



## TECHNICAL DATA

AN EXCLUSIVE RADIO SHACK SERVICE TO THE EXPERIMENTER

### SP0256 NARRATOR™ SPEECH PROCESSOR

#### Features

- Natural Speech
- Stand Alone Operation with Inexpensive Support Components
- Wide Operating Voltage
- Word, Phrase, or Sentence Library, ROM Expandable
- Expandable to 491K of ROM Directly
- Simple Interface to Most Microcomputers or Microprocessors
- Supports L.P.C. Synthesis: Formant Synthesis: Allophone Synthesis

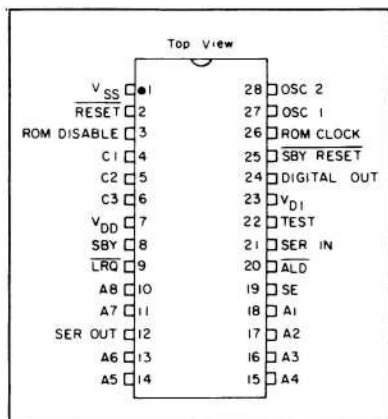
#### General Description

The SP0256 (Speech Processor) is a single chip N-Channel MOS LSI device that is able, using its stored program, to synthesize speech or complex sounds.

The achievable output is equivalent to a flat frequency response ranging from 0 to 5 kHz, a dynamic range of 42dB, and a signal to noise ratio of approximately 35dB.

The SP0256 incorporates four basic functions:

- A software programmable digital filter that can be made to model a VOCAL TRACT.
- A 16K ROM which stores both data and instructions (THE PROGRAM).
- A MICROCONTROLLER which controls the data flow from the ROM to the digital filter, the assembly of the "word strings" necessary for linking speech elements together, and the amplitude and pitch information to excite the digital filter.
- A PULSE WIDTH MODULATOR that creates a digital output which is con-



PIN CONFIGURATION

verted to an analog signal when filtered by an external low pass filter.

#### Allophone Based Speech Processor — SP0256-AL2

One example of a preprogrammed SP0256 is the AL2 pattern.

#### Allophone Usage with a Microprocessor

The SP0256-AL2 requires the use of a processor to concatenate the speech sounds to form words.

The SP0256 is controlled using the address pins (A1-A8), ALD (Address Load), and SE (Strobe Enable). The object for controlling the chip is to load an address into it which contains the desired allophone. The speech data for the allophone set is contained within the internal 16K ROM of the SP0256-AL2.

This particular application (Allophone Set) requires only six address pins (A1-A6) to address all the 59 allophones plus five pauses, a total of 64 locations. For simplicity, since only six address pins are needed to address the 64 locations, pins A7 and A8 can be tied low (to ground) and now any further references to the address bus will include A1-A6 and A7=A8=0.

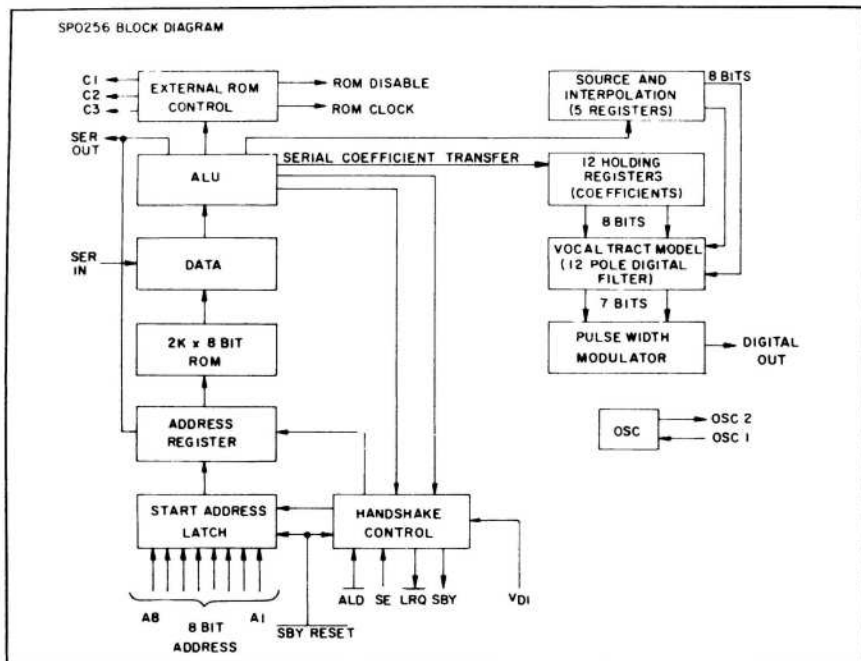
There are two modes available for loading an address into the chip. SE (Strobe Enable) controls the mode that will be used.

Mode 0 (SE=0) will latch in an address when any one or more of the address pins makes a low to high transition. For example, to load the address one (1), A2 to A6=0 and A1 is pulsed high. To load the address twelve (12 octal), A1=A3=A5=A6=0, A2 and A4 are pulsed high simultaneously. (Note that an address of zero cannot be loaded using this mode).

Mode 1 (SE=1) will latch in an address using the ALD pin. First, setup the desired address on the address bus (A1-A6)

and then pulse ALD low. Any address can be loaded using this mode, but certain setup and hold times are required (refer to the attached timing diagram for the specific times).

Two microprocessor interface pins are available for quick loading of addresses. They are LRQ and SBY. LRQ (Load Request) tells the processor when the input buffer is full. SBY (Stand By) tells the processor that the chip has stopped talking and no new address has been loaded. Either interface pin can be used when concatenating allophones. LRQ is an active low signal, when LRQ goes low it is time to load a new address to the chip. If LRQ is high, then simply wait for it to go low before loading the address. SBY will stay high until an address is loaded, then it will go low and stay low until all the internal instructions (Speech Code) from that one address are completed. Once this signal goes high, it is time to load a new address. Since speech does not require very fast address loading, it would be acceptable to use SBY to interface to the processor.



