Subscriber line automatic identification number device

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Abstract

The subscriber line automatic identification number device, SLAIN device, is an apparatus that may be utilized as the subscriber's end section of a telephone privatization system. This system will not utilize any equipment available at the central office except for outside connections to the subscriber wires. As part of the Capstone Design Course of the Polytechnic University of Puerto Rico, the subscriber's end device was designed and a breadboard prototype was completed. If the complete system is to be implemented, only a computer with the correct DTMF detection devices and subscriber codes stored would be needed at the central office in order to complete the privatization system.

Sinopsis

Aparato de identificación automática del subscriptor

El aparato de identificación automática del subscriptor es un dispositivo que se puede usar para identificar líneas en un sistema de privatización de teléfonos. El aparato no necesita más equipo de la oficina central de teléfonos para operar que una conexión en el sistema de líneas de teléfonos. Como parte del curso final de diseño de la Universidad Politécnica se diseñó el aparato y se construyó un prototipo en un "breadboard". Si se fuera a implantar este sistema, la única necesidad adicional del sistema de privatización sería una computadora que detecte tonos DTMF, con memoria suficiente para almacenar todos los números de identificación de los subscriptores.

Introduction

Project EE-02-01-95 encompassed the design and development of an automatic tone dialer that could be utilized as the subscriber end device of a telephone privatization system. The official name of the project is the Subscriber Line Automatic Identification Number device. As the project's name suggests, its function is to automatically dial an identification number that corresponds to a single subscriber loop. The dialed number would be transmitted through the telephone pair to a computer outside the central office. This computer would decode the number and identify the loop for billing purposes.

This paper describes the design process that concluded in a probable implementation of the subscriber line automatic identification number device, hereunto referred to as the SLAIN device. The paper will cover the objectives, problems, alternatives, possible solutions and the final design the team decided would be the most appropriate for implementation.

Objectives

The objectives for this project, as dictated by the Electrical Engineering Department of the Polytechnic University of Puerto Rico, must meet the following requirements:

- The device is to be of small size and unobtrusive
- It must be powered from the telephone pair. At no time will the device have an external source of power.
- The device must be easily installed by the subscriber. This is probably the most important characteristic of the design, since many subscribers have no knowledge of the installation of telephones or telephone related devices. An instruction manual will be included with each device for easy installation by the subscriber.

- The automatic identification number that the device will produce is to be automatically dialed by the device. There are to be no external devices that allow dialing by the subscriber. Furthermore, in no way should the subscriber access the identification number.

- The device should have a five-year median life.

- The device will be impact resistant. Since the device may be placed on top of furniture or near ground level, it should resist falls and compressions without damaging the components inside or performance degradation due to impacts.

- The SLAIN device will dial from 16 to 20 digits for number identification.

- The dialing of the number will occur only at the time the telephone handset is picked up to make a call. The SLAIN device will not transmit an identification number neither when the telephone handset is picked up as the result of answering an incoming call nor at any other time.

- Either a programmable device or one with a fixed number in memory is acceptable. This opens alternatives as to what devices may be incorporated in the project. Possibilities range from PALs to microcontrollers to any other number of storing and dialing devices.

- The standard cost of the product should not exceed $10.00. If possible, the device should reach a minimum price, so as to be given free to the subscribers. Therefore, if possible, the device should be adaptable for mass production techniques that will lower its cost. The device is expected to have a production volume of 50,000 units.

Figure 1 shows a possible application of the SLAIN device. The device would be connected between the subscriber's telephone and the billing computers of the service providers. This way, the only portion of the telephone system used by the service provider is the telephone lines.

