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# TECHNICAL DATA

AN EXCLUSIVE RADIO SHACK SERVICE TO THE EXPERIMENTER

## SPO256 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 491 K of ROM Directly
- Simple Interface to Most Microcomputers or Microprocessors
- Supports L.P.C. Synthesis: Formant Synthesis: Allophone Synthesis

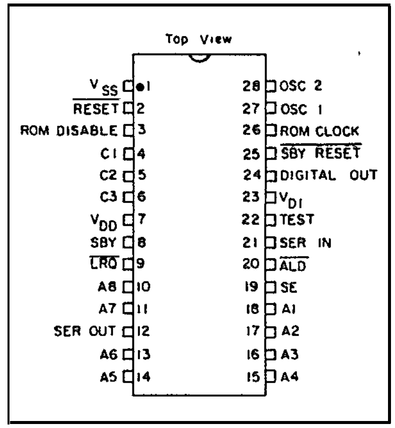
### Generel Description

The SPO256 (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 programable 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 converted to an analog signal when filtered by an external low pass filter.




PIN CONFIGURATION

### Allophone Based Speech Processor – SPO256-AL2

One example of a preprogramed SPO256 is the AL2 pattern.

### Allophone Usage with a Microprocessor

The SPO256-AL2 requires the use of a processor to concatenate the speech sounds to form words.

The SPO256 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 SPO256-AL2.

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This particular application (Allophone Set) requires only six address Pins (A1-A6) to address all the 69 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 end A7=A8=0

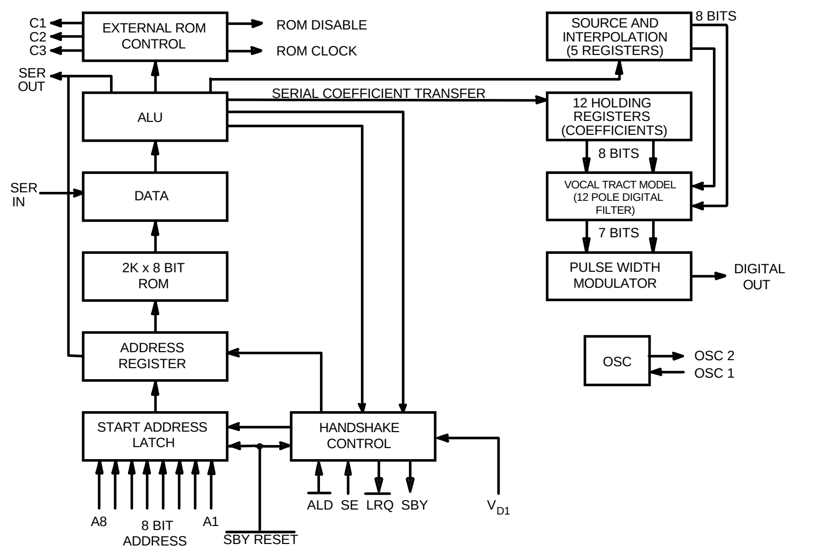
There are two modes available for loading an address into the chip. SE (Strobe Enable) controls the mode that will be used.

Mode 0 (SE=0) will latch is 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 pln. First, setup the desired address on the address bus (A1-A6) and low. Any address can be loaded using this mode, but certain setup and hold times are then pulse ALD 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.

**SPO256 BLOCK DIAGRAM**






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 Vss.........-0.3 to 8.0V

Storage Temperature............-25°C to 125°C

**Standard Conditions**

Clock - Crystal Frequency ...........3.120 MHz

Operating Temperature (Ta).......0°C to 70°C

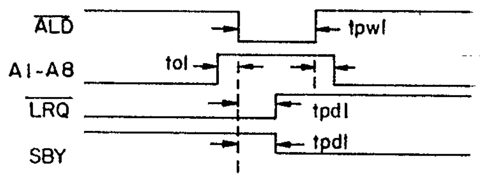
**DC CHARACTERISTICS/SPO 256**

*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 im-plied. Operating ranges are specified in Standard Condi-tions. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

