INSTRUMENTATION & TECHNIQUES

A programmable multiple-tone generator

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A simple tone generator that allows software control of auditory stimuli is described. The circuit provides for the simultaneous generation, timing, and amplification of three different tones. Its low cost, ease of construction, and versatility make it an attractive alternative to conventional auditory stimulus hardware.

The advent of microprocessor technology has spurred the development of a variety of useful stimulus producing devices that are easily controlled by software instructions. This article describes a device that has proved quite helpful for the generation and presentation of precisely defined auditory signals. The circuit is based upon the AY3-8910 programmable sound generator (PSG) by General Instruments. It has several advantages over previously described tone and noise generators (e.g., Erdreich, 1978; Feth & Donohue, 1982; Meinrath & D'Amato, 1979; Williams & Hoskin, 1976; Wolf & Bilger, 1977) because of its wide frequency capability, control over the form of the output signal (i.e., envelope characteristics), adaptability to virtually any bus-oriented system, and compact size. In our laboratory, it is used to generate tones for event-related brain potential paradigms governed by a MINC LSI-11/23 (Digital Equipment Corporation). Because of the versatility and programming capability of the PSG, however, it can easily serve as an auditory stimulus source in any situation in which computer-controlled tone or simple chord presentations are required.

CIRCUIT DESCRIPTION

The schematic of the overall circuit is presented in Figure 1, with the parts list given in Table 1. The tone generator consists of four basic components: The 7404s, 74121, and 7400 interface between a parallel output port and the PSG chip. The LM386 is a simple audio amplifier compatible with the PSG that is used to increase the gain of the output signal. The 4013 divides the standard color burst crystal frequency in half to provide the correct clock frequency to the PSG, thereby controlling the tone frequencies produced. The

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Figure 1. Circuit diagram for programmable multiple-tone generator.

Table 1
Parts List

Integrated Circuits	Resistors	Capacitors
1 AY3-8910	1 33 kohm	2 20 picoF
2 7404	1 300 ohm	1 .01 microF
1 74121	1 1 kohm	1 5 microF
1 4013	1 5.1 kohm	1 300 picoF
1 4069	1 10 megohm	1 250 microF
1 7805	1 500-ohm potentiometer	1 10 microF
1 LM386		

AY3-8910 sound generator is the primary component of the circuit. It requires a 5-V power supply, a digital clock, and a processing controller for operation. While the circuit illustrated in Figure 1 incorporates a specific interface for an LSI-11/23 using 9 bits of parallel I/O, the PSG can work with any computer with an 8-bit parallel I/O and strobe bit (e.g., Brocaw, 1981). Construction of the entire circuit involves about \$50 in parts and 3 days of a competent electronic technician's time.

The main element of the PSG is an array of 16 read/

write control registers. These are presented in Table 2 in conjunction with the appropriate bit configurations required for register functioning. The corresponding pin assignments are listed graphically in Table 3. Thus, Registers R0-R5 control the square-wave tone frequencies for each of the three independently programmable channels (A, B, C). Register R6 controls a frequency-modulated pseudorandom-width pulse for noise generation. Register R7 enables the output of the oscillators for each channel. Registers R10-R12 provide the D/A converters with either a fixed or variable amplitude pattern. The fixed amplitude is under direct computer control, whereas the programmable amplitude envelope is accomplished by using Registers R13-R15. Registers R16-R17 are two I/O ports that allow interfacing between the PSG and other devices. Data to/from the computer bus may be read/written to either of the two 8-bit ports without affecting any other function of the PSG.

Table 2
PSG Register Array

REGISTER	BIT NUMBER							
	B7	B6	B5	B4	B3	B2	B1	B0
R0	8-Bit Fine Tune A							
R1	4-Bit Coarse Tune A							
R2	8-Bit Fine Tune B							
R3	4-Bit Coarse Tune B							
R4	8-Bit Fine Tune C							
R5	4-Bit Coarse Tune C							
R6	5-Bit Period Control							
R7	IN/OUT ---Noise--- ---Tone---							
	IOB	IOA	C	B	A	C	B	A
R10	Channel A Amplitude	---	---	---	M	L3	L2	L1
R11	Channel B Amplitude	---	---	---	M	L3	L2	L1
R12	Channel C Amplitude	---	---	---	M	L3	L2	L1
R13	8-Bit Fine Tune E							
R14	8-Bit Fine Coarse E							
R15	Envelope Shape/Cycle	---	---	---	---	Cont.	Att.	Hold
R16	I/O Port A Data Store	8-Bit Parallel I/O on Port A						
R17	I/O Port B Data Store	8-Bit Parallel I/O on Port B						

Table 3
PSG Pin Assignments (Top View)

Function	Pin #	Pin #	Function
Vss (GND)	1	40	Vcc (+5V)
N.C.	2	39	TEST 1
Analog Channel B	3	38	Analog Channel C
Analog Channel A	4	37	DA0
N.C.	5	36	DA1
IOB7	6	35	DA2
IOB6	7	34	DA3
IOB5	8	33	DA4
IOB4	9	32	DA5
IOB3	10	31	DA6
IOB2	11	30	DA7
IOB1	12	29	BC1
IOB0	13	28	BC2
IOA7	14	27	BDIR
IOA6	15	26	TEST 2
IOA5	16	25	A0
IOA4	17	24	A9
IOA3	18	23	RESET
IOA2	19	22	Clock
IOA1	20	21	IOAO

