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Add a Voice to Your Computer for $35

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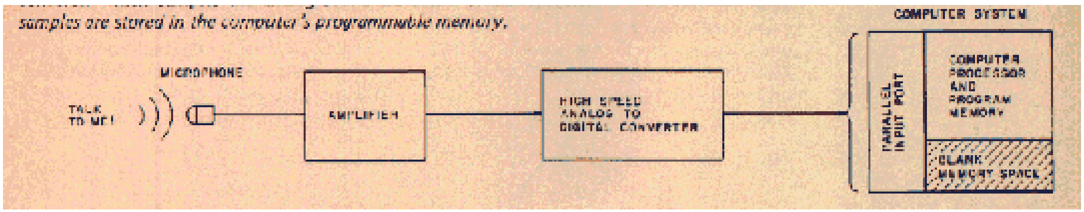
Talk to Me!

Talk to me! Talk to me!"
"OK! I'll talk to you if you need it that much!" Ken called out as he descended the stairs into my cellar workshop. "You sure you aren't going a little buggy"
I looked up from the video monitor and parted the piles of cassette tapes and printouts. Ken was a good neighbor and I knew his comment was only in jest. I hit the carriage return and the speaker said, "Talk to me!"
Ken smiled when he realized I was just exercising the voice synthesizer option I had previously added to my system.
"This synthesizer is part of the reason I'm here this evening," he said.
"What's the problem?" I asked.
"No problem really. We just got a microcomputer in'my company's R and D lab and I've been playing with it lately. It's pretty sophisticated and has plenty of memory space. What would it cost to put that type of synthesized voice on our computer? I can probably raise $50 among the technicians for it. They'd get a kick out of it."
"Well, depending on the manufacturer and the particular interface, they usually run from $400 to $800 and up." I looked at the startled expression on Ken's face. It was what I normally call "peripheral face," the look you get when you tell someone that it'll cost $1100 for a video terminal to communicate with the computer he just bought for $250.
"So much for that idea. How's the weather been lately?"
"Wait!" I interjected. "How much memory do you have on your lab microcomputer?"
"40 K, I believe. Why?"
"How much of a vocabulary do you need?"
"I suspect we'd only need the numbers 0 through 9 and a few letters. We want to monitor data and verbally record channel number and input value. But at that price it's far too expensive to justify."
"How about digitized speech? You probably have enough memory for that."
"What's that?"
"It's a process to record speech digitally. For all practical purposes it's like a tape recorder, but instead of magnetic tape for the storage medium it uses the computer's programmable

memory. The tape recorder uses an analog storage method while the computer stores the information digitally."
"If it's that simple why don't more people use it?"
"It's mostly because it's not very memory efficient. A voice synthesizer is an analog voltage generator that creates the speech phoneme sounds through a hard wired circuit. In its most advanced form a single 8 bit byte can be used to tell the synthesizer what discrete sound It should make. By sending it a series of byte codes, words can be made from the discrete sounds. That's the way my Votrax synthesizer works." I pulled out a pad to sketch my explanation. "In digitized speech the analog voice input is sampled very quickly with a high speed analog to digital converter, and the samples are stored In memory. To reconvert to analog or "say" the words, the stored digital data is sent to a digital to analog converter at the same rate and in the same order the samples were taken. The concept of digitized speech has been around for a long time, but up until recently the cost of a system dedicated to this was prohibitive. You already have the computer and enough memory for limited applications. All you need is the high speed analog to digital and digital to analog converters and the knowledge to do it."
"And what is that going to cost me, $500?" Ken was still skeptical.
I opened a drawer under the bench. It was my "junk box" (in my case one corner of my cellar is a junk room). I rummaged through the prototype boards from previous experiments and pulled out a particular one. "Ah, here we are. You remember a few months ago when I designed that 8 channel digital voltmeter (December 1977 BYTE, page 76, and January 1978 BYTE, page 37).

Figure 1a: Block diagram of a digital speech recording system. Speech is picked up as sound waves by the microphone and is amplified and processed through a high speed analog to digital converter which samples the analog' sound waveform several thousand times a second. These samples are stored in the computer's programmable memory.

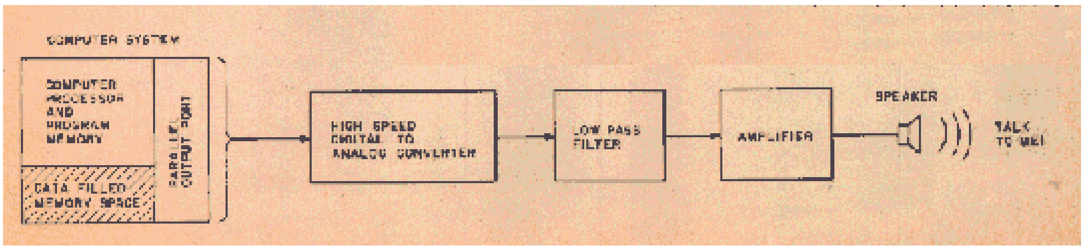


I needed it to troubleshoot this board. This is all you need for digitized speech." I tossed the board to Ken. "It contains a 100,000 sample per second 8 bit analog to digital converter and an equivalent speed digital to analog converter. And now the beauty part: It cost less than $35 to build."
"Great! Tell me how to use it. How much memory does it need? What kind of program does it use? Can you tell me how to use it so I can borrow it for work tomorrow?"
"Well, let's go over the concept in more detail...."