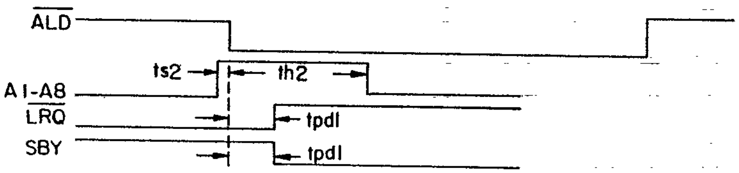
Data labeled "typical" is presented for design guidance only and is not guaranteed

| Characteristic | Sym | Min | Typ | Max | Units | Conditions |
|---|---|---|---|---|---|---|
| Supply Voltage | $V_{DD}$ | 4.6 | — | 7.0 | V | |
| | $V_{D1}$ | 4.6 | — | 7.0 | V | |
| Supply Current | $I_{DD}$ | — | — | 90 | mA | $T_A$ = 25ºC, $V_{D1}$ , $V_{DD}$ = 7.0V<br>$\overline{\text{Reset}}$ & $\overline{\text{SBY}}$ Reset high.<br>All outputs floating. |
| | $I_{D1}$ | — | — | 21 | mA | Same as above. |
| INPUTS<br>A1-A8, $\overline{\text{ALD}}$, SERIN, TEST, SE | | | | | | |
| LOGIC 0 | $V_{IL}$ | 0.0 | — | 0.6 | V | |
| LOGIC 1 | $V_{IH}$ | 2.4 | — | $V_{D1}$ | V | |
| CAPACITANCE | $C_{IN}$ | — | — | 10 | pF | 0 Volts bias, f = 3.12 MHz |
| LEAKAGE | $I_L$ | — | — | +10 | µa | $V_{PIN}$ = 7.0V Other Pins = 0.0V |
| $\overline{\text{RESET}}$, $\overline{\text{SBY RESET}}$ | | | | | | |
| LOGIC 0 | $V_{IL}$ | 0.0 | — | 0.6 | V | |
| LOGIC 1 | $V_{IH}$ | 3.6 | — | $V_{D1}$ | V | |
| OUTPUTS<br>SBY, Digital Out, C1, C2, C3,<br>$\overline{\text{LRQ}}$, ROM DIS, ROM CLK,<br>SEROUT | | | | | | |
| LOGIC 0 | $V_{OL}$ | 0.0 | — | 0.6 | V | $I_{OL}$ = 0.72ma (2LS TTL Loads) |
| LOGIC 1 | $V_{OH}$ | 2.5 | — | $V_{D1}$ | V | $I_{OH}$ = -50 µa (2LS TTL Loads) |
| OSCILLATOR<br>OSC 2 (Output) | | | | | | When driven from external source. |
| LOGIC 0 | $V_{OL}$ | 0.0 | — | 0.6 | V | OSC 1 (Input) = 3.90 V MIN |
| LOGIC 1 | $V_{OH}$ | 2.5 | — | $V_{D1}$ | V | OSC 1 (Input) = 0.60 V MAX |

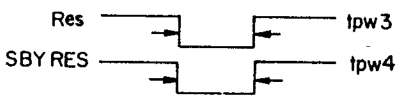
| AC CHARACTERISTICS | SYM | MIN | TYP | MAX | UNITS | CONDITIONS |
|---|---|---|---|---|---|---|
| $\overline{ALD}$ | tpw1 | 200 | — | 1100 | ns | 200 ≤ $\overline{ALD}$ ≤ 1100 ns |
| A1-A8 Set Up | ts1 | 0 | — | — | ns | |
| Hold | th1 | 160 | — | — | ns | |
| $\overline{LRQ}$ | tpd1 | — | — | 300 | ns | |
| SBY | tpd2 | — | — | 300 | ns | |



