Basic CTCSS & DCS Primer

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Basic CG and DCG Primer

People new to two-way radio often get confused about some of the common terms related to guarded squelch operation.

They wonder what are the differences between ***CTCSS***, *PL, CG* and tone squelch?

…They're all the same thing!

Basic CG and DCG Primer

History:

CTCSS *(**C**ontinuous **T**one **C**oded **S**quelch **S**ystem)* and ***tone squelch*** are the generic terms for a subaudible tone signaling scheme used in two-way radio to prevent a radio from hearing undesired signals on a radio channel. Introduced in the early 1960s, "*tone squelch*" was referred to by radio manufacturers under several different and unique product names:

General Electric's	***Channel Guard®***	**(CG)**
Motorola's	***Private Line®***	**(PL)**
E.F. Johnson's	***Call Guard®***	**(CG)**
RCA's	***Quiet Channel®***	**(QC)**

Just as the name above implies, CTCSS is a continuous tone that is so low in frequency and amplitude that it is next to impossible to hear with the un-aided ear. *Motorola* originally came up with a way to get more than one land mobile customer on the same frequency at almost the same time. Their Engineers 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 under its commonly known name *PL®* , short for ***Private line®***.

This is not to be confused with another simpler *Motorola* tone signaling scheme known as *AUTOMUTE®*, which used a <u>single</u> tone transmitted only once at the beginning of a series of transmissions. This single tone system is still used today in Europe, and is referred to as "Tone Burst", with the most common tone being 1750 Hz.

Other manufacturers of the era finding that the system was absolutely necessary to stay competitive came up with *Channel Guard®*, *Call Guard®*, *Quiet Channel®* and many other names for the same thing to avoid lawsuits from Motorola.

Basic CG and DCG Primer

A Low Level, Precision Hum:

…In its simplest form, CTCSS is akin to 'precision humming'.

In a nutshell, that's all that CTCSS really is! When you transmit on a two-way radio, a very low level hum is added to your voice. All of your other radios are looking for this particular hum frequency. When they finally see it, they turn on the speaker of the radio and your voice comes through.

Other people may use the same radio channel as you, but they have different CTCSS hum frequencies, so your radio doesn't turn on its speaker for them, only your own group.

The system is designed around a set of low frequency (sub-audible) tones ranging from 67.0 Hz to 250.3 Hz. These tones are a perfect sine wave and a very tight frequency tolerance, typically +/- 0.5 Hz. TIA/EIA-603 Specifications recommend a deviation level of 0.500 kHz for 5 kHz deviation systems (Wideband) and 0.350 kHz deviation for 2.5 kHz systems (Narrowband).

[See TIA/EIA-603 Para 1.3.5.3 – Standard CTCSS Modulation]

Basic CG and DCG Primer

This subaudible tone is sent over the air with a tone encoder to the receiving station which, in turn, has a tone decoder. The decoder doesn't let any sound through to the speaker until it hears the specific tone it was programmed to listen for. This allows users to be on one frequency without causing interference to stations using different subaudible tones.

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.***

The EIA (Electronic Industry Association) standardized 33 of these tones in their publication TIA/EIA-603.

Basic CG and DCG Primer

Military CTCSS Tone:

The US Military saw how useful system this was and adopted 150.0 Hz as their tone, which later became the standard CTCSS tone for military units belonging to NATO / Canadian Forces / UK MoD / Australian / New Zealand.

It should be noted that standard Military tactical radio systems, from the old ***AN/PRC-8's*** through the modern SINCGARS radios in the 30 to 88 MHz frequency

range all use the original pre-1965 "wideband" deviation system:

15 kHz for VOICE deviation level
3 kHz for CTCSS deviation level

Basic CG and DCG Primer

Selecting CTCSS tones in Land-Mobile Radio Systems:

Regarding the use of CTCSS tones on land-mobile radios, the following recommendations are given:
If used in North America where electrical power systems are using a *line frequency of* ***60 Hz***, the use of CTCSS frequencies at or near multiples of 60 Hz is not recommended.

58.8 Hz (60 Hz x 1)
63.0 Hz (60 Hz x 1)
123.0 Hz (60 Hz x 2)
179.9 Hz (60 Hz x 3)
241.8 Hz (60 Hz x 4)

In areas of the world where electrical power systems are using a *line frequency of* ***50 Hz**,* the use of CTCSS frequencies at or near multiples of 50 Hz is not recommended.

49.2 Hz (50 Hz x 1)
51.2 Hz (50 Hz x 1)
100.0 Hz (50 Hz x 2)
151.4 Hz (50 Hz x 3)
203.5 Hz (50 Hz x 4)
250.3 Hz (50 Hz x 5)

By avoiding using CTCSS tones on or adjacent to these frequencies you can limit the amount of power line ‘buzz’ introduced into your radio equipment in weak signal areas.