What is Digitized Speech?
Digitized speech is simply a standard a data acquisition technique with a new definition. For years people have been using computers to scan analog to digital input converters and store the results in memory. Often, in high speed applications such as wind tunnels and nuclear experiments, the sample rates can exceed thousands of samples a second. In cases where the critical event is of short duration, these thousands of samples are stored directly into memory to increase system throughput capabilities. When the event has passed and

sampling has stopped, the computer memory contains a record of that event in discretely timed intervals. The stored data is now available to be reduced, analyzed or listed. It's often listed in "slow motion." This technique employs an analog pen recorder and a digital to analog converter. Each sample is successively processed through a digital to analog converter at a slow rate to the pen recorder. The result is an expanded view of a short event. An alternative method for utilizing this stored data is to play it back in real time.
In this case the computer outputs the stored data to the digital to analog converter at the same rate the data is taken. The output of the converter would then exactly duplicate the values of the event previously recorded (at the times the samples were taken).
Digitized speech is a specific application of this type of data recording technique. Your voice, when applied to a microphone and amplifier, creates a fluctuating analog voltage that varies at the frequency rate of the sound. If this analog signal is applied to the input of a high speed (greater than 10,000 samples per second) analog to digital converter and stored in memory, the computer won't care whether the source is speech or
a nuclear reaction. The analog fluctuations are "digitized" at discrete sampling intervals and stored (figure 1a). If the stored memory table is sent to a digital to analog converter at the same rate it was initially sampled, the
speech is reproduced exactly. Of course there are trade-offs and limitations that have to be considered to produce a usable system (figure lb). We will consider them in detail later.

Figure lb: Block diagram of a digital speech playback system. Digital sample points stored by the system in figure la are converted by a high speed digital to analog converter intQ an analog speech waveform. A low pass filter is used to smooth the signa4 which is then amplified and played back through a speaker.



A digitized speech system creates its output waveform by digital to analog conversion rather than by completely analog generation as in the case of a voice synthesizer. The major consideration that limits the usefulness of digital speech is the vast quantity of data which must be stored to reproduce a single spoken word.
choosing the Correct Sampling Rate

The 8 channel digital voltmeter mentioned earlier has a maximum sampling rate of 25 conversions a second. A slow speed analog to digital converter of this type is of no value in this application. The normal human voice occupies a bandwidth of 4000 Hz, and taking

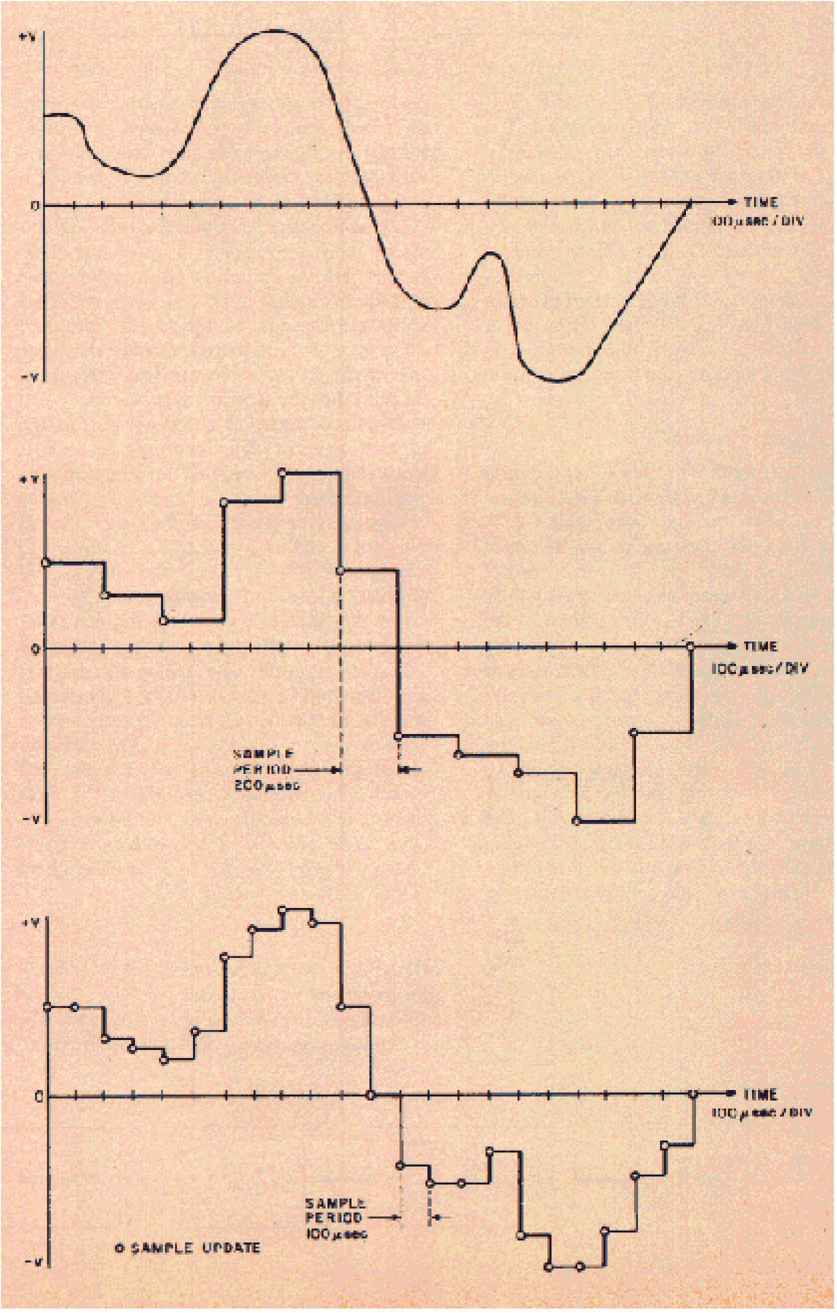


Figure 2a: A waveform (considerably simplified) which is characteristic of the voice.