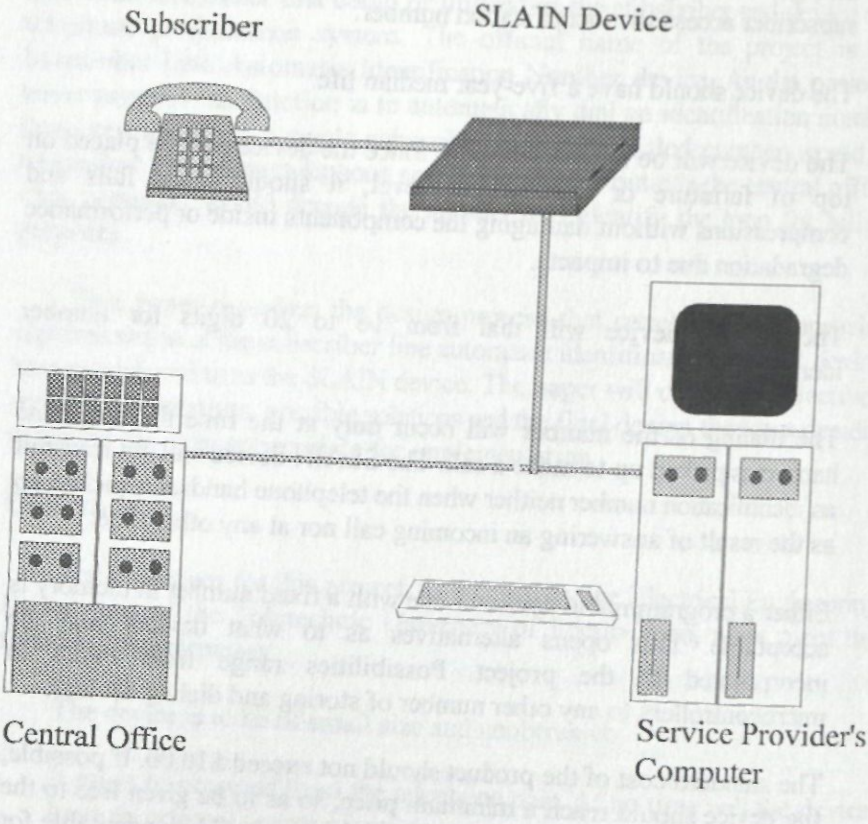

Figure 1. Possible application for the SLAIN device

Problems to be solved

A number of problems arise from the specifications outlined in the previous section. Five basic problems the design team inferred from these specifications were power, Federal Communications Comission (FCC) regulations, tone generation, loop tone detection and budget.

As stated in the objectives, the SLAIN device is to be powered from the subscriber's telephone line. Therefore, the final design would have to be most economical with regards to current consumption in order to connect it to the loop system because of FCC restrictions. This brings up the problem of making the SLAIN device in such a way that the design falls within Part 68 of FCC regulations. If the device draws too much power from the loop line, the central office may interpret this power consumption as an off-hook condition[1]. To solve this problem, the device must meet guidelines set by these regulations in order for the integrated system to work correctly. It is obvious that these two first problems are closely related and dealt with accordingly.

The third problem is tone generation by the SLAIN device. The device generates a series of DTMF tones that would identify the individual subscriber whenever the subscriber's loop attempts to generate a call within the system. The tone generating device should not draw too much power when generating the tones, but it should also generate the tones with a power level that can be detected by the billing computer. The fourth problem, tone detection, refers to the ability of the SLAIN device to distinguish the different working tones within the telephone network because the SLAIN device should send its tones only when the subscriber is about to place a telephone call and not at any other moment. Last, the SLAIN device should meet a budget limit.

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[1] Reeve, W., 1992, *Subscriber Loop Signaling and Transmission Handbook (Analog)*, IEEE Press

Design alternatives

This section is divided into two subsections: the power section and the command section. The power section deals with the generation of power for the SLAIN device. The command section comprises the tone detection and DTMF generation device or devices.

