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Introduction

The purpose of this Application Note is to provide information on the operation and application of DTMF Receivers. The MT8870 Integrated DTMF Receiver will be discussed in detail and its use illustrated in the application examples which follow.

More than 25 years ago the need for an improved method for transferring dialling information through the telephone network was recognized. The traditional method, Dial pulse signalling, was not only slow, suffering severe distortion over long wire loops, but required a DC path through the communications channel. A signalling scheme was developed utilizing voice frequency tones and implemented as a very reliable alternative to pulse dialling. This scheme is known as DTMF (Dual Tone Multi-Frequency), Touch-Tone™ or simply, tone dialling. As its acronym suggests, a valid DTMF signal is the sum of two tones, one from a low group (697-941Hz) and one from a high group (1209-1633Hz) with each group containing four individual tones. The tone

frequencies were carefully chosen such that they are not harmonically related and that their intermodulation products result in minimal signalling impairment (Fig. 1a). This scheme allows for 16 unique combinations. Ten of these codes represent the numerals zero through nine, the remaining six (*,#,A,B,C,D) being reserved for special signalling. Most telephone keypads contain ten numeric push buttons plus the asterisk (*) and octothorp (#). The buttons are arranged in a matrix, each selecting its low group tone from its respective row and its high group tone from its respective column (Fig. 1b).

The DTMF coding scheme ensures that each signal contains one and only one component from each of the high and low groups. This significantly simplifies decoding because the composite DTMF signal may be separated with bandpass filters, into its two single frequency components each of which may be handled individually. As a result DTMF coding has proven to provide a flexible signalling scheme of excellent reliability, hence motivating innovative and competitive decoder design.

Development

Early DTMF decoders (receivers) utilized banks of bandpass filters making them somewhat cumbersome and expensive to implement. This generally restricted their application to central offices (telephone exchanges).

The first generation receiver typically used LC filters, active filters and/or phase locked loop techniques to

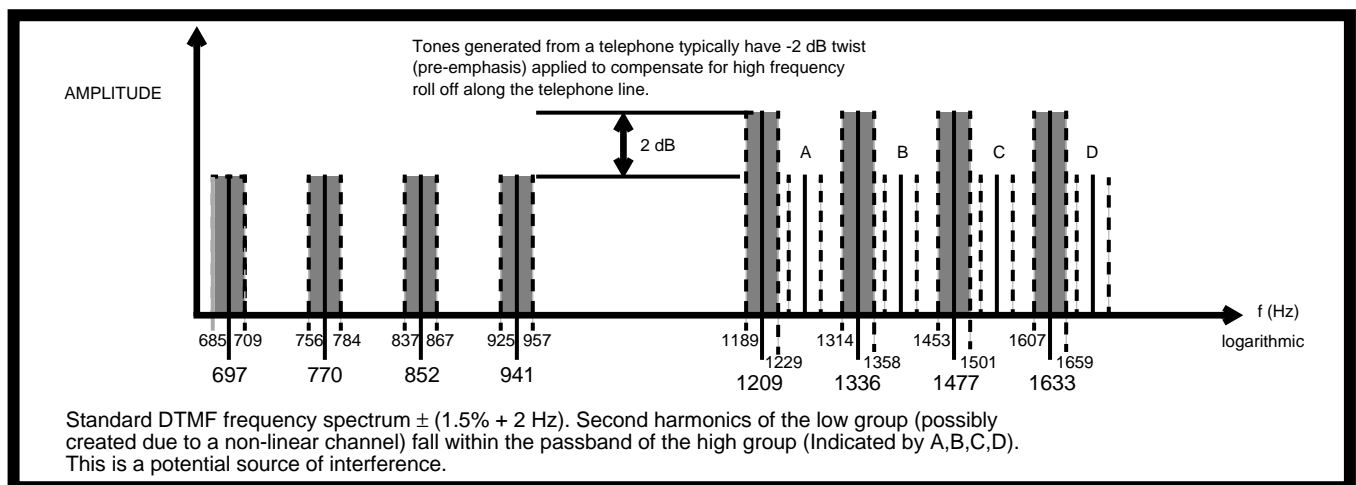


Figure 1a - The Dual Tone Multifrequency (DTMF) Spectrum

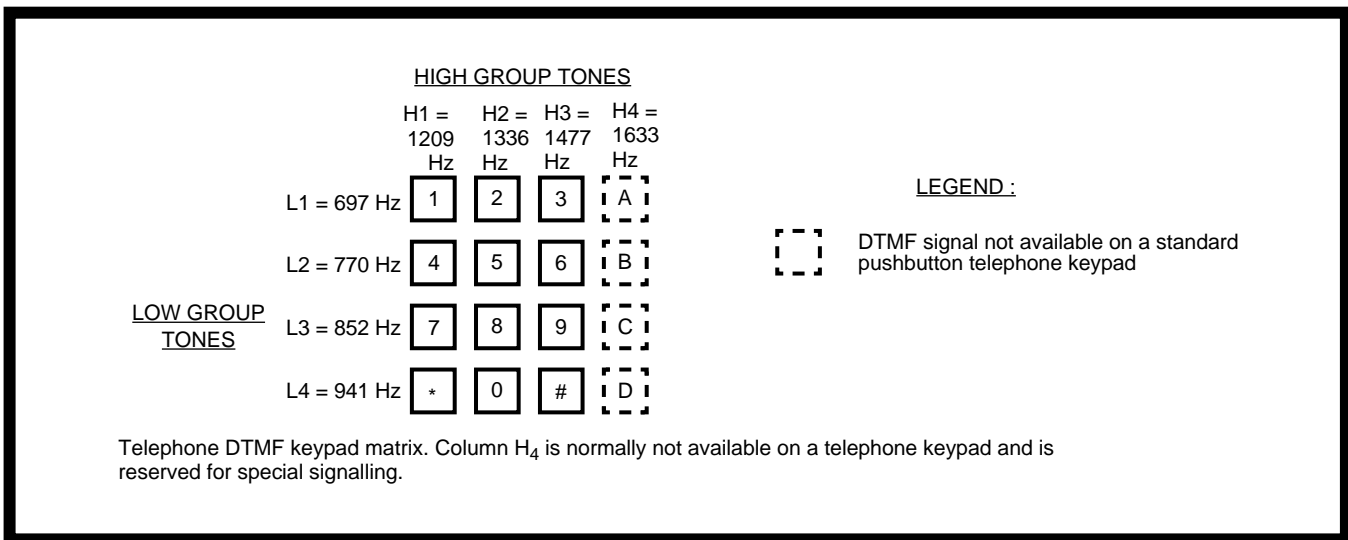
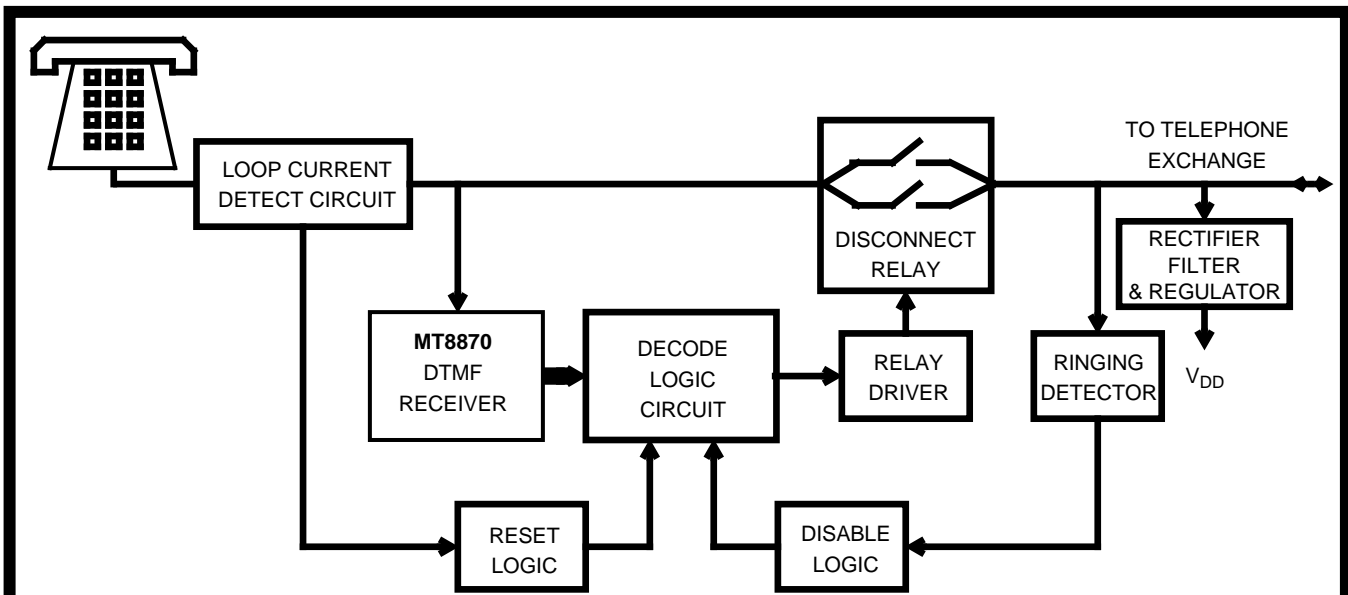
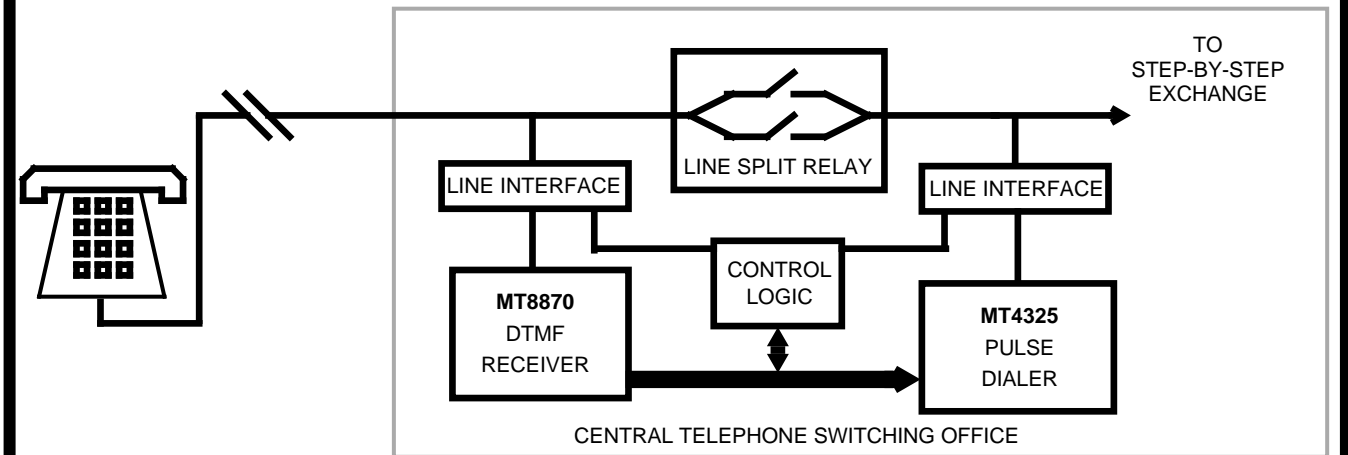


Figure 1b - The Dual Tone Multifrequency (DTMF) Keypad



a) Block diagram of a toll call restrictor. This could be implemented on a small pc board and installed in a telephone to disallow long distance calling.



b) Block diagram of a simple tone to pulse converter to allow TOUCH-TONE dialing into a step-by-step or crossbar exchange.

Figure 2 - Typical DTMF Receiver Applications

receive and decode DTMF tones. Initial functions were, commonly, phone number decoders and toll call restrictors. A DTMF receiver is also frequently used as a building block in a tone-to-pulse converter which allows Touch-Tone dialling access to mechanical step-by-step and crossbar exchanges (Fig. 2).

The introduction of MOS/LSI digital techniques brought about the second generation of tone receiver development. These devices were used to digitally decode the two discrete tones that result from decomposition of the composite signal. Two analog bandpass filters were used to perform the decomposition.

Totally self-contained receivers implemented in thick film hybrid technology depicted the start of third generation devices. Typically, they also used analog active filters to bandsplit the composite signal and MOS digital devices to decode the tones.

The development of silicon-implemented switched capacitor sampled filters marked the birth of the fourth and current generation of DTMF receiver technology. Initially single chip bandpass filters were combined with currently available decoders enabling a two chip receiver design. A further advance in integration has merged both functions onto a single chip allowing DTMF receivers to be realized in minimal space at a low cost.

The second and third generation technologies saw a tendency to shift complexity away from the analog circuitry towards the digital LSI circuitry in order to reduce the complexity of analog filters and their inherent problems. Now that the filters themselves can be implemented in silicon, the distribution of complexity becomes more a function of performance and silicon real estate.

Inside The MT8870

The MT8870 is a state of the art single chip DTMF receiver incorporating switched capacitor filter technology and an advanced digital counting/averaging algorithm for period measurement. The block diagram (Fig. 3) illustrates the internal workings of this device.

To aid design flexibility, the DTMF input signal is first buffered by an input op-amp which allows adjustment of gain and choice of input configuration. The input stage is followed by a low pass continuous RC active filter which performs an antialiasing function. Dial tone at 350 and 440Hz is then rejected by a third order switched capacitor notch filter. The

signal, still in its composite form, is then split into its individual high and low frequency components by two sixth order switched capacitor and pass filters. Each component tone is then smoothed by an output filter and squared up by a hard limiting comparator.

The two resulting rectangular waves are applied to digital circuitry where a counting algorithm measures and averages their periods. An accurate reference clock is derived from an inexpensive external 3.58MHz colourburst crystal.