To end a word using allophones it is necessary to load a pause to complete the word. For example, the word "TWO"

can be implemented using the following allophones, TT2-VW2-PA1. PA1 is actually not an allophone but a pause which is needed to end the word.

## ELECTRICAL CHARACTERISTICS

### Maximum Ratings\*

All pins with respect to  $V_{SS}$   
Storage Temperature

- 0.3 to 8.0V  
- 25°C to 125°C

### Standard Conditions

Clock - Crystal Frequency

3.120 MHz

Operating Temperature ( $T_A$ )

0°C to 70°C

## DC CHARACTERISTICS/SPO 256

\*Exceeding these ratings could cause permanent damage to the device. This is a stress rating only and functional operation of this device at these conditions is not implied. Operating ranges are specified in Standard Conditions. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Data labeled "typical" is presented for design guidance only and is not guaranteed

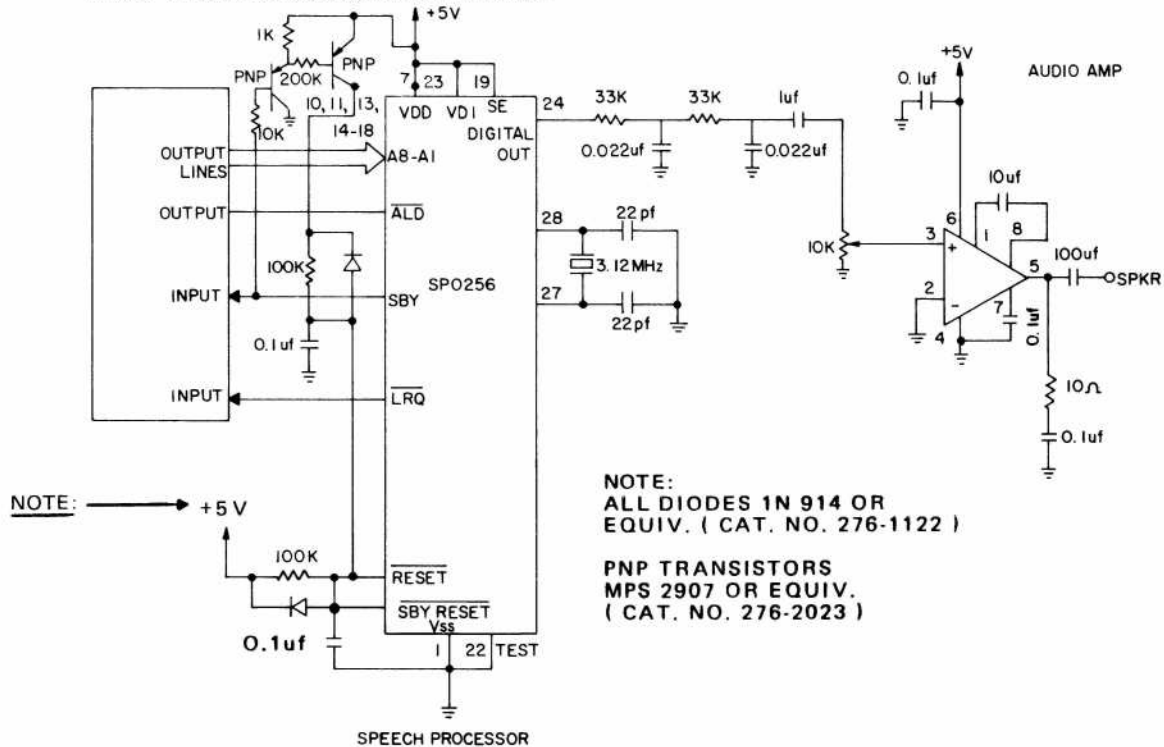
Characteristic	Sym	Min	Typ	Max	Units	Conditions
Supply Voltage	V <sub>DD</sub>	4.6	—	7.0	V	
	V <sub>D1</sub>	4.6	—	7.0	V	
Supply Current	I <sub>DD</sub>	—	—	90	mA	T <sub>A</sub> = 25°C. V <sub>D1</sub> , V <sub>DD</sub> = 7.0V· Reset & SBY Reset high. All outputs floating.
	I <sub>D1</sub>	—	—	21	mA	Same as above.
INPUTS						
A1-A8, <u>ALD</u> , SERIN, TEST, SE						0 Volts bias, f = 3.12 MHz V <sub>PIN</sub> = 7.0V Other Pins = 0.0V
LOGIC 0	V <sub>IL</sub>	0.0	—	0.6	V	
LOGIC 1	V <sub>IH</sub>	2.4	—	V <sub>D1</sub>	V	
CAPACITANCE	C <sub>IN</sub>	—	—	10	pf	
LEAKAGE	I <sub>L</sub>	—	—	+10	μa	
<u>RESET</u> , <u>SBY RESET</u>						
LOGIC 0	V <sub>IL</sub>	0.0	—	0.6	V	
LOGIC 1	V <sub>IH</sub>	3.6	—	V <sub>D1</sub>	V	
OUTPUTS						
SBY, Digital Out, C1, C2, C3, <u>LRQ</u> , ROM DIS, ROM CLK, SEROUT						
LOGIC 0	V <sub>OL</sub>	0.0	—	0.6	V	I <sub>OL</sub> = 0.72ma (2LS TTL Loads)
LOGIC 1	V <sub>OH</sub>	2.5	—	V <sub>D1</sub>	V	I <sub>OH</sub> = -50 μa (2LS TTL Loads)
OSCILLATOR						
OSC 2 (Output)						When driven from external source.
LOGIC 0	V <sub>OL</sub>	0.0	—	0.6	V	OSC 1 (Input) = 3.90 V MIN
LOGIC 1	V <sub>OH</sub>	2.5	—	V <sub>D1</sub>	V	OSC 1 (Input) = 0.60 V MAX

