CTCSS

Introduction

Long ago and not so far away, Motorola came up with a way to get more than one Land Mobile customer on the same frequency at almost the same time. They figured that different customers could coexist on the same frequency if they did not have to listen to each other routinely. They invented Continuous Tone Coded Squelch System or CTCSS for short and patented it as "PL" short for "Private line". Other manufacturers, finding that the system was absolutely necessary to stay competitive came up with "Channel Guard," "Quiet Channel," "Call Guard," and many other names for the same thing to avoid lawsuits for marketing a patented system.

The manufacturers of amateur equipment seem to have settled on "tone" for encode only and "tone squelch" for encode/decode. Most of the amateur VHF and UHF equipment manufactured in the last ten years has at least encode capability (standard or optional) and many have decode capability (standard or optional).

When it is available, it is simply a plug in circuit board. Aftermarket encoders and encoder/decoders can be added to virtually any transceiver since they have now been developed smaller than a postage stamp.

The system is based on a "subaudible" tone injected after the audio stages into the transmitter during encode and the tone is detected before the audio circuits in the receiver. The decoder switch is then used to perform some function, usually to unmute the receiver when the tone is decoded.

In the commercial equipment, the audio bandwidth tends to be narrower than our amateur equipment and there are circuits installed to filter out the tones so they are truly subaudible. Most of our amateur equipment transmits and receives a much broader audio bandwidth and has no special tone filters, so most hear the tones. The lower the tone frequency the less audible it tends to be.

Details on CTCSS

The system is designed around a set of relatively low frequency tones (32 or 38 depending on which "standard" you use) ranging from 67.0 Hz to 250.3 Hz. The tones are a perfect sine wave and the frequency tolerance is very tight, typically +/- 0.5 Hz. The tone is encoded and injected into the transmitter after the audio shaping circuits. The frequency deviation (level) is typically 0.4 to 0.8 kHz, which is rather insignificant when compared to the typical 5 kHz voice deviation.

In the receiver, the tone is detected right off the discriminator before any audio processing and decoded allowing the receiver to unmute. Commercial radios filter out the tone, but our amateur radios do not so the tone is usually noticeable. It is sometimes mistaken for a power supply hum.

CTCSS does not alleviate RF interference. If two FM signals are on the same frequency at the same time, there will still be a heterodyne or beat note (unless one is 6 dB stronger than the other). But if CTCSS is being utilized and both systems use different CTCSS tones, they will not have to listen to the other system's traffic.

With the advent of commercial repeater stations, several customers can use the same repeater without listening to each other’s transmissions. In a commercial installation, the microphone hanger is grounded and when the mic is hung up, the decoder is turned on, thus muting the receiver. When the operator picks up the mic, the decoder is disabled and the receiver becomes "carrier squelch," hearing everything within range. If nothing is heard, the call is made. If another user is heard, they are supposed to monitor until the traffic clears and then make their call. Base station mics have a "monitor" button next to the PTT button to disable the decoder, allowing the operator to check for traffic.

Amateur radios do not have this automatic feature since the CTCSS system is used to allow users to restrict what they want to listen to, not to allow several fleets of radios to operate on the same frequency. Most handheld radios that can be factory equipped for full CTCSS encode and decode have a monitor button, usually around the PTT bar. Unfortunately, amateur mobiles have to manually turn off the tone to monitor the channel in the carrier squelch mode.

Some repeaters use CTCSS decode to keep from being keyed up by distant stations using other co-channel repeaters. Others use CTCSS to keep all but subscribing members off the repeater. If the intent of the repeater operator is to restrict the access to members only, it is called a closed repeater.