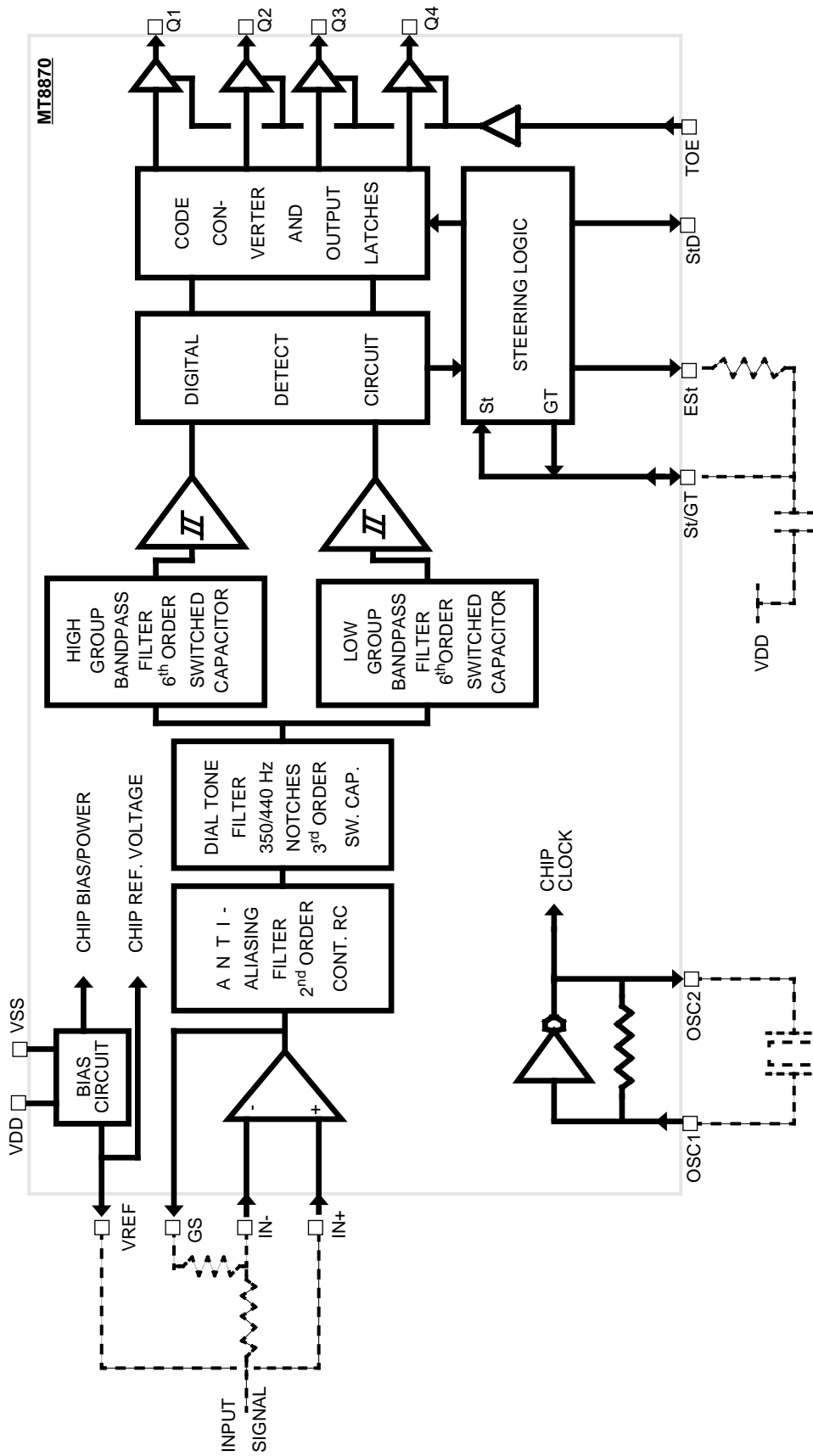
The timing diagram (Fig. 4) illustrates the sequence of events which follow digital detection of a DTMF tone pair. Upon recognition of a valid frequency from each tone group the Early Steering (ESt) output is raised. The time required to detect the presence of two valid tones, t_{DP} is a function of the decode algorithm, the tone frequency and the previous state of the decode logic. ESt indicates that two tones of proper frequency have been detected and initiates an RC timing circuit. If both tones are present for the minimum guard time, t_{GTP} which is determined by the external RC network, the DTMF signal is decoded and the resulting data (Table 1) is latched in the output register. The Delayed Steering (StD) output is raised and indicates that new data is available. The time required to receive a valid DTMF signal, t_{REC} , is equal to the sum of t_{DP} and t_{GTP} .

| f _{LOW} | f _{HIGH} | KEY | TOE | Q ₄ | Q ₃ | Q ₂ | Q ₁ |
|------------------|-------------------|-----|-----|----------------|----------------|----------------|----------------|
| 697 | 1209 | 1 | 1 | 0 | 0 | 0 | 1 |
| 697 | 1336 | 2 | 1 | 0 | 0 | 1 | 0 |
| 697 | 1477 | 3 | 1 | 0 | 0 | 1 | 1 |
| 770 | 1209 | 4 | 1 | 0 | 1 | 0 | 0 |
| 770 | 1336 | 5 | 1 | 0 | 1 | 0 | 1 |
| 770 | 1477 | 6 | 1 | 0 | 1 | 1 | 0 |
| 852 | 1209 | 7 | 1 | 0 | 1 | 1 | 1 |
| 852 | 1336 | 8 | 1 | 1 | 0 | 0 | 0 |
| 852 | 1477 | 9 | 1 | 1 | 0 | 0 | 1 |
| 941 | 1209 | 0 | 1 | 1 | 0 | 1 | 0 |
| 941 | 1336 | * | 1 | 1 | 0 | 1 | 1 |
| 941 | 1477 | # | 1 | 1 | 1 | 0 | 0 |
| 697 | 1633 | A | 1 | 1 | 1 | 0 | 1 |
| 770 | 1633 | B | 1 | 1 | 1 | 1 | 0 |
| 852 | 1633 | C | 1 | 1 | 1 | 1 | 1 |
| 941 | 1633 | D | 1 | 0 | 0 | 0 | 0 |
| - | - | ANY | 0 | Z | Z | Z | Z |

Table 1. MT8870 Output Truth Table

0=LOGIC LOW 1=LOGIC HIGH Z=HIGH IMPEDANCE
Output truth table. Note that key "0" is output as "1010₂
(ie:10₁₀)" corresponding to standard telephony coding.

A simplified circuit diagram (Fig. 5) illustrates how the chip's steering circuit drives the external RC network to generate guard times. Pin 17, St/GT (Steering/Guard Time), is a bidirectional signal pin which controls StD, the output latches, and resets the timing circuit. When St/GT is in its input mode (St function) both Q₁ and Q₂ are turned off and the voltage level at St/GT is compared to the steering threshold voltage V_{TSt} . A transition from below to above V_{TSt} will switch the comparator's output from



External guard time, input, and clock components (dashed) are included for clarity.

Figure 3 - MT8870 Functional Block Diagram

low to high strobing new data into the output latches, and raising the StD output. As long as an input level above V_{TSst} is maintained StD will remain high indicating the presence of a valid DTMF signal.

Initially, when no valid tone-pairs are present, capacitor C is fully charged applying a low voltage to St/GT. This causes a low at the comparator's output and since Est is also low, Q₂ turns on ensuring that C is completely charged. In this condition St/GT is in its output mode (GT function). When a valid tone-pair is received Est is raised turning off Q₂ which puts St/GT in its high impedance input mode and allows C to discharge through R. If this condition

persists for the tone-present guard time, t_{GTP} the voltage at St/GT rises above V_{TSst} raising StD which indicates reception of a valid DTMF signal. If the tone pair drops out before the duration of t_{GTP} Est is lowered turning on Q₂ which charges C resetting the tone-present guard time.

Once a DTMF signal is recognized as valid both Est and the comparator output are high. This turns on Q₁ which discharges C and initializes the tone-absent guard time, t_{GTA} . After the DTMF signal is removed, Est is lowered, Q₁ turns off placing St/GT in its input mode and C begins to charge through R.

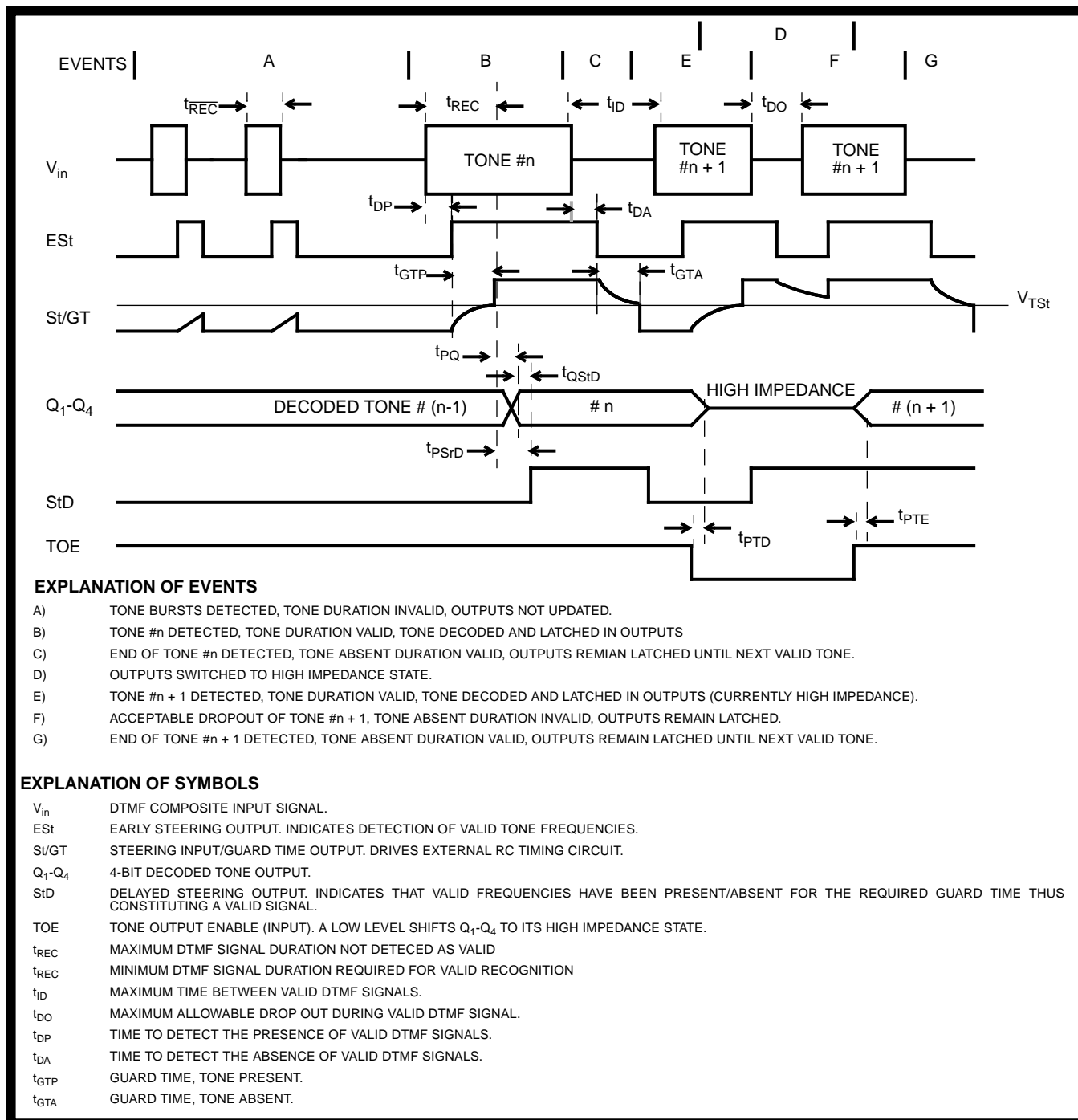


Figure 4 - MT8870 Timing Diagram

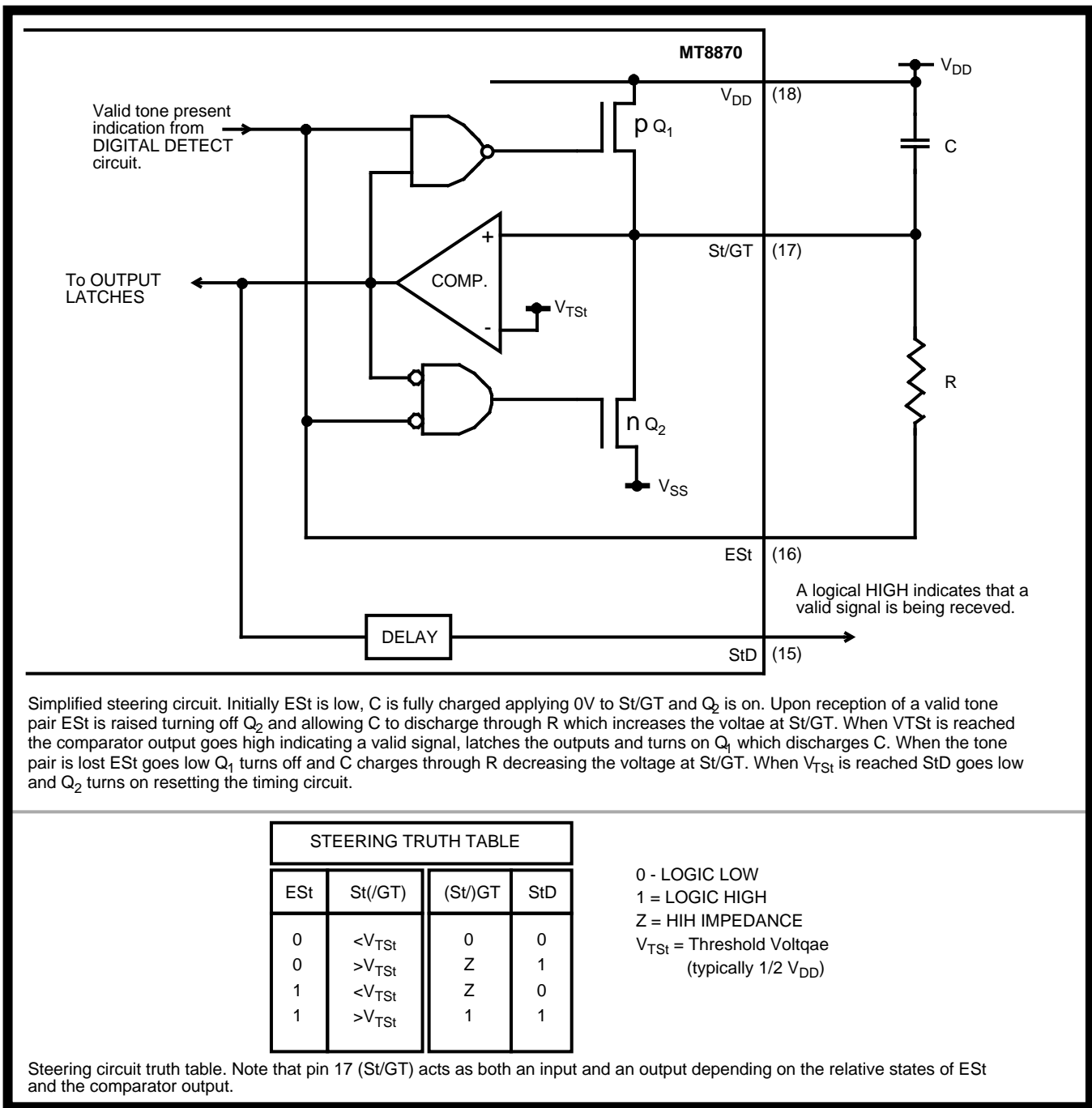


Figure 5 - MT8870 Steering And GuardTime Circuit Operation

If the same valid tone-pair does not reappear before t_{GTA} then the voltage at St/GT falls below V_{TSt} which resets the timing circuit via Q₂ and prepares the device to receive another signal. If the same valid tone-pair reappears before t_{GTA} , Est is raised turning on Q₁ and discharging C which resets t_{GTA} . In this case StD remains high and the tone dropout is disregarded as noise.