Power section

Among the alternatives examined while designing the power section were voltage dividers, a buck regulator and a step up-down regulator. The voltage divider network was discarded early in the selection process because its inflexibility to the different changes found in the telephone network. The power level of the different signals in the network would enter the divider network at different current and voltage levels, with the resulting output being voltage and current levels corresponding to the inputs. Next, the buck regulator was considered. Even though the buck regulator is a fine alternative, when the telephone is on- or off-hook, it would not regulate correctly or in a predictable manner when an AC voltage is applied to the device. Such AC voltages are found in the telephone network when the central office signals a certain loop for determined conditions such as ring signaling and extended off-hook conditions. The last alternative, the step up-down regulator was considered the best alternative because it operates in both AC and DC conditions and with different voltage levels in both AC and DC.

Command section

The command section itself is made up of two parts: the detector section and the DTMF generator. The detector section interprets the data it receives. These data are in the form of the different tones used by the telephone network to signal the individual loops. When the detector determines that the telephone is off-hook to place a call, it advises the DTMF generator to send the tones that identify that particular device.

Initially, the detector stage would be a state machine that would run all the time. When the condition of off-hook would be detected, the state machine would send a command to a logic circuit consisting of a DTMF generator and a storage device that would have the DTMF digits for an individual SLAIN device. This scheme would draw a significant amount of power, so simpler alternatives were sought. One of those alternatives was a telephone integrated circuit connected to the state machine. The state machine would also store the tone digits in this scheme. This alternative was dropped because of two reasons: telephone IC chips were discontinued in some cases, but mainly for the complexity of the final circuit. The chosen alternative was a microcontroller-based system that would both detect line conditions and generate the specific tones. The microcontroller offers small power consumption, a single IC based system, and the flexibility to utilize both inputs and outputs of the device to perform different device functions such as detection and DTMF generation. In addition, DTMF tones can be synthesized with microcontrollers.[2] The only problem with this scheme was to choose early in the proposal phase of the project what microcontroller would be used in the system in order to invest time in learning the microcontroller's programming structures and language.

Other design problems dealt with during project development were the size of the project and the enclosure of the device. The size problem can be addressed by utilizing as much surface-mount technology as possible within budget limits. The enclosure is as important as any other component of the SLAIN device because it will protect the internal circuits from tampering and atmospheric conditions and contamination. A phenol case was chosen from Mouser Electronics[3] since Mouser was the dealer with the leats expensive impact-resistant cases. These cases also have their own circuit mounts, so no additional costs would be added to the project.

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[2] National Semiconductor, 1992, *Embedded Controllers Databook.*

[3] Mouser Electronics, 1995, *Purchasing Manual #583*, June-October.

Final solution

This section of the paper summarizes the final solutions adopted by the team to prepare the design of the SLAIN device. It also includes some of the mathematical formulae that were utilized to complete the prototype.

Power supply design

The design came down to choosing between a linear voltage regulator and a switching voltage regulator. After looking at the advantages and disadvantages, we decided to use a switching voltage regulator. The next step was to select the standard operating mode of the switching voltage regulator. There are five basic operating modes: the step - up, step - down, inverter, flyback and buck-boost operating modes. Using the requirements of Vin = 48 volts and Vout =5 volts left us with two alternatives: the buck and the flyback regulators.

Because the flyback regulator requires the use of a transformer and a lot more linear and nonlinear electronic components than the buck regulator, this operating mode was discarded . This decision left us with the buck regulator to work with. Different kinds of buck regulators were studied and researched, utilizing as the key parameter for selection that the regulator could sustain an input voltage of 48 volts and higher, so that the regulator may not need an overvoltage protection circuit. Because the great majority of regulators come with the constraint that maximum input voltage [Vin(max)] is 40 volts, the only regulators that could meet our parameters were National Semiconductors' LM257X-HV series. These regulators have the same circuit configuration , the difference being the output current delivered to the load. The LM2574-HV series delivers an output current of 0.5A. The LM2575-HV series delivers an output current of 1 ampere. The LM2576-HV series delivers an output current of 3 amperes. The LM2575-HV series was selected because it was less expensive than other devices and because of its higher output current. The LM2575 series come in two versions: fixed output regulator

(3.3V,5V,12V,15V) and an adjustable output regulator (1.23V to 57V)[4].

