

AN INTRODUCTION TO THE DARTMOUTH MUSIC LANGUAGE

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CONTENTS

PAGE

1. Introduction	1
2. The Digital Synthesizer	4
2.1 Waveforms and Timbre Number	4
2.2 Frequency Modulation	5
2.3 Speakers and Grouping of Oscillators	5
3. Typing a Composition in Dartmouth Music Language	7
3.1 The First Parameter on a Note Line	8
3.2 Using Commas or Dittos	8
3.3 Using the '=' Sign	9
3.4 Using the \$NAME Facility	9
3.5 Examples of Different Methods of Entering the Same Note	11
4. Summary of Allowed Parameter Types and Their Limits	12
4.1 Time	12
4.2 Frequency	12
4.3 Volume	12
4.4 Index	12
4.5 Speaker Mode	12
4.6 Comments and Headings	13
4.7 Instrument Names	13
5. Commands to the DML Compiler	14
5.1 SPACE	14
5.2 REST	15
5.3 TIME	15
5.4 WAVE 128	16
5.5 KEYBOARD	16
5.6 GRADVOL	18
5.7 GRADINDEX	20
5.8 GRADFREQ	21
6. Playing a Composition - The SING Commands	22
6.1 SING 20.	22
6.2 SING LIST 200	22
6.3 SING TABULATE	23
6.4 SING SORT 10.	23
6.5 SING SORT TABULATE	23
6.6 SING TRY	23

APPENDIXES

PAGE

1. Frequency Modulation	1
2. Instrument PITCH	5
3. Instrument WIND	8
4. Instrument KLANG	14

## 1. Introduction

A composition in Dartmouth Music Language (DML) consists of a series of lines which each define a 'note' or an instruction to the DML compiler. All lines in the composition must begin with a line number.

Notes are made on 'instruments' (which are machine language programs) that control one or more oscillators of the digital synthesizer according to the frequency, timbre and timing parameters which follow the instrument name in the composition.

A typical note might be typed in like this:

150 12.5 PITCH 440 .8 75 A 0 64 .08 .5 CR

150 is the line number (for editing purposes)

12.6 is the time that the note should begin, measured in seconds from the start of the composition.

PITCH is the name of the instrument, (see below)

440 is the fundamental frequency of the note in Hertz.

.85 is the sustain time duration from start of note to start of decay time.

75 is the volume (loudness), maximum of 100

A means that the note should be played on speaker A (see section 4.5)

0 is the frequency modulation index in synthesizer units.

64 is the synthesizer timbre number for a sine wave.

.08 is the attack time.

.5 is the decay time.

The end of the parameters being signalled by the Carriage Return CR.

In the above example, at 12.6 seconds from the time you start to play the composition which includes line 150, the instrument PITCH takes a free oscillator (and if all oscillators are being used by other notes then Pitch must wait until an oscillator is released) and sets the oscillator waveform to be a sine wave at a frequency of 440 Hertz. Then in a time of .08 seconds Pitch sweeps the volume of the oscillator from 0 to 75, leaves it at that level until .85 seconds from the time that the note started and then sweeps it back to zero in .5 seconds before releasing the oscillator for other notes to use. If the parameter line was not complete then standard default parameters will be used.

PITCH is the simplest of the instruments at present available. Using the various waveform choices on the synthesizer we can give such a note produced on a single oscillator, almost any timbre or harmonic structure we desire, but we cannot alter its timbre gradually during a note - for this we need to use F.M.

F.M. timbres are produced by frequency modulating the waveform on one oscillator (the 'carrier') by that on an (adjacent) second oscillator, the depth of modulation being controlled by the 'index'. The higher the modulation index the more harmonics will be present in the carrier output. This is used as a means of controlling the evolution of the timbre during a note. (See appendix on F.M.)

Details of each of the instruments available and the order and effect of the parameters used with them are given in the appendix.

Composing in DML would be extremely arduous if one had to type in from ten to fifteen parameters for every note. To avoid this there are several features of the language which allow you to define a note by typing in only changes from the previous line or just changes from any previously named line, see section 3.

Once you have typed in your composition you can store it for future use on (digital) magnetic disc or tape, you can edit it using various EDIT commands available on the system (see appendix for details) or you can play it by typing SING. SING may be followed by various other command words for example SING LIST will print your composition so that corresponding parameters lie in the same column. Section 6 explains the various commands that you can use in conjunction with SING.



## 2. The Digital Synthesizer




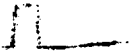

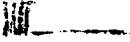
The present digital synthesizer has 16 oscillators on each of which may be controlled, (in real time):

- 1.) Frequency
- 2.) Waveform
- 3.) Volume (both maximum volume and envelope characteristics)
- 4.) Index of frequency modulation

### 2.1 Waveforms and Timbre Numbers

The waveform is set on a given oscillator by the timbre number for which the meaningful values are given in the following list:

<u>Timbre numbers</u>		<u>Waveform</u>
16-23		Very noisy quasi - random digital combinations of the following waveforms. Sometimes Harpsichord-like in certain registers.
64		Sine wave (Reserved wave shape memory)
80-87		Noisy quasi - random waveforms
128	Any shape	Using the 'WAVE 128' command in DML you can set this waveform to have any desired harmonic structure. See section 5.4.
144-157		Noisy quasi - random waveforms.
208		Triangle

<u>Timbre numbers</u>	<u>Waveform</u>	<u>Waveform</u>
209		Ramp
210		Square and Ramp
212		Square
213		1/2 pulse square (1/4 duty cycle)
214		1/4 pulse (1/8 duty cycle)
215		Double quarter pulse

### 2.2 F.M.

If on any oscillator the index of modulation is set to be greater than zero then the waveform of that oscillator will modulate the adjacent (higher numbered) oscillator. This will change the waveform (and thus the timbre) of the modulated 'carrier' oscillator. The carrier waveform will change according to both the value of the index and the ratio of Carrier to Modulating frequencies (see appendix on F.M. and details of instrument KLANG). Note that on this system, the waveform of the modulating oscillator is unchanged and will be heard (at whatever volume it is set) along with the modulated carrier output.