To provide good reliability in a typical telephony environment, a DTMF receiver should be designed to recognize a valid tone-pair greater than 40mS in duration and, to accept as successive digits, tone-pairs that are greater than 40mS apart. However in

other environments, such as two-way radio, the optimum tone duration and intra-digit times may differ due to noise considerations.

By adding an extra resistor and steering diode (Fig. 6b, 6c) t_{GTP} and t_{GTA} can be set to different values. Guard time adjustment allows tailoring of noise immunity and talk-off performance to meet specific system needs.

Talk-off is a measure of errors that occur when the receiver falsely detects a tone pair due to speech or background noise simulating a DTMF signal. Increasing t_{GTP} improves talk off performance since

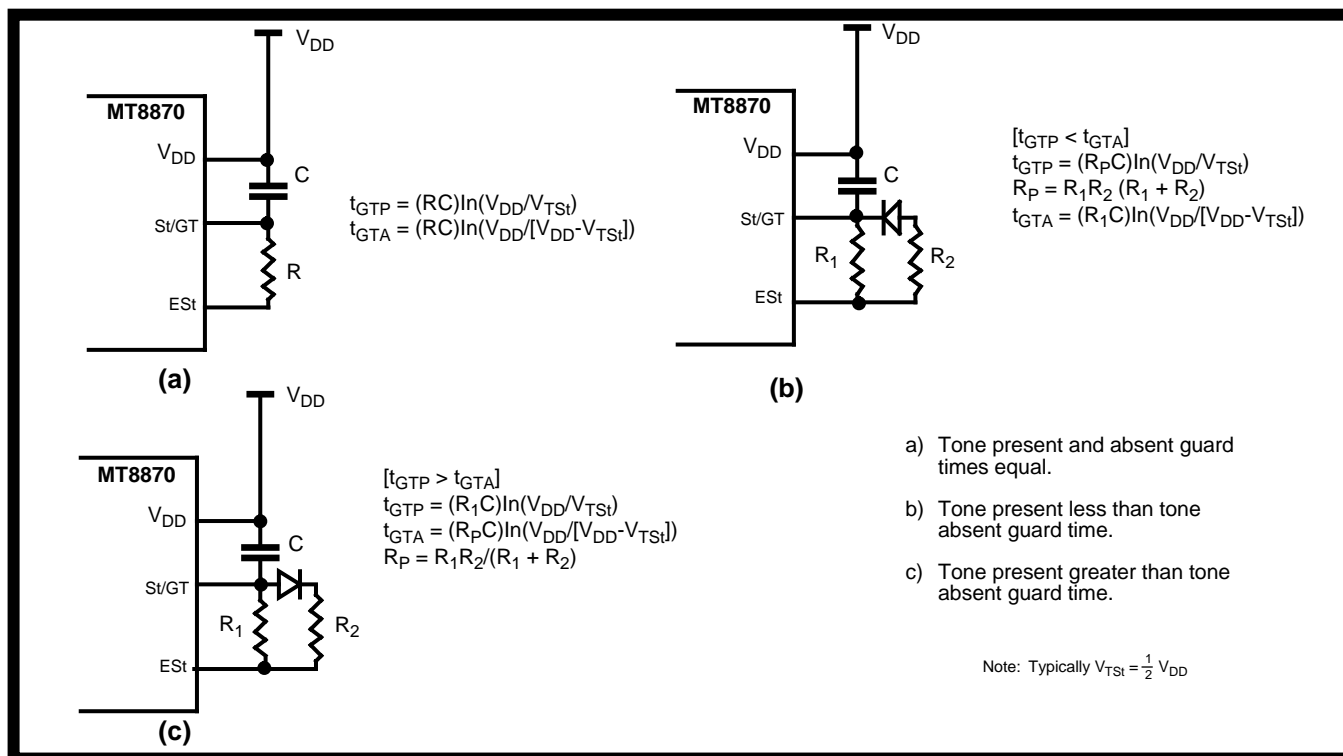


Figure 6 - Guard Time Circuits

it reduces the probability that speech will maintain DTMF simulation long enough to be considered valid. The trade-off here is decreased noise immunity because dropout (longer than t_{DA}) due to noise pulses will restart t_{GTP} . Therefore, for noisy environments, t_{GTP} should be decreased. The signal absent guard time, t_{GTA} , determines the minimum time allowed between successive DTMF signals. A dropout shorter than t_{GTA} will be considered noise and will not register as a successive valid tone detection. This guards against multiple reception of a single character. Therefore, lengthening t_{GTA} will increase noise immunity and tolerance to the presence of an unwanted third tone at the expense of decreasing the maximum signalling rate.

The intricacies of the digital detection algorithm have a significant impact on the overall receiver performance. It is here that the initial decision is made to accept the signal as valid or reject it as speech or noise.

Trade-offs must be made between eliminating talk off errors and eliminating the effects of unwanted third tone signals and noise. These are mutually conflicting events. On one hand valid DTMF signals present in noise must be recognized which requires relaxation of the detection criteria. On the other hand, relaxing the detection criteria increases the probability of receiving "hits" due to talk off errors.

Many considerations must be taken into account in evaluating criteria for noise rejection. In the telephony environment two sources of noise are predominant. These are, third tone interference, which generally comes from dial tone harmonics, and band-limited white noise. In the MT8870 a complex digital averaging algorithm provides excellent immunity to voice, third tone and noise signals which prevail in a typical voice bandwidth channel.

The algorithm used in the MT8870 combines the best features from two previous generations of Mitel digital decoders with improvements resulting from years of practical use within the telephone environment. The algorithm has evolved through a combination of statistical calculations and empirical "tweaks" to result in the realization of an extremely reliable decoder.

Applications

The proven reliability of DTMF signalling has created a vast spectrum of possible applications. Until recently, many of these applications were rendered ineffective due to cost or size considerations. Now that a complete DTMF receiver can be designed with merely a single chip and a few external passive components one can take full advantage of a highly developed signalling scheme as a small, cost-effective signalling solution.

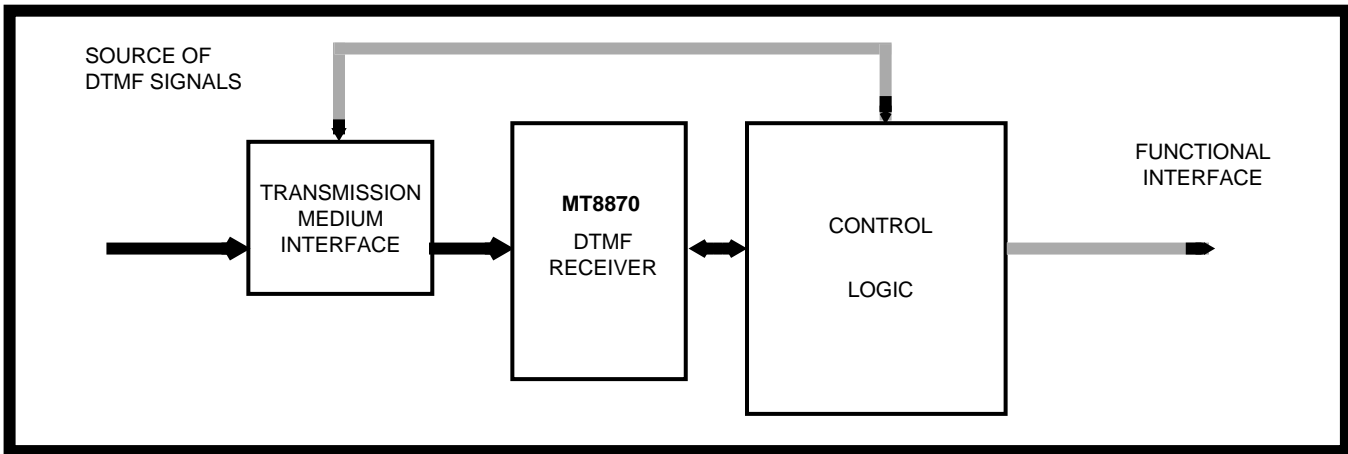


Figure 7 - Modular Approach to DTMF Receiver Systems

The design of a DTMF receiving system can generally be broken down into three functional blocks (Fig. 7). The first consideration is the interface to the transmission medium. This may be as simple as a few passive components to adequately configure the MT8870's input stage or as complex as some form of demodulation, multiplexing or analog switching system. The second functional block is the DTMF receiver itself. This is where the receiving system's parameters can be optimized for the specific signal conditions delivered from the "front end" interface. The third, and perhaps most widely varying function, is the output control logic. This may be as simple as a 4 to 16 line decoder, controlling a specific function for each DTMF code, or as complex as a full blown computer handling system protocols and adaptively varying the tone receiver's parameters to adjust for changing signal conditions. Several currently applied and conceptually designed applications are described subsequently but first let's consider the design of a typical input stage.

The input arrangement of the MT8870 provides a differential input op amp as well as a bias source (V_{REF}) which is used to bias the inputs at mid-rail. The output of this op amp is available to provide feedback for gain adjustment.

A typical single ended input configuration having unity gain is shown in Figure 8.

For balanced line applications good common mode rejection is offered by the differential configuration (Fig. 9). In both cases, the inputs are biased to $1/2 V_{DD}$ by V_{Ref} . Consider an input stage which will interface to a 600Ω balanced line. To reject common mode noise signals, a balanced differential amplifier input provides the solution.

With the input configured for unity gain the MT8870 will accept maximum signal levels of +1 dBm (into 600Ω). The lowest DTMF frequency that must be detected is approximately 685Hz. Allowing 0.1dB of

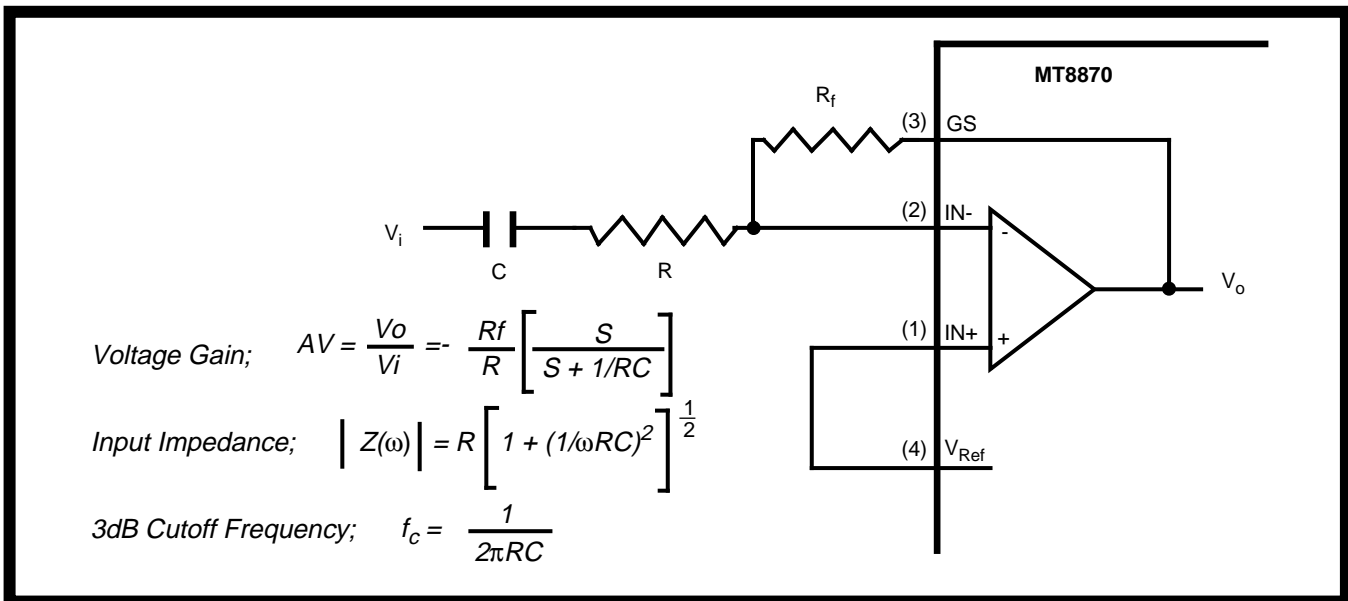


Figure 8 - Single Ended Input Configuration

attenuation at 685Hz, the required input time constant may be derived from;

$$M(\omega)_{dB} = 20 \log_{10} \frac{R_f}{R} + 20 \log_{10} \frac{\omega\tau}{\{(\omega\tau)^2 + 1\}^{1/2}}$$

where $M(\omega)_{dB}$ is the amplifier gain in decibels

ω is the radian frequency

τ is the input time constant

$$\text{Therefore } -0.1 = 20 \log_{10} \frac{(2\pi)685\tau}{\{[(2\pi)685\tau]^2 + 1\}^{1/2}}$$

$$\text{or } \tau = 1.52mS$$

Now, choosing $R=220K$ gives a high input impedance (440K in the passband) and $C = \tau/R = 6.9nF$ (use a standard value of 10 nF). For unity gain in the passband we choose $R_f=R$. R_a and R_b are biasing resistors. The choice of R_a is not critical and could be set at, say... 68K. Bias resistor R_a adds a zero to the non-inverting path through the differential amplifier but has no effect on the inverting

path. This zero can be exactly cancelled by the added pole due to R_b if R_b is chosen as;

$$R_b = \frac{R_a R_f}{R_a + R_f}$$

With appropriate input transient protection, this circuit will provide an excellent bridging interface across a properly terminated telephone line for end-to-end or key system applications. Transient protection may be achieved by splitting the input resistors and inserting zener diodes to achieve voltage clamping (Fig. 10). This allows the transient energy to be dissipated in the resistors and diodes and limits the maximum voltage that may appear at the op-amp inputs.