AC CHARACTERISTICS	SYM	MIN	TYP	MAX	UNITS	CONDITIONS
$\overline{\text{ALD}}$	$\uparrow\text{pw1}$	200	—	1100	ns	$200 \leq \overline{\text{ALD}} \leq 1100$ ns
A1-A8 Set Up	$\uparrow\text{ts1}$	0	—	—	ns	
Hold	$\uparrow\text{th1}$	160	—	—	ns	
$\overline{\text{LRQ}}$	$\uparrow\text{pd1}$	—	—	300	ns	
$\overline{\text{SBY}}$	$\uparrow\text{pd2}$	—	—	300	ns	

AC CHARACTERISTICS	SYM	MIN	TYP	MAX	UNITS	CONDITIONS
$\overline{\text{ALD}}$	$\uparrow\text{pw2}$	1100	—	—	ns	$\overline{\text{ALD}} > 1100$ ns
A1-A8 Set Up	$\uparrow\text{ts2}$	0	—	—	ns	
Hold	$\uparrow\text{th2}$	1120	—	—	ns	
$\overline{\text{LRQ}}$	$\uparrow\text{pd1}$	—	—	300	ns	
$\overline{\text{SBY}}$	$\uparrow\text{pd2}$	—	—	300	ns	

AC CHARACTERISTICS	SYM	MIN	TYP	MAX	UNITS	CONDITIONS
Clock Frequency	F	—	3.120	—	MHz	Crystal Oscillator driven from external.
Clock Duty Cycle	—	48	—	52	%	
Reset	$\uparrow\text{pw3}$	100	—	—	us	
$\overline{\text{SBY}}$ Reset	$\uparrow\text{pw4}$	100	—	—	us	

# TYPICAL APPLICATION MICROCOMPUTER INTERFACE



## PIN FUNCTIONS

PIN NUMBER	NAME	FUNCTION
1	V <sub>SS</sub>	Ground
2	RESET	A logic 0 resets that portion of the SP powered by V <sub>DD</sub> . Must be returned to a logic 1 for normal operation.
3	ROM DISABLE	For use with an external serial speech ROM, a logic 1 disables the external ROM.
4, 5, 6	C1, C2, C3	Output control lines for use with an external serial speech ROM. Refer to the SPR016 Data Sheet for details.
7	V <sub>DD</sub>	Power supply for all portions of the SP except the microprocessor interface logic.
8	SBY	STANDBY. A logic 1 output indicates that the SP is inactive and V <sub>DD</sub> can be powered down externally to conserve power. When the SP is reactivated by an address being loaded, SBY will go to a logic 0.
9	LRQ	LOAD REQUEST. LRQ is a logic 1 output whenever the input buffer is full. When LRQ goes to a logic 0, the input port may be loaded by placing the 8 address bits on A1-A8 and pulsing the ALD output.
10, 11, 13, 14, 15, 16, 17, 18	A8, A7, A6, A5, A4, A3, A2, A1	8 bit address which defines any one of 256 speech entry points.
12	SER OUT	SERIAL ADDRESS OUT. This output transfers a 16-bit address serially to an external speech ROM.
19	SE	STROBE ENABLE. Normally held in a logic 1 state. When tied to ground, ALD is disabled and the SP will automatically latch in the address on the input bus approximately 1 $\mu$ s after detecting a logic 1 on any address line.
20	ALD	ADDRESS LOAD. A negative pulse on this input loads the 8 address bits into the input port. The negative edge of this pulse causes LRQ to go high.
21	SER IN	SERIAL IN. This is an 8-bit serial data input from an external speech ROM.

## Pin Functions Continued

PIN NUMBER	NAME	FUNCTION
22	TEST	This pin should be grounded for normal operation.
23	VD1	Power supply for the microprocessor interface logic and controller.
24	DIGITAL OUT	Pulse width modulated digital speech output which, when filtered by a 5KHz low pass filter and amplified, will drive a loudspeaker.
25	SBY RESET	STANDBY RESET. A logic 0 resets the microprocessor interface logic and the address latches. Must be returned to a logic 1 for normal operation.
26	ROM CLOCK	This is a 1.56MHz clock output used to drive an external serial speech ROM.
27	OSC1	XTAL IN. Input connection for a 3.12MHz crystal.
28	OSC2	XTAL OUT. Output connection for a 3.12MHz crystal.

## ALLOPHONE SPEECH SYNTHESIS

### Introduction

The allophone speech synthesis technique provides the user with the ability to synthesize an unlimited vocabulary at a very low bit rate. Fifty-nine discrete speech sounds (called allophones) are five pauses are stored at different addresses in the SP0256 internal ROM. Each speech sound was excised from a word and analyzed using linear predictive coding (LPC). Any English word or phrase can be created by addressing the appropriate combination of allophones and pauses. Since there is a total of 64 address locations each requires a 6 bit address. Assuming that speech contains 10 to 12 sounds per second, allophone synthesis requires addressing less than 100 bits per second.

### Linguistics

A few basic linguistic concepts will help you start your own library of "allophone words". (See Table 1 for the General Instrument Allophone Dictionary). First, there is no one-to-one correspondence between written letters and speech sounds; secondly, speech sounds are acoustically different depending upon their position within a word; and lastly, the human ear may perceive the same acoustic signal differently in the context of different sounds.

The first point compares to the problem that a child encounters when learning to read. Each sound in a language may be represented by more than one letter and, conversely each letter may represent more than one sound. (See the examples in Table 2.) Because of these spelling irregularities, it is necessary to think in terms of **sounds**, not letters, when using allophones.

The second, and equally important, point to understand, is that the acoustic signal of a speech sound may differ depending upon its position within a word. For example, the initial **K** sound in **coop** will be acoustically different from the **K**'s in **keep** and **speak**. The **K**'s in **coop** and **keep** differ due to the influence of the vowels which follow them, and the final **K** in **speak** is usually not as loud as initial **K**'s.

Finally, a listener may identify the same acoustic signal differently depending on the context in which it is perceived. Don't be surprised, therefore, if an allophone word sounds slightly different when used in various phrases.

## Phonemes Of English

The sounds of a language are called phonemes, and each language has a set which is slightly different from that of other languages. Table 3 contains a chart of all the consonant phonemes of English, Table 4 all the vowel phonemes.