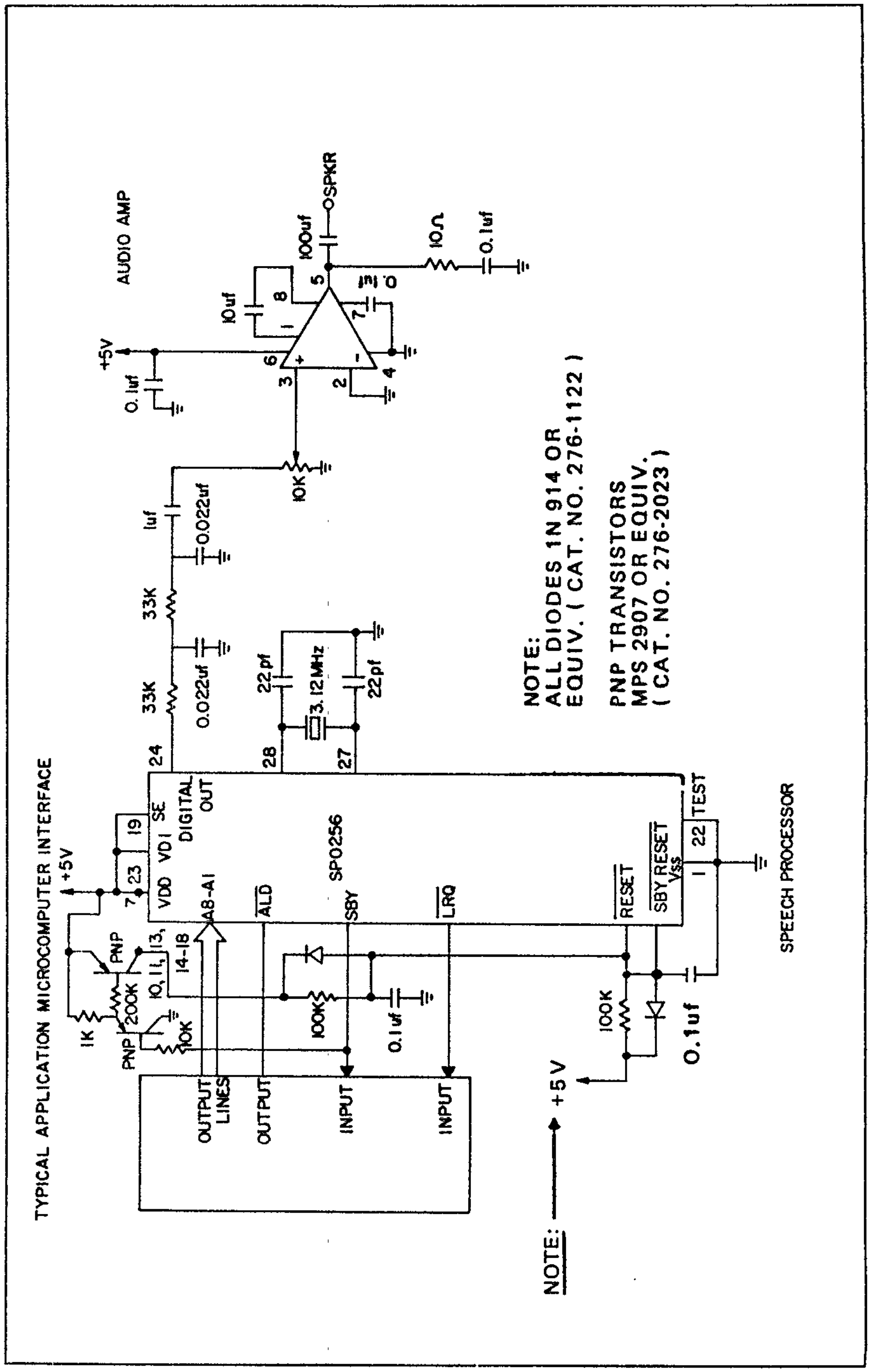

| AC CHARACTERISTICS | SYM | MIN | TYP | MAX | UNITS | CONDITIONS |
|---|---|---|---|---|---|---|
| $\overline{ALD}$ | tpw2 | 1100 | — | — | ns | $\overline{ALD}$ > 1100 ns |
| A1-A8 Set Up | ts2 | 0 | — | — | ns | |
| Hold | th2 | 1120 | — | — | ns | |
| $\overline{LRQ}$ | tpd1 | — | — | 300 | ns | |
| SBY | tpd2 | — | — | 300 | ns | |