### 2.3 Speakers and Grouping of Oscillators

The 16 oscillators of the synthesizer are arranged in four groups of four named A,B,C and D. When on a student terminal, only one of those groups is available to you and the speaker letters in the note parameter line are ignored. On the master terminals all four speakers are available and



the system will put your notes on the group of speakers that you have requested provided there are still free oscillators in that group. 'M' denotes Mono, ie the note may appear on any speaker, 'L' denotes Left ie A or B and 'R' denotes Right ie on speakers C or D. A,B,C and D may be used if you are working quadrophonically.

F.M. instruments (eg. KLANG) use two oscillators so only two FM notes may be played simultaneously on one speaker. If your composition demands a note on a speaker that is already 'full' then the system will place the note wherever it can find spare oscillators. If all oscillators are in use then further notes will be delayed until other notes terminate and release their oscillators. Whenever a note is delayed, a message will appear on your terminal giving the time and line number of the delayed note.

### 3. Typing a Composition in Dartmouth Music Language

To illustrate the process of building up a composition without having to type in every parameter on every line let us suppose that you already have typed the following heading (lines 4 and 5) and notes (line 10-150), and that after typing SING LIST CR, the output on your terminal is as follows:

```

4   'TIME INSTRUMENT 1   2   3   4   5   6   7   8
5   'TIME INSTRUMENT FREQ SUS VOL SPK INX TBR ATK DEC
10  0.   PITCH      G#4  .2  50  M   0   18  0.  .4 @0.2
20  . . . . .
30  . . . . .

150 12.6 PITCH      440  .8  75  A   0   64  .08 .5 @13.4

```

The effect of line 150 was described in the introduction (see also appendix 2 on 'PITCH'). Notice that SING has inserted '@13.4' at the end of the line and that although you typed (probably) only one space between the parameters, 'SING' has tabulated corresponding parameters so that they lie in the appropriate column.

On lines 4 and 5 the apostrophe denotes that the rest of the line is a heading only. Such headings may be inserted at any point in the program and are tabulated so that words lie in successive columns.

Consider now that you are about to type in another note with line number 160.

### 3.1 The First Parameter on a Note Line

Only if the first parameter you type is a time will it go into the time column and become the starting time of the new note. If the first parameter is not a time (ie not a number with a decimal point) then the note on line 160 will start at the end of the previous note's sustain period, in this case @13.4 seconds which is the time 'SING' inserted at the end of line 150. (See section 5.1 for a modification of this by the 'SPACE' command.)

If the first parameter is a frequency (ie an integer or like A4 or A#4) then it will go straight into the frequency column.

If the first character is an instrument name (including one that you have defined yourself, see 3.4) then it goes into the instrument column and resets all the current values of the parameters according to the values in force in the instrument definition. If the instrument name is not inserted then unless new values are inserted on this line, parameters stay unchanged from those in force on the previous line.

### 3.2 Using Commas or Dittos (double apostrophe)

A comma or ditto can be used to skip past a field (column) that is to remain unchanged. (Spaces are not necessary on either side of commas or dittos).

#### EXAMPLES

160 A4 1.1 CR      would mean a note like that on line 150, of frequency A4 and a sustain of 1.1 seconds.

but:

160 A4,,,,208 CR      would mean a note like line 150 but frequency A4 and a triangle waveform. The commas determine where "208" will fall.

If a comma is the first field that follows the line number then it will go into the instrument column, not the time column. If you want a note to start at the same time as the previous note you must type in the same starting time.

To see if the SING program has done what you intended, type SING LIST to check that the parameters go into the correct columns, and that the times at the end of the lines are as you expected.

### 3.3 Using the = Sign

If you wish to skip over many parameters then it is often easier to name the column number to which you wish to go using an = sign, rather than having to count a long string of commas. Suppose in line 160 you want a 'PITCH' like line 150 but of frequency A4, starting at 14.0 seconds and having an attack time of 0.2 seconds. The following two lines both have this effect.

```
160 14.0,A4,,,,.2 CR
```

```
160 14.0,A4 7=.2 CR
```

The attack is the seventh parameter after the instrument name - as the heading on line 4 indicates.

Once again, the first few times you use these facilities use SING LIST to verify that the parameters have in fact gone into the correct fields.

### 3.4 Using the \$NAME Facility

If the note that you want on line 160 is very unlike the note on the previous line (150) but does resemble a note that you have on an earlier line

in the composition then the quickest way of proceeding is to make yourself a new instrument name using the *\$NAME* facility and then to use it with whatever changes you need.

Suppose you want (on line 160) a note like line 10 but with a frequency of A4 and a sustain of .4 seconds, then you need only type:

```
15 $HARPS CR
160 HARPS A4 .4 CR
```

The effect of line 15 is to define a new instrument of name 'HARPS' which is a 'PITCH' but whose default parameters are all those parameters in force on line 15. This instrument may then be called in the same way as PITCH, changing only those parameters you require.

Notice that the new frequency and sustain could have been included in the definition as follows:

```
15 $HARPS,A4 .4 CR
160 HARPS CR
```

The note produced on line 160 is the same in both cases. Once an instrument is defined in this way it may be used throughout the composition. A suggested technique in composition is to put any instrument definition that you particularly like into a file reserved for such definitions. Then when you start a new composition insert the definition file into it at the beginning, so that all the definitions are instantly available.

### 3.5 Examples of Different Methods of Entering the Same Note

To check your understanding of this section, look at the following different ways of making the same note on line 160 and satisfy yourself that in fact each method does produce the same note. For ease of understanding only, the parameters in a b and f are spaced out to the correct columns as 'SING LIST' would do when the composition was played. Notice the way a defined instrument can be used to define yet another instrument (in e).