Consonants are produced by creating an occlusion or constriction in the vocal tract which produces an aperiodic sound source. If the vocal cords are vibrating at the same time, as in the case of the voiced fricatives **VV**, **DH**, **ZZ**, and **ZH**, (See Table 5) there are two sound sources: one which is aperiodic and one which is periodic.

Vowels are usually produced with a relatively open vocal tract and a periodic sound source provided by the vibrating vocal cords. They are classified according to whether the front or back of the tongue is high or low (See Table 4 whether they are long or short, and whether the lips are rounded or unrounded). In English all rounded vowels are produced in or near the back of the mouth (**UW**, **UH**, **OW**, **AO**, **OR**, **AW**).

Speech sounds which have features in common behave in similar ways. For example, the voiceless stop consonants **PP**, **TT**, and **KK** (See Table 3) should be preceded by 50-80 msec of silence, and the voiced stop consonants **BB**, **DD**, and **GG** by 10-30 msec of silence.

## Allophones

Phoneme is the name given to a group of similar sounds in a language. Recall that a phoneme is acoustically different depending upon its position within a word. Each of these positional variants is an allophone of the same phoneme. An allophone, therefore, is the manifestation of a phoneme in true speech signal. It is for this reason that our inventory of English speech sounds is called an allophone set.

## How To Use The Allophone Set

(See Table 1 for instructions on how to create all the sample words mentioned in this section.) The allophone set (Refer to Table 5) contains two or three versions of some phonemes. It may be necessary to use one allophone of a particular phoneme for word-or-syllable-final position. A detailed set of guidelines for using the allophones is given in Table 5. Note that these are suggestions, not rules.

For example, **DD2** sounds good in initial position and **DD1** sounds good in final position, as in "daughter" and "collide". One of the differences between the initial and final versions of a consonant is that an initial version may be longer than the final version. Therefore, to create an initial **SS**, you can use two **SSs** instead of the usual single **SS** at the end of a word or syllable, as in "sister". Note that this can be done with **TH**, and **FF**, and the inherently short vowels (to be discussed below), but with no other consonants. You will want to experiment with some consonants such as **str**, **cl** to discover which version works best in the cluster. For example, **KK1** sounds good before **LL** as in "clown", and **KK2** sounds good before **WW** as in "square". One allophone of a particular phoneme may sound better before or after back vowels and another before or after front vowels. **KK3** sounds good before **UH** and **KK1** sounds good before **IY**, as in "cookie". Some sounds (**PP**, **BB**, **TT**, **DD**, **KK**, **GG**, **CH**, and **JH**) require a brief duration of silence before them. For most of these, the silence has already been added but you may decide you want to add more. Therefore there are several pauses included in the



allophone set varying from 10-200 msec. To create the final sounds in the words "letter" and "little" use the allophones ER and EL.

Remember that you must always think about how a word **sounds**, not how it is spelled. For example, the NG sound is represented by the letter N in "uncle". And remember that some sounds may not even be represented in words by any letters, as the YY in "computer".

As mentioned earlier there are some vowels which can be doubled to make longer versions for stressed syllables. These are the inherently short vowels IH, EH, AE, AX, AA, and UH. For example, in the word "extent" use one EH in the first syllable, which is unstressed and two EHs in the second syllable which is stressed. Of the inherently long vowels there is one, UW, which has a long and

short version. The short one, UW1, sounds good after YY in computer. The long version, UW2, sounds good in monosyllabic words like "two". Included in the vowel set is a group called R-colored vowels. These are vowel + R combinations. For example, the AR in "alarm" and the OR in "score". Of the R-colored vowels there is one, ER, which has a long and short version. The short version is good for polysyllabic words with final ER sounds like "letter", and the long version is good for monosyllabic words like "fir". One final suggestion is that you may want to add a pause of 30-50 msec between words, when creating sentences, and a pause of 100-200 msec between clauses.

Note: Every utterance must be followed by a pause in order to make the chip stop talking the last allophone.

**Table 1:**

**NUMBERS:**

zero	ZZ YR OW
one, won	WW SX AX NN1
two, to, too	TT2 UW2
three	TH RR1 IY
four, for, fore	FF FF OR
five	FF FF AY VV
six	SS SS IH IH PA3 KK2 SS
seven	SS SS EH EH VV IH NN1
eight, ate	EY PA3 TT2
nine	NN1 AA AY NN1
ten	TT2 EH EH NN1
eleven	IH LL EH EH VV IH NN1
twelve	TT2 WH EH EH LL VV
thirteen	TH ER1 PA2 PA3 TT2 IY NN1
fourteen	FF OR PA2 PA3 TT2 IY NN1
fifteen	FF IH FF PA2 PA3 TT2 IY NN1
sixteen	SS SS IH PA3 KK2 SS PA2 PA3 TT2 IY NN1

seventeen	SS SS EH VV TH NN1 PA2 PA3 TT2 IY NN1
eighteen	EY PA2 PA3 TT2 IY NN1
nineteen	NN1 AY NN1 PA2 PA3 TT2 IY NN1
twenty	TT2 WH EH EH NN1 PA2 PA3 TT2 IY
thirty	TH ER2 PA2 PA3 TT2 IY
forty	FF OR PA3 TT2 IY
fifty	FF FF IH FF FF PA2 PA3 TT2 IY
sixty	SS SS IH PA3 KK2 SS PA2 PA3 TT2 IY
seventy	SS SS EH VV IH NN1 PA2 PA3 TT2 IY
eighty	EY PA3 TT2 IY
ninety	NN1 AY NN1 PA3 TT2 IY
hundred	HH2 AX AX NN1 PA2 DD2 RR2 IH IH PA1 DD1
thousand	TH AA AW ZZ TH PA1 PA1 NN1 DD1
million	MM IH IH LL YY1 AX NN1

