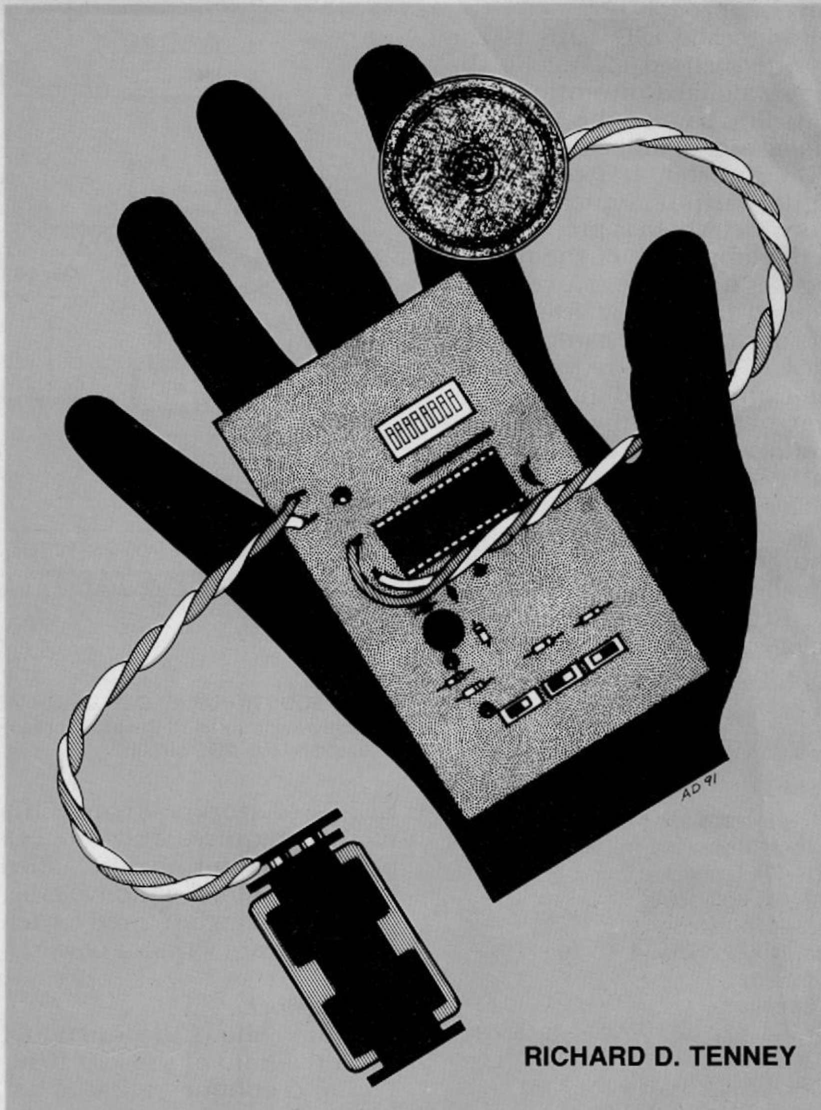
TALKING DEVICES SEEM TO BE ALL around us today. Virtually everywhere we go we're being spoken to by vending machines, arcade games, toys, cars, and even computer-spoken junk phone calls! There seems to be no limit to applications for devices that mimic the human voice, but the quality of the voice emanating from most talking devices has several serious flaws. It's usually monotone, lacking the natural inflection of real speech, and has less than adequate enunciation. In other words, most machine speech sounds "robotic." Worse yet is the necessity of programming a ROM (Read Only Memory) in order to change the message. It's obvious that the standard solutions are less than ideal.

The ISD 1016 Single-Chip Voice Messaging System (Information Storage Devices, Inc., Austin, TX) eliminates all those drawbacks while at the same time introducing several features and functions which greatly enhance its versatility and simplify system design.



RICHARD D. TENNEY

SINGLE-CHIP MESSAGING SYSTEM

Our one-chip voice messaging system makes it easy to add audio-storage capability to your next project!

Features

As the industry's first non-volatile analog storage chip, the ISD 1016 can record and play back up to 16 seconds of analog, or "audio" information. All analog signal conditioning circuits, amplification, and digital control circuits are contained in the single 28-pin package. Therefore, a complete voice record/playback system can be implemented by simply connecting an external microphone and speaker, and a few capacitors, resistors, and switches to the analog storage chip.