Parameters for the design

- Vout = regulated output voltage
- Vin(max) = maximum input voltage
- Iload(max) = maximum load current

Electrical components selection

Inductor (L1) is selected from the inductor selection guide in the regulators data sheet. This is done by identifying the inductance region intersected by VIN(MAX) and ILOAD(MAX) and noting the inductor code for that region. The inductor chosen must have a current rating of 1.15 amperes.

For stable operation and acceptable output ripple voltage a value between 100 µF and 470 µF is recommended. The capacitor voltage rating should be at least 1.5 the output voltage. The diode current rating must be at least 1.2 times greater than the maximum load current. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.
An aluminum or tantalum electrolytic bypass capacitor is needed for stable operation at the regulator's input. The design for the 5volt fixed output voltage calls for the following characteristics:

Vout = 5V   Vin(max) = 60V   Iload(max) = .7A=700mA

From the selection guide in the data sheet the inductance region intersected by the 60V line and .7A is L470 so the value required for the inductor is 470 µH. The inductor current rating is 0.81 A.

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[4] National Semiconductor, 1995, *Power IC's Databook.*

The output capacitor (C2) is a 100μF standard aluminum electrolitic one. Its voltage rating is 7.5 V (1.5 * 5= 7.5). The input capacitor (C1) is a 47 μF, 25 V and provides sufficient bypassing.

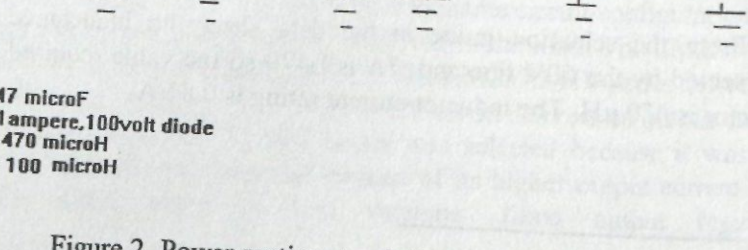
The diode current rating is 0.84 A (12*0.7=0.84). Its reverse voltage is 75 V (1.25 * 60 = 75). A 100V, 1 A diode was selected.

The total power dissipated by the regulator can be estimated by the following equation:

$$\begin{aligned} Pd &= (Vin)(Iq) + (Vo/Vin)(Iload)(Vsat) \\ &= (7V)(0.0175A) + (5V/7V)(0.7A)(0.9V) \\ &= 573mW \end{aligned} \quad (1)$$

where Iq is the quiescent current, Vsat is the saturation voltage, Vin is the minimum input voltage, Vo is the regulator output voltage and Iload is the load current.

The diagram in figure 2 shows the power section as it would look in a stand-alone configuration.



C1=47 microF
D1=1ampere,100volt diode
L1= 470 microH
C2 = 100 microH

Figure 2. Power section stand-alone circuit diagram

Command section

The command section did not involve numerical calculations at all. The COP 800 microcontroller series manual dictates the circuits and related charts that are to be used for support functions of the microcontroller. However, the method of DTMF synthesis dictated that a resistor network was to be used at the microcontroller's outputs in order to combine the different outputs on these pins and create a DTMF tone. As per Part 68, FCC Regulations, no device will be connected to the telephone system if its power output exceeds an output greater than -13dBm0 for more than 3 seconds. [5] Even though many test devices transmit at -16dBm, for this project the levels of DTMF transmission are the ones to be taken into consideration. At the telephone device the levels of DTMF applied should be between +4 and -14 dBm per frequency, with a spacing between tones of 50ms and tone transmission time for at least 40ms.

