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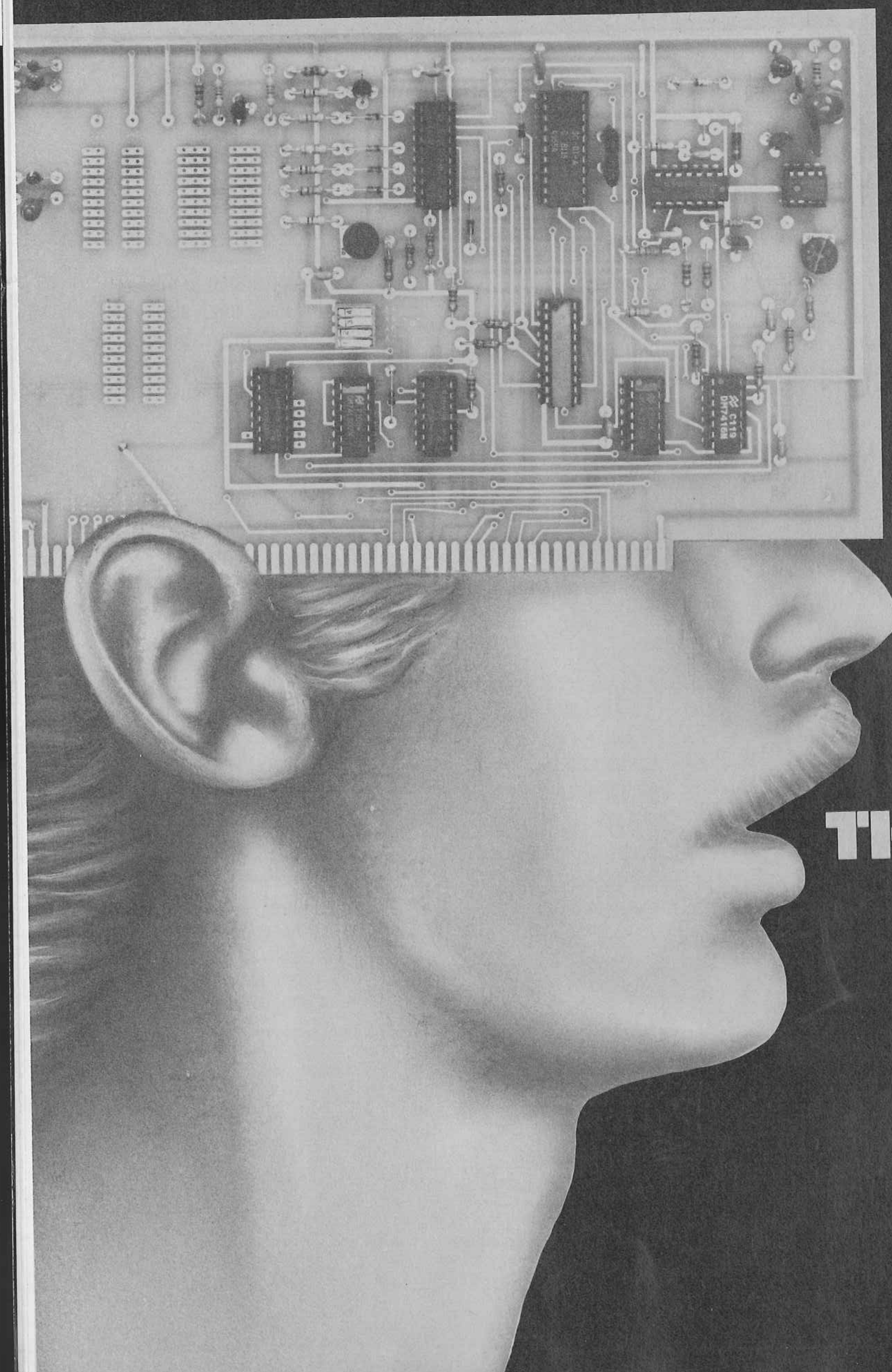


THIS IS YOUR COMPUTER SPEAKING

PART I

BY RANDY CARLSTROM

***Talk is now cheap—
Here's a speech synthesizer you can build
for use with an S-100 bus computer***

"GOOD morning. It is 10:15, Friday, September fifteenth. You have a doctor's appointment at 2:30 this afternoon."