4	'TIME	INSTRUMENT	1	2	3	4	5	6	7	8	
5	'TIME	INSTRUMENT	FREQ	SUS	VOL	SPK	INX	TBR	ATK	DEC	
10	0.	PITCH	G#4	.2	50	M	0	18	0.	.4	@0.2
150	12.6	PITCH	440	.8	75	A	0	64	.08	.5	@13.4
<u>a.</u>	160	13.4	G#4	,	,	,	,	18	.0		
<u>b.</u>	160		G#4					6=18	.0		
<u>c.</u>	15	\$HARP,,	.8	7.5	A	0	,,	.5			
	160	HARP									
<u>d.</u>	15	\$HARPA									
	160	HARPA,	.8	7.5	A	0,,	.5				
<u>e.</u>	15	\$HARPA									
	155	\$HARPB HARPA,	.8	7.5	A	0,,	.5				
	160	HARPB									
<u>f.</u>	160	13.4	PITCH	G#4	.8	75	A	0	18	.0	.5

#### 4. Summary of Allowed Parameter Types and Their Limits

##### 4.1 Time

All times should be typed in seconds with a decimal point. A time of one second must be typed as 1. or 1.0 to be recognized as a time. The maximum time is 655.35 seconds (about 11 minutes), and the smallest unit of time is .01 seconds.

##### 4.2 Frequency

May be typed in well tempered form eg. B<sup>4</sup>, B<sup>#4</sup> or B<sup>-4</sup> with octaves running from 0-9, otherwise as an integer which is the frequency in Hertz in the range 8-16,000.

##### 4.3 Volume

Integers from 0 - 100

##### 4.4 Index

An integer from 0 - 2040

##### 4.5 Speaker Mode

A single letter: M is for mono - the note may appear on any speaker  
L on speaker A or B  
R on speaker C or D  
A,B,C or D only on the corresponding speaker.

#### 4.6 Comments and Headings

Whenever the DML compiler encounters a field that begins with an apostrophe, the rest of the line is assumed to be a comment. If the apostrophe follows the line number (but after a space) then the comment is tabulated out to the heads of the columns whenever you type SING LIST or SING TABULATE. This is a convenient way of making headings for the columns.

#### 4.7 Instrument Names

To be used in the \$NAME definition. The name given to an instrument may be any sequence of characters which does not include a space, a comma, or a ditto and which cannot be confused with any of the foregoing parameters or the DML commands in the following section.

##### Examples of valid names:

FLUTE, FLUTEL, 100A, A↑B, !!?!#

##### Example of non valid names:

M, A4, SPACE, 10, Anything that includes a comma, ditto or space



## 5. Commands to the Compiler

These are commands which cause no note to be played, but instead instruct the DML compiler how to deal with the following notes. Do not use any of these command words for an instrument name.

### 5.1 SPACE

Example: 100 SPACE 1.2 CR

'SPACE' should be followed by a time then CR. In section 3.1 it was shown how notes that do not begin with a time, will start at the end of the sustain (or the start of the decay) of the previous note (so that there will be some overlap between consecutive notes). Line 100, above, increases the amount of time between consecutive notes by 1.2 seconds. This facility is particularly useful with percussive notes which normally have a zero sustain and so which cannot be made to follow each other consecutively except by using the 'SPACE' command. You may use a negative time after SPACE. 100 SPACE -.5 CR would increase the amount of overlap between notes so that each note would start .5 seconds before the end of the sustain on the previous note. Once set, the note spacing will continue to be added between consecutive notes until changed by another 'SPACE' command. If anything other than a time follows 'SPACE' then the spacing will be reset to zero - as it is when the composition begins. Set the space command between the first two notes that you wish to be spaced.

5.2 REST

Example: 200 REST 2.3 CR

When entering notes consecutively, a 'REST' statement between two notes will put a rest (of the time indicated) between them. This rest is in addition to any spacing that is introduced through a previous SPACE command. As with space, a negative time after REST will decrease the amount of time between the two notes. 'REST' has an effect only on the timing of the note before which it is placed. Anything other than a time following 'REST' (for example a Carriage Return) will give a rest value equivalent to a missing note.

5.3 TIME

Example: 300 TIME 14.6

The effect of the above line is to add 14.6 seconds to all subsequent note starting times. It is particularly useful when you wish to merge two compositions, the second starting (in this case) 14.6 seconds after the beginning of the first. Place the above TIME statement after the first composition then 'APPEND' the second. The first time you use this command, 'SING LIST' your new combined composition to make sure that the timing of the second composition is what you expected. If you don't put a statement of TIME 0. after this combined composition then any notes that you place after this time statement will also have 14.6 seconds added to their starting times.

If using EDIT APPEND you want to repeat a block of notes which have explicit starting times then you will have to insert a new 'TIME' statement between each block to get the blocks to follow each other. An easier way to

do this is to write the section to be repeated without explicit starting times by using the 'SPACE' and 'REST' commands, then repeated copies of the section will automatically follow each other.

By putting a TIME statement in the middle of a composition you can move a section forwards or back in time.

#### 5.4 WAVE 128

Example: 400 WAVE 128 100 100 80 0 30 CR

This command sets the waveform corresponding to timbre no. 128, to have a harmonic spectrum whose relative amplitudes are given by the integers following the 'WAVE 128'. In this case when timbre number 128 is used, the oscillator will have a waveform of: -1st harmonic equal in intensity to the fundamental, 2nd harmonic 80% as strong as the fundamental, 4th harmonic 30% of the fundamental, and all other harmonics absent.

At present there is no way that you can reset the timbre number 128 part of the way through a composition, the last 'WAVE' instruction in the composition will set that timbre for the whole composition, from the start to the end.