Figure 2b: Waveform in figure 2a after being processed through a digital to analog converter at a sample rate of 5000 samples per second.

Figure 2c: Waveform in figure 2a after being processed through a digital to analog converter at a sample rate of 10,000 samples per second.

25 samples within a period of one second - could not effectively record the event. At what sampling rate should audio speech be digitized?

There is a specific law used to determine this rate, called the Nyquist criterion. It states that, at the very minimum, the sampling rate of the digitizer must be twice the maximum frequency of the input sample. If human voice extends to 4 kHz, the minimum sample rate should be 8 kHz. This presumes that there is an ideal low pass filter on the output of the converter. Ideal filters are something like perpetual motion, impossible to attain. In reality the sampling rate should be three or four times the highest input frequency. This means that to digitize voice fully you need a sample rate of from 12 to 16 kHz.

It is easier to explain the digitization process visually. Figure 2 illustrates an expanded view of a typical speechlike waveform. Voice waveforms are complex: the majority of the voice sounds exist below 1500 Hz, but intonation and accent occupy the higher frequencies. It is these added harmonics and inflections that make one voice different from another, and capturing and recording them is an important consideration. The waveform in figure 2 has been digitized at two different rates for comparison. Figure 2a is the original waveform which consists of a fundamental frequency of approximatley 500 Hz and some added components of higher frequency. If this waveform is "digitized' or sampled at a 5000 samples per second rate and the stored values are sent to a digital to analog converter, the resultant waveform would be that shown in figure 2b. It is easy to see that only a vague representation of the original waveform would be recorded. Even though this output is filtered before being amplified, the higher frequency components of the original input would be lost. Increasing the sampling rate to 10,000 samples per second as in figure 2c gives a better record of the higher frequencies. The addition of a good low pass filter would eliminate the sharp transitions between samples.

Tradeoffs to be Considered

The benefits associated with the reduced cost of the voice input and output circuitry

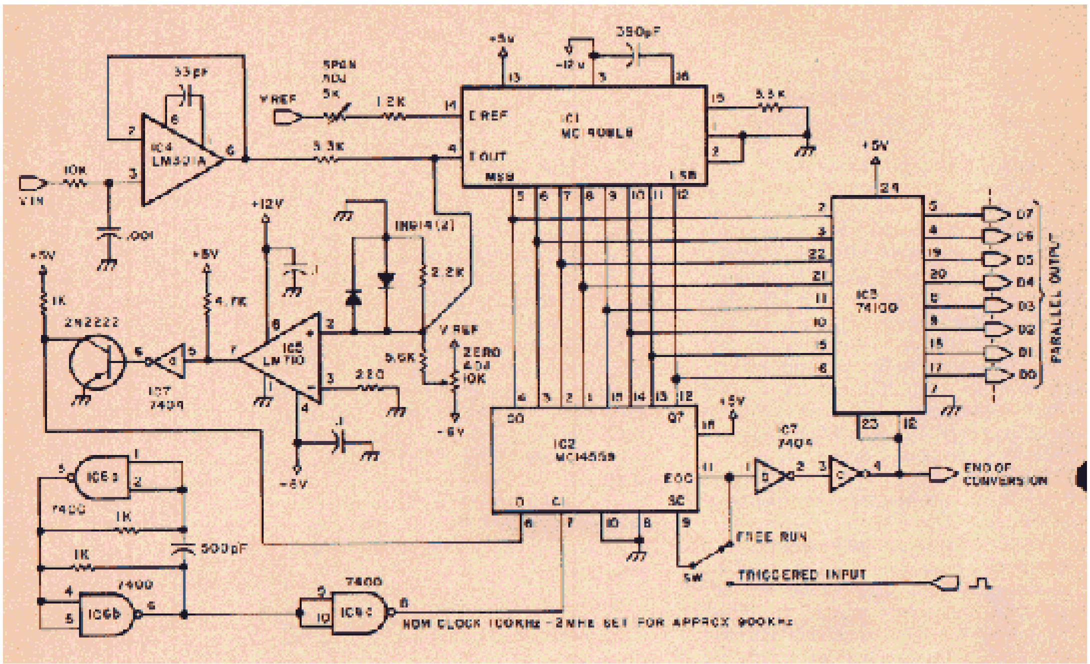


Figure 3a: An 8 bit successive approximation analog to digital converter.

are counteracted by the increased memory requirements. Digitized speech uses a lot of memory. In the previous example, if the voice input is sampled at 10,000 samples per second, the table in memory needed to store one second of data would be 10,000 bytes long (presuming an 8 bit analog to digital converter). If Increased fidelity is required and the sampling rate Is set for 16 kHz, the table would fill up at a rate of 16,000 bytes per second. Obviously, systems like my own, which already have considerable amounts of programmable memory, would be easy to use for experimenting with digital speech. I do not recommend buying additional memory just to store a few words, but, if you have it, you'll be surprised at the results.