Table 4
Example of Machine Language PSG Subroutine

	TITLE	PSGIO	
PSGIO::	DIO	=171262	;ADDRESS OF I/O PORT
	TST	(R5)+	;SKIP ARGUMENT COUNT
	MOV	(R5)+,PSGREG	;ADDRESSED REGISTER INTO PSGREG
	MOV	(R5)+,DATA	;PUT DATA IN DATA
	BIS	#400,PSGREG	;INDICATE ADDRESS MODE
	MOV	PSGREG, #DIO	;PUT ADDRESS ON PSG BUS
WRDATA:	BIC	#400, #DIO	;REMOVE ADDRESS BIT
	BIC	#400,DATA	;INDICATE DATA MODE
	MOV	DATA, #DIO	;DATA NOW ON PSG BUS
	RTS	PC	;RETURN TO MAIN PROGRAM
DATA:	.WORD	0	
PSGREG:	.WORD	0	
	.END		

The circuit illustrated in Figure 1 makes the AY3-8910 PSG compatible with the general-purpose I/O ports found on most mini- and microcomputers. The turn-on and turn-off of tones are accomplished by programming the PSG's registers. Considering a Logic 1 value as TTL low, addressing a given register is obtained by: (1) setting D8 FALSE, (2) placing the register's address on D0-D7, (3) making D9 TRUE, and (4) making D8 TRUE and then FALSE. Once a register is addressed, it will stay addressed until changed. Latching data into an addressed register is obtained by: (1) setting D8 FALSE, (2) placing the data on D0-D7, (3) making D9 FALSE, and (4) making D8 TRUE and then FALSE. In most instances, D8 will be connected to the write strobe of the host computer's output port.

The three independent square-wave tone generators of the PSG labeled A, B, and C output on Pins 3, 4, and 38, respectively. Although the signal from these channels is amplified by a common device (the LM386 chip), this operation does not affect the independence of the three outputs. Note that each channel of the PSG produces a square wave of variable period and amplitude that can be controlled by means of precisely defining the envelope characteristics of the signal. If pure sine-wave stimuli are absolutely necessary, this device is not acceptable. However, with proper register settings, a wide variety of tones, chords, and auditory sequences can be easily produced by software instructions. Specific register codes for PSG operation can be obtained from the catalog data sheets or from the manufacturer's instruction manual (General Instruments, 600 West John Street, Hicksville, New York 11802), which is also available from major distributors and retail outlets (e.g., Advanced Computer Products, Inc., 1710 B East Edinger, Santa Ana, California 92704). In addition to containing the specific register codes, the instruction manual includes a complete block diagram of the PSG, signal output spectra, and many illustrative application examples.

PROGRAMMING

Software control can be achieved by means of a simple machine language subroutine called by a higher level general control program. An example of such a subroutine is listed in Table 4. Here, the control program calls the subroutine [e.g., CALL PSGIO (PSGREG,

DATA)] and passes it the register number and an octal instruction code. Once set, these are held by the PSG until reset. Thus, several stimulus parameters for each channel (e.g., frequency, envelope, etc.) can be set or varied independently with each call. While we employed this subroutine arrangement with FORTRAN, any other programming languages that directly address computer memory locations (e.g., the C programming language) are also applicable.

APPLICATIONS

Because of its precise envelope characteristics and wide frequency response, the PSG can be used in a large number of research settings. Aside from the presentation of well formed, simple tones that can be changed with computer instruction, combinations of frequencies can be simultaneously programmed to effect more complex chords. These chords can be easily shifted in key or changed in octave under software control. This capability lends itself well to situations in which complex sound effects are needed. In addition, the "noise" generation function of the PSG makes it a ready source for controlled bursts of unusual sounds or additional compo-

nents to musical output. Thus, the versatility of the PSG obtained from digital control over sound generation produces a highly adaptable, yet accurate and reliable auditory stimulus source for a wide range of applications.

REFERENCES

- BROCAW, R. L. Polyphonic sound synthesis. *80 Microcomputing*, 1981, 18(June), 166-170.
- ERDREICH, J. A simple stimulus generator for evoked response studies. *Behavior Research Methods & Instrumentation*, 1978, 10, 23-24.
- FETH, L. L., & DONOHUE, M. J. A programmable ripple-noise generator for auditory research. *Behavior Research Methods & Instrumentation*, 1982, 14, 9-12.
- MEINRATH, M., & D'AMATO, M. R. An inexpensive white-noise and tone generator. *Behavior Research Methods & Instrumentation*, 1979, 11, 472.
- WILLIAMS, D. B., & HOSKIN, R. K. A programmable tone generator for presenting melodic and harmonic patterns in music research. *Behavior Research Methods & Instrumentation*, 1976, 8, 447-449.
- WOLF, R. V., & BILGER, R. C. A digital noise and sine-wave generator. *Behavior Research Methods & Instrumentation*, 1977, 9, 345-348.

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