Basic CG and DCG Primer

Squelch Tail Elimination:

A couple of other common terms you might hear in conjunction with CTCSS are: "reverse burst" and "squelch tail elimination" (or STE).

The reverse burst concept was started back in the good ole days where the tone was conceived and detected by mechanical tone reeds in the radios. To generate the CTCSS tone, a mechanical reed vibrated at a predetermined frequency causing an electronic sine wave to be generated, and was added to the voice transmission sent over the air. When the receiving radio heard this specific tone, its decoding reed vibrated in harmony at a same frequency, indicating resonance and thereby causing a valid CTCSS indication. The receiving radio then unmutes.

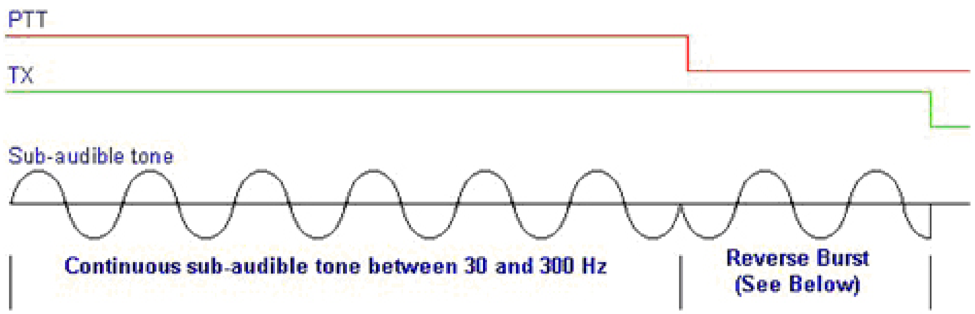
When the transmit CTCSS goes away, the mechanical reed will continue to vibrate for a few hundred milliseconds causing a fairly long squelch tail (or white noise burst). In order to eliminate this squelch tail noise at the end of a transmission, the user unkeys the radio and it automatically sends a reverse burst by changing the phase of the CTCSS signal for a specific time period before the transmitter turns off. This causes the receive CTCSS reed to come to a quicker stop and mute the receiver before the signal goes away. There are four(4) common forms of STE in use today. The first two are described in the TIA/EIA-603 standard.

[See TIA/EIA-603 Para 1.3.5.4 – CTCSS Reverse Burst]

Basic CG and DCG Primer

Squelch Tail Elimination:

Today, radios of North American manufacture still use reverse burst for eliminating squelch tails. However, some offshore brands of radios either do not have any kind of squelch tail eliminator. They simply turn off their CTCSS encoder about 200 milliseconds before transmitter turns off. The following graphic shows PTT, Transmitter, and Tone coordination.



EIA STE Format-1:
Advances the phase of the CTCSS tone forward by 120 degrees for a period of 180 milliseconds at the end of the transmission prior to turning off the RF carrier. (aka: General Electric Format)
EIA STE Format-2:
Advances the tone phase forward 180 degrees for 150 milliseconds. (aka: Motorola Format)
Australian/New Zealand STE Format:
Advances the tone phase forward 180 degrees for 130 milliseconds.
Japanese STE Format:
The final STE format comes to us from the Japanese equipment manufacturers. It simply shuts off the CTCSS tone for about 100-200 milliseconds before turning off the RF carrier.

Basic CG and DCG Primer

DIGITAL CHANNEL GUARD (DCG):

DCG, also called DCS, is a digital subaudible selective signaling system. It uses a code composed of 23 bits sent repeatedly at rate of 134.3 bits per second. The code is based on the ***Golay*** (23,12) code first published in 1949. This code has the ability to detect and correct any three bit or less error that occurs in the 23 bit word. The word is composed of a 12 bit data field and an 11 bit parity vector. In usage, the 12 bits are divided into 4 octal digits, the first always being set to 100 (octal), the 2nd, 3rd and 4th digits form the three octal digit DCG code number. The word format is:

Shift Direction --> Out
PPPPPPPPPPPFFFCCCCCCCCC

Where **P's** are parity bits, **F's** are the fixed octal digit bits, and **C's** are the octal digit bits. For the DCG code "023" this would be the binary word:

PARITY BITS											ALWAYS 4			THREE DIGIT DCS CODE								
P 11	P 10	P 9	P 8	P 7	P 6	P 5	P 4	P 3	P 2	P 1	F 3	F 2	F 1	C 9	C 8	C 7	C 6	C 5	C 4	C 3	C 2	C 1
1	1	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	1	1
															0			2			3	

Basic CG and DCG Primer

DIGITAL CHANNEL GUARD (DCG):

Parity Bit Generation
The original Golay algorithm used a binary polynomial to generate the parity bits, but this method uses too much microcontroller time and memory.