Several configuration options are available including multiple message, continuous repeat, and fast forward. These options are in addition to, but mutually exclusive of, the message addressing mode, which allows the user to directly address any segment of the analog storage array. By offering capabilities such as direct analog input, analog storage, and analog output, the ISD 1016 provides a high-grade voice record and playback system.

Novel approach

Key to the ISD 1016 is the unique method of storing the analog signal. Conventional circuits first sample the incoming analog signal and send it to an A/D converter that provides a digital output, typically eight bits wide, which is proportional to the amplitude of the incoming signal. Therefore, this method requires at least eight bits of storage per sample. Playback of the data requires that the eight bits of digital data be sent to a D/A converter to reproduce the original analog signal.

The ISD 1016 eliminates the A/D and D/A conversions by using CMOS EEPROM (Electrically Eraseable Programmable Read Only Memory) technology and storing the sampled data as an analog level in the EEPROM storage array. This method requires only one cell per sample and has the added advantage of being nonvolatile. The signal can be stored for ten or more years without power.

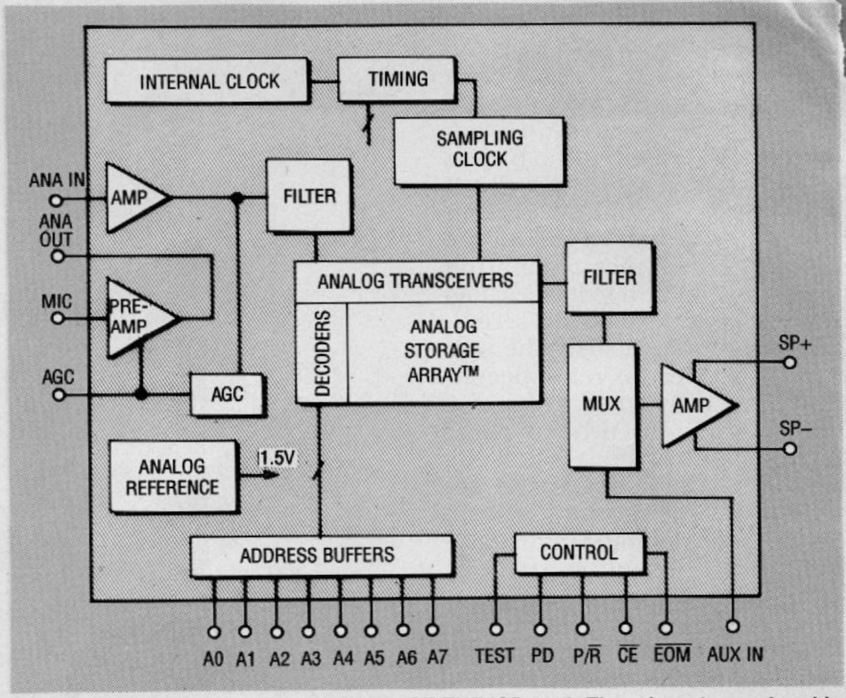


FIG. 1—FUNCTIONAL BLOCK DIAGRAM OF THE ISD 1016. The microphone signal is capacitively coupled to the input preamp, and the gain of the preamp is dynamically adjusted by the AGC circuit.

PARTS LIST

All resistors are ¼-watt, 10%, unless otherwise noted.

R1—2000 ohms
R2—10,000 ohms
R3—470,000 ohms
R4—1000 ohms × 9, 10-pin SIP resistor

Capacitors

C1, C4—22 µF, 16 volts, tantalum
C2, C6—0.1 µF, ceramic
C3—4.7 µF, 16 volts tantalum
C5—0.22 µF, polystyrene
C7—1 µF, 16 volts, tantalum

Semiconductors

IC1—ISD 1016 Voice Messaging System

Other components

S1–S3—SPDT miniature slide switch
S4—8 position DIP switch
MIC1—miniature electret microphone

Miscellaneous: 28-pin IC socket, 16-ohm speaker, power source of at least 5 volts, wire, solder, etc.