#### 5.5 KEYBOARD

This command is unlike the others in this section in that it is a form of instrument and may have a starting time and sustain time. It is used to set notes on to the keyboard according to which of the switches above the keyboard is depressed. If switch number 1 is depressed then the first note

following the keyboard line will be played (the note on line 510 in the following example).

Example:

```

500 10. KEYBOARD C8 60. CR
510   KLANG, .8 255 ..... CR (Switch #1)
520   , , 0.                               (Switch #2)
530   PITCH, .8 , ..... CR (Switch #3)
540   END

```

Lines 500 to 540 are all part of the KEYBOARD statement. Line 500 indicates that if you play the keyboard during the period 10 seconds to 70 seconds from the start of the composition, then according to which number switch is set you will hear the corresponding note of those defined on lines 150 - 530, but with a frequency according to the key depressed, where C8 is the uppermost key. Since there are seven switches, you may enter up to seven different notes between the 'KEYBOARD' line, (500) and the 'END' statement (line 540). These notes may be typed in using any of the methods described in section 3, the frequency and starting times will be ignored but the sustain time has a different effect depending on whether it is zero or non zero. If like line 520 in the example, the sustain time is defined as zero (as it usually is for percussive instruments) then the note will rise to its maximum then immediately start to decay according to the decay parameter defined. The note will be ended abruptly if you release the key before the note has completed its decay. If the effective sustain time for the note is not zero, then the note will be held on until you release the key and will then die away according to the decay defined in the note.

In brief a zero sustain gives percussive instruments, any other sustain gives organ like instruments.

In the above example, line 520 (switch number 2) will give a note exactly like that on switch number 1 except that the note on switch number 2 will be like a percussive instrument and that on switch number 1 like an organ - only the sustain is changed on line 520.

As with other instruments you may have multiple **KEYBOARD** assignments, at the same time, overlapping, or following each other sequentially. Whenever the keyboard assignments overlap then when you depress a key you will hear a note for each keyboard statement valid at that time (providing you have enough free oscillators). Using this facility you can program the keyboard instrument to change in synchronism with your typed program or you can construct more complicated timbres by playing different notes simultaneously.

If instead of supplying a sustain time of 60. seconds (in line 500) you type *CR* following the keyboard top frequency C8 (500 10. **KEYBOARD C8 CR**) then this keyboard call will be operative from 10 seconds but continuing indefinitely or until you interrupt the computer by typing 'S'.

### 5.6 GRADVOL

'GRADVOL' (for graduate volume) is a means of making a crescendo or decrescendo on a block of notes. The word **GRADVOL** must be followed by a starting percentage, an ending percentage and an identifier letter. The notes should be followed by a line with **END** and the same identifier letter that followed the **GRADVOL** statement to be terminated.

## Example:

410	GRADVOL	50	150	B
420	5.0 PITCH	A4	20	20
430	10.	B4	2.	40
440	END B			

Lines 410 and 440 serve to bracket the notes to be crescendoed. The crescendo will start at the time of the first note in the block and will end with the last note in the block to terminate. In the example, the crescendo will last over the duration of the A4 Pitch - from 5 seconds to 25 seconds. This pitch will start at a volume of 10 (50% of 20) and rise to a volume of 60 (150% of 20). The B4 Pitch, line 430 which starts at 10. seconds will also be crescendoed, always keeping its volume in the same proportion to the first, A4 Pitch, line 420. No note can have a volume outside the range 0-100 so if due to a GRADVOL statement the volume of a note reaches one of these bounds, the note's volume will change no more.

If you wish the volume to change in step fashion instead of smoothly, you may enter a time before the identifier letter 'B' in line 410. The time is the interval between volume alterations, a small time (.01 - .05 seconds) will give a smooth alteration, a large time (eg 1. or 2. seconds) will result in audible steps in the volume.

Multiple GRAD statements may be made, they may overlap or be contained within each other. When making overlapping statements you must use a different identifier letter for each GRAD statement.

Example:

110		GRADVOL	100	200	A
120	2.3	PITCH	A4	5.	
130		GRADVOL	100	0	B
140	3.4	WIND	B4		
150	4.4	WIND	C5		
160		END	B		
170	5.6	PITCH	D5	1.	
180		END	A		

The 'B' statement will reduce the volume of the two notes 140 and 150 faster than the A statement is increasing them. If lines 160 and 180 were interchanged so that the 'A' crescendo ended before line 170 and the 'B' decrescendo included line 170 then line 170 would hardly be heard, whereas at present it is the loudest note in the section.

There is no limit to the number of notes that may be included in a GRAD statement, one note or a whole composition may be included. However you may have no more than sixteen GRAD statements operative at any one instant of time in your composition (if so you will get an error message when you play it). This applies to GRADVOL, GRADINDEX and GRADFREQ statements.

### 5.7 GRADINDEX

GRADINDEX works in exactly the same fashion as GRADVOL but it is the value of the index which is graduated not the volume.

5.8 GRADFREQ

Is used to glissando a composition or notes within it, it is used in exactly the same fashion as GRADVOL. Notes within one GRADFREQ statement will keep their original interval relationships during the glissando.



## 6. Playing a Composition - The SING commands

As with the EDIT commands, there are various command words which may follow SING; for each of them you need only type the first three characters of the command with (at least) one space between commands. All commands work on your current file only, several commands may be combined on a line. Typing 'SING' alone will cause your whole composition to be played. If there is an error in your composition, such as a name used more than once to define an instrument, then an error message will be printed out. Certain errors cause the computer to stop, but most just cause the line containing the error to be ignored.

If you type CR while your composition is being played, then the time and line number reached in your composition will be printed out on your terminal.

If at any time your composition tries to use more oscillators than are available then the time and line number at which this happened will be printed out, followed by an error message.

### 6.1 SING 20

If you put a time after 'SING', as above, then SING will only play notes from that time on in your composition.

