

WHAT

is

DTMF TONE



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1 Introduction

Dual Tone Multi Frequency, or DTMF as it is popularly known, is the technical term for the sound frequencies produced when a telephonic key is pressed. DTMF also known as touch tone was primarily used for telephone signaling to and from the local exchange, though today it finds several applications in the field of telecommunications and call centers.

A different frequency is assigned to each key in the telephone and there are two tones – one low frequency and another high frequency – that are played simultaneously when a key is pressed. This combination of two tones makes it nearly impossible to reproduce by the human voice.

Each of the four rows of keys in a telephone is assigned a low frequency tone and each of the three columns is assigned a high frequency tone. A fourth column of keys labeled as A, B, C, and D is optional and is mostly used in military networks.

2 History and Evolution

Before DTMF was introduced, telephone networks were dependent on pulse dialing. In pulse dialing, pulses are generated by rapidly connecting and disconnecting the telephone connection. Typically, each number corresponded to the same number of clicks, thus 1 was represented by one click, 2 by two clicks and so on. The numbers were dialed with a short gap between each digit in order to avoid the digit bleeding into the next digit. Pulse dialing had the disadvantage that it was limited to the local exchange connections and required an operator for connecting long distance calls. It was also easy to trick the phone system by tapping the hook, which is pushed down when the telephone is hung up.

Research on DTMF was initiated by Bell labs in the late fifties in an attempt to allow tone signals for long distance dialing. DTMF was being developed as the future of electronic telecommunications as opposed to the mechanical telecommunication networks that were prevalent at that time.

DTMF was introduced on November 18, 1963 under the trademark of 'Touch Tone' by Bell Systems. The first Touch Tone telephone was the Western Electric model 1500 with ten buttons, which was introduced on the same year. Using audio tones for signaling was not new and the Multi-Frequency signaling (MF) which was used by telephone exchanges for communicating with each other using in-band signaling was already around. Multi-frequency signaling uses a combination of two pure sine wave frequencies for signaling. Both CCITT and Bell System devised various MF signaling protocols. The in-band signaling between exchanges was based on a sixteen-digit keypad, which a telephone operator used to input the next leg of the destination telephone number for connecting to the downstream telephone operator. This semi-automated signaling and switching technology had the twin advantage of cost and time effectiveness as it was faster and cheaper to use MF.

The MF technology was a great success among specialists for establishing long distance telephone calls. The Touch Tone was an extension of this technology to the end consumer and was offered as a 'modern way' of placing calls where consumers can dial the destination telephone number directly without having to talk to a telephone operator. AT&T described the product as "a method for pushbutton signaling from customer stations using the voice transmission path". Engineers who designed the Touch Tone experimented with the keypad layout which would replace the rotary dial on telephone sets and the current layout with 1 in the upper-left and 0 at the bottom was chosen after testing nearly fifteen different layouts. During the initial days, mechanical switches were used in the keypads to select different taps on tuned coils and the microphone was disconnected every time a key was pressed in order to prevent the background noise from interfering with the DTMF tones that were transmitted. Each button activated two contacts, and the system was called dual tone multi frequency because of the two tones and multiple frequencies generated. The tones were then decoded by the switching center to identify which key was pressed.

When it came to selecting the frequencies for DTMF, the engineers wanted a set of frequencies that would not interfere with the MF based switching between telephone exchanges. Accordingly,

DTMF's frequencies were different from all pre-existing MF signaling protocols at that time – R2, R1, CCS4, and CCS5.

DTMF as used in consumer telephone push-button tone dialing was known by the trademark Touch Tone. Other vendors who manufactured equipment compatible with DTMF called the feature Tone dialing or used their own registered trademarks (as in the case of 'Digitone' of Northern Electric).

The initial research team had also examined the possibility of accessing computers through telephone lines and surveyed several companies to identify their needs for this. The # (hash) and *(star) keys were added based on the inputs received. A set of lettered keys A, B, C, and D were also added to facilitate menu selection, though it was later dropped from most phones. However, it was several years before these keys were widely used for suppressing caller IDs or for entering service codes. It was also used by public payphones that would accept credit cards for sending information from the magnetic strip.