It is important to consider the amount of shunt capacitance introduced by the protection devices. In this case the parasitic capacitances of the zener diodes are in series which reduces their effect. Relatively large shunt capacitances will attenuate the high group frequencies causing the input signal to "twist" which degrades receiver performance.

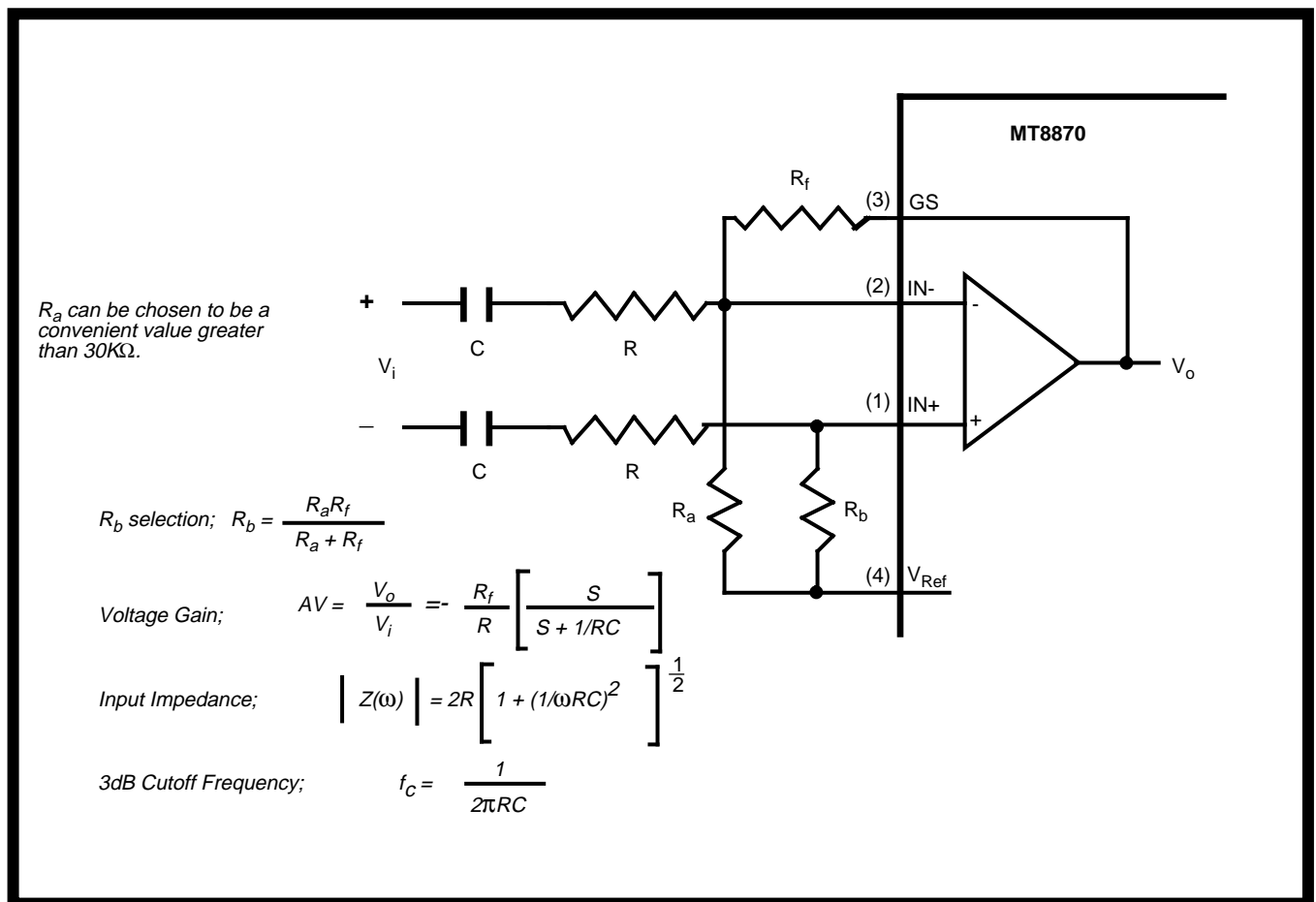


Figure 9 - Differential Input Configuration

"Twist" is known as the difference in amplitude between the low and high group tones. It is specified in dB as:

$$TWIST = 20 \log_{10} \frac{V_L}{V_H}$$

where V_L is the amplitude of the low frequency tone

and V_H is the amplitude of the high frequency tone.

Twist is usually caused by the frequency response characteristic of the communication channel. Along a telephone line higher frequencies tend to roll off faster than the lower ones so the line response is usually compensated for by applying pre-emphasis (negative twist) to the originating DTMF signal. In extreme cases the receiver may require compensation. This could be realized with a filter arrangement utilizing the input op amp.

Any communication path that can pass the human voice spectrum is eligible for DTMF signalling. Therefore a variety of "front-end" interfaces may be applicable in a given control system. More commonly used media are copper wire and RF channels. An optical fibre could carry a light beam modulated by DTMF. Although this would incur a large overhead in terms of bandwidth utilization, optical fibres do offer isolation from external electromagnetic interference. For example, if control or data signals must be sent near a high power transmission line environment, strong electric and magnetic fields could have a devastating effect on signals transmitted over wires. DTMF over fibre-

optics could easily be employed as a highly reliable communications method in a harsh interference infested environment.

In modern digital switching equipment the MT8870 can easily be interfaced to a digital PCM line by using a codec as an input interface (Fig. 11). Actually, all that is required for the interface is a PCM decoder. In fact, the output filter that normally is associated with PCM decoders is not required since the high group DTMF bandpass filter has an upper cutoff frequency low enough to meet the required roll-off of the PCM filter.

DTMF In Mobile Radio Applications

DTMF signalling plays an important role in distributed communications systems, such as multi-user mobile radio (Fig. 12). It is a "natural" in the two-way radio environment since it slips neatly into the center of the voice spectrum, has excellent noise immunity and highly integrated methods of implementation are currently available. It is also directly compatible with telephone signalling, simplifying automatic phone patch systems.

Several emergency medical service networks currently use DTMF signals to control radio repeaters. Functions are, typically, mobile identification, selection of appropriate repeater links, selection of repeater frequencies, reading of repeater status, and for completing automatic phone patch links.

If available in a system of this type, audio from a long distance communications link (microwave,

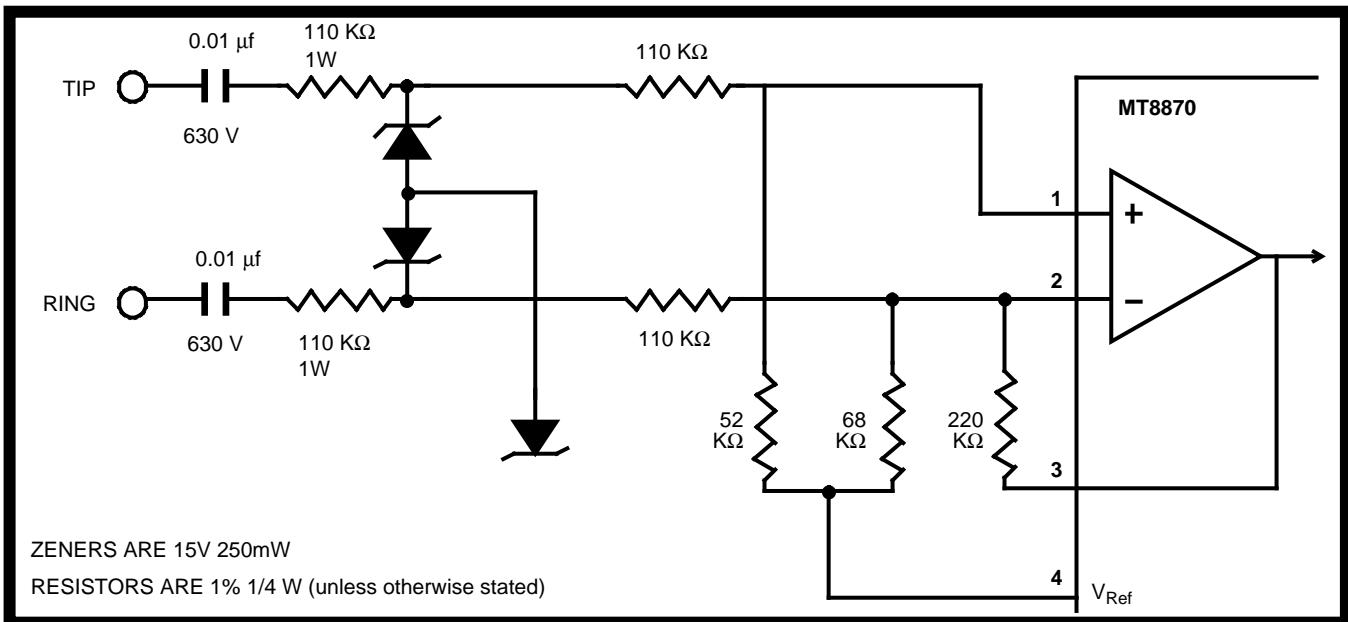


Figure 10 - MT8870 Front End Protection Circuit

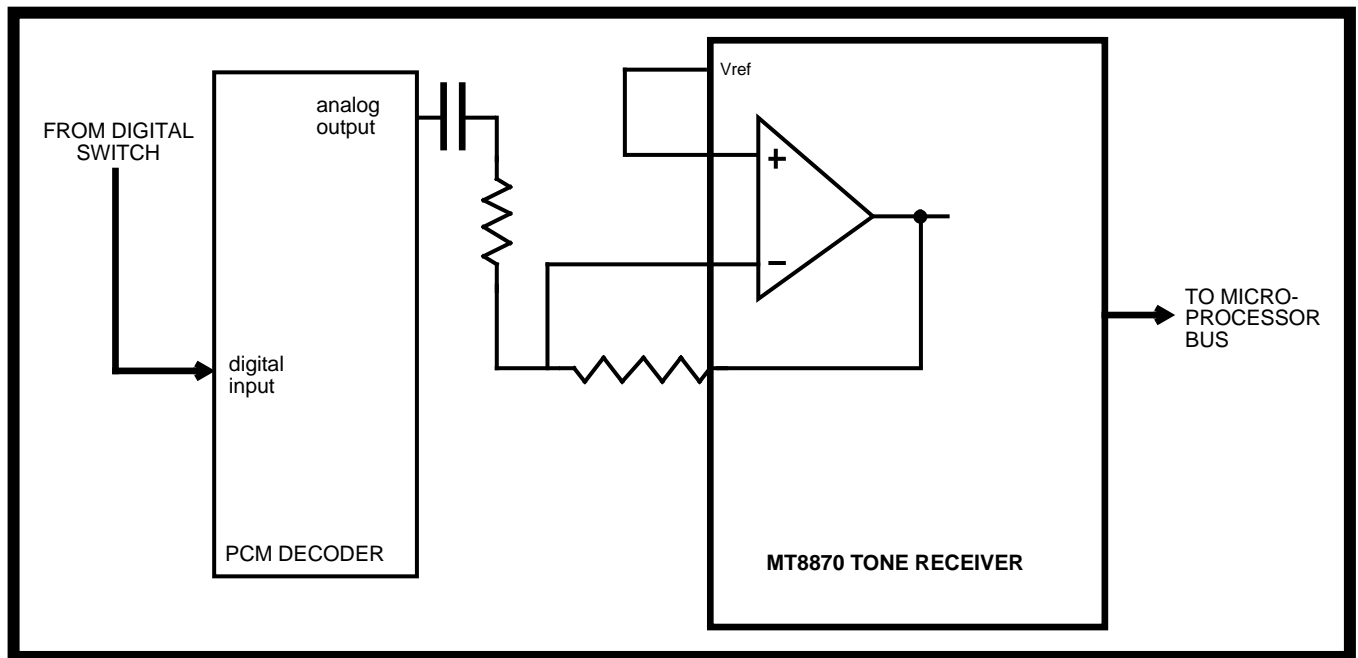
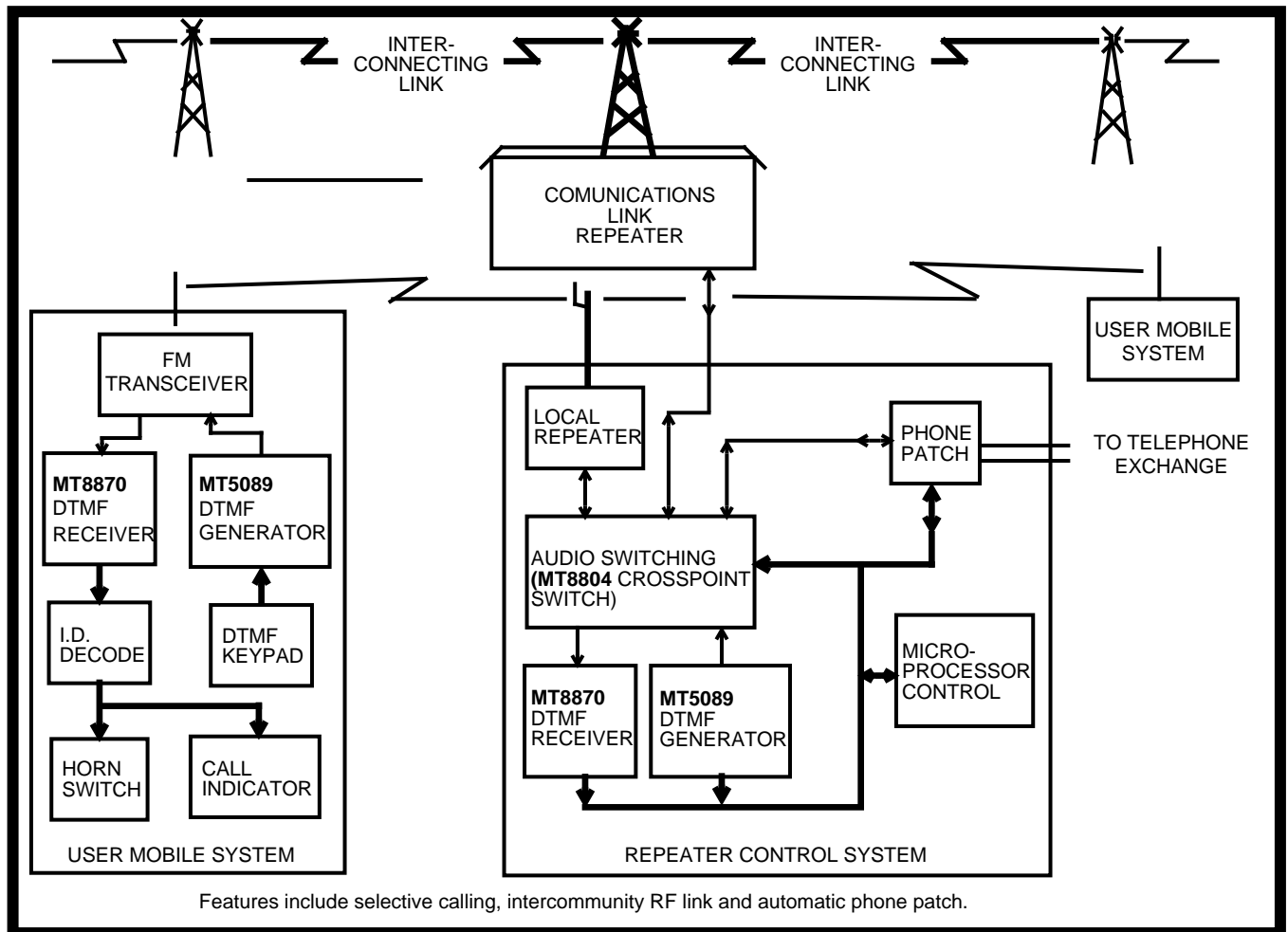


Figure 11 - Interfacing The MT8870 To A Digital PABX Or Central Office

satellite, etc.) could be switched, via commands from the user's DTMF keypad, into the local repeater. This would offer the mobile user a variety of paths for

communication without the assistance of a human operator.