**Table 1 Continued**

**DAY OF THE WEEK:**

Sunday	SS SS AX AX NN1 PA2 DD2 EY
Monday	MM AX AX NN1 PA2 DD2 EY
Tuesday	TT2 UW2 ZZ PA2 DD2 EY
Wednesday	WW EH EH NN1 ZZ PA2 DD2 EY
Thursday	TH ER2 ZZ PA2 DD2 EY
Friday	FF RR2 AY PA2 DD2 EY
Saturday	SS SS AE PA3 TT2 PA2 DD2 EY

**MONTHS:**

January	JH AE AE NN1 YY2 XR 1Y
February	FF EH EH PA1 BR RR2 UW2 XR 1Y
March	MM AR PA3 CH
April	EY PA3 PP RR2 IH IH LL
May	MM EY
June	JH UW2 NN1
July	JH UW1 LL AY
August	AO AO PA2 GG2 AX SS PA3 TT1
September	SS SS EH PA3 PP PA3 TT2 EH EH PA1 BB2 ER1
October	AA PA2 KK2 PA3 TT2 OW PA1 BB2 ER1
November	NN2 OW VV EH EH MM PA1 BB2 ER1
December	DD2 IY SS SS EH EH MM PA1 BB2 ER1

**LETTERS:**

A	EY
B	BB2 IY
C	SS SS IY
D	DD2 IY
E	IY
F	EH EH FF FF
G	JH IY
H	EY PA2 PA3 CH
I	AA AY
J	JH EH EY

K	KK1 EH EY
L	EH EH EL
M	EH EH MM
N	EH EH NN1
O	OW
P	PP IY
Q	KK1 YY1 UW2
R	AR
S	EH EH SS SS
T	TT2 IY
U	YY1 UW2
V	VV IY
W	DD2 AX PA2 BB2 EL YY1 UW2
X	EH EH PA3 KK2 SS SS
Y	WW AY
Z	ZZ IY

**DICTIONARY:**

alarm	AX LL AR MM
bathe	BB2 EY DH2
bather	BB2 EY DH2 ER1
bathing	BB2 EY DH2 IH NG
beer	BB2 YR
bread	BB1 RR2 EH EH PA1 DD1
by	BB2 AA AY
calendar	KK1 AE AE LL EH NN1 PA2 DD2 ER1
clock	KK1 LL AA AA PA3 KK2
clown	KK1 LL AW NN1
check	CH EH EH PA3 KK2
checked	CH EH EH PA3 KK2 PA2 TT2
checker	CH EH EH PA3 KK1 ER1
checkers	CH EH EH PA3 KK1 ER1 ZZ
checking	CH EH EH PA3 KK1 IH NG
checks	CH EH EH PA3 KK1 SS
cognitive	KK3 AA AA GG3 NN1 IH PA3 TT2 IH VV
collide	KK3 AX LL AY DD1
computer	KK1 AX MM PP1 YY1 UW1 TT2 ER
cookie	KK3 UH KK1 IY

coop	KK3 UW2 PA3 PP	fir	FF ER2
correct	KK1 ER2 EH EH	fraise	FF FF RR1 IY ZZ
	PA2 KK2 PA2 TT1	freezer	FF FF RR1 IY ZZ
corrected	KK1 ER2 EH EH		ER1
	PA2 KK2 PA2 TT2	freezers	FF FF RR1 IY ZZ
	IH PA2 DD1		ER1 ZZ
correcting	KK1 ER2 EH EH	freezing	FF FF RR1 IY ZZ
	PA2 KK2 PA2 TT2		IH NG
	IH NG	frozen	FF FF RR1 OW ZZ
corrects	KK1 ER2 EH EH		EH NN1
	PA2 KK2 PA2 TT1		
	SS	gauge	GG1 EY PA2 JH
crown	KK1 RR2 AW NN1	guaged	GG1 EY PA2 JH
date	DD2 EY PA3 TT2		PA2 DD1
daughter	DD2 AO TT2 ER1	guages	GG1 EY PA2 JH
day	DD2 EH EY		IH ZZ
divided	DD2 IH VV AY	guaging	GG1 EY PA2 JH
	PA2 DD2 IH PA2		IH NG
	DD1	hello	HH EH LL AX OW
emotional	IY MM OW SH AX	hour	AW ER1
	NN1 AX EL		
engage	EH EH PA1 NN1	infinitive	IH NN1 FF FF IH
	GG1 EY PA2 JH		IH NN1 IH PA2 PA3
engagement	EH EH PA1 NN1		TT2 IH VV
	GG1 EY PA2 JH MM	intrigue	IH NN1 PA3 TT2
	EH EH NN1 PA2		RR2 IY PA1 GG3
	PA3 TT2	intrigued	IH NN1 PA3 TT2
engages	EH EH PA1 NN1		RR2 IY PA1 GG3
	GG1 EY PA2 JH IH		PA2 DD1
	ZZ	intrigues	IH NN1 PA3 TT2
engaging	EH EH PA1 NN1		RR2 IY PA1 GG3
	GG1 EY PA2 JH IH		ZZ
	NG	intriguing	IH NN1 PA3 TT2
enrage	EH NN1 RR1 EY		RR2 IY PA1 GG3
	PA2 JH		IH NG
enraged	EH NN1 RR1 EY	investigate	IH IH NN1 VV EH
	PA2 JH PA2 DD1		EH SS PA2 PA3
enrages	EH NN1 RR1 EY		TT2 IH PA1 GG1
	PA2 JH IH ZZ		EY PA2 TT2
enraging	EH NN1 RR1 EY	investigated	IH IH NN1 VV EH
	PA2 JH IH NG		EH SS PA2 PA3
escape	EH SS SS PA3		TT2 IH PA1 GG1
	KK1 PA2 PA3 PP		EY PA2 TT2 IH PA2
escaped	EH SS SS PA3		DD1
	KK1 PA2 PA3 PP	investigator	IH IH NN1 VV EH
	PA2 TT2		EH SS PA2 PA3
escapes	EH SS SS PA3 KK1		TT2 IH PA1 GG1
	PA2 PA3 PP SS		EY PA2 TT2 ER1
escaping	EH SS SS PA3 KK1	investigators	IH IH NN1 VV EH
	PA2 PA3 PP IH NG		EH SS PA2 PA3
equal	IY PA2 PA3 KK3		TT2 IH PA1 GG1
	WH AX EL		EY PA2 TT2 ER1
equals	IY PA2 PA3 KK3		ZZ
	WH AX EL ZZ	investigates	IH IH NN1 VV EH
error	EH XR OR		EH SS PA2 PA3
extent	EH KK1 SS TT2 EH		TT2 IH PA1 GG1
	EH NN1 TT2		EY PA2 TT1 SS