Yet another use for the letter keys was by the military, where it was used to prioritize the calls. The relabeled letters were used to define the priority of the calls before dialing, in order to cut currently active calls, if required, allowing the more important traffic to flow through uninterrupted. The levels of priority available were Flash Override (A), Flash (B), Immediate (C), and Priority (D), in decreasing order of priority. Pressing any of these keys prioritized the call, overriding other calls on the network. For example, if B was pressed before dialing a number, the telephone switch would first look for available lines and if unavailable, try to disconnect any no-priority calls. If also unavailable, then it would disconnect the D and C priority calls in that order so as to free a line for this call. A Flash Override would stop all other calls on the trunks between the origin and destination of the current call and hence it was limited to the White House Communications Agency. However, this method of precedence dialing is largely obsolete today as military networks use number combinations to prioritize calls.

Once DTMF was launched, pulse dialing lost its significance. As a result, DTMF controlled switching systems were introduced in telephone exchanges in lieu of the equipment circuits that were used. Customer telephone sets were also upgraded to use DTMF circuits and tone dialing. Several tests were performed during the sixties on the DTMF system and it was made official during that time. Since then, DTMF has been used as the de facto telecommunications dialing and switching system.

3 Technology

DTMF is a very reliable means of signaling used by telecom companies to process information from customers. Whenever a number is dialed, the DTMF is decoded by the local exchange in order to route the call.

DTMF can be transmitted over telephone lines as well as over the internet. The tones are decoded on the receiving end and used for practical applications such as interacting with computer systems and answering machines. The interaction with a computer system is achieved using an IVR system. Over a regular landline, DTMF is sent as audio signals. DTMF tones are transmitted through the same wires that carry the voice signals. In the case of mobile phones, DTMF tones can be generated only after the connection is established. This feature is often used by call centers for gathering inputs from callers for selection of IVR menus, capturing account information for phone banking facilities and so on. In a VoIP phone, DTMF is transmitted as a data packet over the internet, however this is prone to errors such as echo or packet loss during transmission, distorting the data and making it difficult to rebuild the key press combination at the receiving end.

DTMF technology supports acoustic transfer. This means that DTMF tones can be transmitted by a standard speaker and received by a standard microphone.

Speech recognition technologies are another alternative used by call centers to offer the callers more flexibility for providing inputs during a call. However, speech recognition technologies have still a long way to go to achieve a high degree of accuracy and therefore most call centers prefer DTMF for user inputs as it is more reliable. The flip side of using DTMF is that with just 16 distinct tones, there are a limited number of permutations that can be used to transmit information.

3.1 DTMF Keys

When the DTMF enabled telephone sets were introduced, AT&T attempted to remove the letter codes that were affixed to the digits in the older pulse dial phones. Thus, the Touch Tone devices in the early sixties did not have letters above the digits. However, the use of named telephone numbers in ad campaigns forced AT&T to bring back the letter codes on the digit buttons. Typically, telephone sets (both rotary dial and tone dial ones) do not have any letters associated with the digit 1. Some sets did have the letters Q and Z on the 1 digit, but this is more of an exception rather than the rule. Several cellular phones put Q on the digit 7 and Z on the digit 9, but this again is different from land phones. As a result, marketing campaigns with named telephone numbers are best advised to avoid the use of the letters Q and Z. The letter codes assigned to each of the twelve numeric keys on a standard keypad is shown in the table below:

Key	Character
1	1
2	A, B, C, 2
3	D, E, F, 3

4	G, H, I, 4
5	J, K, L, 5
6	M, N, O, 6
7	P, Q, R, S, 7
8	T, U, V, 8
9	W, X, Y, Z, 9
0	(Zero)
*	(Clear)
#	(Enter)

3.2 DTMF Frequencies

There are sixteen DTMF signals, each of which is made up of two tones from eight different frequency signals. Twelve of these are commonly used by consumers with four being reserved for military use or use by exchanges. The keys A, B, C, D are usually absent from telephone sets used in homes and offices. These keys are system tones used for configuring telephone exchanges and to carry out special functions. The DTMF keypad for consumer use is designed in a four-row by three-column matrix. Each dial row is represented by a low tone frequency and each column by a high tone frequency.