Building a Voice Digitizer

To experiment fully with digitized speech, it is necessary to have a high speed analog to digital converter to store the analog Input and a high speed digital to analog converter to reconstruct the analog output.
Figure 3a shows the schematic of an 8 bit analog to digital converter capable of sample rates in excess of 200,000 samples per second. With an 900 kHz clock rate it will run at a modest 100,000 samples per second. Figure 3b shows an 8 bit digital to analog converter and low pass filter with similar capabilIties. The estimated total cost for parts is $35.
The analog to digital converter is a general purpose high speed 8 bit converter that can

IC Number	Type	+5 V	Gnd	+12 V	−12 V	−6 V
IC1	MC1408L8	13	1		3	
IC2	MC14559	16	8			
IC3	74100	24	7			
IC4	LM301A			7		4
IC5	LM710			8		4
IC6	7400	14	7			
IC7	7404	14	7			
IC8	MC1408L8	13	1		3	
IC9	LM301A			7	4	

Table 1: Power wiring table for figures 3a and 3b.

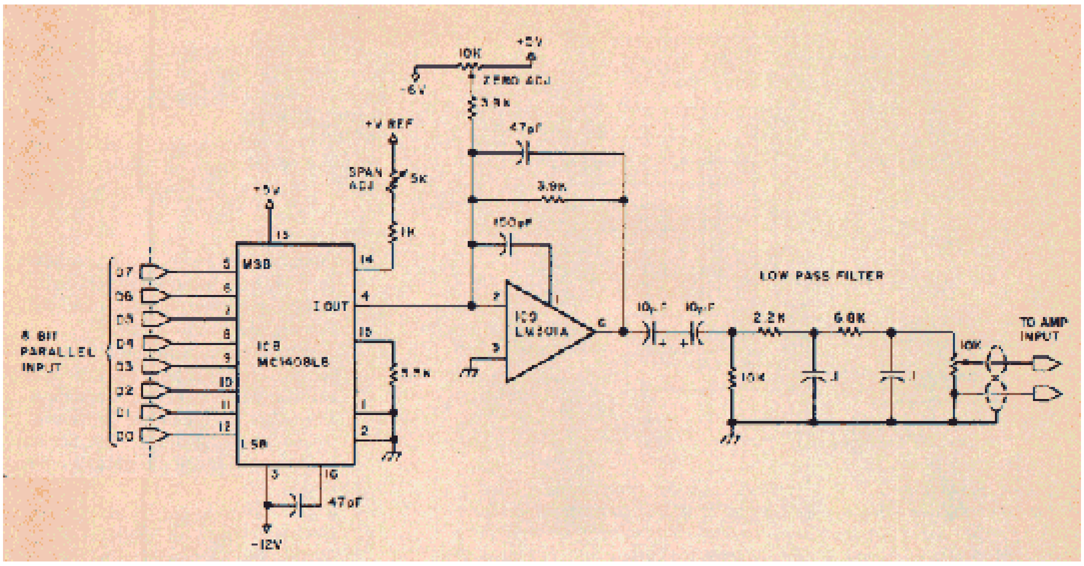


Figure 3b: An 8 bit digital to analog converter and low pass filter.

be used for any data acquisition application requiring high speed. The technique used to attain this speed is called successive approximation. The circular logic of successive approximation is best explained in a block diagram (see figure 4).
Initially, the output of the Successive Approximation Register (SAR) and mutual IV connected digital to analog converter is at a zero level. After a start conversion pulse, the

register enables the output bits one at a time starting with the most significant bit (MSB). As each bit is enabled, the comparator gives an output signifying whether the amplitude of the Input signal is greater than or less than the amplitude of the converter. If the converter output is greater, that particular bit is set equal to 0; if less than, it is set to 1. The register moves successively to the next least significant bit (retaining the setting on the previously tested bit or bits) and performs the same test. After all the bits of the converter have been tested, an EOC Is output and then the conversion cycle is complete. The entire conversion period takes only nine clock cycles, and

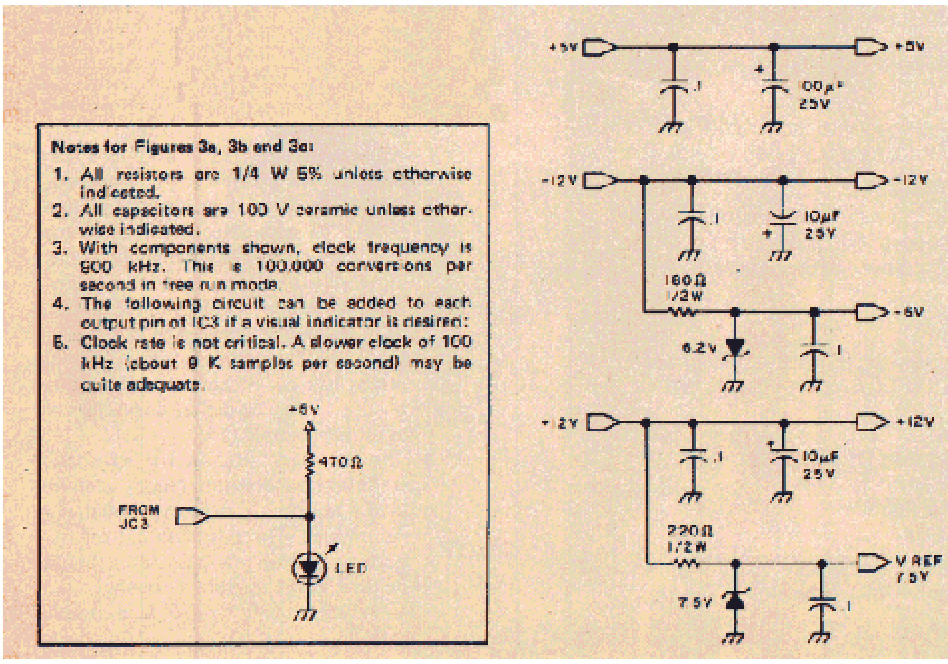


Figure 3c: Power supply circuitry for figures 3a and 3b.