Features include selective calling, intercommunity RF link and automatic phone patch.

Figure 12 - DTMF Controlled Radio Repeater

A multi-channel repeater system serving a multitude of user groups may be found to achieve its most effective performance in the "trunked" mode. In this case, one RF channel is reserved for system signalling. System operation could be achieved as follows.

Each mobile plus the repeater system contain a DTMF receiver, DTMF generator and appropriate control logic. Mobiles are assigned individual DTMF I.D. codes and always monitor the signalling channel when idle. An originating mobile automatically sends a DTMF sequence containing its own I.D. and the I.D. of the called party. This is recognized by the repeater control which retransmits the called party's I.D. The answering mobile returns a DTMF handshake indicating to the repeater control that it is available to accept a call. At this time the repeater control sends a DTMF command sequence to both the originating and answering mobiles which instructs their logic circuits to switch to a specific, available channel. If all channels are busy the repeater control could send DTMF sequences to put both mobiles on "hold" and add their I.D.'s to a "channel-request" queue. This arrangement would

allow users to access any available frequency and converse privately instead of being restricted to one assigned channel which is shared among several user groups.

As well as an individual I.D., each mobile belonging to a particular organization could also have a common group I.D. This would allow dispatch messages to be sent to all company mobiles simultaneously. Since mobiles would be under DTMF control, messages could be sent to an unattended vehicle and, at the user's convenience, displayed on a readout .

Each radio link either established or attempted would result in DTMF I.D. codes being sent to the repeater control. These occurrences could easily be collected by a computer for statistical analysis or billing information. Customers who have defaulted on rental payments could be denied access to the system.

Simplified block diagrams of the control systems for both the repeater and mobiles are shown in Figures 13 and 14 respectively.

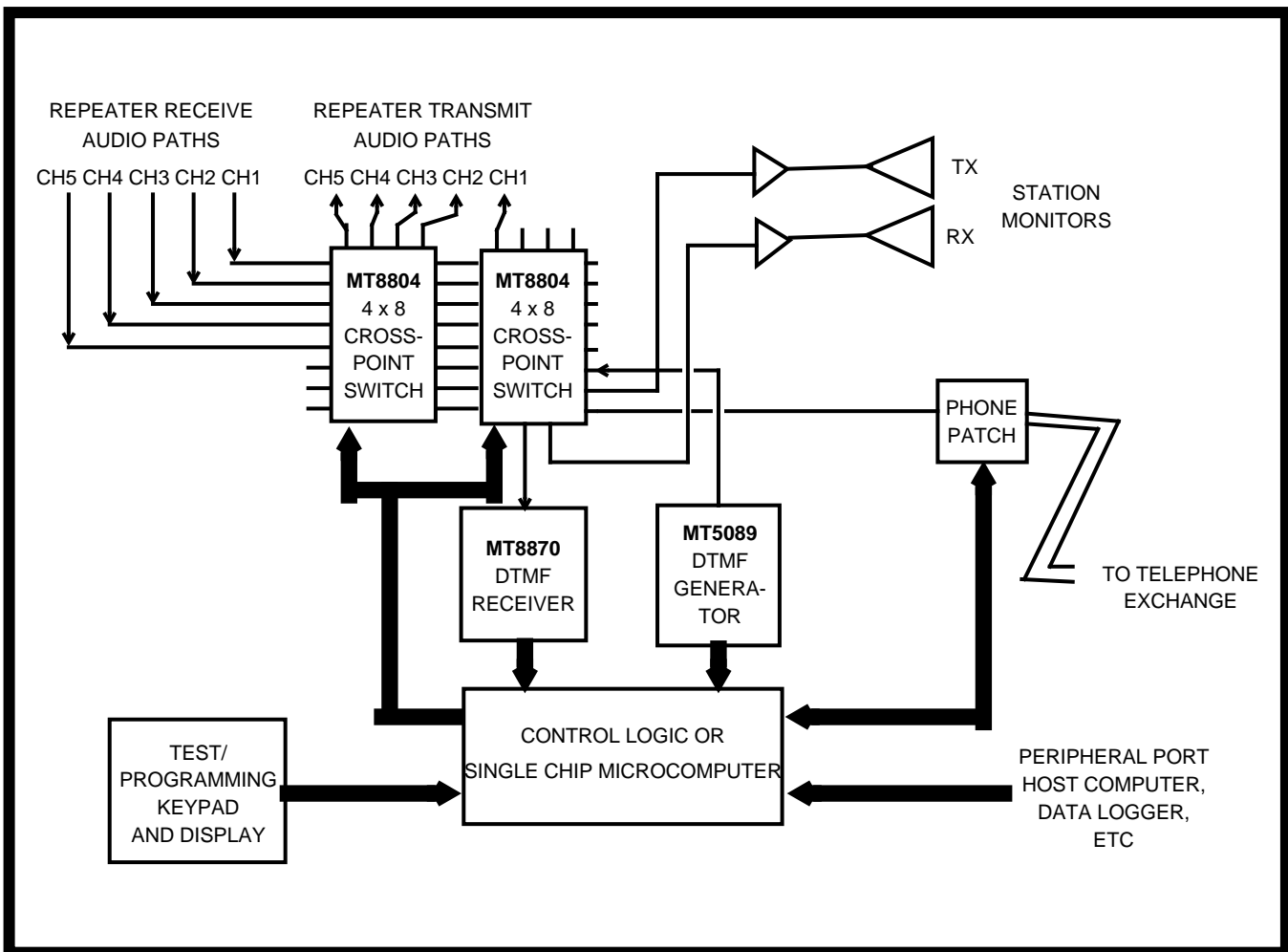


Figure 13 - Block Diagram of Control for "Trunked" Repeater System"

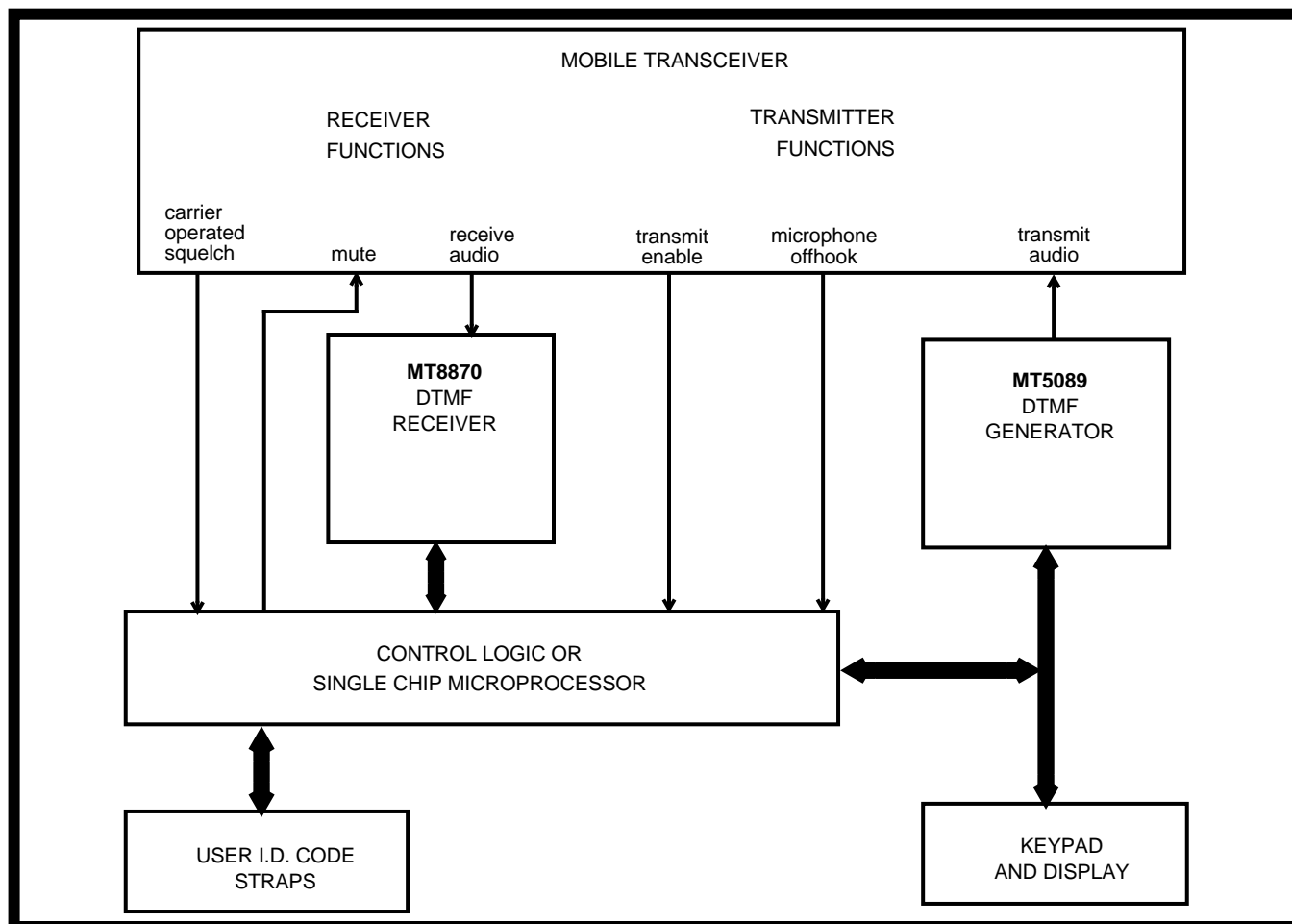


Figure 14 - Block Diagram of Mobile Radio Control System

Distributed Control Systems

There are many other applications which also fall into the distributed communications/control class. That is, several devices being controlled via a common communications medium whether it be RF, copper wire or optical fibres, etc.

Consider, for example, an existing pair of wires circulating throughout a plant. By connecting DTMF receivers at strategic points along this path one could conceivably control the whole plant from a single DTMF transmitter (Fig. 15). Each DTMF receiver would monitor the common line until its specific I.D. was received, at which time it would transfer data to its functional control logic.

With some simple logic a circuit can be devised to recognize a sequence of programmed DTMF code. Figure 16 illustrates a method of detecting a DTMF code sequence of arbitrary length, N. The object is to compare N sequential 4-bit DTMF data words to N preprogrammed 4-bit I.D. words. Programming the I.D. code is accomplished by applying the desired logic levels to the inputs of N 4-bit bus buffers. This may be achieved with straps as

shown, dipswitches or thumbwheels. Pull-up resistors should be applied to the buffer inputs. Initially, after a RESET has occurred, Q_0 of the presettable shift register is set logically high, the remaining outputs are reset. This activates the first bus buffer which applies its outputs to the Y inputs of a 4-bit comparator. The "LAST DIGIT" latch is reset, the "ERROR-" flip-flop and "VALID DIGIT" latch are set. These three signals are ANDed indicating a "no-match" condition. When a valid DTMF signal is received its data appears at the comparators "X" inputs, a comparison occurs and the result appears at the "X=Y" output. After $3.4 \mu\text{s}$ (typical) Std rises indicating that the MT8870 output data is valid and strobes "X=Y" into the "VALID DIGIT" latch. The shift register advances one position which enables the next bus buffer. If the result of the comparison was true then the "VALID DIGIT" output is high. If all digits of the sequence match then the high output from the shift register "wraps around" from Q_{N-1} to Q_0 , which strobes the "LAST DIGIT" latch high. This activates the three input AND gate indicating a "match" condition. If non-matching data is received any time during the detection sequence the "ERROR-" flip-flop is reset which disables the AND gate until a system "RESET" occurs. "RESET" may be generated in a variety of ways depending on the