No, this needn't be your secretary reminding you of your day's schedule. It could be coming from a disembodied voice! Moreover, the physical make-up of this voice might consist of only a very small piece of silicon and some fine wires. As such, it is part of a rapidly growing family of devices that are revolutionizing computer output techniques called speech (or voice) synthesizers.

Electronic Analog. To successfully design a voice synthesizer, the techniques by which the human vocal system produces the basic unit sounds of speech (called *phonemes*) must be considered. For instance, how is the production of the sound *er* different than the production of the sound *oo*? An analysis of this kind would require a comprehensive knowledge of such speech characteristics as *format frequencies, diphthongs*, and so on, which is beyond the scope of this article and better left for the speech scientists.

For our purposes it is sufficient to know that a phoneme is composed of many different frequencies (as determined by the dynamic frequency response of the vocal tract), and it is the relationship of these frequencies to each other and their relative amplitudes that determine the type of sound that will be heard.

An important instrument used in the analysis of speech is the voiceprint machine (or "Sonagraph"). This is a special type of spectrum analyzer that displays both frequency and the relative amplitude of each frequency of the input signal as a function of time. With this instrument, measurements can be made of the various parameters of any speech utterance. Utilizing data obtained from such measurements, electronic filter networks can be designed to model the human vocal tract. An algorithm for controlling the filters in such a way as to produce artificial speech can also be developed using these measurements.

An electronic analog of the human vocal system is shown in Fig. 1. The dashed lines represent parameter control lines, which allow the various parameters of the model (voicing amplitude and frequency, filter network frequency response, etc.) to be externally controlled. These may be control bits from a digital computer, corresponding to signals from the brain. Through proper sequencing of the filter parameters and excitation sources, an electronic model can generate quite intelligible synthetic speech. The overwhelming, and almost formidable, task of controlling these parameters, however, is where the similarities of speech synthesizers end.

Phoneme Synthesizer. One approach to electronic speech synthesis is the *phoneme synthesizer*. This type of synthesizer is capable of generating a number of different phonemes which, when combined in the appropriate sequences, can synthesize any word. The phoneme-generation control circuits incorporated into such a synthesizer make it possible to generate continuous speech without the complex methods associated with synthesizers commonly used before. The phoneme synthesizer is ideally suited for the experimenter, because it allows a virtually *unlimited* vocabulary for a minimum in support hardware and software.

Until very recently, the cost of phoneme synthesizers has been prohibitive. However, a recent development in speech synthesis technology has brought the price and amount of required support hardware down substantially. This significant achievement was made by the Votrax company with the introduction of the first *single-chip* phoneme synthesizer. Called the *SC-01*, this device is capable of generating 64 different phonemes, accessed by a 6-bit code.

An on-chip parametric control generator enables the device to *automatically* generate each phoneme necessary for any given word; its internal parameters never need to be updated by the user. This translates into an input data rate of only 70 bits (less than 9 bytes) per second for continuous speech output. A dynamic articulation controller (also on chip) provides smooth transitions from one phoneme to the next as speech is synthesized from each of the 64 possible phonemes, which is essential to the production of intelligible speech. The speech synthesizer described here uses this SC-01 chip.

Circuit Operation. In the synthesizer interface circuit shown in Fig. 2, *IC1, IC2*, and *IC3* decode selected S-100 bus address and control lines to generate four input and four output port control signals. In this application, only ports *n*1 and *n*2 are used, with the remaining I/O ports for future use.

The value of *n*, a hexadecimal number representing the upper four bits of the decoded port address, is selected via switches *S1* through *S4*. When all four switches are closed (associated pins grounded), $n=0$; with *S4* open and *S1* through *S3* closed, $n=1$; etc. The vocabulary software to be described later requires that $n=3$ (*S1* and *S2* closed, *S3* and *S4* open).

Also shown in Fig. 2 are the two power supplies required. *IC4* delivers +5 volts regulated to the board, while *IC5* delivers +12 volts regulated.

The phoneme synthesizer is *IC7* of Fig. 3. The data bus is buffered by elements of *IC6*, while pull-up resistors *R2* through *R7* insure that the minimum input-high requirement of *IC7* is met. The inflection (pitch) data from the CPU is latched by *IC8*, with elements of *IC9*, in conjunction with *R10* and *R11*, providing the level-shift buffering required by the MOS inputs of *IC7*. The timing signal to *IC7* and *IC8* is provided by *IC9F* reacting to an OUT *n*0 instruction from *IC3* pin 15 (Fig. 2). The rising edge of this signal latches the contents of the data bus (which contains the phoneme access code and inflection information) into *IC7* and *IC8*.