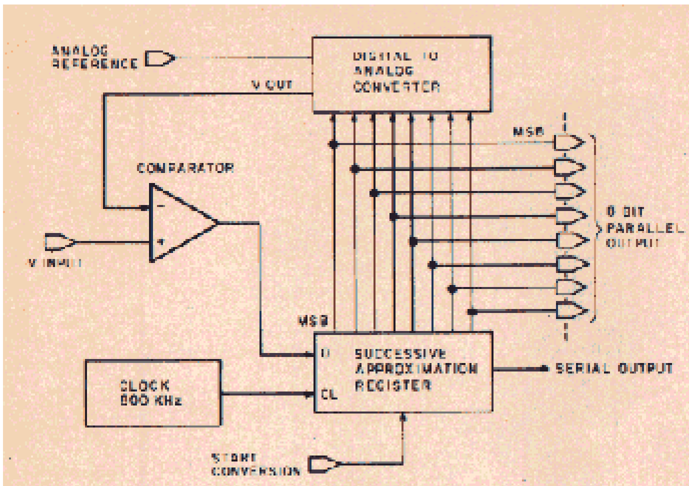


Figure 4: Block diagram of a typical successive approximation analog to digital converter The device uses a digital to analog converter to perform its function. The successive approximation register is initially set to 0. After a start conversion pulse, the register enables the output bits one at a time, starting with the most significant bit (MSB). As each bit Is enabled, the comparator gives an output signifying whether the amplitude of the Input signal is greater than or less than the amplitude of the digItal to analog converter. if the converter output Is greater, the bit in question is set equal to 0. Otherwise it Is set to 1. The process continues for the remaining bits, until the conversion Is complete.

another conversion begins on the next clock pulse when in free run mode. To retain the 8 bit value between conversions, an 8 bit register (1C3) has been added (see "Control the World," September 1977 BYTE, page 30, for a complete description of MCl408 digital to analog converter operation).

Assembly and Testing

1. Component types and values are chosen to allow high speed operation. Substitution of slower devices may cornpromise overall performance.
2. Assemble components on a prototype board as neatly as possible. Keep wires between components short and dIrect. The MCI 4559 is a CMOS device and it should be handled carefully. Sockets are suggested for all integrated circuits.
3. Check power supply voltage before inserting integrated circuits. Then insert Clock oscillator 1C6. The clock frequency should be around 900 kHz.
4. Insert the rest of the integrated circuits and ground the V input connection of 1C4. Slowly rotate the zero adjust pot until the parallel output of 1C3 reads binary 10000000. This output can be read either through a computer program which scans and displays this value or with LEDs attached to the output pins. In practice, the LEDs are easier in the long run.
5. Remove the short on V input and apply a voltage of +2 V. Adjust the span adjust pot until the displayed output Is 11111111. The result of this procedure is an analog to digital converter with an input range of -2 to +2 V represented by binary 00000000 and 11111111 patterns respectively. o V is represented by 10000000. Any
voltage span between + and -5 V can be set on this circuit using this method.
6. The digital to analog converter section should be assembled with the same care. Insert all ICs. With all parallel input pins at a logic zero level, adjust the zero pot until 1C9 pin 6 reads 0 V.
7. With all parallel input pins at a logic 1 level, adjust the span pot until the output at 1C9 pin 6 equals the +V setting of the analog to digital converter, or as in the example (2 V).
8. The low pass filter in the schematic is optimized for the speech samples in the text, but can be experimentally
determined. The optimum cut off frequency of the low pass filter should be the sampling rate frequency. (ie:
10 kHz cut off for 10 kllz sample rate).
9. The easiest way to test the entire unit is to attach the analog to digital converter output to the digital to analog converter input. What goes in should come out! Since both units would be running continuously at the 100,000 samples per second rate, this will give the experimenter firsthand knowledge of the ultimate fidelity of the system. Don't expect miracles with an 8 bit unit; 12 bit units would be far superior, but 8 bit precision is more than adequate, A standard cassette recorder in the record mode serves as a handy amplifier. The amplified output is available at the earphone jack on most recorders.

Using the Interface with a Computer

Not everyone will want to add a voice to their home computer but the concept is none the less intriguing. Once you have built the analog to digital converter and digital to analog converter of figure 3 you are ready to digitize the spoken word. Listing 1 is a simple program that reads the analog to digital converter output and puts the values sequentially in a memory table. Hardware for the experiment should be arranged as in figure 1b. When the program is executed It will scan the input port containing the analog to digital converter information and will compare this value to hexadecimal AS (when speech is started, the

audio level will presumably exceed this trigger level). The amplifier should be adjusted to eliminate false triggering because of background noise.
When the input level is attained, the digitization process begins. The program sets the beginning address of the memory and sequentially reads the input port and stores the value. The rate at which the sampling occurs is determined by the value of a constant, "SAMP." A value of hexadecimal 38 is approximately 3 kHz on my Z-80 system. When the table is filled, the program stops: All programs in this article, while written on a Z-80, use only 8080 instructions.
Once the table is filled with digital values corresponding to a voice input we are ready for the next phase: voice output The hardware is configured as in figure 1b, and the output program shown in listing 2 should be used. The same values as those of the input program should be used for START, END and SAMP. When the - program is executed, the recorded data gives a speech output.
As with most computer experimenters, hearing is believing. To allow people to try out the concept without having to construct the analog to digital converter I have included a predigitized listing of a few words. This 2000 byte listing (listing 3), will say "Talk to me" when read out using the program of listing 2. Since I could not presume that everyone had the patience to hand load a 10,000 byte table with good fidelity, a compromise was in order. The sample rate on this table is only 3 kHz, but the speech will still be understandable. It should also be realized that since this example of digitized speech is actually recorded sounds, the words "Talk to me" will be in my voice. The fact that I have a fairly low voice allows understandable speech even at these very low sample rates.