The frequencies used are 697 Hz, 770 Hz, 852 Hz, 941 Hz, 1209 Hz, 1336 Hz, 1477Hz, and 1633 Hz. The frequencies were carefully chosen in such a way as to prevent harmonics. Thus, one can notice that no frequency is a multiple of another and the difference or sum between any two frequencies is not equal to any other frequency. The frequencies were initially designed with a ratio of 21/19, which is slightly less than a whole tone.

Additionally, the frequencies generated have to be within an error tolerance of 1.5% and the higher frequency is transmitted at 3 dB louder to compensate for any high frequency roll-off. The pair of signals represents the digit or symbol at the intersection of the row and column. For example, if the digit 5 has to be sent, the frequencies transmitted are 1336 Hz and 770 Hz in a sinusoidal combination.

	1209 Hz	1336 Hz	1477 Hz	Optional	
				Consumer	Military
				1633 Hz	
697 Hz	1	2	3	A	FO
770 Hz	4	5	6	B	F
852 Hz	7	8	9	C	I

941 Hz	*	0	#	D	P
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It is necessary that transmission paths are linear and distortion free in order to permit the accurate transmission of DTMF signals. Any distortion between the source and the decoder can result in inter-modulation products and consequent unreliable decoding. An example is the 2A-B inert modulation calculation where a distortion in the transmission path can cause a star (941 Hz and 1209 Hz) to be decoded as a pound (941 and 1477). Here A = 1209 and B = 941 and the formula will give $2A-B = 1477$ which represents a pound.

When we talk about a 'DTMF signal', it does not refer to an electrical signal or an audio signal. It is a combination of two sine waves that can be represented in any form. For example, when transmitted from a mobile phone, the DTMF starts as an electric signal generated from the audio signal that is then encoded on an electromagnetic wave during transmission and is again converted back to an electric signal at the receiving end, which is finally converted back to an audible sound signal.

A DTMF Decoder is an Integrated Circuit (IC) which can decode the incoming DTMF signal and show the corresponding key as a four bit data output which is also known as a nibble or half byte.

3.3 Special Tones

Other than the tones for the digits described in the previous section, national telephone systems usually define special tones to denote the status of the equipment, the line or the result of calls. These tones may consist of a single frequency or two frequencies. These are standardized for each country. Most special tones in the US are based on a dual frequency system whereas European nations use a single frequency for most events. The table below indicates the frequencies used in US:

Event	Low frequency	High frequency
Busy signal	480 Hz	620 Hz
Ring-back tone	440 Hz	480 Hz
Dial tone	350 Hz	440 Hz

The European tones are given in the table below. Most European nations use the standard 425 Hz frequency to represent the busy signal, the ring-back tone, and the dial tone.

Event	Low frequency	High frequency
Busy signal (UK)	400 Hz	----
Busy signal (Rest of Europe)	425 Hz	----
Ringback tone (UK & Ireland)	400 Hz	450 Hz
Ringback tone (Rest of Europe)	425 Hz	----

Dial tone (UK)	350 Hz	440 Hz
Dial tone (Rest of Europe)	425 Hz	----

3.4 DTMF Transmission

DTMF was originally design for control signals and not for data transfer. As a result, the focus was on choosing frequencies in such a way that frequency filters can be easily designed for transmission through standard telephone lines. The bandwidth available for a telephone line is between 300 Hz and 3.5 KHz and the frequencies chosen were within this range. With the help of an encoder/decoder, a DTMF can be used for data transfer, albeit at a very slow rate of ten tones per second. Ideally, a DTMF tone should be played for at least 50 milliseconds with a 50 milliseconds interval between two successive tones.

DTMF signals can be transmitted either manually or automatically through a DTMF encoder. It is faster to use an automatic encoder, which presses the digits much faster than manual DTMF. Automatic DTMF encoders can be programmed to store the DTMF code in the device. This can later be forwarded to send an entire DTMF string of alphanumeric characters. Hence, these devices are also known as ‘Store and Forward’ encoders. Typical examples of a ‘Store and Forward’ DTMF encoder include a programmable microphone or a two-way radio.