Note: The following items are available from R. Tenney, 33 Eastmeadow Way, Manchester, N.H. 03109:

- **ISD 1016 IC—$35.00**
- **Etched and drilled PC board—$9.75**
- **A kit of all parts except speaker—$55.00.**

Please add $2.50 postage and handling.

How it works

Figure 1 shows the functional block diagram of the ISD 1016. The microphone signal is capacitively coupled to the input preamp. The gain of the preamp is dynamically adjusted by the AGC (Automatic Gain Control) circuit, which reduces the gain of the preamp for large input signal levels, and increases it for lower-level signals, thereby expanding the range of input signal levels that can be accommodated without distortion.

The output of the preamp is then coupled to an additional amplifier stage through an external capacitor. This stage has two main functions. One is to provide an input to the AGC circuitry so it can adjust the gain of the preamp according to the strength of the incoming signal. The second role of this stage is to drive the filter network which will remove noise and other unwanted signals outside of its passband.

The gain-adjusted and filtered signal is then fed to the analog transceivers. In the record mode, these transceivers take their input from the input filter and send the signal to the analog storage array. In playback mode they take their input from the analog storage array and send it to the output filter network.

Timing circuitry internal to the ISD 1016 synchronizes the operation of the analog storage array and the analog transceivers, and also generates a sampling clock. The analog audio input signal is sampled by that clock at an 8-kHz rate, which is adequate for an audio passband of 3.4 kHz (about the same as a telephone), and is stored in the analog storage array as a voltage level. During playback, the storage array is sampled and sent to the output filter via the analog transceivers. This filtered signal is then sent to one input of an analog multiplexer, which will select one of its two inputs to drive the power amp. In playback mode, the stored message will be selected, amplified, and sent to the speaker. When not in record mode, and not playing

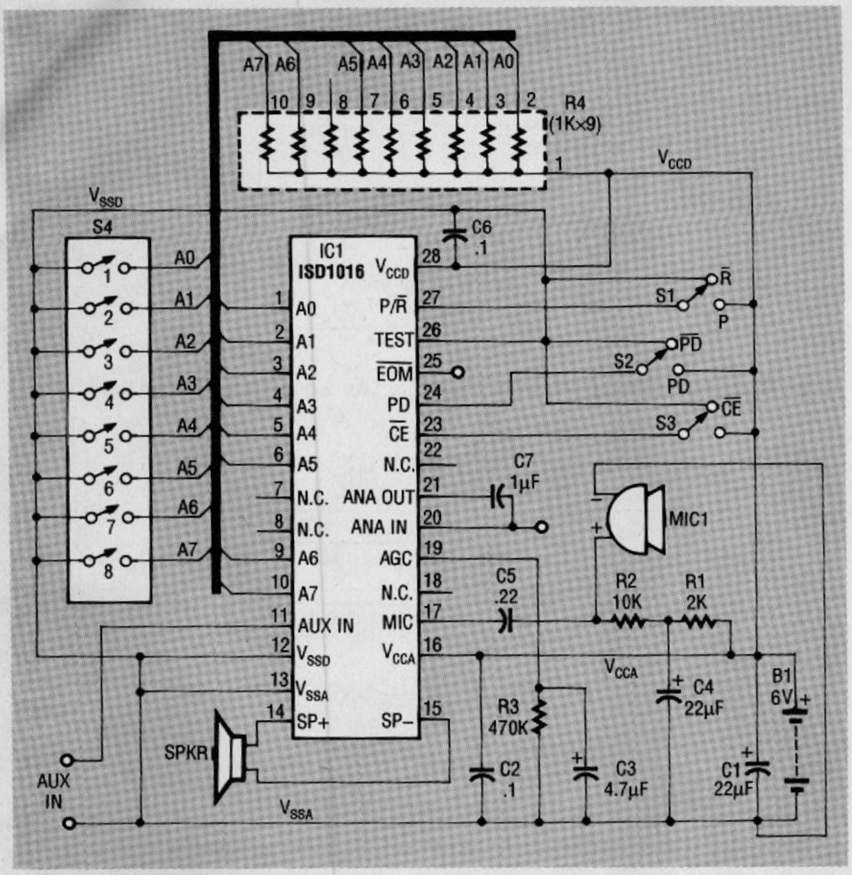


FIG. 2—SCHEMATIC DIAGRAM of the complete voice recording and playback system capable of storing up to 16 seconds of telephone-grade audio.

back a message, the multiplexer will select the auxiliary input as its source, thus allowing us to take advantage of the output amplifier when the ISD 1016 is otherwise idle.