### 6.2 SING LIST 200

Will list your composition tabulated so that parameters lie in the appropriate columns. If (as in this case) you put a line number after 'LIST' then SING will list only lines from that number on. Note that SING LIST does not alter the spacing of your current file.

### 6.3 SING TABULATE

If you wish your current file to be spaced out the same way that SING LIST would display it, then you may type SING TAB. This is only to be used for short compositions since the spaces that TAB has to insert take up a lot of computer storage.

### 6.4 SING SORT 10.

SING SORT will display your composition with notes in the order in which they are played. If a time follows SORT then only notes starting after that time will be displayed, otherwise your definitions will first be displayed followed by all notes in order of time. Notes will be printed out tabulated in a standard format with the starting time inserted for every note.

### 6.5 SING SORT TABULATE

This command is similar in effect to the above (without the time), but the sorted output becomes your current file instead of being printed on your terminal. Note that since notes are in order of time, their line numbers are likely to be out of order. If you wish to edit your sorted current file you should first type EDIT RESEQUENCE to renumber the lines.

### 6.6 SING TRY CR

This is intended to be a means of quickly trying out different parameters on an instrument. After you type SING TRY CR, 'SING' will respond with a question mark on a new line. You should then type in the instrument name, followed by any further parameters you wish to change (using any of methods 3.1 to 3.3 in section 3) followed by a Carriage Return CR. Every time that you

type *CR* the computer will play the note then type another question mark whereupon you may type a new note or alterations to the note as though you were typing a further line in a composition, but without needing the line number or starting time. If you type *LIST*, *SING* will print out the current value of all the parameters.

To exit from *SING TRY*, type *EXIT*.

## Appendix I.

Frequency Modulation

The purpose of this section is to give composers some insight into how the modulation index and frequency parameters will affect the timbre in FM instruments on the Dartmouth Music System. Those interested in a more detailed explanation of FM should consult John Chownings paper "The Synthesis of Audio Spectra by means of Frequency Modulation" (J. audio Eng. Soc. N.Y. vol 27 no.7, Sept. 7th, 1973) from which much of the information in this section is derived.

All FM instruments on the Dartmouth Music System use two oscillators. According to the value of the modulation index set on the modulating oscillator, a number of pairs of side-frequencies are produced above and below the carrier frequency. Each pair of frequencies is formed by adding and subtracting a multiple of the modulating frequency from the carrier frequency, the higher the value of the index, the higher the multiples of the modulating frequency that will be included.

Let us assume that both oscillators are set to produce a sine wave, then where  $c$  is the (original) carrier frequency and  $m$  is the modulating frequency, the spectrum of the carrier will successively become:

<u>Frequencies</u>	<u>Values of Index</u> (approximate, in synthesizer units)
$c$	0
$c-m, c, c+m$	100
$c-2m, c-m, c, c+m, c+2m,$	200
$c-3m, c-2m, c-m, c, c+m, c+2m, c+3m$	300
$c-nm, \dots \dots \dots \text{etc} \dots \dots \dots c+nm$	$nx100$

Where negative frequencies produced by this table are to be read as positive (a phase reversal is involved). If the frequency  $m$  is very much less than the original frequency of the carrier oscillator,  $c$ , then the result is a cluster of frequencies close to the carrier frequency.

If  $m$  is of similar size to  $c$  then increasing index values may give a very wide frequency distribution, the character of which depends on the ratio of  $c/m$ . If the ratio of  $c/m$  is that of small integers (ie  $1/1$ ,  $1/2$ ,  $2/1$  .....  $4/3$  ....  $2/5$  etc.) then the impression given is that of a harmonic series. If the ratio is that of large integers ( $10/11$ ,  $11/23$ ,  $7/9$ ) then the spectrum produced appears non harmonic.

I. As an example consider the case where  $c=200$  Hz.  $m=300$  Hz and  $I$  is about 200 (synthesizer units). There will be two appreciable pairs of side frequencies, giving the following spectrum:

200,  $(200 + 300)$ ,  $(200 - 300)$ ,  $(200 + 600)$ . which gives, in ascending order:  $(-)$  100, 200,  $(-)$  400, 500, 800 ie a harmonic series of fundamental 100 with missing 3rd, 6th and 7th harmonics.

II. If we now change the values of  $c$  and  $m$  to  $c=200$  and  $m=350$ , (ratio  $c/m$  of  $20/35$ ) the spectrum becomes 200,  $(200 + 350)$ ,  $(200 - 350)$ ,  $(200 + 700)$ , Hz. or 150, 200, 500, 550, 900 Hz. which while it might be claimed to be a harmonic spectrum of fundamental 50 Hz, has such large gaps (including fundamental and first harmonic) that it will be heard as non harmonic.

III. Consider also  $c=100$ ,  $m=100$  ( $c/m=1/1$ ),  $I=200$  which gives a spectrum of: (-) 100, 0, 100, 200, 300 or ignoring minus signs and the zero frequency is 100, 200, 300, Hz. - Harmonic whereas  $c=100$ ,  $m=90$  ( $c/m=10/9$ ,  $I=200$ ) gives 10, 80, 100, 190, 280 which is definitely non harmonic.

Due to the phase reversal in the -100 Hz frequency, this frequency may partially cancel out the positive 100 Hz frequency.

It would perhaps be emphasized here that the actual amplitudes of the various components of the modulated carrier's spectrum vary with the value of the index in a very complicated way and that if you set any other waveform than a sine wave on to carrier and modulating oscillators then a great many more side frequencies will appear in the carrier spectrum.

This explanation of FM spectra has been much simplified but will explain the following major points.

1. The effective timbre of the modulated carrier oscillator depends on the ratio of carrier to modulating frequency, the value of the index set on the modulating oscillator, and the timbre numbers set on the two oscillators.
2. The perceived pitch of the carrier oscillator depends on the values of the carrier and modulating frequencies and on the value of the index. For an index of zero only the carrier frequency will be heard. As the index rises the apparent pitch of the carrier may drop to the carrier frequency minus a multiple of the modulating frequency.
3. As the index rises the carrier frequency spectrum becomes more complex.