**Table 1 Continued**

investigating	IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 EY PA2 TT2 IH NG KK1 IY	pledging	PP LL EH EH PA3 JH IH NG
key		plus	PP LL AX AX SS SS
legislate	LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2	ray	RR1 EH EY
legislated	LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2 IH DD1	rays	RR1 EH EY ZZ
legislates	LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT1 SS	ready	RR1 EH EH PA1 DD2 IY
legislating	LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2 IH NG	red	RR1 EH FH PA1 DD1
legislature	LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 CH ER1	robot	RR1 OW PA2 BB2 AA PA3 TT2
letter	LL EH EH PA3 TT2 ER1	robots	RR1 OW PA2 BB2 AA PA3 TT1 SS
litter	LL IH IH PA3 TT2 ER1	score	SS SS PA3 KK3 OR
little	LL IH IH PA3 TT2 EL	second	SS SS EH PA3 KK1 IH NN1 PA2 DD1
memory	MM EH EH MM ER2 IY	sensitive	SS SS EH EH NN1 SS SS IH PA2 PA3 TT2 IH VV
memories	MM EH EH MM ER2 IY ZZ	sensitivity	SS SS EH EH NN1 SS SS IH PA2 PA3 TT2 IH VV IH PA2 PA3 TT2 IY
minute	MM IH NN1 IH PA3 TT2	sincere	SS SS IH IH NN1 SS SS YR
month	MM AX NN1 TH	sincerely	SS SS IH IH NN1 SS SS YR LL IY
nip	NN1 IH IH PA2 PA3 PP	sincerity	SS SS IH IH NN1 SS SS EH EH RR1 IH PA2 PA3 TT2 IY
nipped	NN1 IH IH PA2 PA3 PP PA3 TT2	sister	SS SS IH IH SS PA3 TT2 ER1
nipping	NN1 IH IH PA2 PA3 PP IH NG	speak	SS SS PA3 IY PA3 KK2
nips	NN1 IH IH PA2 PA3 PP SS	spell	SS SS PA3 PP EH EH EL
no	NN2 AX OW	spelled	SS SS PA3 PP EH EH EL PA3 DD1
physical	FF FF IH ZZ IH PA3 KK1 AX EL	speller	SS SS PA3 PP EH EH EL ER2
pin	PP IH IH NN1	spellers	SS SS PA3 PP EH EH EL ER2 ZZ
pinned	PP IH IH NN1 PA2 DD1	spelling	SS SS PA3 PP EH EH EL IH NG
pinning	PP IH IH NN1 IH NG1	spells	SS SS PA3 PP EH EH EL ZZ
pins	PP IH IH NN1 ZZ	start	SS SS PA3 TT2 AR PA3 TT2
pledge	PP LL EH FH PA3 JH	started	SS SS PA3 TT2 AR PA3 TT2 IH PA1 DD2
pledged	PP LL EH EH PA3 JH PA2 DD1	starter	SS SS PA3 TT2 AR PA3 TT2 ER1
pledges	PP LL EH EH PA3 JH IH ZZ		

starting	SS SS PP3 TT2 AR PA3 TT2 IH NG	thread	TH RR1 EH EH PA2 DD1
starts	SS SS PP3 TT2 AR PA3 TT1 SS	threaded	TH RR1 EH EH PA2 DD2 IH PA2 DD1
stop	SS SS PA3 TT1 AA AA PA3 PP	threader	TH RR1 EH EH PA2 DD2 ER1
stopped	SS SS PA3 TT1 AA AA PA3 PP PA3 TT2	threaders	TH RR1 EH EH PA2 DD2 ER1 ZZ
stopper	SS SS PA3 TT1 AA AA PA3 PP ER1	threading	TH RR1 EH EH PA2 DD2 IH NG
stopping	SS SS PA3 TT1 AA AA PA3 PP IH NG	threads	TH RR1 EH EH PA2 DD2 ZZ
stops	SS SS PA3 TT1 AA AA PA3 PP SS	then	DH1 EH EH NN1
subject (noun)	SS SS AX AX PA2 BB1 PA2 JH EH PA3 KK2 PA3 TT2	time	TT2 AA AY MM
subject (verb)	SS SS AX PA2 BB1 PA2 JH EH EH PA3 KK2 PA3 TT2	times	TT2 AA AY MM ZZ
sweat	SS SS WW EH EH PA3 TT2	uncle	AX NG PA3 KK3 EL
sweated	SS SS WW EH EH PA3 TT2 IH PA3 DD1	whale	WW EY EL
sweater	SS SS WW EH EH PA3 TT2 ER1	whaler	WW EY LL ER1
sweaters	SS SS WW EH EH PA3 TT2 ER1 ZZ	whalers	WW EY LL ER1 ZZ
sweating	SS SS WW EH EH PA3 TT2 IH NG	whales	WW EY EL ZZ
sweats	SS SS WW EH EH PA3 TT2 SS	whaling	WW EY LL TH NG
switch	SS SS WH IH IH PA3 CH	year	YY2 YR
switched	SS SS WH IH IH PA3 CH PA3 TT2	yes	YY2 EH EH SS SS
switches	SS SS WH IH IH PA3 CH IH ZZ2		
switching	SS SS WH IH IH PA3 CH IH NG2		
system	SS SS IH IH SS SS PA3 TT2 EH MM		
systems	SS SS IH IH SS SS PA3 TT2 EH MM ZZ		
talk	TT2 AO AO PA2 KK2		
talked	TT2 AO AO PA3 KK2 PA3 TT2		
talker	TT2 AO AO PA3 KK1 ER1		
talkers	TT2 AO AO PA3 KK1 ER1 ZZ		
talking	TT2 AO AO PA3 KK1 IH NG		
talks	TT2 AO AO PA2 KK2 SS		