| AC CHARACTERISTICS | SYM | MIN | TYP | MAX | UNITS | CONDITIONS |
|---|---|---|---|---|---|---|
| Clock Frequency | F | — | 3.120 | — | MHz | Crystal Oscillator |
| Clock Duty Cycle | — | 48 | — | 52 | % | driven from |
| $\overline{Reset}$ | tpw3 | 100 | — | — | us | external. |
| $\overline{SBY\ Reset}$ | tpw4 | 100 | — | — | us | |





## PIN FUNCTIONS

| PIN NUMBER | NAME | FUNCTION |
|---|---|---|
| 1 | $V_{SS}$ | Ground |
| 2 | RESET | A logic 0 resets that portion of the SP powered by VDD. 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 | Cl, C2, C3 | Output control lines for use with an external serial speech ROM. Refer to the SPR016 Data Sheet for details. |
| 7 | $V_{DD}$ | 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 VDD 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. |
| B | 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. A 1 | 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 lus 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 E-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 SPO256 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 mono-syllabic 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 A A A Y NN1 |
| ten | TT2 EH EH NN1 |
| eleven | IH LL EH EH VV IH NN1 |
| | 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 IY |
| 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 NNI |
| 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 E R |
| cookie | KK3 UH KK1 IY |
| coop | KK3 UW2 PA3 PP |
| correct | KK1 ER2 EH E H PA2 KK2 PA2 TT1 |
| corrected | KK1 ER2 EH EH PA2 KK2 PA2 TT2 IH PA2 DDI |
| correcting | KKI ER2 EH EH PA2 KK2 PA2 TT2 IH NG |
| corrects | KK1 ER2 EH E H PA2 KK2 PA2 TT1 ss |
| crown | KK1 RR2 AW NN1 |
| date | DD2 EY PA3 TT2 |
| daughter | DD2 A0 TT2 ER1 |
| day | DD2 EH EY |
| divided | DD2 IH VV AY PA2 DD2 IH PA2 DD1 |
| emational | IY MM OW SH AX NN1 AX EL |
| engage | EH EH PA1 NN1 GG1 EY PA2 JH |
| engagement | EH EH PA1 NN1 GG1 EY PA2 JH MM EH EH NN1 PA2 PA3 TT2 |
| engages | EH EH PA1 NN1 GG1 EY PA2 JH IH z z |
| engaging | EH EH PA1 NN1 GG1 EY PA2 JH IH NG |
| enrage | EH NN1 RR1 EY PA2 JH |
| enraged | EH NN1 RR1 EY PA2 JH PA2 DD1 |
| enrages | EH NN1 RR1 EY PA2 JH IH ZZ |
| enraging | EH NN1 RR1 EY PA2 JH IH NG |
| escape | EH SS SS PA3 KK1 PA2 PA3 PP |
| escaped | EH SS SS PA3 KK1 PA2 PA3 PP PA2 TT2 |
| escapes | EH SS SS PA3 KK1 PA2 PA3 PP SS |