4. For harmonic frequency spectra (typically wind and string instruments), the ratio of carrier to modulating frequency should be as the ratio of two small integers, typically integers less than 5. See appendix on instrument WIND.

5. For non harmonic frequency spectra (typically bells, cymbals, drums) the ratio of carrier to modulating frequency should be that of the ratio of large integers eg  $11/9$  or  $135/80$ . See also appendix on instrument KLANG.

## Appendix 2

Instrument PITCH

'PITCH' constructs a linear attack and a linear decay on one oscillator of the digital synthesizer. The following example shows a typical heading and note written in Dartmouth Music Language.

```

3   'TIME INSTRUMENTS 1   2   3   4   5   6   7   8
4   '   INSTRUMENT  FREQ SUS VOL SPK INX TBR ATK DEC
150      PITCH      440 .85 75  A  D   64 .08 .5

```

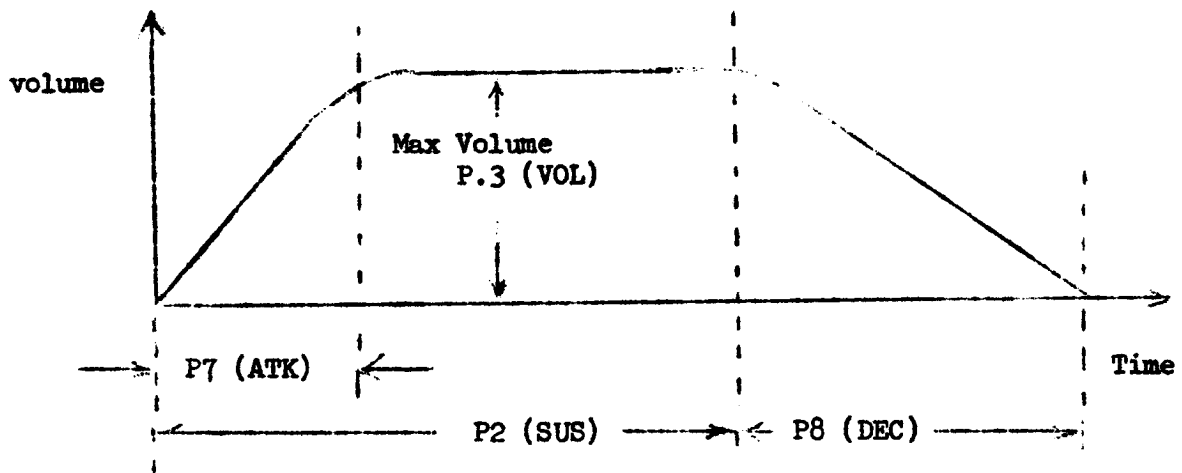
The effect of this note has been explained in the introduction. The effect of the parameters is as follows:

P.	Type	
1. (FREQ)	Hertz or A#4	Is the frequency set on the oscillator
2. (SUS)	time	Is the 'sustain' ie the time from the start of the attack to the start of the decay. However if the sustain is less than the attack (p.7) then the attack will be completed and then the decay started immediately afterwards.
3. (VOL)	integer	Is the volume held during the sustained part of the note.
4. (SPK)	letter	The speaker (group) on which the note will be played. (See sections 4.5 and 2.3)



5. (INX) integer 0-2040 If the index is non-zero here then this oscillator will frequency modulate the next higher oscillator (if it is in use). Because you do not have full control over which oscillators are used by notes it is difficult to predict what oscillator will be modulated. Normally this parameter should be zero.
6. (TBR) timbre # The timbre number to be set on the oscillator. This is the only control of timbre for notes made on pitch. (See list of timbre numbers section 2.1)
7. (ATK) Time The attack time - the time taken for the volume to rise to its maximum value (p.3).
8. (DEC) Time The decay time. The time taken for the note to decay away to zero volume.

The volume envelope constructed by PITCH is as follows:



For a harpsichord-like sound, set attack and sustain to zero and use the 'random' timbre numbers 16-23, 80-87 or 144-151.

The default parameters for Pitch are as follows:

FREQ	SUS	VOL	SPK	.INX	TBR	ATK	DEC
440	.5	50	M	0	208	0	.5

## Appendix 3

Instrument 'WIND'

'WIND' constructs a linear attack and a linear decay on two oscillators of the digital synthesizer and in addition sweeps the index value up from zero during the attack time. Frequencies are set on carrier and modulating channels according to the values of several parameters.

The following example shows a sample heading and a typical note as typed in Dartmouth Music Language.

```

100 'TIME INSTRUMENT 1 2 3 4 5 .6 7 8 9 .10 11 12 13
110 ' INSTRUMENT FREQ SUS VOL SPK INX TRC ATK DEC FRC FRM VM VIB TRM
120 WIND 500 2. 100 M 250 64 .15 .5 300 200 0 1 64

```

The meaning of the parameters is as follows:

P. No.	Type	
1. (FREQ)	HERTZ or A#4	Is the defining frequency for the note, used in calculating carrier and modulator oscillator frequencies.. See 9, 10 and 12.
2. (SUS)	Time	Is the sustain time ie the time from the start of the attack to the beginning of the decay. If the attack time (parameter 7) is greater then the sustain then the attack will be completed and the decay start immediately afterwards. Try zero sustain for percussive notes.