The microcontroller's program takes care of the transmission time requirements by generating any DTMF tone for 100ms and a spacing of 100ms between tones. The transmission levels of the SLAIN device are determined by the resistor ladder that combines the six microcontroller outputs. The following calculations will show how the output current of the device had to be modified in order to provide at least -13 dBm. The device output provides 1.6 mA at 0.4VDC, which translates to -1.92 dBm, well within the specified limits. [6]

The greatest challenge of the command section of the SLAIN device was the development of a microcontroller program that could both detect tones and generate DTMF tones when certain conditions are met. While researching for microcontrollers, a synthesis method was outlined by National Semiconductors to generate DTMF tones using the COP 840 microcontroller. The outline also

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[5]Bigelow, Stephen, 1991, *Comprendiendo Teléfonos Electrónicos*

[6]Reeve, Whitham, 1992, *Subscriber Loop Signaling and Transmission Handbook (Analog)*. IEEE Press.

included programs that utilized different methods of DTMF synthesis.[7] One of these programs was adapted for the DTMF generator, and with the addition of subroutines designed by the team to detect the different working tones in a telephone line a program that could both detect and generate tones was completed.

The method by which the detection of the working tones of the telephone pair was accomplished can be understood better if figure 3 is addressed. It is noted that figure 3 represents the logic equivalent of the off- and on-hook tones and the ringing tone of the line as seen from the subscriber's end when filtered to logic levels by a resistor voltage divider. If the telephone is ringing, an incoming call is in progress. When the telephone rings, both inputs will be at logic 0 or 1 at the same time during 50 ms. The next condition, an on-hook condition, is represented as a 0 on pin I0 and a 1 on pin I1. We do not wish to send the tones at any of these times. However, an off-hook condition is represented by a logic 0 entering both input pins. A problem arises at this time: how to distinguish the ring tone from the off-hook condition. Starting from the premise that the ring tone changes every 50 ms, a distinction can be made from off-hook and ring tone. If the signal is an off-hook one, the logic low should remain constant for the duration of the tone. The microcontroller is then programmed to sample the inputs for changes every 50 ms for two cycles (100 ms). The ring tone changes twice from low to high during this time frame. However, the off-hook condition remains at logic 0 during this time. Thus, a sequence of events representing the subscriber's placement or reception of a call could be summarized as follows:

Call placement

- Telephone goes off hook.
- Logic 0 at both inputs are detected.
- Sample twice. If during the sampling periods the input remains low, send the DTMF identification tones.

[7] National Semiconductor, 1992, *COP 800 Handbook*.

Call reception

- Telephone rings.
- Pulsing highs at microcontroller inputs.
- Sample twice. If there is any variation of logic levels between the inputs (either voltage variations from pin to pin or simultaneously during a period of time) do not send the ID tones.

Pins 7 and 8 of the COP 840 are two of the I-Port pins of the device. These pins detect the changes of the telephone lines, changes that can be interpreted as on-or off-hook and ring tone conditions (table 1). Pins 11 thru 16 are the L-Port of the COP 840, and are the DTMF output of the microcontroller. These pins are connected to the resistor ladder that mixes the outputs and generate the identification DTMF tones.

Table 1. Detection and interpretation of the changes in the lines

Status	Phone voltage	Pin I0	Pin I1
Off hook	-8 Vdc	Low	Low
On hook	-48 Vdc	Low	High
Ringing	48vdc+86vr ms at 20 Hz	Pulsing high at 20 Hz	Pulsing high at 20 Hz

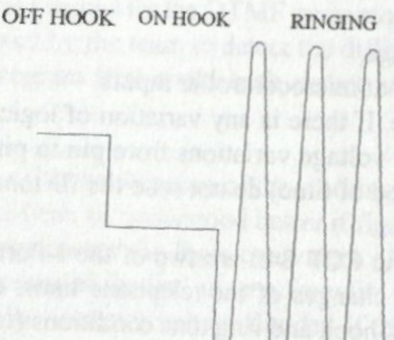

Figure 3. Logic equivalents of different telephone network tones

Appendix 1 shows the code for the tone detection and execution part of the program used in the prototype for the final presentation of the Capstone Design Course. Because of space constraints, the whole program is not shown in this document. The entire program is available through the authors of this paper and the Capstone Design Course Coordinator's office at the Polytechnic University of Puerto Rico.