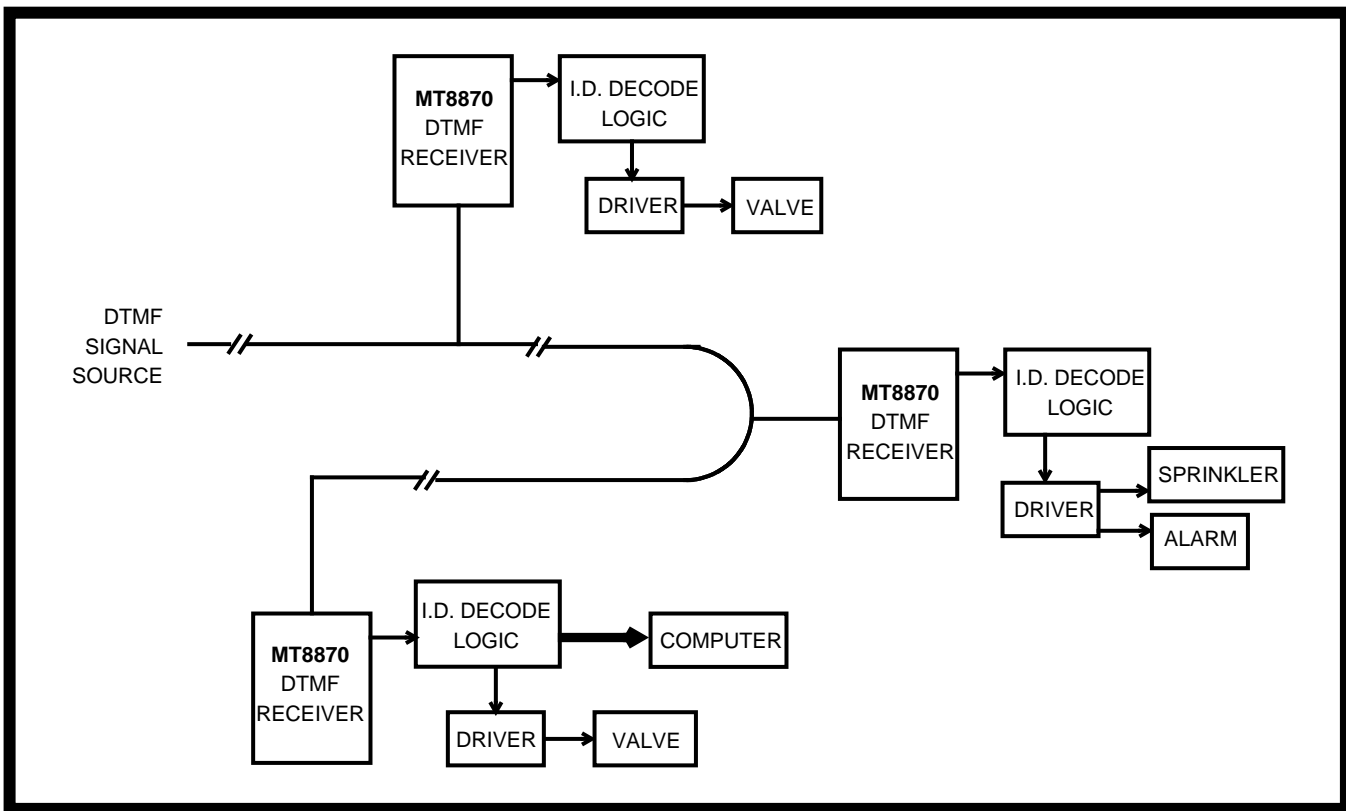


Figure 15 - Distributed Control System

system design objective. If one DTMF code is reserved exclusively for the "RESET" function then the MT8870 outputs can be decoded directly. This requires that the controller send a "RESET" command prior to sending an I.D. sequence. Alternatively a "time-out" timer, triggered by StD, could serve to generate a system reset if a certain time lapse occurs between received signals. This method places time constraints on the system but eliminates the need to consume a DTMF command for the "RESET" function.

The concept of using a common transmission medium for control signalling applies to several possible situations. Plant process control, remote measurement control, selective intercom call systems, institutional intercom systems, two way radio control, pocket pagers and model car or boat remote control, just to mention a few.

Conversely, data could be collected from distributed sources. Implemented on a circulating wire or an RF channel, as illustrated in Figure 17, information could be collected by a central unit which individually polls each monitor to ask for data. Alternatively, the system could be interrupt driven (Fig.18). In this case each monitor, when ready to send data, generates an interrupt request by sending a DTMF I.D. sequence followed by a data stream. Interrupt masking or prioritizing could be achieved from the the central control end by applying DC levels across

a wire pair or sending a pilot tone in an RF system. Remote data collection units would monitor this signal to detect when a higher priority interrupt is being handled or the communications channel is busy.

Data Communication Using DTMF

There is a vast array of potential applications for DTMF signalling using the existing telephone network. Considering that there are millions of ready-made data sets installed in convenient locations (i.e. the Touch Tone telephone) remote control and data entry may be performed by users without requiring them to carry around bulky data modems.

Potential applications include:

- home remote control
- remote data entry from any Touch-Tone keypad
- credit card verification and inquiry
- salesman order entry
- catalogue store (stock/price returned via voice synthesis)
- stock broker buy/sell/inquire -using stock exchange listing mnemonics
- answering machine message retrieval
- automatic switchboard extension forwarding

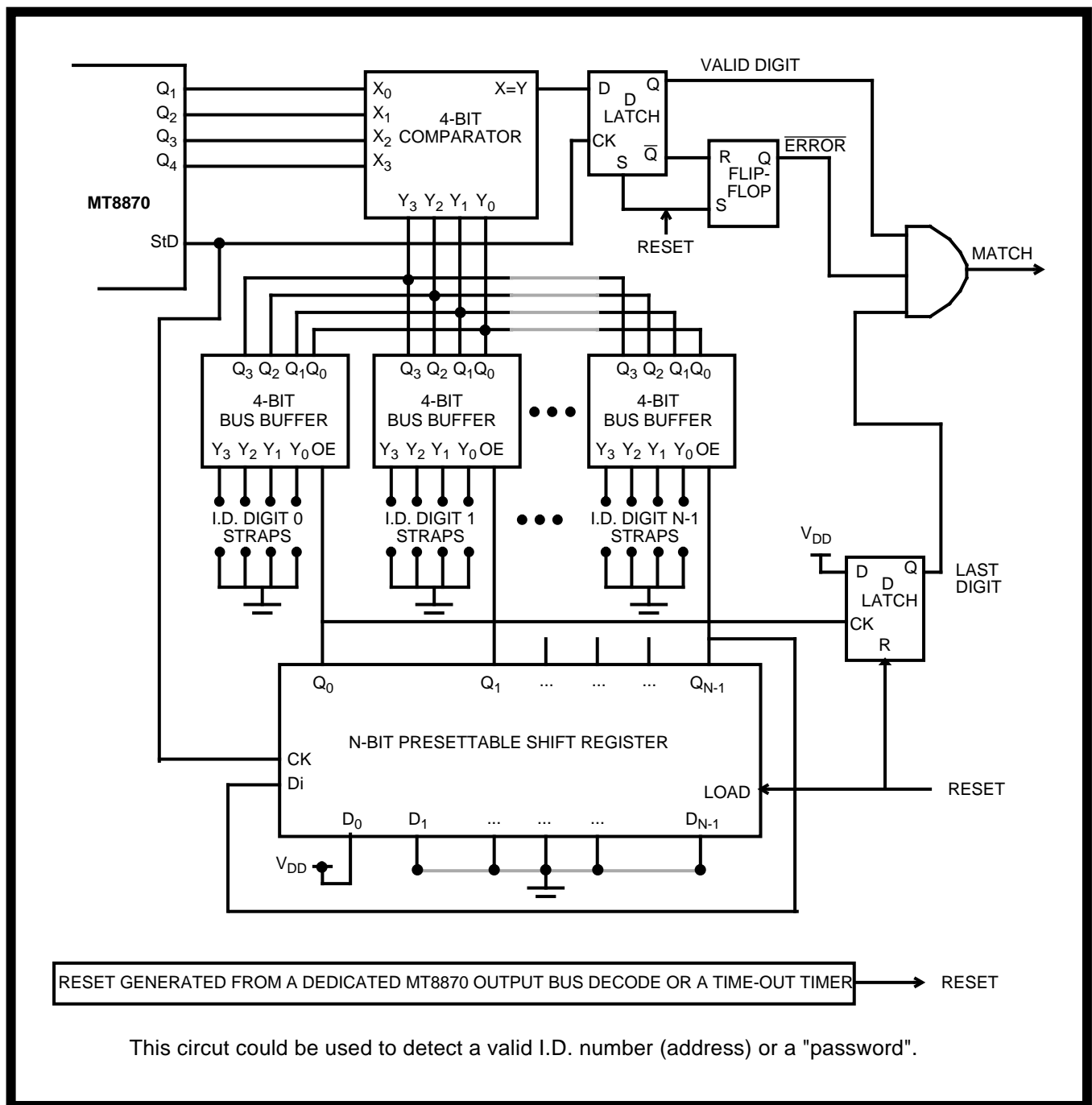


Figure 16 - N-Character Sequence Identifier

A household DTMF remote control system with an optional data port can boast a variety of conveniences (Fig. 19). Remote ON/OFF control may be given to electric appliances such as a slow cooker, exterior lighting and garage heater. An electro-mechanical solenoid operated valve allows remote control of a garden sprinkler. Video buffs could interface to their VCR remote control inputs and record T.V. shows with a few keystrokes of their friend's telephone. This would enhance the function of timers which are currently available on most VCR's. Schedule changes or unexpected broadcasts could be captured from any remote

location featuring a Touch-Tone™ phone. Security systems could be controlled and a microphone could be switched in for remote audio monitoring. Interfacing a home computer to the data port makes an excellent family message center. At the remote end messages are entered from a telephone keypad. The computer responds with voice messages generated by a speech synthesizer. In the home, messages to be left are entered via the computer keyboard. Messages to be read may be displayed on the computer monitor or "played back" through the speech synthesizer.