Each time *IC7* (the phoneme synthesizer) completes the production of a phoneme, and is ready to accept new data, it requests an interrupt of the CPU via *IC11A* which gates the interrupt request only when the synthesizer is enabled (*IC10*, pin 19 of Fig. 4 is high). The output of *IC11A* (pin 3) can be connected to the desired vector-interrupt (VI0 through VI7) of the system. If your particular system does not have vector-interrupt capability, the output of *IC11A* can be connected to the system $\overline{\text{PINT}}$ line of the S-100 bus. Interrupt requests from this line will be acknowledged by a restart at memory location 0038H (RST7), in the same manner as a VI0 vectored interrupt. This is because the data bus is floating high during the Interrupt Acknowledge period.

When the synthesizer is not being used, the synthesizer enable bit at *IC10*, pin 19 (Fig. 4) should be cleared to prevent *IC7* from interrupting the CPU, should the interrupt system be enabled. This can be done by outputting 0*xxxxxxx* (*x* means don't care) to port *n*1. The synthesizer's interrupt circuit is automatically disabled at power-up via the $\overline{\text{POC}}$ signal.

Parameter control latch *IC10* is updated via pin 11 whenever the CPU executes an OUT *n*1 instruction. This signal is decoded at *IC3* pin 14, and passed through *IC9E* to *IC10*. The eight outputs of *IC10* (Q1 through Q8) form the "control" word for the synthesizer output volume via Q6 and Q7, the master clock frequency via Q1 to Q5, the mode via Q5, and the interrupt control circuit via Q8. The control word is fully described in Fig. 5.

As shown in Fig. 4, *Q1*, *Q2*, *R14* through *R24*, and *D3* through *D7* form a programmable current source whose output is coupled to timing capacitor *C5* (Fig. 4). In conjunction with *IC7* pin 16, this determines the clock frequency at pin 15. Varying the amount of current varies the frequency which, in

(Text continues on page 26)

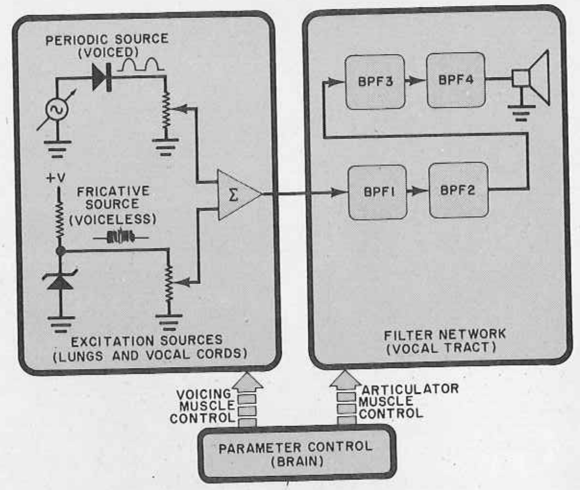


Fig. 1. Block diagram representing the electronic analog of the human speech mechanism with analogous parts marked.