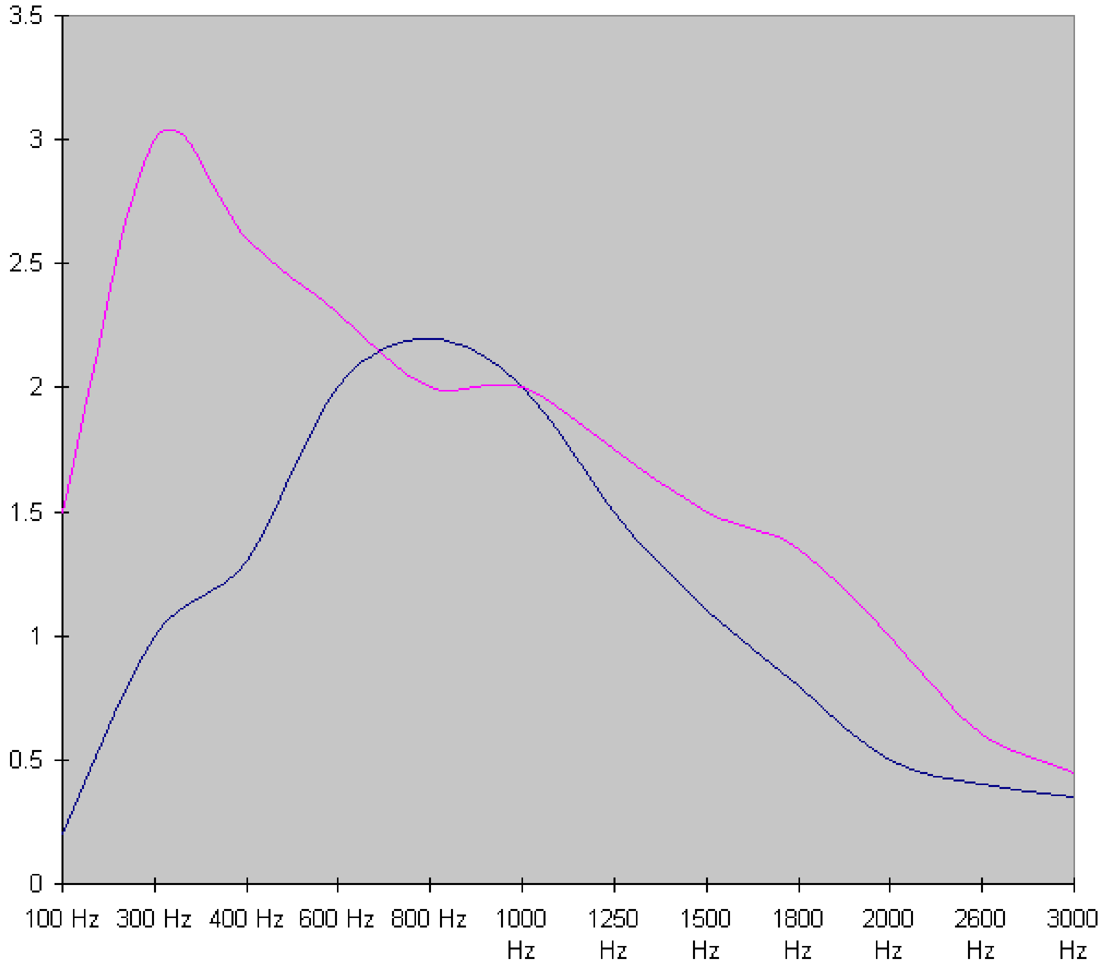
There are many repeaters that require CTCSS tones to activate them who welcome any and all users regardless of membership status. They have CTCSS access for some other reason, usually to cut down the needless traffic and static caused when a distant station working another repeater keys up two or three repeaters at the same time. These usually list the tone frequency in the remarks section of the Repeater Directory.

Theory of operation

Radios in a professional two-way radio system using CTCSS always transmit their own tone code whenever the transmit button is pressed. This is called CTCSS *encoding*. CTCSS continuously superimposes any one of about 50 low-pitch audio tones on the transmitted signal, ranging from 67 to 257 Hz. The tones used may be referred to as *sub-audible tones*. In an FM two-way radio system, CTCSS encoder levels are usually set for 15% of system deviation. For example, in a 5 kHz deviation system, the CTCSS tone level would normally be set to 750 Hz deviation. Engineered systems may call for different level settings in the 500 Hz to 1 kHz (10-20%) range.