The generation of the DTMF tones is accomplished by sampling the fundamental frequencies that make up the 16 DTMF tones and storing those values in two tables within the microcontroller's EPROM. The tables simulate the upper and lower frequencies, with differences in the baseline value of each table with respect to the other so that the 2db between high and low frequencies is simulated. The arithmetic combination of upper and lower values for a determined tone is output on pins L0-L5 of the COP 840; the values are updated every 177 microseconds. [8] As stated before, the complete program has a complete explanation.

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[8] National Semiconductor, 1992, *Embedded Controllers Databook.*

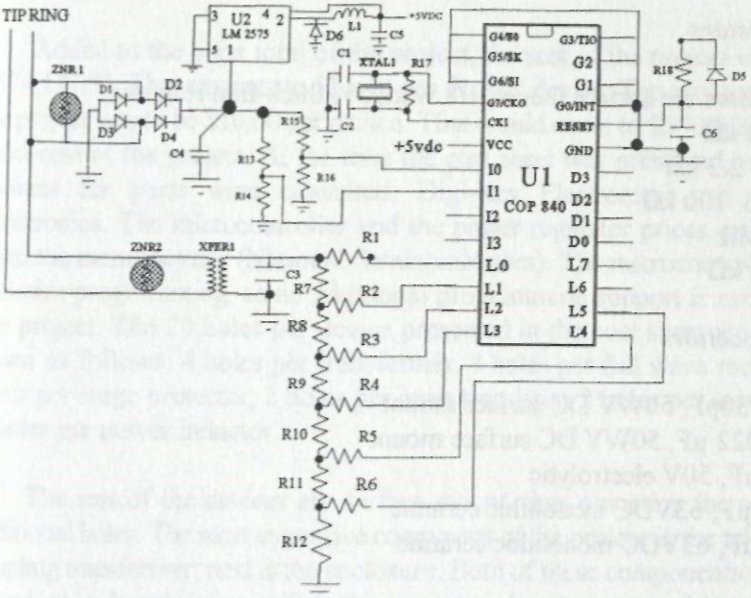

Figure 4. Circuit diagram of the SLAIN device

Parts list for the SLAIN device

Semiconductors

U1: National Semiconductor COP840 microcontroller

U2: National Semiconductor LM 2575-HV fixed output 1A step-dow voltage regulator

D1-D4: 1N4005 silicon rectifier

D5: 1N914 general purpose diode
D6: 1N5817 zener diode

Resistors

(All resistors are surface mount, 1/8 watt, 5% thick-film resistors)
R1-R6: 1 kΩ
R7-R12: 2.2 kΩ
R13-R16: 100 kΩ
R17: 1 MΩ
R18: 2.2 kΩ

Capacitors

C1, C2: 30pF, 50WV DC surface mount
C3: 0.0022 μF, 50WV DC surface mount
C4: 47 μF, 50V electrolytic
C5:100 μF, 63VDC monolithic ceramic
C6: 47 μF, 63VDC monolithic ceramic

Additional parts and materials

ZNR 1,2: "ZNR" transient/surge absorber, 130VAC
L1: 470 μH inductor
XFER1: telephone coupling transformer
XTAL1: 3.58 Mhz crystal
Case, telephone cable, telephone input connector, telephone jack

Budget

Among the costs that apply to the project are the following:

Logbook: $8.00

Two consultors working a total of 121.6 days (64.35 days for the initial phase of the project, 57.25 days for the implementation phase) an average of 4 man-hours per day: 121.6 days x 4 man-hours x 2 = 972.8 hours at $15.00 per hour gives a total of $14,592.00