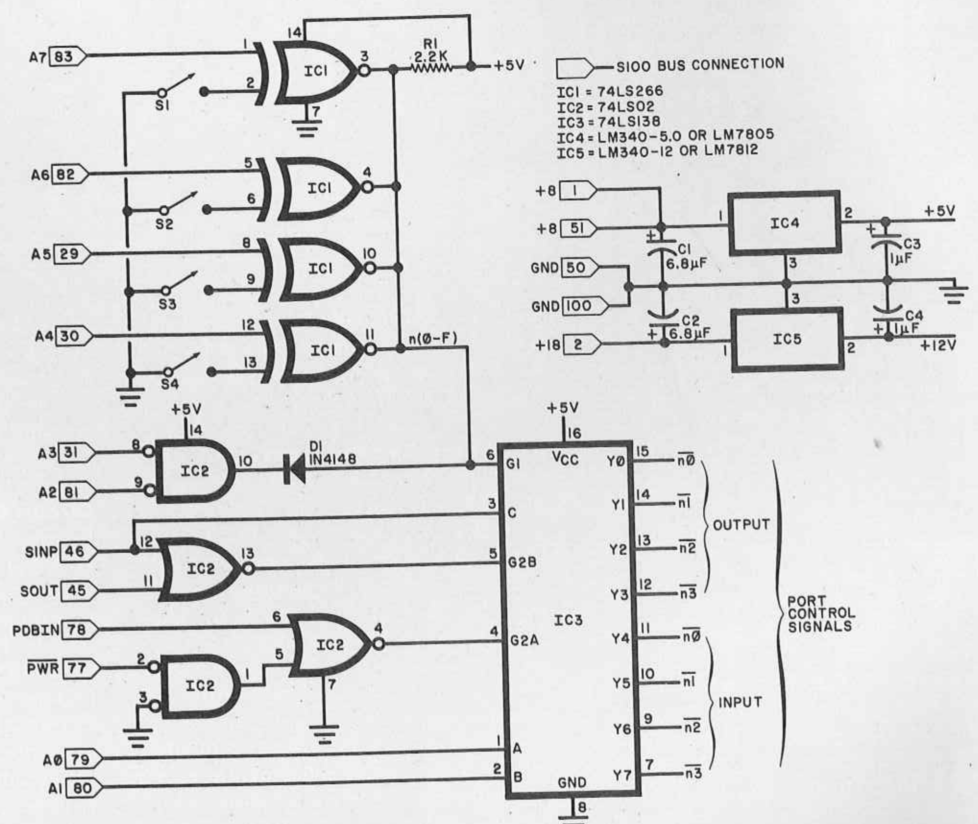


Fig. 2. This circuit decodes the selected S-100 bus lines.

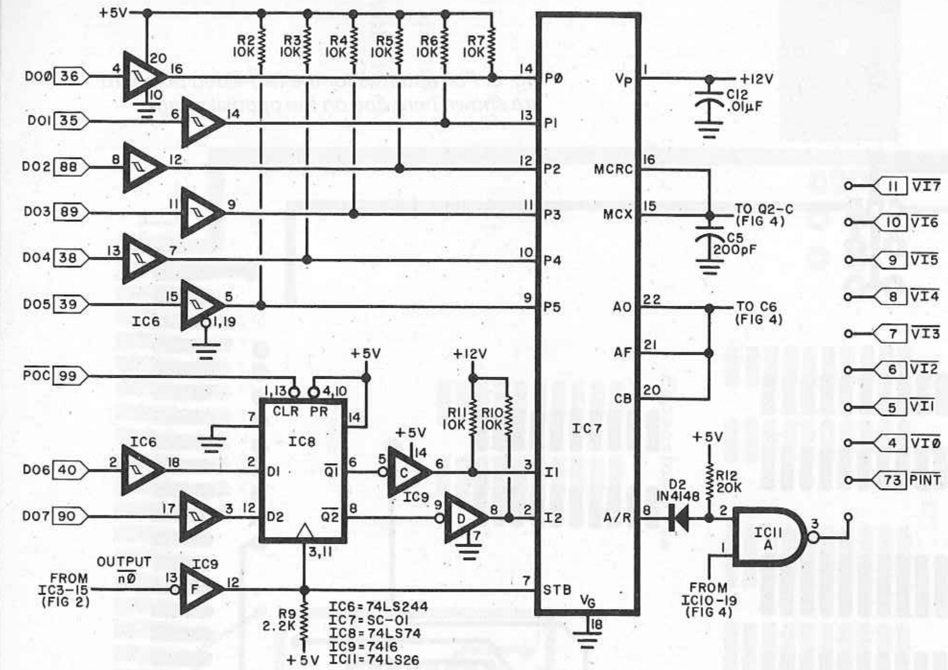


Fig. 3. The phoneme synthesizer is IC7. Pitch data from the CPU is latched by IC8.