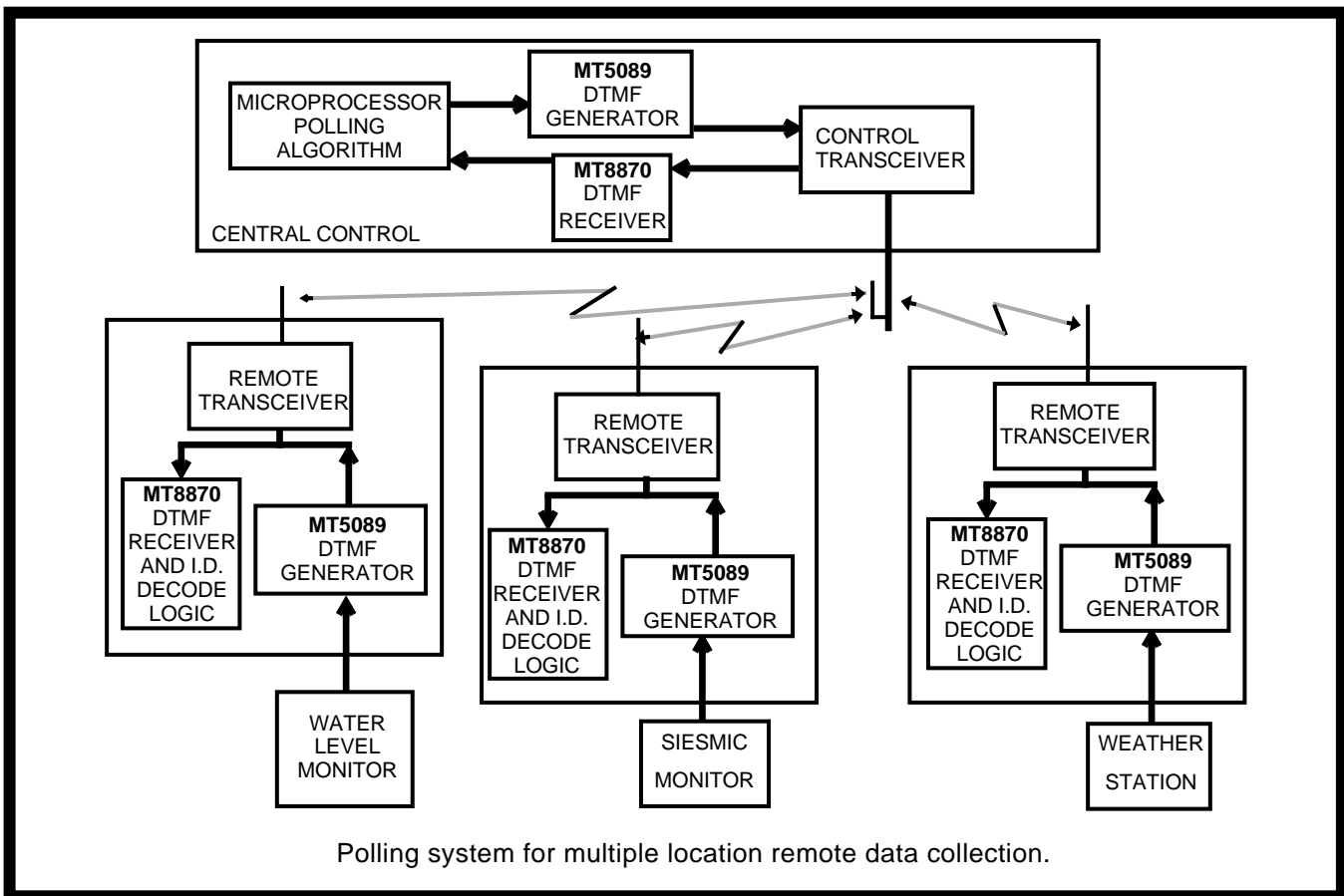


Figure 17 - DTMF Controlled Data Collection

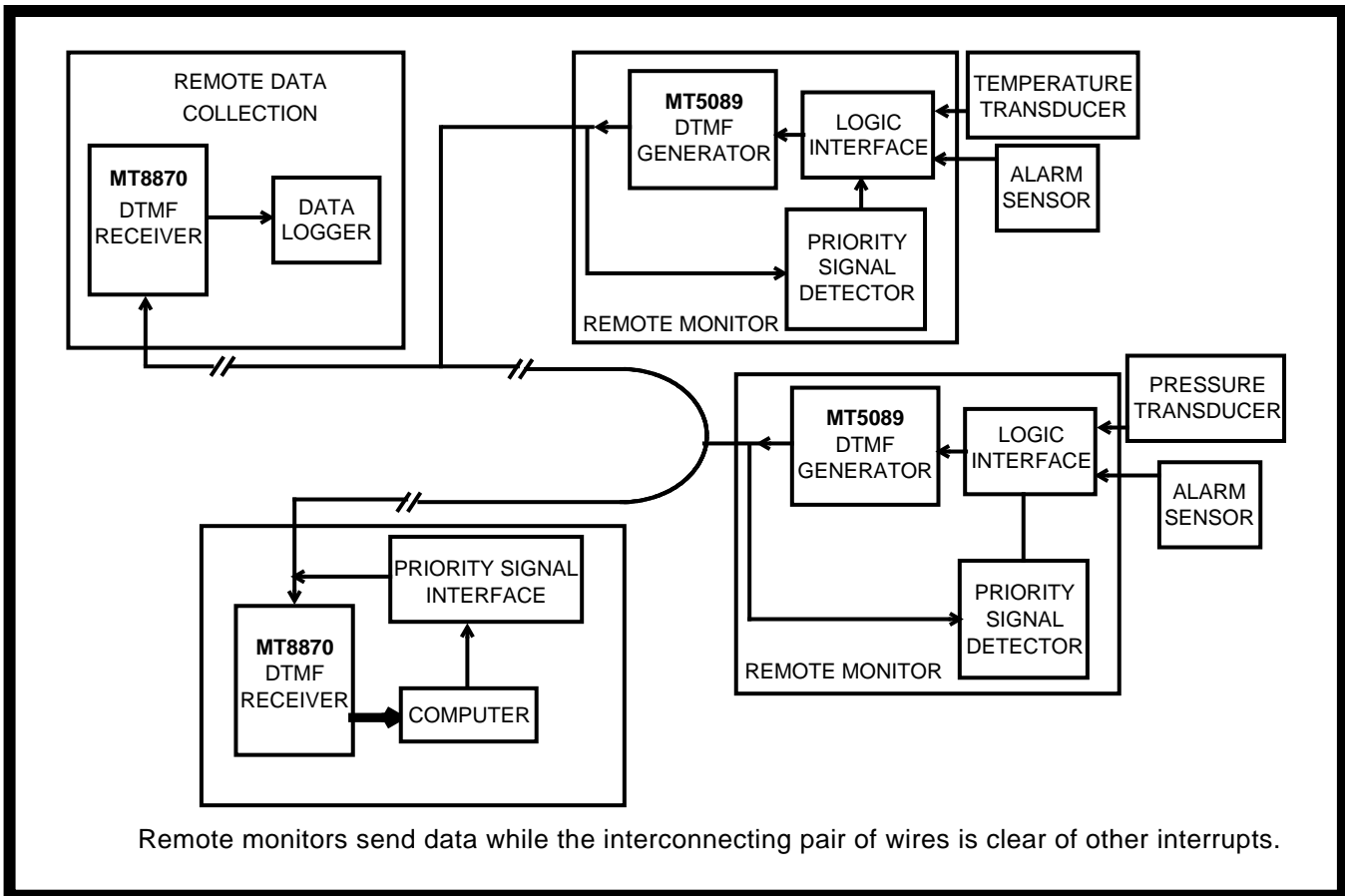


Figure 18 - Interrupt Driven Data Collection System

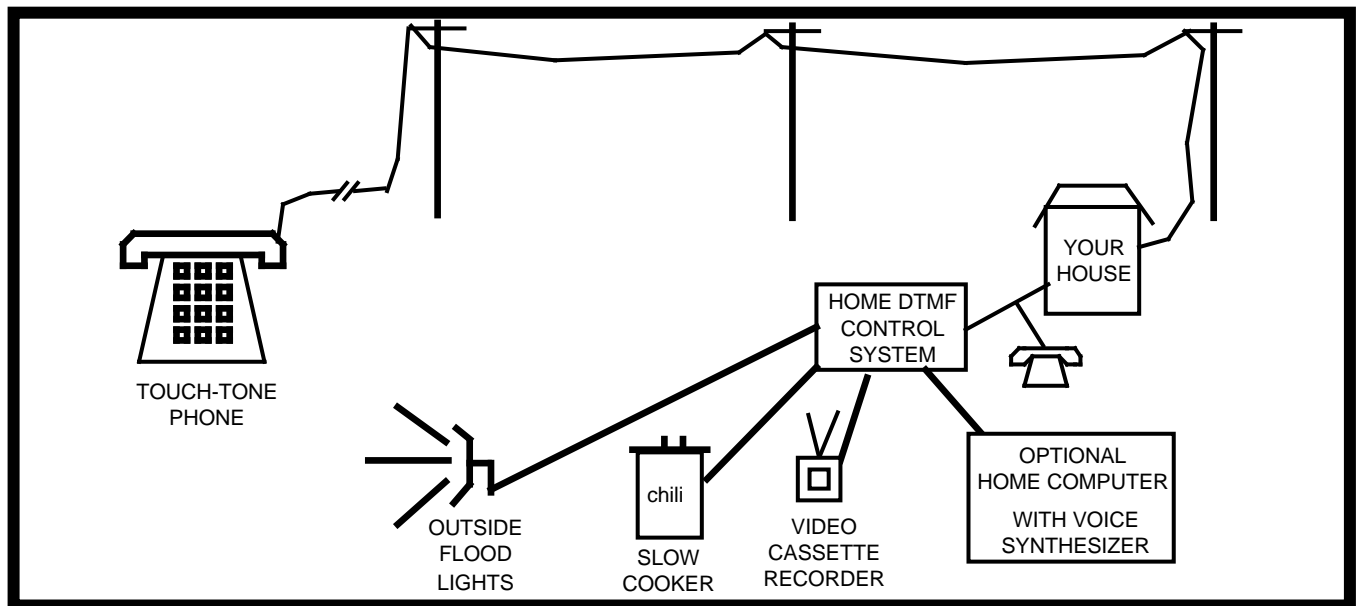


Figure 19 - Home DTMF Remote Control System

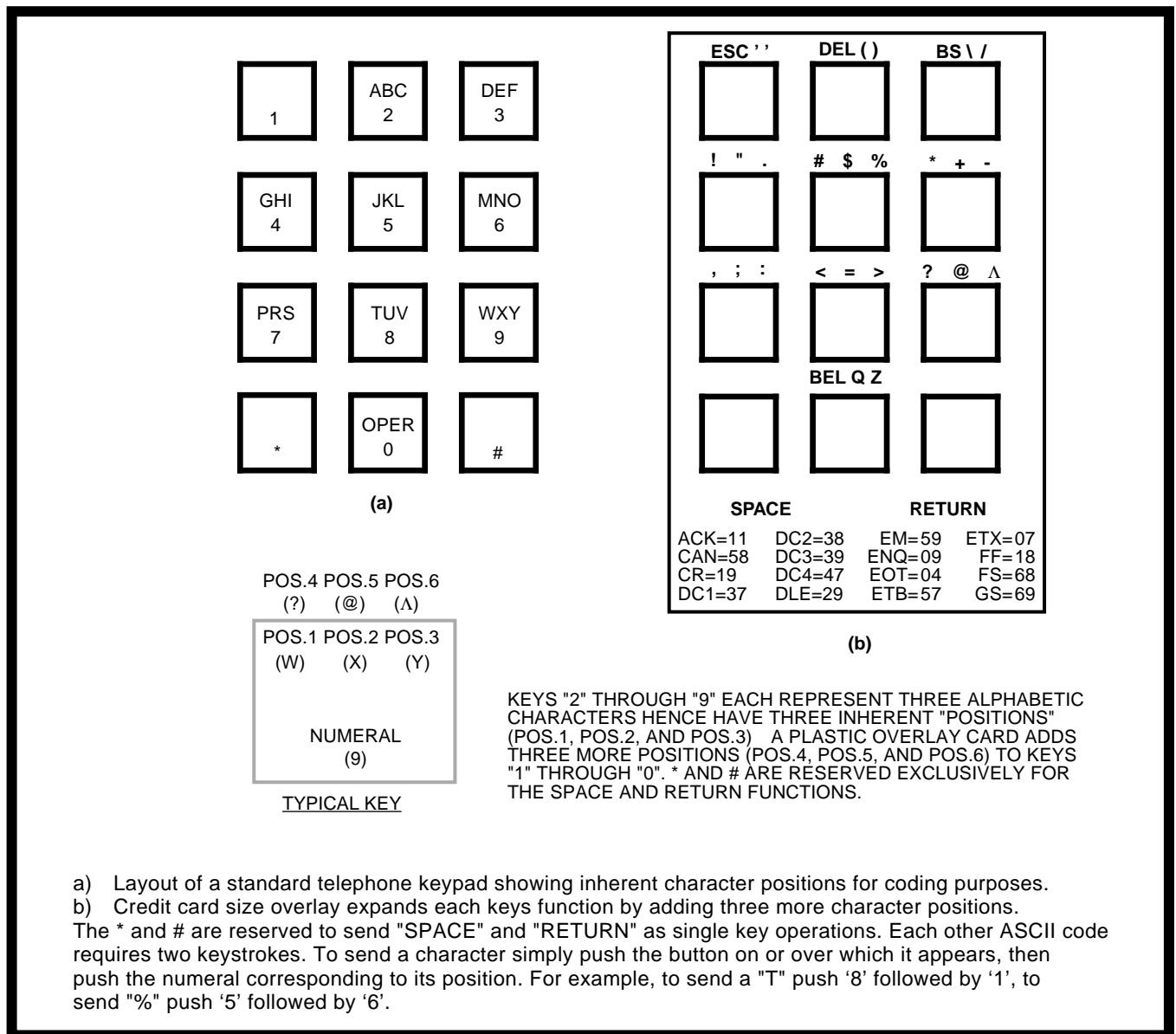


Figure 20 - Using A Pushbutton Phone As A Data Terminal

A scheme for coding ASCII characters using one and two digit DTMF signals is outlined in the appendix. Notice that on a telephone keypad keys 2 through 9 are represented by three alpha-characters as well as a numeral. To send an alpha-character, using this scheme, first press the key on which the character appears then press the key corresponding to the position in which the character appears on its key (1, 2 or 3). Numerals are sent by touching the desired number followed by a zero. The asterisk (*) and octothorp (#) have been reserved for "space" and "return" respectively. A plastic overlay the size of a credit card expands the number of useable "positions" on each button (Fig. 20). This serves as a guide for sending other ASCII codes and fits snug into a credit card wallet. ASCII control characters that are not commonly used could be listed at the bottom of the card. This user-friendly algorithm

eliminates the need to memorize conversion codes and allows significant functionality even without the overlay reference.

A simple block diagram shows how this scheme may be implemented for a home DTMF control system (Fig. 21). A ringing voltage detector signals the microprocessor of an incoming call. The microprocessor, after the prescribed number of rings, closes the answer relay engaging the proper terminating impedance. A two-to-four wire converter splits bidirectional audio from the balanced telephone line into separate single ended transmit and receive paths.

Receive audio is then switched to the DTMF receiver through the crosspoint switch. Upon receiving a valid DTMF signal, the microprocessor is alerted by

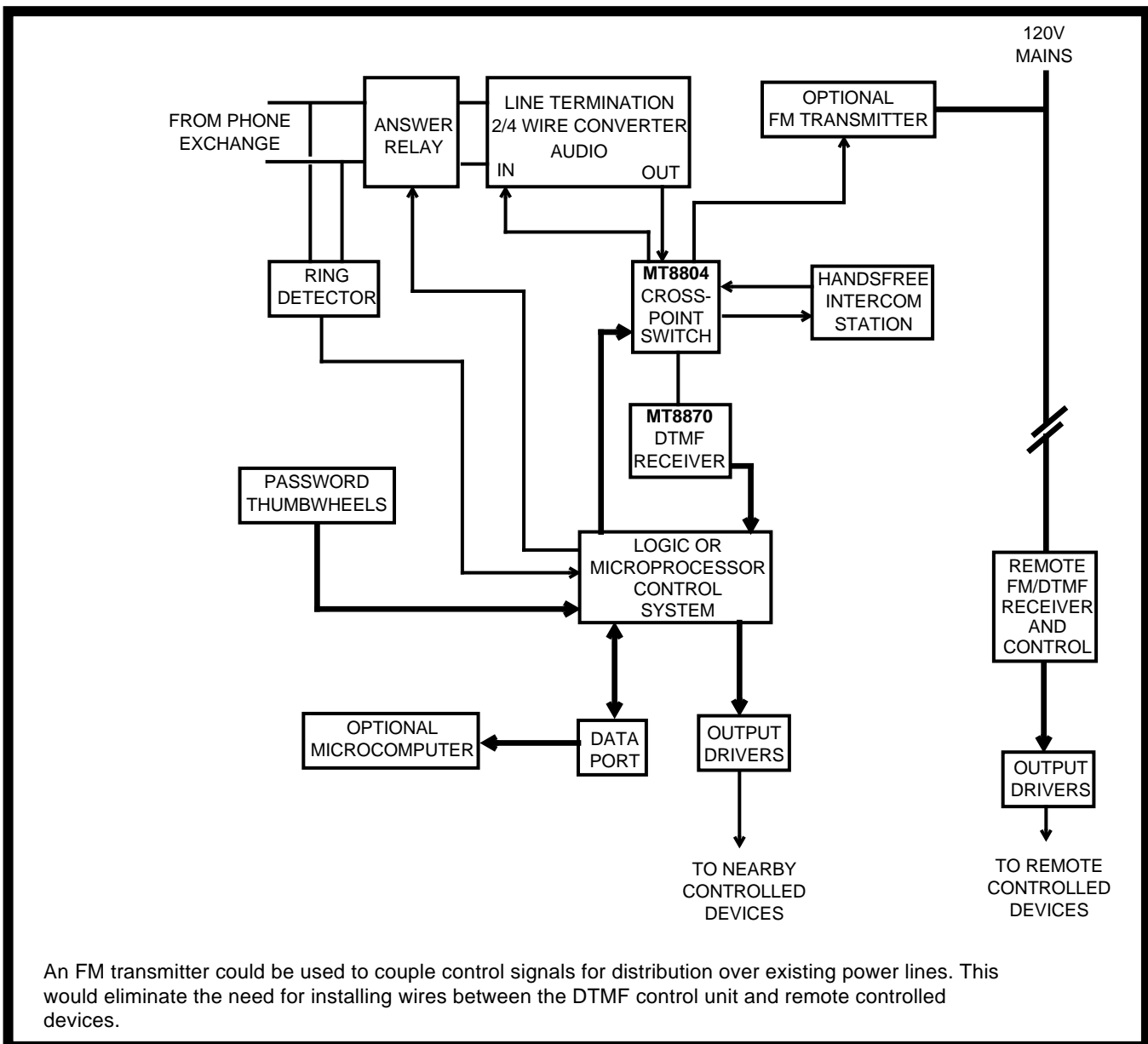


Figure 21 - Block Diagram of Home DTMF Remote Control System

the rising edge of StD. The microprocessor then checks for a valid password sequence and decodes subsequent commands. A command can be entered to put the system into remote-control mode. In this case the crosspoint switch is configured to route DTMF signals into the FM-over-mains transmitter as well as the system tone receiver. Forwarding of control signals is accomplished by applying an FM carrier to the power line. This eliminates the need to string control wires haphazardly about the house. The appropriate device is selected by its unique DTMF I.D. code. The microcomputer keeps track of all device locations and their I.D. codes since it must decide when to supply function outputs to the "nearby" devices and when to let the "remote" receivers handle the data. Subsequent data is transmitted to a selected device until a 'reset' command is entered.