| escaping | EH SS SS PA3 KK1 PA2 PA3 PP IH NG |
| equal | IY PA2 PA3 KK3 WH AX EL |
| equals | IY PA2 PA3 KK3 WH AX EL ZZ |
| error | EH XR OR |
| extent | EH KK1 SS TT2 EH EH NN1 TT2 |
| fir | FF ER2 |
| freeze | FF FF RR1 IY ZZ |
| freezer | FF FF RR1 IY ZZ ER1 |
| freezers | FF FF RR1 IY ZZ ER1 ZZ |
| freezing | FF FF RR1 IY ZZ IH NG |
| frozen | FF FF RR1 OW ZZ EH NN1 |
| gauge | GG1 EY PA2 JH |
| guaged | GG1 EY PA2 JH PA2 DD1 |
| guager | GG1 EY PA2 JH IH ZZ |
| guaging | GG1 EY PA2 JH IH NG |
| hello | HH EH LL AX OW |
| hour | AW ER1 |
| infinitive | IH NN1 FF FF IH IH NN1 IH PA2 PA3 TT2 IH VV |
| intrigue | IN NN1 PA3 TT2 RR2 IY PA1 GG3 |
| intrigued | IH NN1 PA3 TT2 RR2 IY PA1 GG3 PA2 DD1 |
| intrigues | IH NN1 PA3 T-I-2 RR2 IY PA1 GG3 zz |
| intriguing | IH NN1 PA3 TT2 RR2 IY PA1 GG3 IH NG |
| investigate | IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 EY PA2 TT2 |
| Investigated | IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 EY PA2 TT2 IH PA2 DD1 |
| Investigator | IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 EY PA2 TT2 ER1 |
| investigators | IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 EY PA2 TT2 ER1 zz |
| investigates | IH IH NN1 VV EH EH SS PA2 PA3 TT2 IH PA1 GG1 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 |
| key | KK1 IY |
| legislate | LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2 |
| legislated | LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2 IH DD1 |
| legislates | LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT1 SS |
| legislating | LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 TT2 IH NG |
| legislature | LL EH EH PA2 JH JH SS SS LL EY PA2 PA3 CH ER1 |
| letter | LL EH EH PA3 TT2 ER1 |
| litter | LL IH IH PA3 TT2 ER1 |
| little | LL IH IH PA3 TT2 EL |
| memory | MM EH EH MM ER2 IY |
| memories | MM EH EH MM ER2 IY ZZ |
| minute | MM 1H NN1 IH PA3 TT2 |
| month | MM AX NN1 TH |
| nip | NN1 IH IH PA2 PA3 PP |
| nipped | NN1 IH IH PA2 PA3 PP PA3 TT2 |
| nipping | NN1 IH IH PA2 PA3 PP IH NG |
| nips | NN1 IH IH PA2 PA3 PP SS |
| no | NN2 AX OW |
| physical | FF FF IH ZZ IH PA3 KK1 AX EL |
| pin | PP IH IH NN1 |
| pinned | PP IH IH NN1 PA2 DD1 |
| pinning | PP IH IH NN1 IH NG1 |
| pins | PP IH IH NN1 ZZ |
| pledge | PP LL EH EH PA3 JH |
| pledged | PP LL EH EH PA3 JH PA2 DD1 |
| pledges | PP LL EH EH PA3 JH IH ZZ |
| pledging | PP LL EH EH PA3 JH IH NG |