At the transmitter end, the signal strength of the DTMF low frequency tone should be between +1 dBm and -10.5 dBm and that of the high frequency tone should be between +1 dBm and -8.5dBm. The frequencies generated by the transmitted should not vary beyond 1.5% of the defined values and the receiver should not accept any deviation that is greater than 3.5% from the defined values. Any leakage of tone must not exceed -55dBm.

At the received end, there are several checks performed before interpreting an incoming signal as a DTMF signal.

1. Two simultaneous tones – one from low frequency and one from high frequency has to be present and the tones should persist for at least 40 milliseconds.
2. Other frequencies must be absent or less than -55 dBm.
3. There must be an interval of at least 40 milliseconds between two signals during which there is no DTMF frequency
4. The minimum duty cycle is 85 milliseconds. (sum of tone duration and interval duration)
5. The signal strength should be between -25 dBm and 0 dBm
6. The high frequency tone must be -8dBm to +4dBm relative to the low frequency tone.

The duration of a DTMF signal is known as Mark and the interval is known as Space. The difference in transmission levels between the low and high frequencies is known as twist. Errors caused due to incorrect implementation of this are known as twist errors. If the amount of twist is greater than the receiver's tolerance levels, then the system will fail to decode the buttons pressed. This is often misdiagnosed as a problem with the repeater controller, though the actual problem lies with the receiver. Modern decoders are designed in such a way as to easily overcome this and decipher the right digits despite twist errors.

The tone duration and the inter-digit interval mentioned above are as per AT&T standards. ANSI standard T1.401-1988 defines minimum tone duration as 50 milliseconds, inter digit interval as 45 milliseconds and duty cycle as 100 milliseconds. Further, popular telephone equipment manufacturers and modem manufacturers typically generate DTMF tones of 70 milliseconds or more duration in order to avoid dialing troubles.

3.5 DTMF Programming

There are several ways in which DTMF sequences can be used to program characters. The table below shows how alphabets and numerals can be transmitted using a standard DTMF sequence.

Character	DTMF Sequence
0	0
1	1
2	2222
3	3333
4	4444
5	5555
6	6666
7	77777
8	8888
9	99999
A	2
B	22
C	222
D	3
E	33
F	333
G	4
H	44
I	444

J	5
K	55
L	555
M	6
N	66
O	666
P	7
Q	77
R	777
S	7777
T	8
U	88
V	888
W	9
X	99
Y	999
Z	9999
Clear, Reset, Back, Exit	*
Enter, Ok, Next	#

However, the sequence varies with the equipment or application that is being used. The above table shows the sequence on a standard 3X4 keypad where the digit 1 has no corresponding alphabet value and every other digit has three or four alphabets and one numerical digit associated with them. However, if a keypad were designed in such a way as to assign an alphabetic value to the 1 key, then all other values would change accordingly.

When programming with DTMF, the tones are usually repeated until the specific character is displayed in the display panel of the equipment. Once a character is entered a * or # is entered before the next character is programmed. The * key is used for deleting characters and # is used to indicate a new character, though this can vary with the characteristics of the receiving equipment.

Apart from programming words, DTMF strings can be also used to perform certain functions on an application or equipment.

4 Technical Standards

In order to ensure that devices and applications manufactured by different vendors are compatible with each other, several technical standards have been defined for DTMF technology. DTMF is standardized by ITU-T Recommendation Q.23 titled 'Technical features of push-button telephone sets' and it provides a complete set of standards for all applications that intend to use DTMF signaling.

The ETSI Standard ES 201 235 is a fairly detailed standard which has been developed in conformation to the ITU-T Recommendation Q.23 specifies how DTMF signaling system can be used for transmitters and receivers. The standard applies to DTMF signaling over LAN (local area network) where the transmission path is a two-wire analogue subscriber line as well as over an end-to-end transmission path. This allows manufacturers of telecom equipment to design robust equipment that facilitates reliable DTMF signaling.