Upon receiving any DTMF signal, answer back tones are returned by the microprocessor to acknowledge valid or invalid operations and to indicate the state of an interrogated device. For example, a low to high tone transition could indicate that a particular device is on, a high to low transition indicating the off state. A command could be entered to put the system in an 'external' mode which would allow communications through the data port. A host computer could be connected to this port to broaden the scope of the system.

The resident microprocessor unit contains the software and hardware to control ringing verification,

password and command decoding, answer back tone generation, audio routing, output function latches and an optional data port. Output drivers buffer the latches and switch relays or SCRs to control peripheral devices.

An infinite variety of devices could be controlled by such a system, the spectrum of which is limited only by the ability to provide appropriate interfacing. This system could also be the heart of a DTMF intercom system allowing intercommunication, "phone-patching", and remote control from varied household locations. This type of system concept is, of course, anything but limited to home use. Many applications can provide conveniences to consumers, salespeople and executives.

For example, a merchant could verify credit card accounts quickly utilizing only a telephone keypad for data entry (Fig. 22). Each credit card company could reserve one or more telephone lines to provide this function, reducing the human effort required. The receiving end system would be required to answer the call, provide a short answer back tone or message, receive and decode the credit card account number, verify it, verify the owner's name and give a go/no-go authorization. This return data could easily be provided with the aid of a voice synthesizer. An auto-dialler containing appropriate phone numbers could be installed at the merchant end as an added time saver.

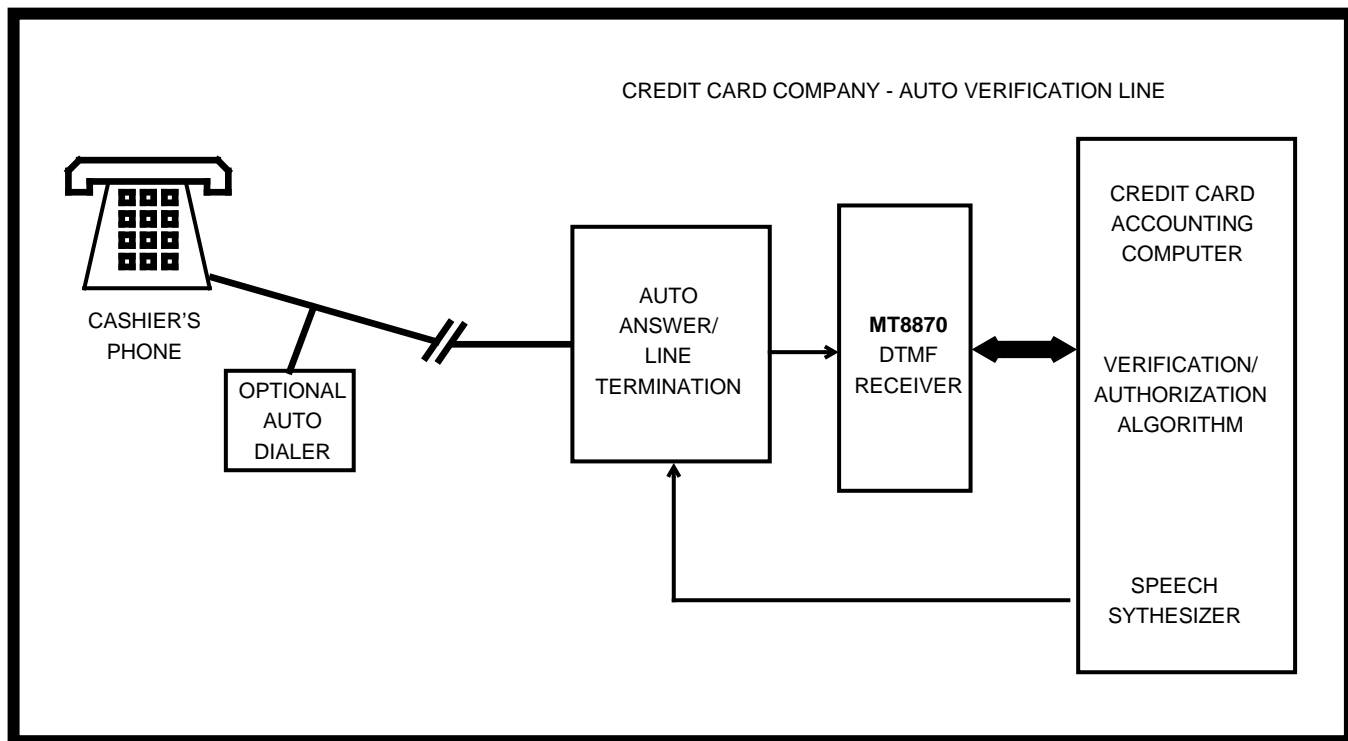


Figure 22 DTMF Data Communications For An Auto Verification Line

With a similar arrangement, a travelling salesman could access price, delivery and customer status, enter or delete merchandise orders and retrieve messages all from the comfort of the customer's office (Fig. 23a). A department store could provide shop-by-phone service to its customers using telephone keypad data entry (Fig. 23b). Brokerage firms, utilizing the stock exchange mnemonic listings could provide trading price information and buy/sell service via telephone keypad entry. A voice synthesizer could provide opening and current trading price, volume of transactions and other pertinent data. A telephone answering system manufacturer could apply this technique, allowing users to access and change outgoing and incoming messages from a Touch-Tone phone.

A PBX manufacturer could offer a feature that relieves the switchboard attendant from unnecessary interaction. A call could be answered automatically and a recording may reply "Thank you for calling XYZ. Please dial the extension you wish to contact or zero for the switchboard". If the caller knows the called party's extension in advance it is not necessary to wait for the switchboard attendant to

forward the call. The attendant could be notified to intervene if there is no action by the caller say, ten seconds after the recording ends. This provides a similar function to a "Direct Inward Dialling" (DID) trunk but without the additional overhead incurred with renting a block of phone numbers as in the DID case.

Now that a DTMF receiver is so easy and inexpensive to implement there are many simple dedicated uses that become attractive. A useful home and office application for DTMF receivers is in a self-contained telephone-line-powered toll call restrictor similar to the block diagram in Fig. 2a. This could be installed in an individual telephone or at the incoming main termination depending on which phone or phones are to be restricted. While disallowing visitors from making unauthorized long distance calls, the owner may still desire access to toll dialling. This could be provided by adding a logic circuit that disables the toll restrictor upon receiving a predetermined sequence of DTMF characters (Fig. 16). In this case, the user must enter his password before dialling a long distance number.

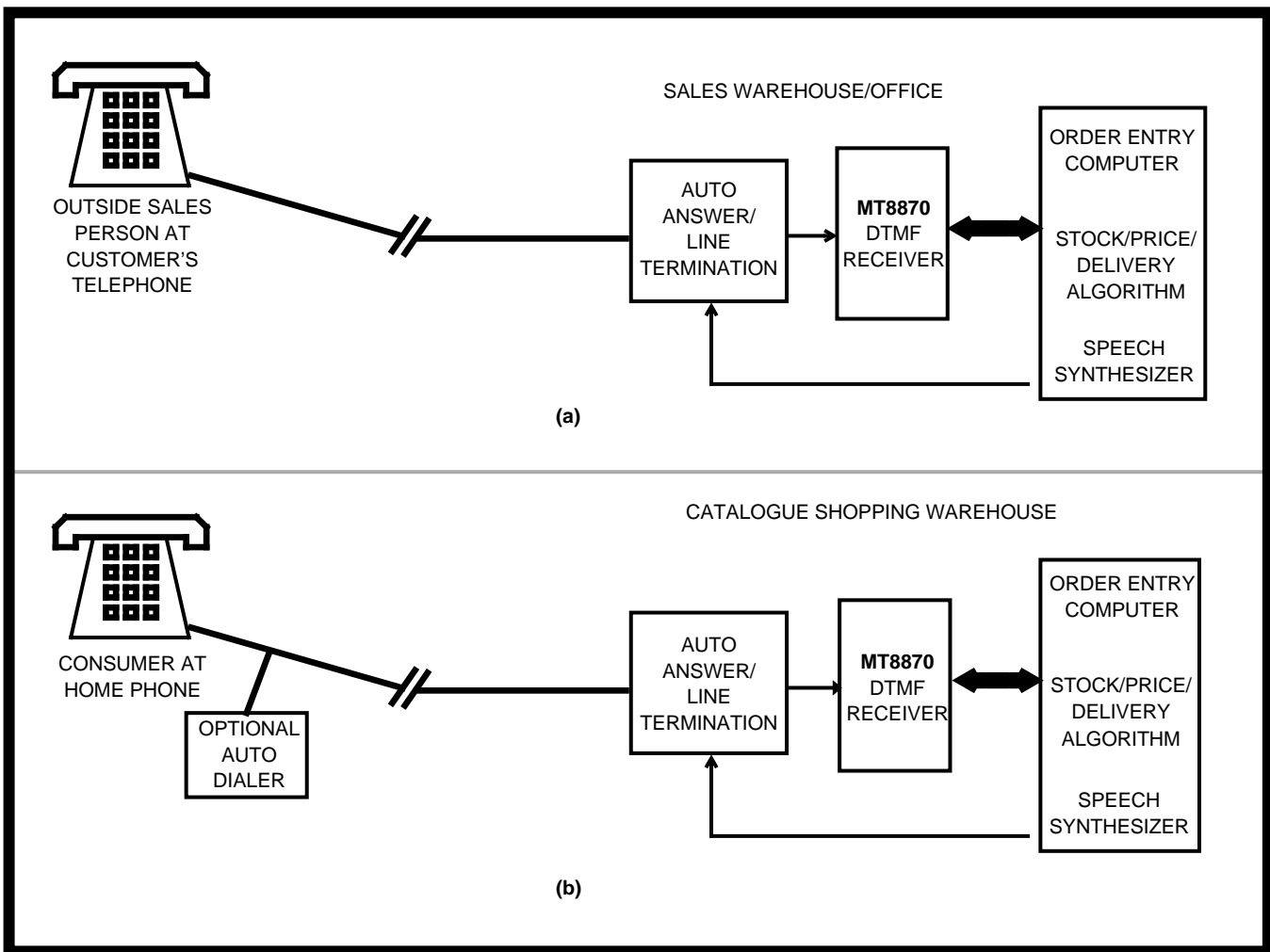


Figure 23 - Two Applications Of DTMF Data Communications

Conclusion

The applications for DTMF signalling are tremendous and due to innovative technological advances its use is increasingly widespread. DTMF offers highly reliable, cost effective signalling solutions which require no development effort on the user's part. The advent of single chip receivers has allowed many products that were previously not cost-effective to be manufactured in production quantities.

DTMF signalling was originally designed for telephony signalling over voice quality telephone lines. This signalling technique has been applied to a multitude of control and data communications systems. All that is required is a voice quality communication channel with appropriate interfacing. The applications are limited only by one's imagination.

Appendix

| ASCII TO DTMF CONVERSION | | | | | | | | |
|--|-----|------|-------|-----|------|-------|-----|------|
| Partial ASCII coding and conversion to 2 sequential DTMF signals | | | | | | | | |
| ASCII | HEX | DTMF | ASCII | HEX | DTMF | ASCII | HEX | DTMF |
| ACK | 06 | 11 | ! | 21 | 44 | A | 41 | 21 |
| BEL | 07 | 01 | " | 22 | 45 | B | 42 | 22 |
| BS | 08 | 34 | # | 23 | 54 | C | 43 | 23 |
| CAN | 18 | 58 | \$ | 24 | 55 | D | 44 | 31 |
| CR | 0D | 19 | % | 25 | 56 | E | 45 | 32 |
| DC1 | 11 | 37 | & | 26 | 79 | F | 46 | 33 |
| DC2 | 12 | 38 | ' | 27 | 16 | G | 47 | 41 |
| DC3 | 13 | 39 | (| 28 | 25 | H | 48 | 42 |
| DC4 | 14 | 47 |) | 29 | 26 | I | 49 | 43 |
| DEL | 7F | 24 | * | 2A | 64 | J | 4A | 51 |
| DLE | 10 | 29 | + | 2B | 65 | K | 4B | 52 |
| EM | 19 | 59 | , | 2C | 74 | L | 4C | 53 |
| ENQ | 05 | 09 | - | 2D | 66 | M | 4D | 61 |
| EOT | 04 | 08 | . | 2E | 46 | N | 4E | 62 |
| ESC | 1B | 14 | / | 2F | 36 | O | 4F | 63 |
| ETB | 17 | 57 | 0 | 30 | 00 | P | 50 | 71 |
| ETX | 03 | 07 | 1 | 31 | 10 | Q | 51 | 02 |
| FF | 0C | 18 | 2 | 32 | 20 | R | 52 | 72 |
| FS | 1C | 68 | 3 | 33 | 30 | S | 53 | 73 |
| GS | 1D | 69 | 4 | 34 | 40 | T | 54 | 81 |
| HT | 09 | 12 | 5 | 35 | 50 | U | 55 | 82 |
| LF | 0A | 13 | 6 | 36 | 60 | V | 56 | 83 |
| NAK | 15 | 48 | 7 | 37 | 70 | W | 57 | 91 |
| NUL | 00 | 04 | 8 | 38 | 80 | X | 58 | 92 |
| RS | 1E | 77 | 9 | 39 | 90 | Y | 59 | 93 |
| S0 | 0E | 27 | : | 3A | 76 | Z | 5A | 03 |
| S1 | 0F | 28 | ; | 3B | 75 | [| 5B | 87 |
| SOH | 01 | 05 | < | 3C | 84 | \ | 5C | 35 |
| SP | 20 | * | = | 3D | 85 |] | 5D | 88 |
| STX | 02 | 06 | > | 3E | 86 | ^ | 5E | 96 |
| SUB | 1A | 67 | ? | 3F | 94 | ¯ | 5F | 89 |
| SYN | 16 | 49 | @ | 40 | 95 | , | 60 | 15 |
| US | 1F | 78 | | | | DEL | 7F | 24 |
| VT | 0B | 17 | | | | | | |