Circuit details

Figure 2 shows the schematic diagram of a complete voice recording and playback system that is capable of storing up to 16 seconds of telephone-grade audio. Before we go over the schematic, let's go over the pin functions of the ISD 1016 to make it easier to understand the overall operation of the circuit.

- Microphone Input (MIC), pin 17—An external microphone is coupled to this input through a series capacitor. The value of the capacitor and the 10K internal resistance of the input determines the low-frequency cutoff for the ISD 1016. A good-quality omni-directional electret microphone is recommended. Its impedance should be about 1K, sensitivity 64 dB, frequency response 50 Hz to 8 kHz, and S/N ratio greater than 40 dB. Refer to the parts list for sources.
- Analog Out (ANA OUT), pin 21—The amplified analog input signal appears on the analog output pin. The gain of the preamp is determined by the voltage level at the AGC pin. Maximum gain is about 24 dB for low-level signals.
- Analog Input (ANA IN), pin 20—This pin has two roles. The analog output (pin 21) of the preamp can be coupled via an external capacitor to this analog input pin. The value of the capacitor and the 2.7K input resistance of this input pin can provide additional cutoff at the low-frequency end of the passband. Alternatively, this pin can be used to input analog signals other than the microphone signal.
- Automatic Gain Control (AGC), pin 19—As described in the section on the block diagram, the AGC circuit will dynamically adjust the gain of the preamp. Peak output voltages of the preamp will be detected and charge an external capacitor. The time it takes for the capacitor to charge to a level that will start to reduce the gain of the preamp (about 1.8V) is known as the "attack time," and is determined by the value of the capacitor and the 5K internal resistance of the AGC input. The "release time" of the AGC is determined by this capacitor in parallel with an external resistor.
- Speaker Outputs (SP+), pin 14 and (SP−), pin 15—The ISD 1016 can directly drive speakers with impedances as low as 16 ohms. The maximum output power of 50 mW is achieved when the speaker is connected between these two pins. In that configuration no coupling capacitor is required. The device can be used in a single-ended configuration; however, an AC coupling capacitor must be used and the output power will be reduced to about 12 mW. While recording, the speaker outputs are disabled. An 8-ohm speaker can be used, but the volume will be louder and some audio distortion can result.
- Power Down (PD), pin 24—This pin serves two purposes in the operation of the chip. First, it provides a low-power mode when the ISD 1016 is at idle (not recording or playing back) and the pin is high. The second function of this pin is to provide a means to reset the address counter. Whenever the ISD 1016 reaches overflow (after 16 seconds total record or playback time) the address counter is at its maximum recording count (9Fh) and an EOM (end of message) pulse will be generated. Activating CE (chip enable) will not restart the device until PD was cycled high and low. NOTE: When recording multiple messages, the user should terminate each message by disabling CE while keeping PD low. That will prevent the address counters from getting reset to zero at the start of the subsequent message, thereby causing the previous message to be overwritten.

• Chip Enable ($\overline{CE}$), pin 23—When taken low, this pin enables all playback and record operations. The address and play/record inputs that meet the setup time (300 ns) are latched on this falling edge. When this pin is taken high, the ISD 1016 is deselected and the auxiliary input is selected as the input to the output power amp.

• Play/Record (P/$\overline{R}$), pin 27—The state of this input is latched into the ISD 1016 on the falling edge of $\overline{CE}$ (along with the address inputs (A0–A7). A logic high selects playback mode and a logic low selects a record operation. The message to be played will start at the address latched when $\overline{CE}$ went low. The message will continue until an $\overline{EOM}$ (end of message) is encountered on pin 25. The $\overline{EOM}$ bit is automatically inserted during a record operation when the storage area is full or when the record operation is terminated by PD going low or $\overline{CE}$ going high. If multiple messages have been recorded, $\overline{CE}$ should be pulsed low for the device to play back a single message. If $\overline{CE}$ is held low (active), all the stored messages will be played back in sequence.