Listing 1: An 8080 assembler program that reads the 8 bit parallel output of the analog to digital converter and stores the samples sequentially in memory. This assembly uses octal notation for machIne codes.

```
120000                 *
120000                 *
120000                 * VOICE TO MEMORY TABLE TEST PROGRAM *
120000                 *               S.CIARCIA
120000                 *
120000                 *
120000                 START   EQU  010000 MEMORY TABLE START HL ADDRESS
120000                 END     EQU  110    MEMORY TABLE END H ADDRESS
120000                 TRIG    EQU  250    INPUT START CONVERSION LEVEL
120000                 IPORT   EQU  020    A/D INPUT PORT NUMBER
120000                 SAMP    EQU  070    SAMPLE RATE TIME CONSTANT
120000                 *
120000                 *
120000                 *
120000 333 020         INP     IN   IPORT  READ A/D INPUT VALUE
120002 376 250                 CP   TRIG   COMP. INPUT TO CONVERT TRIGGER LEVEL
120004 302 000 120             JP   NZ,INP LOOP AGAIN IF NOT SUFFICIENT LEVEL
120007 041 000 010             LD   HL,START LOAD TABLE START ADDRESS
120012 333 020         AGAIN   IN   IPORT  TAKE A SAMPLE
120014 167                     LD   (HL),A STORE SAMPLE IN MEMORY
120015 315 030 120             CALL DELY   SAMPLE TIME DELAY
120020 043                     INC  HL
120021 174                     LD   A,H
120022 376 110                 CP   END    TEST TO SEE IF AT END OF TABLE
120024 302 012 120             JP   NZ,AGAIN IF NOT TAKE ANOTHER SAMPLE
120027 166                     HALT
120030                 *
120030                 *
120030                 * SAMPLE RATE TIMING LOOP *
120030 006 070         DELY    LD   B,SAMP
120032 005             DCR     DEC  B
120033 302 032 120             JP   NZ,DCR
120036 311                     RET
```

Listing 2: An 8080 assembler program designed to output digital speech samples to the digital to analog converter at the correct rate. This assembly uses octal notation for machine codes.

```
120000                 *
120000                 *
120000                 * MEMORY TABLE TO VOICE OUTPUT TEST PROGRAM *
120000                 *               S.CIARCIA
120000                 *
120000                 *
120000                 START   EQU  010000 MEMORY TABLE START HL ADDRESS
120000                 END     EQU  012    MEMORY TABLE END H ADDRESS
120000                 OPORT   EQU  022    D/A OUTPUT PORT NUMBER
120000                 SAMP    EQU  070    SAMPLE RATE TIME CONSTANT
120000                 *
120000                 *
120000                 *
120000 041 000 010             LD   HL,START LOAD TABLE START ADDRESS
120003 176             AGAIN   LD   A,(HL) TABLE VALUE TO ACCUMULATOR
120004 323 022                 OUT  OPORT,A OUTPUT BYTE TO D/A
120006 315 021 120             CALL DELY   SAMPLE TIME DELAY
120011 043                     INC  HL
120012 174                     LD   A,H
120013 376 012                 CP   END    TEST TO SEE IF AT END OF TABLE
120015 302 003 120             JP   NZ,AGAIN IF NOT OUTPUT THE NEXT SAMPLE
120020 166                     HALT
120021                 *
120021                 *
120021                 * SAMPLE RATE TIMING LOOP *
120021 006 070         DELY    LD   B,SAMP
120023 005             DCR     DEC  B
120024 302 023 120             JP   NZ,DCR
120027 311                     RET
```

Listing 2: An 8080 assembler program designed to output digital speech samples to the digital to analog converter at the correct rate. This assembly uses octal notation for machine codes.

Listing 3: A listing of the digital samples making up the phrase Talk to me spoken by the author. This somewhat bandwidth limited signal allows interested readers to reproduce the message through an 8 bit digital to analog convertor without having to build the analog to digital converter.