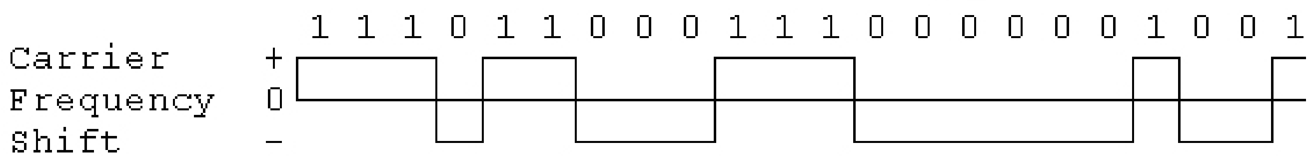
Keeping all 512 23 bit words in rom would take a minimum of 1472 bytes, keeping the parity bits only in rom would take a minimum of 704 bytes. It is possible to save even more rom without taking a lot of microcontroller time by using a simpler way to calculate the needed parity bits. This method uses short calculations, one for each parity bit, based on selected bits from the 9 bit DCG code number:

```
P1  = C1 + C2 + C3 + C4 + C5 + C8 (MODULO TWO ADDITION)
P2  = NOT ( C2 + C3 + C4 + C5 + C6 + C9 )
P3  = C1 + C2 + C6 + C7 + C8
P4  = NOT ( C2 + C3 + C7 + C8 + C9 )
P5  = NOT ( C1 + C2 + C5 + C9 )
P6  = NOT ( C1 + C4 + C5 + C6 + C8 )
P7  = C1 + C3 + C4 + C6 + C7 + C8 + C9
P8  = C2 + C4 + C5 + C7 + C8 + C9
P9  = C3 + C5 + C6 + C8 + C9
P10 = NOT ( C4 + C6 + C7 + C9 )
P11 = NOT ( C1 + C2 + C3 + C4 + C7 )
```

Basic CG and DCG Primer

DIGITAL CHANNEL GUARD (DCG):

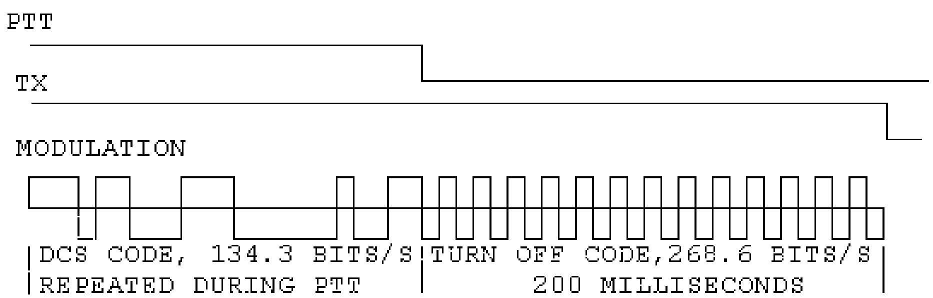
DCG Transmission
The DCG word is transmitted and received in ***NRZ*** *(non-return to zero)* format so modulation polarity is important. The definition of a "1" is an upward frequency shift and a "0" is a downward shift. DCG codes sent with this polarity are considered to be positive polarity. However some radio systems use inverted polarity to avoid interference and these are called negative DCG codes. Because of this, provision must be made to use both polarities. DCG code "+023" would be transmitted as:



Basic CG and DCG Primer

DIGITAL CHANNEL GUARD (DCG):

The DCG word is sent continuously, starting when transmission begins. When the user releases the PTT, the encoder will change the code to a pattern of alternating 1's and 0's at 268.6 bits per second for 180 milliseconds, then stop transmitting.   This "turn off" code pattern also causes receiving decoders to mute, thereby eliminating the squelch tail noise burst, similar to that found in CG tone coded squelch systems.



Basic CG and DCG Primer

DIGITAL CHANNEL GUARD (DCG):

Modulation Characteristics

The normal deviation range is from 10 to 20% of rated system deviation. Most systems are rated for 5 kHz, so this would be 500 to 1000Hz DCG deviation. The DCG modulation must be low pass filtered or have it's waveform generated in such a way that frequency products above 300Hz are reduced, otherwise they will cause an audible 'thrumming' noise on the signal. Also receivers should have a 300Hz high pass audio filter to reduce the DCG signal at the speaker.

DCG Decoding

Because there is no way to accurately determine the start of the 23 bit CDCGS code word, it is not possible to discriminate between all codes, i.e. "+023", "+340", "+766", "-047", "-375" or "-707"... all these result in the same 23 bit pattern, but shifted in time. This prevents convenient usage of all 512 possible codes.

Almost all DCG codes have duplicates, so most radio equipment manufacturers use 83 to 104 of the codes, selected for low number of duplications, low falsing likelihood and good decode sensitivity. Regrettably, no industry standard other than TIA/EIA-603 exists, which does not mandate a list of codes to be used, causing users to try unique code numbers which can false. It is recommended choosing from a "safe" list.