• Address Inputs (A0–A7), pins 1–6, 9, 10—Two functions are performed by the address inputs: mode and option selection, and message address. The ISD 1016 has two modes of operation, Address Mode and Configuration Mode. Address bits 6 and 7 determine which mode will be selected. If either bit 6 or bit 7 is low, Address Mode will be selected. In that mode the address pins specify the starting address of the operation to be performed. If both address 6 and 7 are high, the configuration mode is selected. Table 3 lists the configuration mode options. Of the options listed, continuous repeat and multiple message recording can be of the most use to the experimenter. Further details of their use can be found in the section on "Modes of Operation."

• End Of Message ($\overline{EOM}$), pin 25—At the end of each recorded message, an $\overline{EOM}$ marker is automatically inserted in a nonvolatile register. The $\overline{EOM}$ output will go low at the end of each message and at message overflow. The width of the negative pulse is 12.5 ms minimum. Another function of $\overline{EOM}$ is as a low-power indicator. If power to the chip should drop below 3.5V, $\overline{EOM}$ will be forced low and the ISD 1016 placed in playback mode. This feature helps prevent recording while in an unreliable power condition.

• Auxiliary Input (AUX IN), pin 11—As explained earlier, AUX IN is selected as the input to the output power amplifier when either $\overline{EOM}$ is true or $\overline{CE}$ is not true, thus allowing us to take advantage of the amplifier for other uses when the ISD 1016 is otherwise inactive.

• 5-volt Analog and Digital Power Inputs (V_{CCA}), pin 16 and (V_{CCD}), pin 28—The ISD 1016 voice messaging system chip incorporates both digital and analog circuitry. The digital circuitry generates considerable noise from rapid switching of gates within the device, as does any other digital device. The noise is easily detected by the analog circuitry and can, therefore, be recorded as noise in the analog signal. For that reason, separate power and ground buses are provided for the analog and digital portions of the device. In that manner, currents flowing in the digital portions of the device cannot cause significant voltage fluctuations in the analog power buses. The two power pins should be connected together as close as possible to the power source. That is the *only* location where the two power busses should be connected together. If another direct connection between V_{CCA} and V_{CCD} were to be made at any other point, a "loop" would be formed and slight voltage differences between the two points would cause unwanted currents to flow in this loop, providing another source of noise.

• Analog and Digital Ground Connections (V_{SSA}), pin 13 and (V_{SSD}), pin 12—NOTE: The ground connections for the ISD 1016 do not conform to a stan-

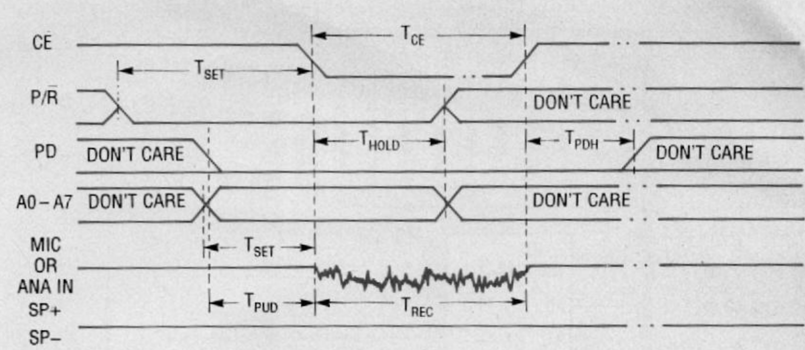


FIG. 3—RECORD TIMING DIAGRAM. See Table 1 for a description of the parameters.