THE FOLLOWING LIST HAS THE ADDRESS LOCATION IN DECIMAL
ALL MEMORY BYTE VALUES ARE GIVEN IN OCTAL NOTATION

32760	277	367	320	250	177	140	377	037	001	000
32770	333	666	000	027	101	220	274	434	300	260
32780	215	210	174	147	100	004	007	331	014	037
32790	303	030	047	040	050	037	050	343	077	140
32800	175	734	361	170	156	117	050	337	047	040
32810	334	003	040	072	077	140	150	127	053	040
32820	037	040	077	133	113	040	077	117	040	057
32830	043	040	076	067	120	077	157	200	174	137
32840	160	143	077	107	077	047	040	373	057	041
32850	044	337	041	034	017	027	040	337	323	040
32860	070	343	040	034	047	060	054	337	340	070
32870	047	345	074	037	040	074	077	140	377	037
32880	377	370	004	124	220	274	127	300	156	047
32890	000	333	000	000	000	077	377	360	300	100
32900	176	377	107	000	077	357	240	017	000	240
32910	130	333	000	000	000	000	377	377	334	000
32920	177	263	320	040	000	340	357	133	336	036
32930	277	320	000	017	000	000	227	377	130	000
32940	101	240	317	061	000	077	377	120	357	043
32950	140	077	303	020	007	000	000	377	377	000
32960	000	277	302	220	000	000	330	314	000	377
32970	137	067	043	014	022	000	000	000	377	377
32980	000	000	311	257	120	000	000	363	174	300
32990	147	140	057	027	030	017	000	000	077	377
33000	240	000	367	140	224	067	000	076	377	240
33010	000	177	353	050	017	003	010	000	000	377
33020	377	000	300	277	237	150	000	000	311	274
33030	000	140	173	037	040	034	017	000	000	037
33040	377	300	300	107	320	230	043	000	137	377
33050	000	054	157	114	074	007	000	004	000	003
33060	377	377	000	056	316	227	140	000	027	373
33070	074	007	101	077	077	006	054	003	000	003
33080	277	377	300	017	221	240	314	000	030	336
33090	147	040	304	147	060	000	067	000	000	003
33100	277	377	000	317	210	237	213	000	077	303
33110	140	037	047	140	014	007	074	000	007	043
33120	000	377	245	300	237	047	220	117	013	303
33130	016	113	060	317	047	070	073	017	074	077
33140	017	140	177	137	141	130	137	120	120	077
33150	047	070	057	257	064	057	043	070	077	073
33160	074	077	107	130	134	117	100	077	077	060
33170	064	027	020	036	037	040	074	047	120	120
33180	077	120	076	137	061	130	077	047	120	077
33190	107	100	077	077	170	130	206	120	120	136
33200	102	120	077	077	120	077	077	071	077	077
33210	100	077	077	103	074	077	070	074	067	060
33220	070	007	061	070	237	060	070	057	060	070
33230	057	061	074	077	130	076	077	077	076	077
33240	073	074	077	067	070	077	067	074	077	067
33250	100	077	077	100	077	077	100	077	077	073
33260	074	077	101	076	077	101	120	077	077	100
33270	077	077	100	077	077	073	077	077	101	077
33280	077	101	077	077	075	076	077	077	074	077
33290	073	070	077	067	074	077	067	074	077	073
33300	074	077	077	074	077	077	073	077	077	075
33310	077	077	073	076	077	071	074	073	070	076
33320	077	041	074	057	341	076	067	061	074	067
33330	062	074	077	065	074	077	067	074	077	067
33340	074	077	067	074	077	067	074	073	073	100
33350	077	077	100	077	077	100	077	077	101	077
33360	077	101	076	077	101	076	077	077	110	077
33370	077	110	077	077	101	077	077	101	077	077
33380	101	077	077	077	076	077	073	076	077	077
33390	076	077	077	074	077	077	074	077	077	074
33400	077	073	074	077	077	074	077	077	071	077
33410	077	075	074	067	075	074	067	070	076	067
33420	060	074	067	061	075	057	063	074	067	062
33430	074	067	063	074	077	071	074	077	067	074
33440	077	067	074	077	067	073	077	067	074	077
33450	073	074	077	077	100	077	077	100	077	077
33460	101	076	077	101	076	077	101	120	077	077
33470	120	077	077	103	077	077	103	077	077	077
33480	110	077	077	110	077	077	076	077	077	076
33490	077	077	074	077	077	071	074	077	071	076
33500	077	071	076	077	071	075	077	071	076	077
33510	060	074	077	067	074	077	065	074	077	061
33520	074	077	063	074	077	063	070	077	063	074
33530	077	063	074	077	063	074	077	067	074	077
33540	067	074	077	067	070	077	067	070	077	073
33550	100	077	077	100	077	077	101	077	077	073
33560	120	077	077	110	077	077	113	077	077	120
33570	077	077	116	077	077	103	077	077	077	110
33580	077	077	100	077	077	100	077	077	100	077
33590	077	104	077	077	073	077	077	071	076	077
33600	073	076	077	071	077	077	061	140	217	143
33610	073	357	033	140	077	013	040	077	043	026
33620	074	357	040	077	077	101	057	027	020	360
33630	027	360	077	143	120	077	077	120	130	377
33640	107	370	074	067	120	137	147	140	077	377
33650	120	134	077	140	130	077	120	074	077	063
33660	077	377	027	060	077	123	074	074	021	030
33670	057	307	074	037	057	040	077	127	143	137
33680	137	200	156	077	060	040	037	020	035	017
33690	013	060	057	062	166	077	107	140	137	137
33700	140	144	147	140	134	077	063	074	047	042
33710	035	037	043	074	077	100	074	077	100	143
33720	137	137	140	134	077	030	074	047	070	077
33730	117	111	120	077	121	140	137	161	174	156
33740	117	074	376	047	040	037	017	020	003	033
33750	000	277	317	320	174	077	010	040	077	121
33760	076	017	073	070	077	051	070	027	000	033
33770	002	003	300	017	147	370	374	147	040	077
33780	077	300	140	117	000	040	017	121	140	167
33790	043	060	017	023	000	060	000	000	157	243
33800	360	260	107	310	134	157	300	130	077	000
33810	030	037	101	377	157	133	074	037	073	060
33820	007	000	000	300	027	220	277	237	103	077
33830	047	140	143	147	043	040	017	040	060	077
33840	073	150	137	127	060	077	042	030	007	001
33850	000	034	147	300	330	177	140	130	117	127
33860	077	077	055	050	037	041	060	074	101	130
33870	077	107	120	077	347	060	054	033	040	037
33880	057	100	150	147	147	160	137	123	120	077
33890	072	070	074	045	360	057	053	160	077	117
33900	150	120	077	061	370	037	040	054	037	071

I don't want you to finish this article and think that digitized speech is as limited as I have represented it so far. It is possible to totally simulate the capabilities of an analog speech synthesizer with more involved software. If you realize that the analog synthesizer works by connecting strings of distinctly independent phonemes, it is not hard to consider that the same can be true for the digital method. Each phoneme could be recorded separately and would occupy approximately 2 K bytes. As in the analog situation, a separate control program determines how these individual phonemes are to be connected together. Besides determining the type of phoneme to be used, the processor must also create the waveform. Such a system uses much more memory and takes considerably more processing time than something like the Votrax, but it is equally as versatile.