3. (VOL) Volume 0-100  
Maximum volume of the modulated waveform on the carrier oscillator.
4. (SPK) Letter  
Defines on what speakers the note may be placed.
5. (INX) INDEX 0-2040  
Is the value of the index set at the end of the attack. The index is swept from zero to this value within the attack time (parameter 7) and then left at this value for the rest of the note.
6. (TRC) Timbre number  
Is the timbre number for the carrier oscillator. Numbers other than 64 (sine wave) will give rise to FM spectra much more complicated than those considered in the appendix on FM. Try 64 and also 128 with the spectrum set to be the fundamental + one high harmonic (eg 7th harmonic). (See section 2.1 on Timbre numbers.)
7. (ATK) Time  
The attack time, the time in which the volume (and the index of modulation) rises from zero to its maximum value on both Carrier and modulating oscillators. Try 0 for percussive notes .2 for a gradual attack. Since the modulating index is swept from zero to the value of parameter 5, both the timbre and the apparent frequency are likely to change during the attack. Try an attack of several seconds to listen to the effect of sweeping the index.
8. (DEC) Time  
The time in which the volume on both oscillators returns to zero. The index stays fixed during the decay.

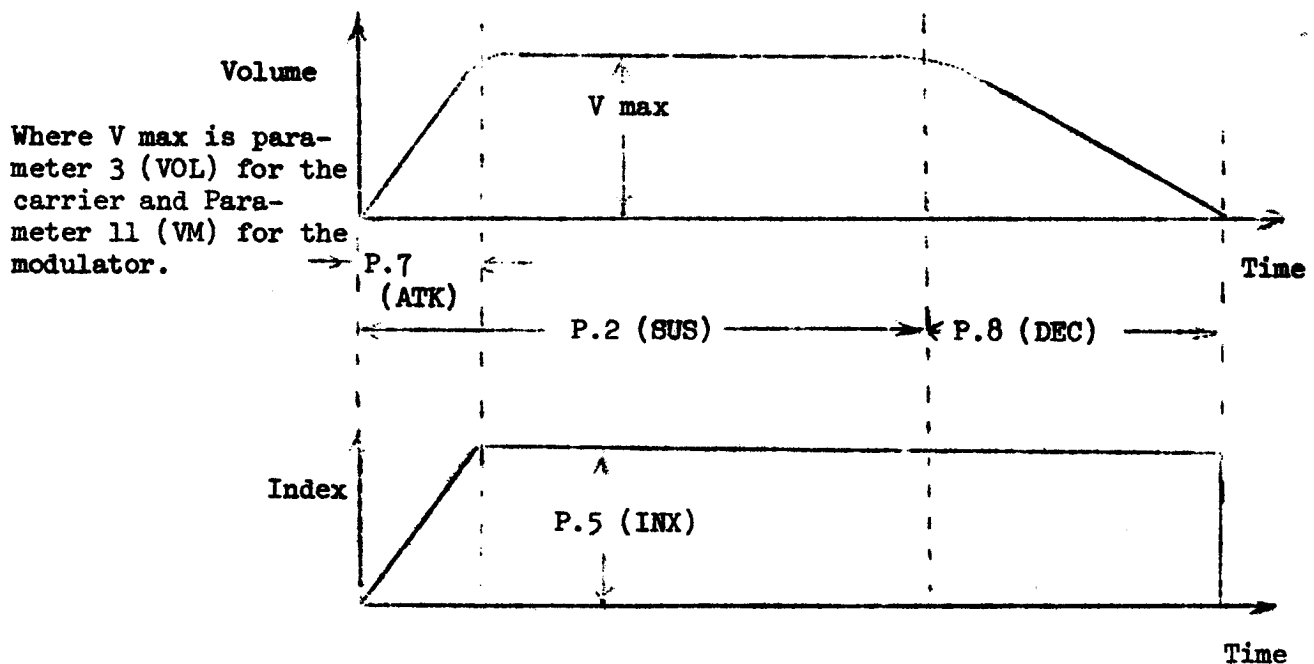
9. (FRC) Integer % Is the percentage of the defining frequency, parameter (1) that should be set on the carrier oscillator. In this case the carrier frequency will be 300 % of 500 = 1500 Hz.
10. (FRM) Integer % Is as parameter 9 but for the modulating oscillator. Here the modulating frequency becomes 200 % of 500 = 1000 Hz. but a complication is that parameter 12 (VIB) is added to the modulating frequency which in this case becomes 1001 Hz.
11. (VM) Integer 0-100 Is the volume of the modulating channel. If this is zero then only the carrier, frequency modulated output will be heard, if non zero then the modulating waveform at the modulating frequency will be heard in addition. In this case the modulating frequency (1001 Hz.) would reinforce the first harmonic of the carrier spectrum.
12. (VIB) Hertz This frequency is added to the modulating frequency calculated from parameter 10. If P.10 is zero then this parameter defines directly the modulating frequency - try 9=100, 10=0 and 12=8 and you will hear the carrier modulated by a vibrato of 8 Hz. If parameters 9 and 10 are set to produce a harmonic carrier spectrum then a very small value for this parameter will (usually) produce beats on the carrier (try values of 1-4 Hz.). If this parameter is large then the ratio of carrier to modulating frequency will change as the defining frequency (P.1) changes, thus the timbre will also change and will often be non-harmonic.

13. (TRM) Timbre Is the timbre number for the modulating oscillator.  
Use 64 here unless you need a really noisy sound.

The effect of frequency parameters 1, 9, 10 and 12.

If VIB (P.12) is small and the ratio of carrier to modulator frequency is that of small integers (as it is in this case:  $3/2$ ) then the carrier frequency spectrum will be a harmonic series whose fundamental is the defining frequency, parameter 1 (FREQ). Note however that whether the fundamental is heard or not depends on the value of the index - at the start of the attack the index is zero and only the carrier frequency of (in this case) 1500 will be heard. For further information see the appendix on F.M. WIND was intended to be able to give timbres like those of real wind instruments. Try using a small value (1 or 2) in VIB (P.12); FRC/FRM of values like 100/100, 200/100, 400/100; with INX (P.5) from 200-500.

