	XSAVE+2,1	
00005	0500 60 4 C0003		CLA*	3,4	
00006	0601 00 0 C0077		STD	NAR	
00007	0500 60 4 C0002		CLA*	2,4	
00010	0601 00 0 C0066		STD	GREAT	
00011	0500 60 4 C0001		CLA*	1,4	
00012	0601 00 0 C0065		STD	SMALL	
00013	0500 00 4 C0004		CLA	4,4	LOCATION OF STOR
00014	0734 00 1 C0000		PAX	,1	
00015	1 00001 1 C0016		TXI	*+1,1,1	
00016	0634 00 1 C0037		SXA	L21,1	
00017	0500 00 4 C0005		CLA	5,4	LOCATION OF OUTL
00020	0734 00 1 C0000		PAX	,1	
00021	1 00001 1 C0022		TXI	*+1,1,1	
00022	0634 00 1 C0047		SXA	L23,1	
00023	0634 00 1 C0027		SXA	L24,1	
00024	1 74060 1 C0025		TXI	*+1,1,-2000	
00025	0634 00 1 C0064		SXA	101,1	
00026	0774 00 2 C3720		AXT	2000,2	
00027	0600 00 2 50121	L24	STZ	OUTL,2	
00030	2 00001 2 C0027		TIX	*-1,2,1	
00031	0500 00 0 C0066		CLA	GREAT	COMPUTE DIFF
00032	0302 00 0 C0065		FSB	SMALL	
00033	0601 00 0 C0067		STD	DIFF	END OF HOUSEKEEPING
00034	0774 00 1 C0001		AXT	1,1	
00035	0774 00 2 C3720		AXT	2000,2	
00036	0774 00 4 C0006	L22	AXT	6,4	
00037	0500 00 1 77462	L21	CLA	NARFA+1,1	SCALE AND PACK THIS RECORD
00040	0302 00 0 C0065		FSB	SMALL	
00041	0241 00 0 C0067		FCP	DIFF	
00042	0260 00 0 C0072		FMP	SEVSIX	
00043	-0300 00 0 C0075		UFA	MAGIC	
00044	0760 00 0 C0011		FRN		
00045	-0320 00 0 C0074		ANA	MASK1	
00046	0767 00 4 C0044		ALS	36,4	
00047	-0602 00 2 50121	L23	ORS	OUTL,2	
00050	1 00001 1 C0051		TXI	*+1,1,1	
00051	1 00006 4 C0052		TXI	*+1,4,6	
00052	-3 00044 4 C0037		TXL	L21,4,36	
00053	2 00001 2 C0036		TIX	L22,2,1	
00054	+077600002225		OCT	077600002225	SDH OUTTAP
00055	0766 00 0 C2225		WTRB	OUTTAP	
00056	-0540 00 0 C0064		RCHB	101	
00057	0061 00 0 C0057		TCOB	*	
00060	0774 00 4 C0000	XSAVE	AXT	** ,4	
00061	0774 00 2 C0000		AXT	** ,2	

SUBROUTINE 10 SCALING AND PACKING ROUTINE

00062	0774 00 1 CCCC0C	AXT	** ,1
00063	0020 00 4 CCCC06	TRA	6,4
00064	-1 03720 0 44202	IO1 IOCT	OUTL-1999,,2000
00065	0 00000 0 CCCC00	SMALL PZE	
00066	0 00000 0 CCCC00	GREAT PZE	
00067	0 00000 0 CCCC00	DIFF PZE	
00070	+000000000006	SIX DEC	6
00071	0 00000 0 CCCC00	LDSIX PZE	
00072	+20677000CCCC	SEVSIX DEC	63.0
00073	+176400000000	PFIVE OCT	176400000000
00074	+000000000077	MASK1 OCT	77
00075	+233000000000	MAGIC OCT	233000000000
00076	+000001000000	ONFDEC OCT	1000000
00077	0 00000 0 CCCC00	NAR PZE	
	00005	OUTTAP EQU	5
	77461	NAREA EQU	32561
	50121	OUTL EQU	20561
		END	