Listing 3, continued:

33910	134	137	153	140	137	127	140	077	077	070
33920	074	047	060	070	057	074	077	117	121	134
33930	077	073	074	047	041	050	047	040	050	077
33940	120	160	127	132	140	077	077	106	077	067
33950	040	040	043	046	074	067	100	077	117	121
33960	077	077	041	064	057	040	050	057	041	076
33970	077	140	150	154	127	120	077	077	070	070
33980	057	040	060	047	060	076	077	120	134	137
33990	111	077	077	047	070	057	041	040	057	067
34000	120	137	143	144	154	137	150	077	077	071
34010	074	057	051	064	057	060	076	077	123	140
34020	077	103	076	076	057	040	037	041	045	057
34030	047	130	137	147	142	140	137	130	077	077
34040	053	070	057	047	073	057	041	074	077	117
34050	140	077	077	074	075	057	060	054	037	060
34060	057	067	120	137	137	140	146	117	107	130
34070	077	043	070	057	041	060	057	057	074	077
34080	107	120	077	077	133	076	057	044	056	037
34090	040	057	077	120	134	137	141	130	077	123
34100	120	077	043	140	037	040	040	076	057	074
34110	077	147	140	134	077	063	060	037	043	024
34120	057	001	020	077	143	130	174	147	125	137
34130	077	140	077	067	040	054	033	060	077	067
34140	100	037	147	140	140	077	067	040	037	040
34150	040	027	005	020	037	160	174	237	167	166
34160	137	077	120	077	077	040	056	007	041	074
34170	057	070	076	117	140	120	077	073	074	057
34180	047	050	037	021	020	074	027	170	177	207
34190	200	136	137	100	130	077	067	073	037	041
34200	060	067	041	074	077	105	140	137	117	076
34210	074	057	060	057	033	040	017	007	040	170
34220	153	201	174	137	140	037	077	077	074	076
34230	041	000	057	053	074	077	101	120	136	142
34240	120	077	067	064	070	047	041	057	077	040
34250	034	047	140	160	177	200	140	137	101	074
34260	077	047	070	057	033	040	057	053	074	077
34270	105	140	140	127	100	076	067	042	070	047
34280	043	054	037	040	070	037	140	173	157	141
34290	140	077	117	110	077	077	064	073	057	044
34300	077	047	074	077	117	121	130	077	063	070
34310	057	041	070	047	043	070	047	051	074	077
34320	131	160	174	141	130	077	077	133	077	067
34330	060	070	047	050	076	067	144	077	117	121
34340	125	077	063	070	047	043	070	057	061	060
34350	007	061	120	137	147	140	137	137	130	077
34360	077	074	076	057	040	057	047	060	077	077
34370	121	130	077	073	074	076	060	073	057	053
34380	073	057	041	074	077	133	140	154	137	130
34390	077	077	100	077	077	070	074	057	060	077
34400	077	130	120	077	071	070	074	040	070	057
34410	047	070	057	051	074	077	063	140	137	133
34420	140	130	077	130	077	077	071	077	077	041
34430	076	067	060	074	037	066	070	047	040	070
34440	077	146	140	154	137	130	077	077	100	077
34450	067	065	057	043	060	076	047	100	077	077
34460	100	077	077	063	076	057	060	070	067	041
34470	074	077	100	077	077	143	120	077	117	136
34480	077	073	107	077	077	075	076	077	067	074
34490	077	062	074	077	047	076	077	063	150	137
34500	124	140	134	107	100	077	067	070	074	057
34510	060	074	057	050	076	037	040	077	047	070
34520	076	063	070	076	077	100	077	077	157	077
34530	077	077	100	077	077	070	077	067	070	074
34540	043	070	074	057	070	074	047	100	077	067
34550	070	072	077	103	076	077	133	077	077	100
34560	076	073	073	077	077	077	101	077	073	074
34570	077	073	100	077	077	110	077	077	106	077
34580	077	077	077	077	073	100	077	077	110	077
34590	077	100	077	077	074	077	077	100	077	077
34600	101	077	077	075	076	077	045	074	073	063
34610	074	077	067	075	077	071	075	077	067	074
34620	047	041	076	077	047	074	077	043	074	077
34630	063	074	077	067	070	077	057	070	077	043
34640	070	077	047	074	077	077	100	077	077	101
34650	077	077	130	076	077	047	074	077	071	074
34660	077	077	074	077	077	100	077	077	100	077
34670	077	103	120	077	101	120	077	103	120	077
34680	077	120	077	077	100	077	077	100	077	077
34690	106	077	077	075	077	077	077	076	077	075
34700	074	077	067	074	077	073	074	077	071	074
34710	077	067	074	077	062	074	076	053	070	077
34720	043	070	077	067	074	077	067	074	077	067
34730	074	077	067	070	077	067	070	076	067	070
34740	076	077	070	074	077	100	077	077	073	077
34750	077	073	074	077	072	074	077	077	130	077
34760	077	110	077	077	101	077	077	103	120	077
34770	102	114	077	077	110	077	077	110	077	077
34780	100	077	077	100	077	077	073	077	077	075
34790	074	077	075	074	077	071	074	077	071	074
34800	077	057	070	077	067	074	077	073	155	014