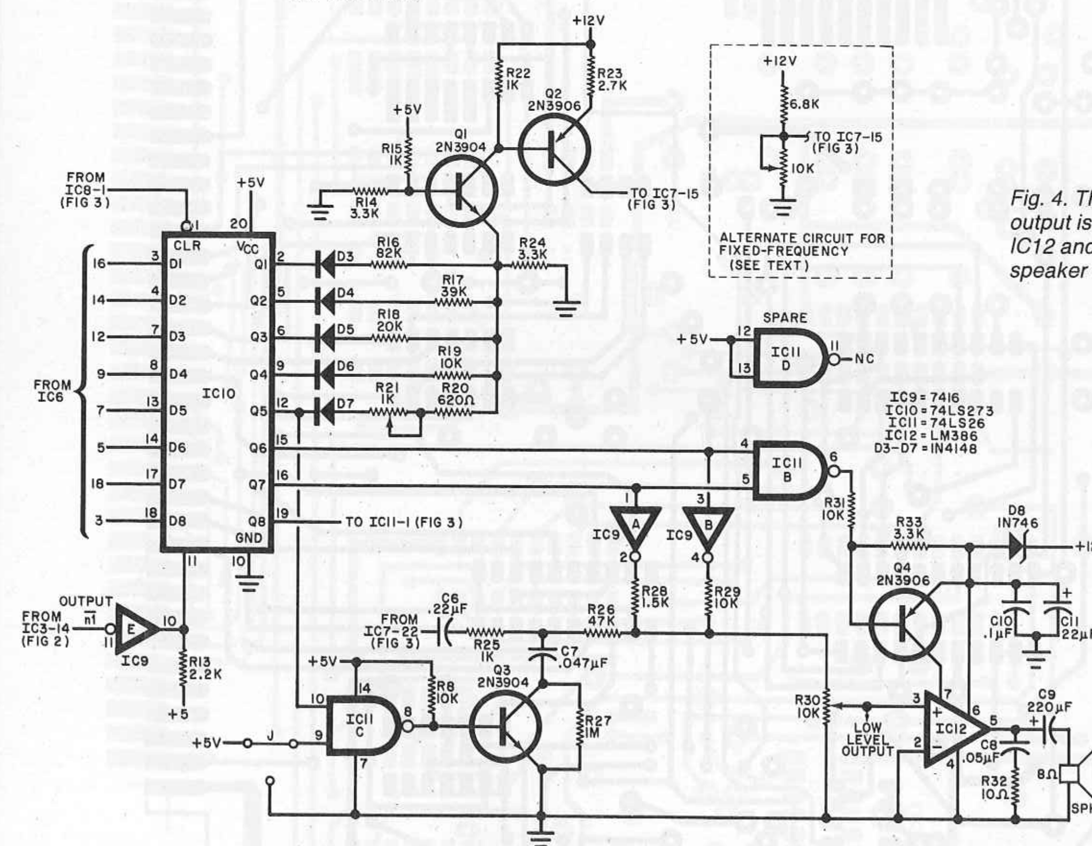


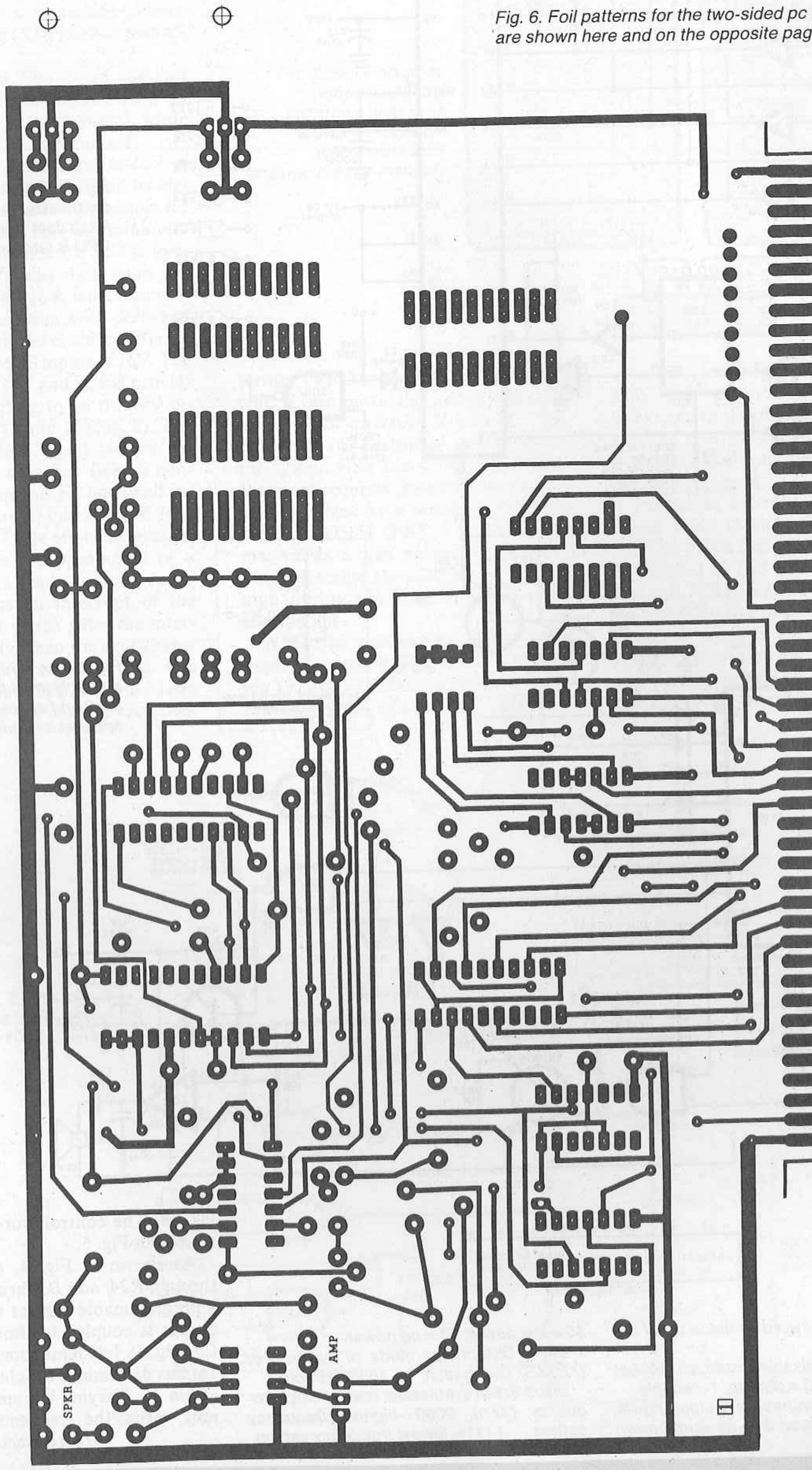
Fig. 4. The synthesizer output is amplified in IC12 and applied to the speaker as shown here.