The ability of a receiver to mute the audio until it detects the correct CTCSS tone is called *decoding*. Receivers are equipped with features to allow the CTCSS "lock" to be disabled. In professional US licensed systems, Federal Communications Commission rules require CTCSS users on shared channels to disable their receiver's CTCSS to check if co-channel users are talking before transmitting. On a base station console, a microphone may have a split push-to-talk button. Pressing one half of the button, (often marked with a speaker icon or the letters "mon",) disables the CTCSS decoder and reverts the receiver to hearing any signal on the channel. This is called the *monitor* function. There is sometimes a mechanical interlock: the user must push down the monitor button or the transmit button is locked and cannot be pressed. This interlock option is called, *compulsory monitor before transmit*. (The user is forced to monitor by the equipment.) On mobile radios, the microphone is usually stored in a hang-up box. When the user pulls the microphone out of the hang-up box to make a call, the receiver reverts to carrier squelch, ("monitor"). In hand-held radios, an LED indicator may glow green, yellow, or orange to indicate another user is talking on the channel. Hand-held radios usually have a toggle switch or push-button to monitor. Some modern radios have a feature called "Busy Channel Lockout", which will not allow the user to transmit as long as the radio is receiving another signal.

A CTCSS decoder is a very narrow bandpass filter which passes the desired CTCSS tone. The filter's output is amplified and rectified, creating a DC voltage whenever the desired tone is present. The DC voltage is used to turn on the receiver's audio stages.



Comparison of two audio curves in two-way radio receivers. Credit to David Jordan for this image. The magenta line is a commercial two-way radio without a CTCSS filter. The blue line is an imported communications receiver. Some trade journal articles say idealized audio curves differ from one language to another. One article said US hand-held radios had their audio response altered to work with an Asian language.

This curve was plotted (in the 1980s) by setting a signal generator to generate a carrier on the receiver's channel with a 1,000 Hz tone at two-thirds system deviation. The receive audio was terminated into a transformer matching the specified speaker impedance. Volume was set for 2 volts across the transformer. Without changing the generator's deviation level, voltage was measured at each frequency along the graph's bottom edge. The numbers were plugged into a spreadsheet and plotted.

In a professional communications receiver designed for CTCSS, a high-pass audio filter is supposed to block CTCSS tones (below 300 Hz) so they are not heard in the speaker. Since audio curves vary from one receiver to another, some radios may pass an audible level of the CTCSS tone to the speaker. Lower tone frequencies generally are less audible. If the magenta audio curve shown at right were plotted from a CTCSS-equipped receiver, it would drop nearly straight down below 300 Hz.

Because period is the inverse of frequency, lower tone frequencies take longer to decode. Receivers in a system using 67.0 Hz will take longer to decode than ones using 203.5 Hz. In some repeater systems, the time lag can be significant. The lower tone may cause one or two syllables to be clipped before the receiver audio is heard. This is because receivers are decoding in a chain. The repeater receiver must first decode the CTCSS tone on the input. When that occurs, its transmitter turns on, encoding the CTCSS tone on the output. All radios in the system start decoding after they recognize the tone on the output as valid.

Engineered systems often use tones in the 127.3 Hz to 162.2 Hz range to balance fast decoding with keeping the tones out of the audible part of the receive audio. Several amateur radio repeaters delay the audio for several milliseconds before it is retransmitted. During this fixed delay period, the CTCSS decoder has enough time to recognize the right tone. This way the problem with lost syllables at the beginning of a transmission can be overcome without having to use high tones.

In early systems, it was common to avoid the use of adjacent tones. On channels where every available tone is not in use, this is good practice. For example, an ideal would be to avoid using 97.4 Hz and 100.0 Hz on the same channel. The tones are so close that some decoders may periodically false trigger. The user occasionally hears a syllable or two of co-channel users on a different CTCSS tone talking. As electronic components age, or through production variances, some radios in a system may be better than others at rejecting nearby tone frequencies.

List of tones

CTCSS tones are standardized and may be listed in equipment manuals or by entities like the Electronics Industry Association. Some systems use non-standard tones. Squelch tones typically come from one of three series as listed below along with the two character PL code used by Motorola to identify tones. The most common set of supported squelch tones is a set of 38 tones including all tones with Motorola PL codes, except for the tones WZ, 8Z, 9Z, and 0Z. The lowest series has adjacent tones that are roughly in the harmonic ratio of $2^{0.05}$ to 1 (~1.035265), while the other two series have adjacent tones roughly in the ratio of $10^{0.015}$ to 1 (~1.035142).