**TABLE 2 – EXAMPLES OF SPELLING IRREGULARITIES**

	Same sound represented by different letters	Different sounds represented by the same letters
<b>Vowels</b>	mEAAt	vElIn
	fEEt	forElgn
	pEte	dElsm
	pEOple	dElcer
	pennY	gElsha
<b>Consonants</b>	SHip	althouGH
	tenSlon	GHastly
	preClous	couGH
	naTlon	hiccouGH

**TABLE 3 — CONSONANT PHONEMES OF ENGLISH\*\***

		LABIAL	LABIO-DENTAL	INTER-DENTAL	ALVEOLAR	PALATAL	VELAR	GLOTTAL
Stops:	Voiceless	PP			TT		KK	
	Voiced	BB			DD		GG	
Fricatives:	Voiceless	WH	FF	TH	SS	SH		HH
	Voiced		VV	DH	ZZ	ZH*		
Affricates:	Voiceless					CH		
	Voiced					JH		
Nasals	Voiced	MM			NN		NG*	
Resonants	Voiced	WW			RR,LL	YY		

\*These do not occur in word-initial position in English.

**Labial:** Upper and Lower Lips  
Touch or Approximate  
**Labio-Dental:** Upper Teeth and Lower Lip Touch  
**Inter-Dental:** Tongue Between Teeth  
**Alveolar:** Tip of Tongue Touches or Approximates Alveolar Ridge (just behind upper teeth)

**Palatal:** Body of Tongue Approximates Palate (roof of mouth)  
**Velar:** Body of Tongue Touches Velum (posterior portion of roof of mouth)  
**Glottal:** Glottis (opening between vocal cords)

**TABLE 4 — VOWEL PHONEMES OF ENGLISH**

	<b>FRONT</b>	<b>CENTRAL</b>	<b>BACK</b>
High	YR IY IH*		UW# UH* #
Mid	EY EH* XR	ER AX*	OW# OY#
Low	AE*	AW# AY AR AA*	AO* # OR#

\* Short Vowels

# Rounded Vowels

# TABLE 5 – GUIDELINES FOR USING THE ALLOPHONES

## Silence

- PA1 ( 10 ms) – before BB, DD, GG, and JH
- PA2 ( 30 ms) – before BB, DD, GG, and JH
- PA3 ( 50 ms) – before PP, TT, KK, and CH, and between words
- PA4 (100 ms) – between clauses and sentences
- PA5 (200 ms) – between clauses and sentences

## Short Vowels

- \*/IH/ – sitting, stranded
- \*/EH/ – extent, gentlemen
- \*/AE/ – extract, acting
- \*/UH/ – cookie, full
- \*/AO/ – talking, song
- \*/AX/ – lapel, instruct
- \*/AA/ – pottery, cotton

## Long Vowels

- /IY/ – treat, people, penny
- /EY/ – great, statement, tray
- /AY/ – kite, sky, mighty
- /OY/ – noise, toy, voice
- /UW1/ – after clusters with YY: computer
- /UW2/ – in monosyllabic words: two, food
- /OW/ – zone, close, snow
- /AW/ – sound, mouse, down
- /EL/ – little, angle, gentlemen

## R-Colored Vowels

- /ER1/ – letter, furniture, interrupt
- /ER2/ – monosyllables: bird, fern, burn
- /OR/ – fortune, adorn, store
- /AR/ – farm, alarm, garment
- /YR/ – hear, earring, irresponsible
- /XR/ – hair, declare, stare

## Resonants

- /WW/ – we, warrant, linguist
- /RR1/ – initial position: read, write, x-ray
- /RR2/ – initial clusters: brown, crane, grease
- /LL/ – like, hello, steel
- /YY1/ – clusters: cute, beauty, computer
- /YY2/ – initial position: yes, yarn, yo-yo

## Voiced Fricatives

- /VV/ – vest, prove, even
- /DH1/ – word-initial position: this, then, they
- /DH2/ – word-final and between vowels: bathe, bathing
- /ZZ/ – zoo, phase
- /ZH/ – beige, pleasure

## Voiceless Fricatives

- \*/FF/ –) These may be doubled for initial position and used singly in final position
- \*/TH/ –)
- \*/SS/ –)
- /SH/ – shirt, leash, nation
- /HH1/ – before front vowels: YR, IY, IH, EY, EH, XR, AE
- /HH2/ – before back vowels: UW, UH, OW, OY, AO, OR, AR
- /WH/ – white, whim, twenty

## Voiced Stops

- /BB1/ – final position: rib; between vowels: fiber, in clusters: bleed, brown
- /BB2/ – initial position before a vowel: beast
- /DD1/ – final position: played, end
- /DD2/ – initial position: down; clusters: drain
- /GG1/ – before high front vowels: YR, IY, IH, EY, EH, XR
- /GG2/ – before high back vowels: UW, UH, OW, OY, AX; and clusters: green, glue
- /GG3/ – before low vowels: AE, AW, AY, AR, AA, AO, OR, ER; and medial clusters: anger; and final position: peg



### **Voiceless Stops**

- /PP/** – pleasure, ample, trip  
**/TT1/** – final clusters before SS: tests  
its  
**/TT2/** – all other positions: test, street  
**/KK1/** – before front vowels: YR, IY,  
IH, EY, EH, XR, AY, AE,  
ER, AX; initial clusters: cute,  
clown, scream  
**/KK2/** – final position: speak; final  
clusters: task  
**/KK3/** – before back vowels: UW, UH,  
OW, OY, OR, AR, AO; initial  
clusters: crane, quick, clown,  
scream

### **Affricates**

- /CH/** – church, feature  
**/JH/** – judge, injure

### **Nasal**

- /MM/** – milk, alarm, ample  
**/NN1/** – before front and central vowels: YR, IY, IH, EY, EH,  
XR, AE, ER, AX, AW, AY,  
UW; final clusters: earn  
**/NN2/** – before back vowels: UH, OW,  
OY, OR, AR, AA  
**/NG/** – string, anger

\* These allophones can be doubled.