SUBROUTINE 11 WRITE A LONG RECORD

C3722 ENTRY SUB11

SUBROUTINE TO WRITE A LONG RECORD

LINKAGE DIRECTOR
00000 0C000C0CCCCC
00001 52642201C16C

		CCC05	OUTTAP	EQU	5	
		CCC05	FTAPE	EQU	5	
C0002			AREA	BSS	2000	
		C3720	L	FQU	2C00	
03722	0634 00 2	C3751	SUB11	SXA	EXIT,2	
03723	0772 00 0	C2205		REWB	OUTTAP	
03724	+0776CC002225			OCT	077600002225	SDHB OUTTAP
03725	-0030 00 0	C3726		TEFB	**1	
03726	0762 00 0	C2225		RTBB	OUTTAP	
03727	-0540 00 0	C3757		RCHB	IO9	
03730	0061 00 0	C3730		TCOB	*	
03731	-0022 00 0	C3732		TRCB	**1	
03732	+0776CC001205			OCT	077600001205	SDLA FTAPE
03733	0766 00 0	C1225		WTBA	FTAPE	
03734	0540 00 0	C3757		RCHA	IO9	
03735	0640 00 0	C3756	DELAY	SCHA	T	
03736	0534 00 2	C3756		LXA	T,2	
03737	-3 02736 2	C3735		TXL	**2,2,AREA+L-N	
03740	0762 00 0	C2225		RTBB	OUTTAP	
03741	-0540 00 0	C3757		RCHB	IO9	
03742	-0061 00 0	C3750		TCNB	END	
03743	-0640 00 0	C3755		SCHB	S	
03744	0534 00 2	C3755		LXA	S,2	
03745	-3 00004 2	C3742		TXL	**3,2,AREA+2	
03746	0544 00 0	C3757		LCHA	IO9	
03747	0C20 00 0	C3735		TRA	DELAY	
03750	0060 00 0	C3750	FNC	TCOA	*	
03751	0774 00 2	CCCC0	EXIT	AXT	**2	
03752	-0030 00 0	C3753		TEFB	**1	
03753	0020 00 4	CCCC01		TRA	1,4	
03754	0000 00 0	CCCC01	ERROR	HTR	1	
03755	0 00000 0	CCCC0	S	PZE		
03756	0 00000 0	CC00C	T	PZE		
		CC764	N	EQU	500	
03757	-1 03720 0	CCCC02	IO9	IOCT	AREA,,L	
				END		

CCUNT 25

CC002

ENTRY

REED

LINKAGE DIRECTOR

00000 000000000000
00001 512525246C6C

00002	0634	00	2	CC012	REED	SXA	EXIT,2
00003	0500	00	4	CCC01		CLA	1,4
00004	0734	00	2	CCC00		PAX	,2
00005	1 50441	2	CCC06		TXI	**1,2,-11999	
00006	0634	00	2	CC014		SXA	10,2
00007	0762	00	0	C2221		RTBB	1
00010	-0540	00	0	CCC14		RCHB	10
00011	0061	00	0	CCC11		TCOB	*
00012	0774	00	2	CC000	EXIT	AXT	**,2
00013	0020	00	4	CCC02		TRA	2,4
00014	-1 27340	0	CCC00	IO	IOCT	**,,12000	
					END		

SUBROUTINE FOR WRITING A5 RITE(STOR)

CC002

*

COUNT

25

ENTRY

RITE

LINKAGE DIRECTOR

00000 000000000000
00001 513163256C6C

00002	0634	00	2	CCC12	RITE	SXA	EXIT,2
00003	0500	00	4	CCC01		CLA	1,4
00004	0734	00	2	CCC00		PAX	,2
00005	1 50441	2	CCC06		TXI	**1,2,-11999	
00006	0634	00	2	CC014		SXA	10,2
00007	0766	00	0	C2221		WTBB	1
00010	-0540	00	0	CCC14		RCHB	10
00011	0061	00	0	CCC11		TCOB	*
00012	0774	00	2	CC000	EXIT	AXT	**,2
00013	0020	00	4	CCC02		TRA	2,4
00014	-1 27340	0	CCC00	IO	IOCT	**,,12000	
					END		