Other technical standards which apply to DTMF signaling include the European Standard EN 300 659 which has an annex that details DTMF-based subscriber line protocol for the support of PSTN display services at the Terminal Equipment.

In the initial days, just like other multi-frequency receivers, DTMF was decoded using tuned filter banks. Later, these were replaced with digital signal processors. Although any frequency domain transform such as the fast Fourier transform can be used for decoding DTMF, the Goertzel algorithm is a preferred choice due to its high performance for DTMF signals.

5 Applications

DTMF decoders are much slower than a good communication modem. While the former can process nearly ten tones per second (or five bytes of data), a modem can transmit nearly 3000 bytes per second. Still, because of its durability under noisy conditions, DTMF signaling is still preferred in several cases. DTMF tones can also be used to transfer caller ID information in telephone systems.

The primary use of DTMF tones is by a telephone exchange for the identification of the dialed number. DTMF tones have a wide variety of applications in areas such as voicemail, phone banking, help desk services, and other types of inbound call centers. DTMF tones are also used by radio and cable TV networks to signal when local insertions (local news content or ads) can be made. It can also be used for station identification as well as for switching the remote transmitters on or off. Radio channels also use DTMF tones to transfer the audio to local airwaves. DTMF tones were often heard during a station identification process, which typically preceded a local insert.

The A, B, C, and D keys are rarely used on present day telephone networks, but some networks still use them for network control purposes. For example, the A key is used to listen in on calls by cycling through different carriers at will. (This is prohibited by most carriers today). These keys are also used in radiophone patch and repeater operations to control the repeater while connected to an active phone line. These keys, along with the # and * keys, are also widely used by amateur radio operators for repeater control, VoIP based communications, and remote-base operations.

Earlier VHS tapes (Video Home System) used DTMF signaling to encode information on the master video tape thereby providing information on settings such as format, duration, volume etc. to automatic duplication machines. This allowed better replication of the master video tapes and these signaling tones can sometimes be heard at the beginning and end of some tapes.

DTMF signals can also be transmitted over a radio to control turning things on and off. Practical applications include remote control of home appliances, activation of warning systems, opening and closing of doors, starting and stopping of motors and in general any binary action.

Using a two-way radio, a number can be transmitted using DTMF tones. A DTMF decoder programmed with the same number at the receiving end and connected to a receiver at the remote location can then be activated and used to control the equipment that has been connected to it. By adding Wildcard characters to the number, information can be embedded in the number thus enabling multi-location control using a single DTMF signal. For example, assume that the lights in your house are controlled using DTMF codes. If each light is mapped to a single DTMF signal, and you have fifteen lights in your house, then in an emergency if you want all lights switched on, you cannot wait for fifteen codes to be transmitted. In such a case, the decoder would be programmed to allow individual lights to be controlled, while also enabling a Master Switch to turn on all lights simultaneously using a Wildcard. Another Wildcard may be programmed to switch on all lights in a single room. Thus, group and sub-group controls are possible using DTMF control.

Similarly, to receive information from a remote site, a transmitter can be added to the two-way radio. This is known as a talkback system or SCADA system and it can send information back to you via DTMF, which can then be used for status indication or for feeding into the computer for further action. Thus, DTMF is a truly interactive signaling format.

5.1 Applications in the Call Center Industry

In the call center industry, DTMF is primarily used to process user requests, to obtain identification information and to route phone calls using the keypad entries made by the user. DTMF technology is used in conjunction with IVR software and ACD systems to offer self-service menu options to call center customers. In a 2005 Datamonitor Pool Survey of over 100 contact center decision makers, to identify the areas and type of calls that they prefer to automate using DTMF, the top three responses were call routing, information access/FAQ, and financial transactions/billing. DTMF signaling is used in several computer-telephony software applications as well.

Even with the advent of speech recognition based applications, most contact centers offer callers the choice to use either DTMF or speech input to capture user inputs. DTMF inputs are often used in IVR based applications for menu navigation, obtaining numerical inputs (such as account number, date of birth PIN number etc.) or even for recognizing a digital pattern.