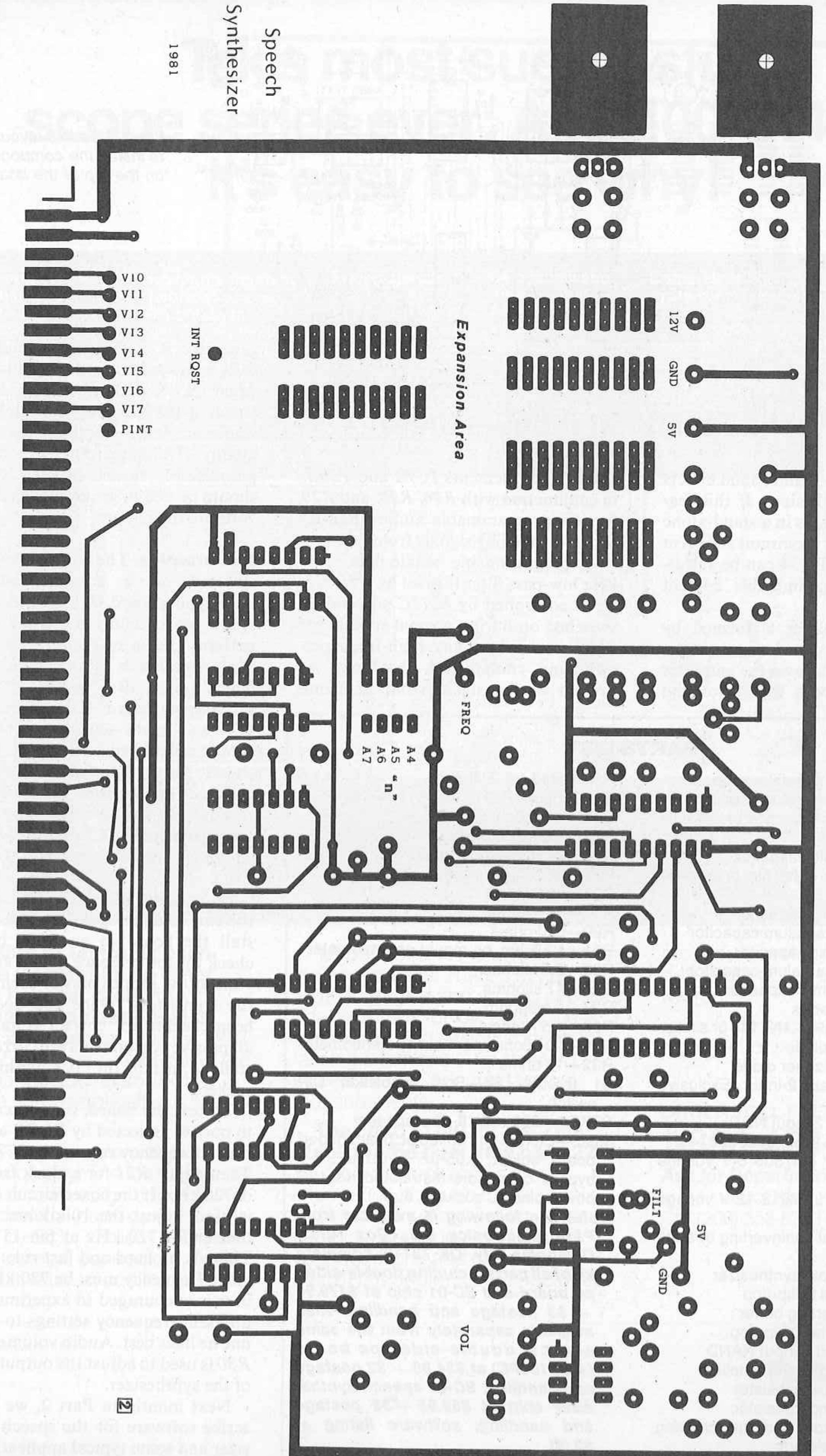
b7	b6	b5	b4	b3	b2	b1	b0
ENABLE	VOLUME		MODE	MASTER CLOCK FREQUENCY			