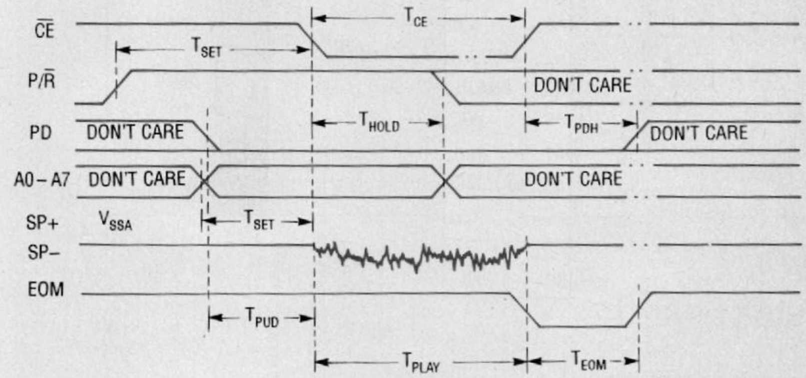
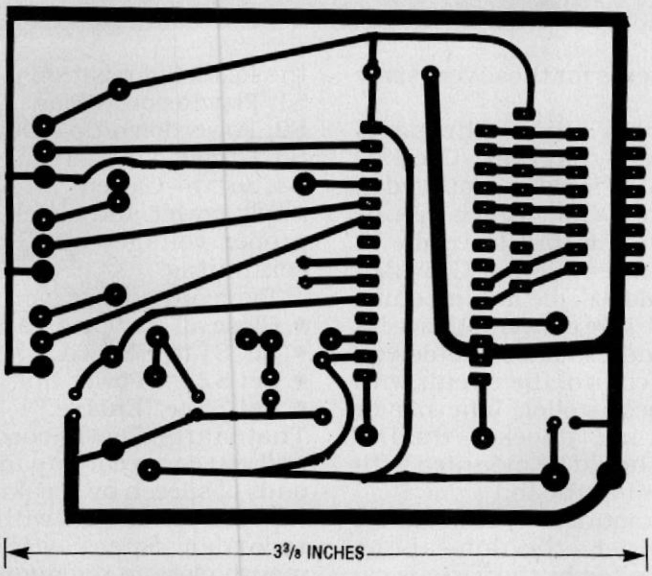


FIG. 4—PLAYBACK TIMING DIAGRAM. When operating the device under microprocessor control or other high-speed device, these parameters must be considered.

TABLE 1—TIMING & VOLTAGE PARAMETERS

Symbol	Parameter	Value
FS	Sampling Freq.	8 kHz
BW	Bandwidth	3400 Hz typ.
P_{OUT}	Speaker Output Power	50 mW max.
V_{IN1}	Mic Input Voltage	20 mV max. p-p
V_{IN2}	Ana Input Voltage	80 mV max. p-p
V_{IN3}	Aux Input Voltage	1.25 V max. p-p
T_{SET}	Control/Address Set-up	300 ns min.
T_{HOLD}	Control/Address Hold	0 ns max.
T_{CE}	$\overline{CE}$ Record Time	100 ns min.
T_{PUD}	Power Up Delay	25 ms min.
T_{PDH}	Power Down Hold	0 ns min.
T_{REC}	Record Time	16 s max.
T_{PLAY}	Playback Time	16 s max.
T_{EOM}	$\overline{EOM}$ Pulse Width	12.5 ms typ.



FOIL PATTERN for the voice messaging system.

dard 28-pin DIP. V_{SSA} and V_{SSD} are the return paths for the analog and digital sections of the device, respectively. Follow precautions similar to those described for the power inputs. Pins 12 and 13 should be tied together at the package, and power should be decoupled using 0.1μF capacitors between V_{CC} and V_{SS}, as close as possible to the package, for both analog and digital power.

- Test Input, pin 26 (TEST)—This pin is used during the manufacturing operation prior to product shipment. For proper device operation this pin *must* be tied low.

Now that we have a better understanding of how the ISD 1016 works, let's go over the schematic (Fig. 2). Resistors R1 and R2 supply the microphone bias for the electret microphone (MIC1) recommended in the parts list. Capacitor C4 provides microphone decoupling and C5 provides input coupling and DC blocking for the microphone while also acting as a single-pole, low-frequency cutoff filter. Capacitor C7 provides AC coupling between the preamp output and the input amplifier, and also provides additional low-frequency cutoff.

Resistor R3 and capacitor C3 provide the AGC attack/release time constants. For strong input signals, the AGC circuit internal to the ISD 1016 starts charging C3. If the signal remains strong long enough for C3 to reach the AGC threshold level (about 1.8V), the gain of the preamp is reduced to prevent it from being overdriven. If the input signal level decreases, C3 starts to discharge through R3, thus increasing the gain of the preamp for low-level signals.