Code	Tone Freq.	Code	Tone Freq.	Code	Tone Freq.
XZ	67.0	1B	107.2	6A	173.8
WZ	69.3	2Z	110.9	6B	179.9
XA	71.9	2A	114.8	7Z	186.2
WA	74.4	2B	118.8	7A	192.8
XB	77.0	3Z	123.0	M1	203.5
WB	79.7	3A	127.3	8Z	206.5
YZ	82.5	3B	131.8	M2	210.7
YA	85.4	4Z	136.5	M3	218.1
YB	88.5	4A	141.3	M4	225.7
ZZ	91.5	4B	146.2	9Z	229.1
ZA	94.8	5Z	151.4	M5	233.6
ZB	97.4	5A	156.7	M6	241.8
1Z	100.0	5B	162.2	M7	250.3
1A	103.5	6Z	167.9	0Z	254.1

Vendor names

CTCSS is often called *PL tone* (for *Private Line*, a trademark of Motorola), or simply *tone*. General Electric's implementation of CTCSS is called *Channel Guard* (or *CG*). Vintage RCA radios called their implementation *Quiet Channel*. Kenwood radios call the feature *Quiet Talk* or *QT*. There are many other company-specific names used by radio vendors to describe compatible options. Any CTCSS system that has compatible tones is interchangeable. Old and new radios with CTCSS and radios across manufacturers are compatible.

In amateur radio, the terms *PL tone*, *PL* and simply *tone* are used most commonly. Often, there is a distinction between the terms *tone* and *tone squelch*, in which the former refers to the use of transmitting a CTCSS tone while using standard carrier squelch on the receiver. Use of transmit-only CTCSS allows stations to communicate with repeaters and other stations using CTCSS while the link is marginal and the CTCSS tones may not be properly decoded. The term *tone squelch* most often includes *tone* and your radio will not only transmit a CTCSS tone to the distant station or repeater, but will squelch all incoming signals that do not also include the CTCSS tone. This is helpful in areas where multiple repeaters may be sharing the same output frequency but have different CTCSS tones, or where local interference is too strong for the front-end of your radio.

One caveat about all CTCSS being interchangeable is that some professional systems use a phase-reversal of the CTCSS tone at the end of a transmission to eliminate the squelch crash or squelch tail. This is common with General Electric Mobile Radio and Motorola systems. The CTCSS tone does a phase shift for about 200 milliseconds at the end of a transmission. In old systems, decoders used mechanical reeds to decode CTCSS tones. When audio at a resonant pitch was fed into the reed, it would vibrate on a set of springs, turning on the speaker audio. The end-of-transmission phase reversal (called "reverse burst" by Motorola and "squelch tail elimination" or "STE" by GE) caused the reed to abruptly stop vibrating and the receive audio would mute. Initially, a phase shift of 180 degrees was used, but experience showed that a shift of ±120 to 135 degrees was optimal in halting the mechanical reeds. These systems often have audio muting logic set for CTCSS only. If a non-Motorola transmitter, (without the phase reversal feature,) is used, the squelch can remain unmuted for as long as the reed continues to vibrate — up to 1.5 seconds at the end of a transmission.

Intermodulation interference

In non-critical uses, CTCSS can also be used to hide the presence of interfering signals such as receiver-produced intermodulation. Receivers with poor specifications — such as scanners or low-cost mobile radios — cannot reject the strong signals present in urban environments. The interference will still be present but the decoder will block it from being heard. It will still degrade system performance but by using selective calling the user will not have to hear the noises produced by receiving the interference.

CTCSS is very commonly used in amateur radio for this purpose. Wideband and extremely sensitive transceivers are common in amateur radio, which imposes limits on achievable intermodulation and adjacent-channel performance. Often all repeaters in a geographical region share the same CTCSS tone as a method of reducing co-channel interference from adjacent regions and increasing frequency reuse. This is a practice linked back to an old FCC practice of coordinating CTCSS tones for business services. In areas where no coordination is necessary, a default of 100 Hz has become a de facto standard.

In systems with life-safety uses such as search and rescue or ambulance company dispatching, the presence of interfering signals should be corrected rather than masked with CTCSS tone squelch. Interfering signals masked by tone squelch will eventually produce apparently random missed messages. Users will not understand why they could not hear a call. The intermittent nature of interfering signals will make the problem difficult to reproduce and troubleshoot.

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