The envelopes constructed by WIND are as follows:



The default parameters for WIND are as follows:

FREQ	SUS	VOL	SPK	INX	TE1	ATK	DEC	FRC	FRM	VM	VIB	TE2
440	.5	50	M	255	64	.05	.5	100	100	0	2	64

## Appendix 4

Instrument KLANG

KLANG is a two oscillator FM instrument very similar to WIND except that both the volume and the index of modulation decay exponentially a typical call heading for KLANG might be:

```

100 'TIME INSTRUMENT 1 2 3 4 5 6 7 8 9 10 11 12 13 14
110 ' INSTRUMENT FREQ SUS VOL SPK IX1 TRC ATK DEC FRC FRM VM VIB TRM IX2
120 KLANG 500 2. 100 M 250 64 .15 95 300 200 0 1 64 50

```

Only parameters 5(IX1), 8(DEC) and 14(IX2) are different in effect from those in WIND.

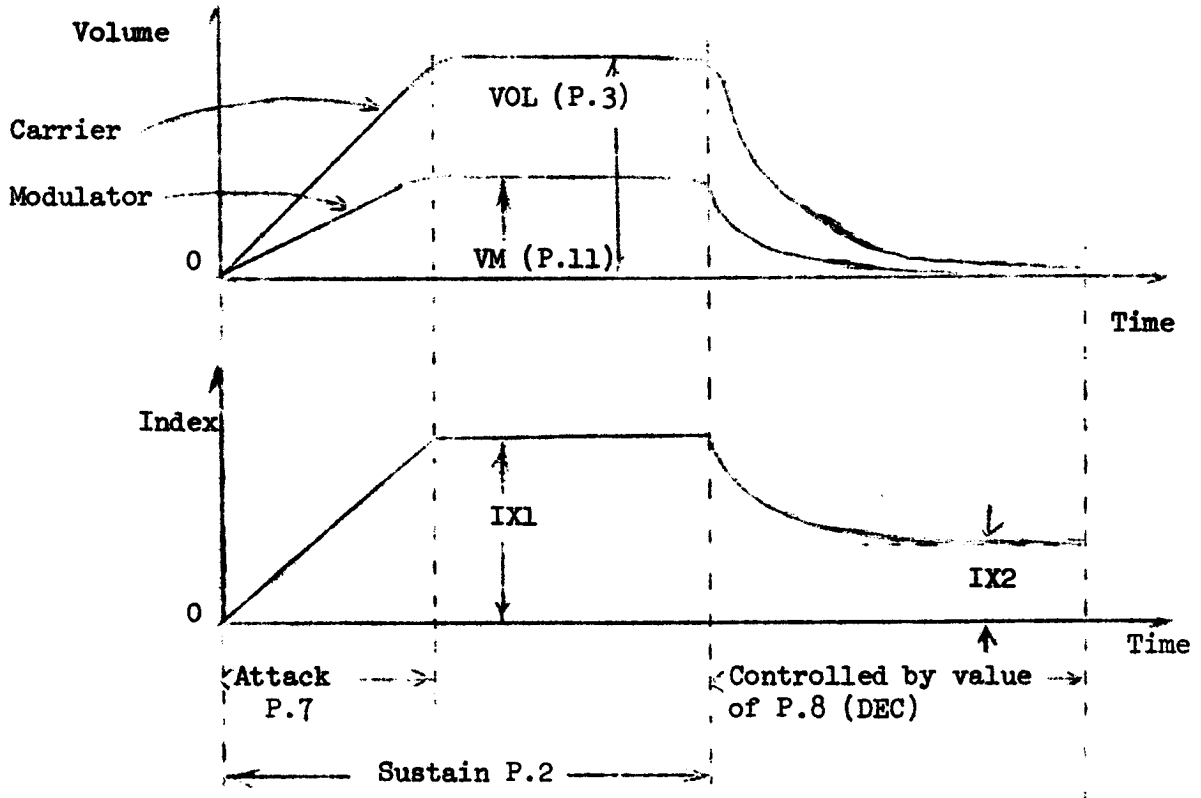
P. No.	TYPE	
5. (IX1)	integer 0-2040	This is still the maximum index, the value held throughout the sustain but in KLANG, during the decay the value of the index drops exponentially to the value of parameter 14 (IX2). If IX2 is greater than or equal to IX1 then as in WIND the index will not change during the decay.
8. (DEC)	integer 0-99	Notice that the decay parameter is no longer a time but is an integer from 0-99 which governs the length of decay according to the following table:

Integer	99	98	97	96	95	94	93....85....82....68....46....2....0
Time	3.91	1.94	1.29	0.96	0.76	0.63	0.54 0.25 .19 .1 .05 .01 0.



14. (IX2) Integer This is an extra parameter for KLANG and is the value to which the index drops during the decay. All other parameters have exactly the same effect as they do in WIND.

The envelopes produced by KLANG are as follows:



KLANG was intended primarily for the synthesis of percussive sounds, for these let the sustain and attack both be zero. For harmonic instruments (piano, harpsichord, guitar try FRC/FRM (p.9/p.10) ratios of 100/100, 200/100, 300/200 etc. as for wind instruments. For non-harmonic instruments (bells, cymbals and drums) try FRC/FRM ratios like 110/90, 170/90, 135/85. For drums try low frequencies (p.1) 50-150 Hz.

If you want the maximum change in the timbre during the decay then set IX2, (P.14) to zero. Using timbre numbers 64, sine waves on both oscillators use an index of 200 and higher. You might try a harpsichord synthesis using a random wave (16-23 etc.) timbre number on the carrier, TRC, (P.6) and a low value of index say 30-100. Further try using timbre number 128 on the carrier, setting its spectrum to be the fundamental and one high harmonic. The default parameters for KLANG are as follows:

FREQ	SUS	VOL	SPK	IX1	TE1	ATK	DEC	FRC	FRM	VM	VIB	TE2	IX2
440	.5	50	M	255	64	.05	98	100	100	0	2	64	0