| plus | PP LL AX AX SS SS |
| ray | RR1 EH EY |
| rays | RR1 EH EY ZZ |
| ready | RR1 EH EH PA1 DD2 IY |
| red | RR1 EH FH PA1 DD1 |
| robot | RR1 OW PA2 BB2 AA PA3 TT2 |
| robots | RR1 OW PA2 BB2 AA PA3 TT1 SS |
| score | SS SS PA3 KK3 OR |
| second | SS SS EH PA3 KK1 IH NN1 PA2 DD1 |
| sensitive | SS SS EH EH NN1 SS SS IH PA2 PA3 TT2 IH VV |
| sensitivity | SS SS EH EH NN1 SS SS IH PA2 PA3 TT2 IH VV IH PA2 PA3 TT2 IY |
| sincere | SS SS IH IH NN1 SS SS YR |
| sincerely | SS SS IH IH NN1 SS SS YR LL IY |
| sincerity | SS SS IH IH NN1 SS SS EH EH RR1 IH PA2 PA3 TT2 IY |
| sister | SS SS IH IH SS PA3 TT2 ER1 |
| speak | SS SS PA3 IY PA3 KK2 |
| spell | SS SS PA3 PP EH EH EL |
| spelled | SS SS PA3 PP EH EH EL PA3 DD1 |
| speller | SS SS PA3 PP EH EH EL ER2 |
| spellers | SS SS PA3 PP EH EH EL ER2 ZZ |
| spelling | SS SS PA3 PP EH EH EL IH NG |
| spells | SS SS PA3 PP EH EH EL ZZ |
| start | SS SS PA3 TT2 AR PA3 TT2 |
| started | SS SS PA3 TT2 AR PA3 TT2 IH PA1 DD2 |
| starter | SS SS PA3 TT2 AR PA3 TT2 ER1 |
| starting | SS SS PP3 TT2 AR PA3 TT2 IH NC |
| starts | SS SS PP3 TT2 AR PA3 TT1 SS |
| stop | SS SS PA3 TT1 AA AA PA3 PP |
| stopped | SS SS PA3 TT1 AA AA PA3 PP PA3 TT2 |
| stopper | SS SS PA3 TT1 AA AA PA3 PP ER1 |
| stopping | SS SS PA3 TT1 AA AA PA3 PP IH NG |
| stops | SS SS PA3 TT1 AA AA PA3 PP SS |
| subject (noun) | SS SS AX AX PA2 BB1 PA2 JH EH PA3 KK2 PA3 TT2 |
| subject (verb) | SS SS AX PA2 BB1 PA2 JH EH EH PA3 KK2 PA3 TT2 |
| sweat | SS SS WW EH EH PA3 TT2 |
| sweated | SS SS WW EH EH PA3 TT2 IH PA3 DD1 |
| sweater | SS SS WW EH EH PA3 TT2 ER1 |
| sweaters | SS SS WW EH EH PA3 TT2 ER1 ZZ |
| sweating | SS SS WW EH EH PA3 TT2 IH NG |
| sweats | SS SS WW EH EH PA3 TT2 SS |
| switch | SS SS WH IH IH PA3 CH |
| switched | SS SS WH IH IH PA3 CH PA3 TT2 |
| 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 |
| thread | TH RR1 EH EH PA2 DD1 |
| threaded | TH RR1 EH EH PA2 DD2 IH PA2 DD1 |
| threader | TH RR1 EH EH PA2 DD2 ER1 |
| threaders | TH RR1 EH EH PA2 DD2 ER1 ZZ |
| threading | TH RR1 EH EH PA2 DD2 IH NG |
| threads | TH RR1 EH EH PA2 DD2 ZZ |
| then | DH1 EH EH NN1 |
| time | TT2 AA AY MM |
| times | TT2 AA AY MM ZZ |
| uncle | AX NG PA3 KK3 EL |
| whale | WW EY EL |
| whaler | WW EY LL ER1 |
| whalers | WW EY LL ER1 ZZ |
| whales | WW EY EL ZZ |
| whaling | WW EY LL TH NG |
| year | YY2 YR |
| yes | YY2 EH EH SS SS |