Capacitor C1 provides V_{CC} decoupling, C2 is the V_{CCA} high-frequency decoupling capacitor, and C6 provides the same function for V_{CCD}. C1 should be located as close to the supply as possible, and C2 should be as close to IC1 as possible. Switches S1, S2, and S3 provide the control functions for PLAYBACK/RECORD, POWERDOWN, and CHIP ENABLE inputs respectively.

Resistor R4 is a SIP (Single-Inline-Package) containing nine resistors, one of which is not used. Those pull-up resistors are used so we can implement the address switches with an inexpensive eight-position DIP switch (S4) instead of eight individual switches.

The output amplifier of the ISD 1016 is designed to drive a 16-ohm speaker; a standard 8-ohm speaker can be used, but you'll end up with slightly louder volume, slightly greater power dissipation, and some distortion. In general, the better the quality of the speaker, the better the sound quality.

Timing diagrams

Figures 3 and 4 show the timing diagrams for the record and playback modes respectively. The parameters referenced are shown in Table 1. When operating the device manually, parameters such as setup and hold times are met by simply following the recommended procedures outlined later in this article. When operating the device under microprocessor control or other high-speed device, these parameters must be considered when controlling the chip. For example, to set up for a record operation the address lines should be set by one instruction and the $\overline{CE}$ line set by a subsequent instruction to ensure the 300-ns control/address setup time (T_{SET}) is met.

Construction

A complete kit of parts, including an etched and drilled

PC board, is available from the source in the parts list. A foil pattern is provided here if you would like to make your own board. None of the component values are critical, but be sure to leave pins 7, 8, 18, and 22 unconnected, no matter what you do.

If you're making your own layout, some simple guidelines should be followed for best results. Note that V_{CCA} and V_{CCD} should be connected at one point only, right where power enters the board. Likewise, V_{SSA} and V_{SSD} should be connected together right at pins 12 and 13 of IC1. That isolates the analog signal and ground paths from the digital paths, thus reducing noise. Also, the analog components should be physically separated from the digital components for those very same reasons.

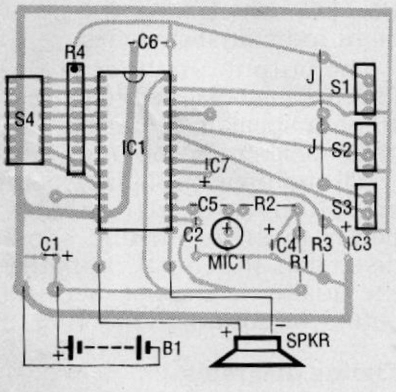


FIG. 5—PARTS PLACEMENT DIAGRAM. Mounting the DIP switch (S4) in a socket will give you convenient access to the address lines if you wish to control the circuit with a microcontroller. Be sure to position switch #1 of the DIP switch at the top.

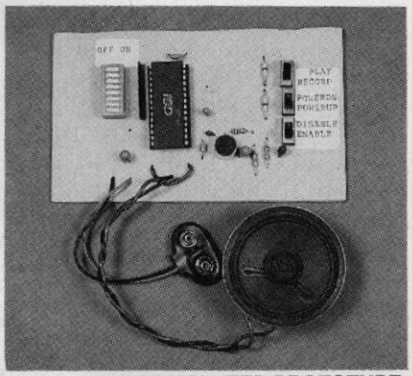


FIG. 6—THE COMPLETED PROTOTYPE. The 9-volt battery clip attaches to a 4-AA cell holder that has a matching connector; the prototype voice messaging system, therefore, is powered from a total of 6 volts.

TABLE 2—OPTIONS

Function	Address Bit	Use
Playback chip enable level activated	5	Provide switch debounce
Message start pointer reset only play/record changed	4	Recording multiple messages
Continuous repeat of message	3	Continuous repeat at $\overline{EOM}$ encounter
During playback $\overline{EOM}$ pulses low at overflow only	2	Concatenate chips for longer messages
$\overline{EOM}$ markers deleted by next message	1	Assures that $\overline{EOM}$ markers are cleaned up when recording over message
Fast forward (speaker output is disabled)	0	Selecting messages when address is unknown

Figure 5 shows the parts placement diagram. The ISD 1016 (IC1) should be mounted in a 28-pin socket, which can be installed now, but leave the IC out for the moment. DIP switch S4 should also be mounted in a socket to give convenient access to the address lines should you wish to control the circuit with a microcontroller. Whether or not you use a socket, the DIP switch should be mounted with switch #1 at the top.