While scripting, one of the following methods is typically used for determining when the user input is complete:

- *Termination Character:* A caller specifies the end of an input by entering a termination key, which is typically the # key.
- *Time Out:* In this case, an input is considered complete, if a specified time has passed without the caller pressing any key.
- *Specified Number of Characters:* In this case, the input is considered complete after the caller has entered a fixed number of tones. This can be used for fixed length inputs such as in cases where the account number is say six digits long.

Most applications will have default settings for each option, which can be overridden using scripts.

Menu navigation using DTMF is achieved by asking the user to press a key to select a menu option. Depending on the menu choice selected, the application can then route the call to a specific group of agents, based on the skill set requirements.

DTMF is used to obtain information from customers, and is employed in a wide variety of industries ranging from financial institutions such as banks and credit card companies to healthcare and insurance organizations.

6 VoIP and DTMF

There are multiple ways in which DTMF tones are transmitted over a VoIP connection. These include:

- *Inband* – In this method, the DTMF tones are transmitted just as normal voice audio using the same codec and with no special coding to identify it as different from the voice.
- *RFC2833* – In this case, DTMF is transmitted based on the defined standards for DTMF tones, fax tones etc.
- *SIP signaling* – This can be done only through SIP channels where DTMF tones are transmitted through an SIP message after a handshake with the receiving end for negotiating preferences and establishing the parameters for the call.

DTMF over VoIP is more prone to errors, as the receiving end often fails to recognize the DTMF or interprets it incorrectly. One of the possible causes of trouble is when there is switching between in-band DTMF and RFC2833 modes in the VoIP route. For example, assume a VoIP device is transmitting an in-band DTMF signal and a switch converts it to RFC2833 DTMF for further transmission, which finally terminates in a system that requires a regeneration of the in-band audible tones. Sometimes, the switch fails to completely remove the audible DTMF tones while converting to RFC2833, thus resulting in a combined garbled message received by the voicemail system, causing it to report an error. Yet another cause of concern is packet loss, which creates issues in DTMF over VoIP transmissions.

Changing the DTMF settings is one way of troubleshooting such problems, and the RFC2833 DTMF setting is the most reliable. The in-band DTMF where the G729 codec is used is the most un-reliable due to compression related issues.

7 Advantages of Using DTMF

There are several advantages for using DTMF technology for automating some of the key parts of a call. Some of these are listed below:

Higher Security

Using DTMF for obtaining user input is more secure and gives callers the assurance that sensitive data is being protected. DTMF tones cannot be interpreted by the human ear, but can be easily decoded by a phone system and computer. Thus, sensitive information can be isolated from the agents as well as from call recording systems. In the absence of DTMF, an agent with a malicious intent can steal sensitive card information from the archived call records.

From a customer's perspective as well, DTMF offers higher security, as they do not have to speak out the card details over the phone, and this protects them from data theft if the call is being made in a crowded environment.

Improved Metrics

In an inbound call center, obtaining user inputs via DTMF can improve key metrics such as Average Handling Time (AHT), since the agents need not repeat the card details back to the caller to confirm the accuracy of the input.

The increased security offered by DTMF also improves customer satisfaction levels, making them feel more comfortable with entering sensitive data using DTMF, and thereby maintaining its anonymity.

Reduced Probability of Errors

It also reduces the possibility of errors, as there is only one point of data entry. Without a DTMF, the caller will have to read out the data and the agent types it into his desktop application, giving rise to two points of error. On the other hand, using DTMF means the caller is directly entering the data, subsequently reducing the chances for error.

8 Conclusion

DTMF was originally designed to use the frequencies in the normal human voice range. As a result, it can easily pass over normal two-way radio channels, narrow band, and wide band. DTMF is a straight forward technology that is easy to understand, compatible with most equipment and can be used to provide the most cost effective and flexible features. It does not require expensive equipment or special channels for transmitting the frequencies.

As pulse dialing has nearly reached the end of its lifespan and voice recognition engines still have a long way to go, DTMF solutions seem to be the answer for call centers for at least the next couple of decades. Even when call centers move to voice recognition systems, it is a good idea to offer the customer the choice of whether he would prefer DTMF or voice inputs.

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