# TABLE 6 – ALLOPHONE ADDRESS TABLE

OCTAL ADDRESS	ALLOPHONE	SAMPLE WORD	DURATION	OCTAL ADDRESS	ALLOPHONE	SAMPLE WORD	DURATION
000	PA1	PAUSE	10MS	040	/AW/	Out	370MS
001	PA2	PAUSE	30MS	041	/DD2/	Do	160MS
002	PA3	PAUSE	50MS	042	/GG3/	Wig	140MS
003	PA4	PAUSE	100MS	043	/VV/	Vest	190MS
004	PA5	PAUSE	200MS	044	/GG1/	Got	80MS
005	/OY/	Boy	420MS	045	/SH/	Ship	160MS
006	/AY/	Sky	260MS	046	/ZH/	Azure	190MS
007	/EH/	End	70MS	047	/RR2/	Brain	120MS
010	/KK3/	Comb	120MS	050	/FF/	Food	150MS
011	/PP/	Pow	210MS	051	/KK2/	Sky	190MS
012	/JH/	Dodge	140MS	052	/KK1/	Can't	160MS
013	/NN1/	Thin	140MS	053	/ZZ/	Zoo	210MS
014	/IH/	Sit	70MS	054	/NG/	Anchor	220MS
015	/TT2/	To	140MS	055	/LL/	Lake	110MS
016	/RR1/	Rural	170MS	056	/WW/	Wool	180MS
017	/AX/	Succeed	70MS	057	/XR/	Repair	360MS
020	/MM/	Milk	180MS	060	/WH/	Whig	200MS
021	/TT1/	Part	100MS	061	/YY1/	Yes	130MS
022	/DH1/	They	290MS	062	/CH/	Church	190MS
023	/IY/	See	250MS	063	/ER1/	Fir	160MS
024	/EY/	Beige	280MS	064	/ER2/	Fir	300MS
025	/DD1/	Could	70MS	065	/OW/	Beau	240MS
026	/UW1/	To	100MS	066	/DH2/	They	240MS
027	/AO/	Aught	100MS	067	/SS/	Vest	90MS
030	/AA/	Hot	100MS	070	/NN2/	No	190MS
031	/YY2/	Yes	180MS	071	/HH2/	Hoe	180MS
032	/AE/	Hat	120MS	072	/OR/	Store	330MS
033	/HH1/	He	130MS	073	/AR/	Alarm	290MS
034	/BB1/	Business	80MS	074	/YR/	Clear	350MS
035	/TH/	Thin	180MS	075	/GG2/	Guest	40MS
036	/UH/	Book	100MS	076	/EL/	Saddle	190MS
037	/UW2/	Food	260MS	077	/BB2/	Business	50MS

## NOTES

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# ADDENDUM

## TABLE 6 – ALLOPHONE ADDRESS TABLE

DECIMAL ADDRESS	OCTAL ADDRESS	ALLOPHONE	SAMPLE WORD	DURATION	DECIMAL ADDRESS	OCTAL ADDRESS	ALLOPHONE	SAMPLE WORD	DURATION
0	000	PA1	PAUSE	10MS	32	040	/AW/	Out	370MS
1	001	PA2	PAUSE	30MS	33	041	/DD2/	Do	160MS
2	002	PA3	PAUSE	50MS	34	042	/GG3/	Wig	140MS
3	003	PA4	PAUSE	100MS	35	043	/VV/	Vest	190MS
4	004	PA5	PAUSE	200MS	36	044	/GG1/	Got	80MS
5	005	/OY/	Boy	420MS	37	045	/SH/	Ship	160MS
6	006	/AY/	Sky	260MS	38	046	/ZH/	Azure	190MS
7	007	/EH/	End	70MS	39	047	/RR2/	Brain	120MS
8	010	/KK3/	Comb	120MS	40	050	/FF/	Food	150MS
9	011	/PP/	Pow	210MS	41	051	/KK2/	Sky	190MS
10	012	/JH/	Dodge	140MS	42	052	/KK1/	Can't	160MS
11	013	/NN1/	Thin	140MS	43	053	/ZZ/	Zoo	210MS
12	014	/IH/	Sit	70MS	44	054	/NG/	Anchor	220MS
13	015	/TT2/	To	140MS	45	055	/LL/	Lake	110MS
14	016	/RR1/	Rural	170MS	46	056	/WW/	Wool	180MS
15	017	/AX/	Succeed	70MS	47	057	/XR/	Repair	360MS
16	020	/MM/	Milk	180MS	48	060	/WH/	Whig	200MS
17	021	/TT1/	Part	100MS	49	061	/YY1/	Yes	130MS
18	022	/DH1/	They	290MS	50	062	/CH/	Church	190MS
19	023	/LY/	See	250MS	51	063	/ER1/	Fir	160MS
20	024	/EY/	Beige	280MS	52	064	/ER2/	Fir	300MS
21	025	/DD1/	Could	70MS	53	065	/OW/	Beau	240MS
22	026	/UW1/	To	100MS	54	066	/DH2/	They	240MS
23	027	/AO/	Aught	100MS	55	067	/SS/	Vest	90MS
24	030	/AA/	Hot	100MS	56	070	/NN2/	No	190MS
25	031	/YY2/	Yes	180MS	57	071	/HH2/	Hoe	180MS
26	032	/AE/	Hat	120MS	58	072	/OR/	Store	330MS
27	033	/HH1/	He	130MS	59	073	/AR/	Alarm	290MS
28	034	/BB1/	Business	80MS	60	074	/YR/	Clear	350MS
29	035	/TH/	Thin	180MS	61	075	/GG2/	Guest	40MS
30	036	/UH/	Book	100MS	62	076	/EL/	Saddle	190MS
31	037	/UW2/	Food	260MS	63	077	/BB2/	Business	50MS