Added to the parts total of the project, the cost of the project would be $574,177.91. That amounts to $11.48 per SLAIN device. The original cost of the project was to be $10.00 per device. That would come to $500,000 for the total cost of the project. At the time the cost sheet was presented, only two sources for parts were consulted: Digi-Key Electronics[9] and Mouser Electronics. The microcontroller and the power regulator prices are quoted form the manufacturer (National Semiconductors). The microcontroller cost includes programming, so no additional programming support is needed for the project. The 20 holes per device presented in the cost sheet are broken down as follows: 4 holes per transformer, 8 holes per full wave rectifier, 2 holes per surge protector, 2 holes per reset transistor, 2 holes per crystal and 2 holes per power inductor.

The rest of the devices are surface mount, thus obviating the need for additional holes. The most expensive component of the project is the telephone coupling transformer; next is the enclosure. Both of these components may be found at a lower price with other sources, but because of insufficient information proving otherwise, the quoted prices were the best seen at the time.

Conclusions

The prototype for the SLAIN device provides a satisfactory answer to the specifications presented at the initial phase of the Capstone Design Course. Even though there were not as many successful simulations of the concept prior to implementation as desired by the members of this group, the overall end product fulfilled the expectancies of the group members and the directives received form the Electrical Engineering Department.

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[9] Digi-Key Corporation, 1995, Catalog #952, March-April.

Appendix 1.

Code for tone detection

```
START:  LD     SP,#02F   ; Initialize stack ptr
;
;              Keyboard hex digit matrix
;                    1 2 3 A
LD     B,#PORTD ;    4 5 6 B
LD     [B],#0   ;    7 8 9 C
LOOP:   RC           * 0 # D
    LD     A,[B]    ; Dtmf test loop
    ADD    A,#5     ; Sequence is 1,5,9,D,4,
    X      A,[B]    ; 8,#,A,7,0,3,B,*,2,6,C,4,4,4,4
    RBIT   4,[B]    ; Hex matrix to lookup
    ADD  A,#020     ;  Table for low true
    LAID            ;  Column/row input to
    JSR  KBRDEC     ;  KBRDEC subroutine
    SC              ; Set C if not single key
    LD     B,#PORTI ; Test bit 0 of porti to
    IFBIT  0,[B]    ;   determine what kind
    NOP             ;  of signal is coming in
    IFBIT   1,[B]
    JP SHIFT_X

BYPA:   JSR     DTMFLP    ; Six ladder outputs on
                          ; L port pins L0 - L5

    LD     B,#TMRLO       ; Initialize timer
    LD     [B+],#0        ;   with a tc count
    LD     [B+],#140      ;    equivalent to
    LD     [B+],#0        ;    100 msec plus
    LD     [B+],#140      ;   a LUP42 time
    LD     [B+],#080      ; timer PWM, no out
    LD     [B-],#011      ; enable tmr intrpt
    SBIT   TRUN,[B]       ; start timer
```

```
; ******** 100ms silence between tones ***********
INTRPT1: LD      PORTLD,#29  ; Base line value
      LD      B,#PSW        ; 100 msec interrupt
      LD      [B-],#0       ;  from timer
      LD      [B],#0        ; clr PSW and cntrl
      LD      B,#SP         ; restore stack
      LD      A,[B]         ;   Pointer (SP)
      INC     A             ;  to its value
      INC     A             ;  before the
      X       A,[B]         ;  interrupt

SHIFT_X:   JP      LOOP     ; Call of subroutine
;
;
;
        .FORM
;
; Keyboard digit matrix table
;
        . = 137
;   This is  the particular id number of the prototype
;        1  5  9  D  4  8  #  A
    .BYTE   0EE,0DD,0BB,077,0ED,0DB,0B7,07E
;        7  0  3  B  *  2  6  C
    .BYTE   0EB,0D7,0BE,07D,0E7,0DE,0BD,07B
;        4  4  4  4
    .BYTE   0ED,0ED,0ED,0ED

;
```