CONTROL WORD

Fig. 5. The control word, is made up of the following bits:
Bit 7: Enables/disables interrupt request from synthesizer. 0 = disable; 1 = enable.
Bit 6,5: Set synthesizer output power (XAn). 00 = full power; 01 = medium power; 10 = low power; 11 = no power.
Bit 4: Determines mode of synthesizer (XE, XS). 0 = speech; 1 = sound effects.
Bits 3-0: Set synthesizer master clock frequency (XFn). 0000 = highest frequency setting . . . 1111 = lowest frequency setting.

Fig. 6. Foil patterns for the two-sided pc board are shown here and on the opposite page.





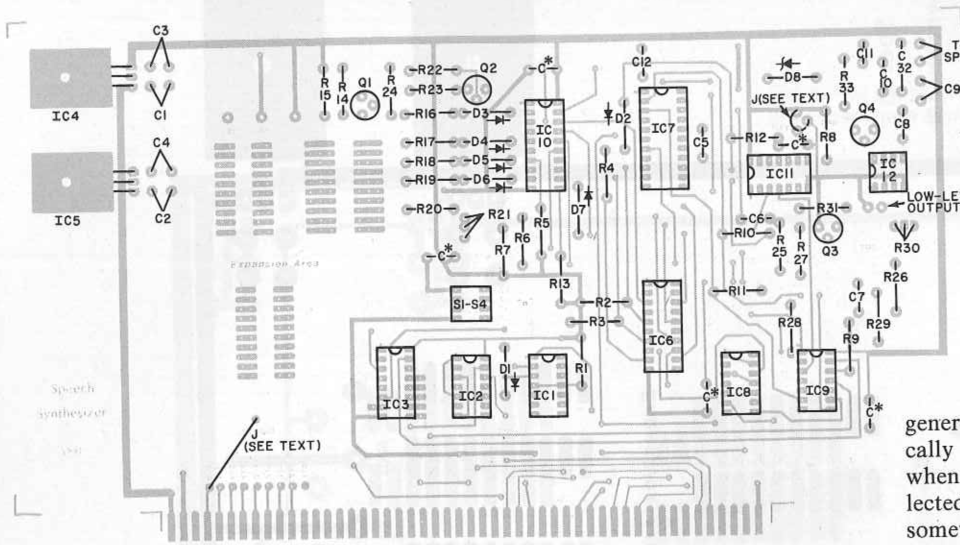


Fig. 7. Use this layout to install the components on the top of the board.

turn, varies the voice and sound effects quality of the synthesizer. If this feature is not required, as in a stand-alone speech synthesizer, the circuit shown in the dashed box in Fig. 4 can be substituted for the programmable current source.

The audio amplifier is formed by *IC12* and its associated components. Transistor *Q4* shuts down the amplifier when *IC11B* decodes that command from *IC10*. Elements *IC9A* and *IC9B*, in conjunction with *R26, R28,* and *R29* form a programmable audio attenuator, controlled by signals from *IC10*.