	CCC21	ENTRY	RONN
	CCC02	ENTRY	ROUN
LINKAGE DIRECTOR			
00000	000000000000		
00001	512445456060		
00002	0560 00 0 CCC16	RDUN	LCQ RDUN+12,0
00003	0200 00 0 CCC17		MPY RDUN+13,0
00004	0763 00 0 CCC04		LLS 4,0
00005	0767 00 0 CCC04		ALS 4,0
00006	0765 00 0 CCC04		LRS 4,0
00007	-0600 00 0 CCC16		STC RDUN+12,0
00010	0400 00 0 CCC16		ADC RDUN+12,0
00011	0601 00 0 CCC16		STO RDUN+12,0
00012	0771 00 0 CCC04		ARS 4,C
00013	-0501 00 0 CCC20		ORA ROUN+14,0
00014	0300 00 0 CCC20		FAO RDUN+14,0
00015	0020 00 4 CCC02		TRA 2,4
00016	+002312421637		OCT 2312421637,1737,200000000000
00017	+000000001737		
00020	+200000000000		
00021	-0634 00 1 CCC51	RDUN	SXD IR1,1
00022	-0634 00 4 CCC52		SXD IR4,4
00023	0534 00 1 CCC44		LXA L20,1
00024	0500 00 0 CCC20		CLA RDUN+14,0
00025	0601 00 0 CCC53		STO C,0
00026	0074 00 4 CCC02		TSX RDUN,4
00027	0761 00 0 CCC00		NOP
00030	0300 00 0 CCC53		FAO C,0
00031	0601 00 0 CCC53		STO C,0
00032	2 00001 1 CCC26		TIK RDNN+5,1,1
00033	0241 00 0 CCC45		FDP L20+1,C
00034	0500 00 0 CCC50		CLA L20+4,0
00035	0763 00 0 CCC43		LLS 35,0
00036	0302 00 0 CCC46		FSB L20+2,0
00037	0765 00 0 CCC43		LRS 35,0
00040	0260 00 0 CCC47		FMP L20+3,0
00041	-0534 00 1 CCC51		LXD IR1,1
00042	-0534 00 4 CCC52		LXD IR4,4
00043	0020 00 4 CCC02		TRA 2,4
00044	0000 00 0 CCC24	L20	HTR 20,0
00045	+205500000000		DEC 20.,.5,15.49193340,0
00046	+200400000000		
00047	+204757573654		
00050	+000000000000		
00051	0000 00 0 CCC00	IR1	HTR C,0
00052	0000 00 0 CCC00	IR4	HTR 0,0
00053	0000 00 0 CCC00	C	HTR 0,0
			END

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The MITRE Corporation Bedford, Massachusetts		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE THE MUSE SYSTEM: DESCRIPTION AND MANUAL FOR OPERATION			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) N/A			
5. AUTHOR(S) (Last name, first name, initial) Slawson, A. Wayne			
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Scientific and Technical Information, Electronic Systems Division L.G. Hanscom Field, Bedford, Mass.	
13. ABSTRACT The MUSE system, an IBM 7090 computer program and associated conversion equipment, has been designed for use as a sound synthesizer. Concise descriptions of complex sounds including human speech are converted by the MUSE system into sound pressure waveforms. The inputs to the MUSE system are specifications of the changing resonance frequencies of multiple acoustic filter networks and of the changing frequencies and amplitudes of the sources of acoustic energy that excite those networks. The output of the MUSE system is a sampled waveform calculated for each resonance by the solution of a second-order difference equation. The results are summed over a single system of resonances and then the resonance systems are also added together. The resulting string of sampled waveform ordinates is written in digital form on magnetic tape. Conversion to a voltage waveform is accomplished by use of the standard IBM 729 IV tape transport unit and a simple digital-to-analog converter. Although the quality of the sound is somewhat degraded by tape wow and flutter, acceptable and highly intelligible speech has been synthesized.			

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1 JAN 64

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Simulation						
Programming (Computers)						
Speech Representation						
Speech						
Voice Communication Systems						
Sound Reproduction Systems						
Sound Generators						

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