## TABLE 2 – EXAMPLES OF SPELLING IRREGULARTIES

| | Same sound represented by different letters | Different sounds represented by the same letters |
|---|---|---|
| Vowels | mEAt | vEIn |
| | fEEt | forEIgn |
| | pEte | dEIsm |
| | pEOple | dEIcer |
| | pennY | gEIsha |
| Consonants | SHip | althouGH |
| | tenSIon | GHastly |
| | preCIous | couGH |
| | naTIon | hiccouGH |

## TABLE 3 - CONSONANT PHONEMES OF ENGLISH**

| | | LABIAL | LABIO-DENTAL | INTER-DENTAL | ALVEO-LAR | 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 Approx-imates 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

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

*** Short Vowels**
**# Rounded Vowels**

# TABLE 5 - GUIDELINES FOR USEING 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: fibber, 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

| HEX ADD | OCTAL ADDRESS | ALLO-PHONE | SAMPLE WORD | DURATION |
|---|---|---|---|---|
| 00 | 000 | PA1 | PAUSE | 1OMS |
| 01 | 001 | PA2 | PAUSE | 30MS |
| 02 | 002 | PA3 | PAUSE | 50MS |
| 03 | 003 | PA4 | PAUSE | 1OOMS |
| 04 | 004 | PA5 | PAUSE | 200MS |
| 05 | 005 | /OY/ | BOY | 420MS |
| 06 | 006 | /AY/ | Sky | 260MS |
| 07 | 007 | /EH/ | End | 70MS |
| 08 | 010 | /KK3/ | Comb | 120MS |
| 09 | 011 | /PP/ | Pow | 21OMS |
| 0A | 012 | /JH/ | Dodge | 140MS |
| 0B | 013 | /NN1/ | Thin | 140MS |
| 0C | 014 | /IH/ | Sit | 70MS |
| 0D | 015 | /TT2/ | To | 140MS |
| 0E | 016 | /RR1/ | Rural | 170MS |
| 0F | 017 | /AX/ | Succeed | 70MS |
| 10 | 020 | /MM/ | Milk | 180MS |
| 11 | 021 | /TT1/ | Part | 1OOMS |
| 12 | 022 | /DH1/ | They | 290MS |
| 13 | 023 | /IY/ | See | 250MS |
| 14 | 024 | /EY/ | Beige | 280MS |
| 15 | 025 | /DD1/ | Could | 70MS |
| 16 | 026 | /UW1/ | To | 1OOMS |
| 17 | 027 | /AO/ | Aught | 1OOMS |
| 18 | 030 | /AA/ | Hot | 1OOMS |
| 19 | 031 | /YY2/ | Yes | 180MS |
| 1A | 032 | /AE/ | Hat | 120MS |
| 1B | 033 | /HH1/ | He | 130MS |
| 1C | 034 | /BB1/ | Business | 80MS |
| 1D | 035 | /TH/ | Thin | 180MS |
| 1E | 036 | /UH/ | Book | 100MS |
| 1F | 037 | /UW2/ | Food | 260MS |
| 20 | 040 | /AW/ | Out | 370MS |
| 21 | 041 | /DD2/ | Do | 160MS |
| 22 | 042 | /GG3/ | Wig | 140MS |
| 23 | 043 | /VV/ | Vest | 19OMS |
| 24 | 044 | /GG1/ | Got | 80MS |
| 25 | 045 | /SH/ | Ship | 160MS |
| 26 | 046 | /ZH/ | Azure | 190MS |
| 27 | 047 | /RR2/ | Brain | 12OMS |
| 28 | 050 | /FF/ | Food | 150MS |
| 29 | 051 | /KK2/ | Sky | 190MS |
| 2A | 052 | /KK1/ | Can't | 160MS |
| 2B | 053 | /ZZ/ | Zoo | 21OMS |
| 2C | 054 | /NG/ | Anchor | 220MS |
| 2D | 055 | /LL/ | Lake | 110MS |
| 2E | 056 | /WW/ | Wool | 180MS |
| 2F | 057 | /XR/ | Repair | 360MS |
| 30 | 060 | /WH/ | Whig | 200MS |
| 31 | 061 | /YY1/ | Yes | 130MS |
| 32 | 062 | /CH/ | Church | 190MS |
| 33 | 063 | /ER1/ | Fir | 160MS |
| 34 | 064 | /ER2/ | Fir | 300MS |
| 35 | 065 | /OW/ | Beau | 240MS |
| 36 | 066 | /DH2/ | They | 240MS |
| 37 | 067 | /SS/ | Vest | 90MS |
| 38 | 070 | /NN2/ | No | 190MS |
| 39 | 071 | /HH2/ | Hoe | 180MS |
| 3A | 072 | /OR/ | Store | 330MS |
| 3B | 073 | /AR/ | Alarm | 290MS |
| 3C | 074 | /YR/ | Clear | 350MS |
| 3D | 075 | /GG2/ | Guest | 40MS |
| 3E | 076 | /EL/ | Saddle | 190MS |
| 3F | 077 | /BB2/ | Business | 50MS |