Next mount SIP resistor R4 (with pin 1—the dot—at the top), followed by the various capacitors, discrete resistors, and the microphone. Be certain to observe polarity when installing C1, C3, C4, C7, and the microphone. Next mount switches S1–S3 and the leads for the speaker and the power source. (The prototype uses a standard 9-volt battery clip and a 4-AA cell holder that snaps onto the 9-volt clip.) Figure 6 shows the completed prototype.

After all components have been mounted, check for any shorts or solder bridges, and verify proper orientation of all components. After these checks have been made, install IC1 in its socket verifying proper orientation, and connect a speaker to the speaker terminals.

Operation

Before connecting power to the circuit, set all switches to the following positions:

S1, Play/Record—Play
S2, Powerdown/Up—Down
S3, Chip Enable—Disable
S4, A0–A7—Closed

Apply power and check for the proper voltages at IC1 before continuing.

To record a message:

- Close all switches on S4.
- Set S1 to "Record."
- Set S2 to "Power up."
- Set S3 to "Enable."

That starts the "Record" time and you can record up to 16 seconds of speech by speaking into the microphone, as with a tape recorder. Speak with your mouth close to the microphone in a normal voice. When you are finished recording your message you should:

- Set S3 to "disable."
- Set S2 to "Powerdown."
- Set S1 to "Play."

To play back a message:

- Set S1 to "Play."
- Set S2 to "Power up."
- Toggle S3 to the "Enable" position and back to the "Disable" position.

Your pre-recorded message will now play back and stop at the end. When the message is complete, set S2 to the "Power down" position.

Addressing mode

The ISD 1016 has two mutually exclusive modes of operation: the "Addressing Mode" and the "Configuration Mode." The addressing mode is selected

continued on page 92

MESSAGING SYSTEM

continued from page 64

whenever A6 or A7, or both, are low at the time $\overline{CE}$ goes low. The ISD 1016's storage array is arranged in 160 segments of 0.1 second each. The segments are numbered 0–9Fh. They may be accessed randomly, however play and record operations will access them sequentially beginning with the address supplied by DIP switch S4 at A0–A7, until an EOM marker is encountered, or the operation is terminated by bringing $\overline{CE}$ high.

To determine the address to use to select a particular message, or to record a message at a specific point in memory, we will use a simple example. Suppose we want to hear a message we know starts at the 5-second point in memory. Each memory segment is 0.1-second long, so our message starts at segment 50 (5/0.1 = 50). Now we simply convert the decimal segment number into hex (50 decimal = 32 hex). Thus S4 switches 1–4 must be a binary "3" and switches 5–8 must be a binary "2," so switches 2, 5, and 6 would be open (bits 1, 4, and 5 high).

Configuration mode

If address bits 6 and 7 are both high (S4 switches 7 and 8 both open) at the time $\overline{CE}$ goes low, the ISD 1016 enters the "Configuration Mode," in which address bits A0–A5 (S4 switches 1–6) take on a different meaning. In this mode, those address bits no longer specify addresses. Instead, they select among the various options available as shown in Table 2.

To illustrate the use of Configuration mode, let's assume we recorded a message using the instructions given earlier, and we would like to have it repeat continuously. (Make sure the message is less than 16 seconds long so the "overflow" condition won't disable the chip after the first replay. Also, the Addressing mode and Configuration mode are mutually exclusive, so you can have only one message in Configuration mode.) To play the message back continuously, we want to be in the Configuration mode; A3, A6, and A7 high (open), and the rest of the address switches closed. Now set Power down/Up to the "up" position, and set Disable/Enable to the "enable" position. The message that your recorded will now repeat continuously until $\overline{CE}$ is set to the "disable" position (or, of course, until your battery's power gets used up). **R-E**