A programmable single-pole, 3.4-kHz low-pass filter formed by *R25, C7, Q3* is controlled by *IC11C* and can be switched on during normal speech operation to reduce any high-frequency switching components that may be present in the signal from phoneme generator *IC7*. This filter is automatically removed from the circuit by *Q3* when the "sound effects" mode is selected by the user program. This action somewhat improves the sound effects quality. If it is desired to leave this filter permanently turned on, *IC11C* pin 9 should be tied to ground instead of +5 volts via the jumper.

Construction. The circuit can be constructed on a conventional S-100 prototyping board, or a double-sided pc board can be fabricated using the foil patterns shown in Fig. 6. The component installation is shown in Fig. 7, which may also be used with a prototyping board. Keep in mind that *IC7* is a static-sensitive device and should be handled accordingly. Sockets should be used for all ICs and DIP packages can be used for switches *S1* through *S4*. Install decoupling capacitors as denoted by C* on Fig. 7 and listed under miscellaneous in the Parts List.

Prior to installing the ICs, and with the two voltage regulators wired in, install the board in an S-100 bus and check for the presence of +5 and +12 volts at the proper pins of each IC and the transistors. Once the board has been checked for correct voltages and all passive components are correctly installed, install the ICs within their sockets.

To test the board, output xxx01000 to port *n*1 (selected by *S1-S4*) and connect a frequency counter to *IC7* pin 15. Then adjust *R21* for a clock frequency of 720 kHz. If the boxed circuit of Fig. 4 is used, adjust the 10-kilohm potentiometer for 720 kHz at pin 15 of *IC7*. There is no hard and fast rule that the clock frequency must be 720 kHz—the user is encouraged to experiment with different frequency settings to find the one he likes best. Audio volume control *R30* is used to adjust the output volume of the synthesizer.

Next month, in Part 2, we will describe software for the speech synthesizer and some typical applications. ◇

PARTS LIST

C1,C2—6.8-μF, 25-V tantalum capacitor
C3,C4—1-μF, 20-V tantalum capacitor
C5—200-pF, 10% silver mica or ceramic capacitor
C6—0.22-μF ceramic capacitor
C7—0.047-μF, 10% metal film or ceramic capacitor
C8—0.05-μF ceramic capacitor
C9—220-μF, 10-V tantalum capacitor
C10—0.1-μF ceramic capacitor
C11—22-μF, 15-V tantalum capacitor
C12—0.01-μF ceramic capacitor
C*—See Miscellaneous
D1 through D7—1N914,1N4148 or similar silicon switching diode
D8—1N746A 3.3-V zener diode
IC1—74LS266 quad 2-input Exclusive NOR
IC2—74LS02 quad 2-input NOR
IC3—74LS138 3-to-8 line decoder
IC4—LM340-5.0 or LM7805 5-V voltage regulator
IC5—LM340-12 or LM7812 12-V voltage regulator
IC6—74LS244 octal noninverting tri-state buffer
IC7—SC-01 phoneme synthesizer
IC8—74LS74A dual D flip-flop
IC9—7416 hex inverting buffer
IC10—74LS273 octal D flip-flop
IC11—74LS26 quad 2-input NAND
IC12—LM386 audio power amplifier
Q1,Q3—2N3904 npn transistor
Q2,Q4—2N3906 pnp transistor
Unless otherwise specified, the following are ¼-W, 5% resistors:
R1,R9,R13—2.2 kilohms
R2 through R8, R10, R11, R19, R29, R31—10 kilohms
R12,R18—20 kilohms
R14,R24,R33—3.3 kilohms
R15,R22,R25—1 kilohm
R16—82 kilohms
R17—39 kilohms
R20—620 ohms
R21—1-kilohm, pc-mount potentiometer
R23—2.7 kilohms
R26—47 kilohms
R27—1 megohm
R28—1.5 kilohms
R30—10-kilohm, pc-mount potentiometer
R32—10 ohms
S1 through S4—Spst 4-position DIP switch
SPKR1—200-mW, 8-ohm speaker
Misc.—Etched and drilled pc board or perf board; solder; 0.05-μF or 0.1-μF, 5-V bypass capacitors distributed near IC power pins; IC sockets; etc.

Note: The following is available from PAIA Electronics Inc., Box 14359, Oklahoma City, OK 73116: complete kit of all parts including double-sided pc board and SC-01 chip at $179.95 + $3 postage and handling. Also available separately from the same source: double-sided pc board (#SS100PC) at $34.95 + $2 postage and handling; SC-01 speech synthesizer chip at $59.95 + $2 postage and handling; software listing at $3.00.