Coherent CW …

"The More You Know About a Signal, the Easier it is to Copy"

by:
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[INSERT PHOTO OF THE CCW STATION]

[INSERT GRAPHIC OF CCW SIGs]

Overview

Coherent CW is a communications mode based on precise code timing and frequency stability to provide more than 20db improvement in signal reception ... the ultimate in QRPp operation! Invented by Ray Petit (W7GHM), CCW has been around for more than 25 years and has been promoted since then by such notables as Woody Woodson (W6NEY), Ade Weiss (W0RSP), Peter Lumb (W3IRM) and Bill de Carle (VE2IQ). We focus in this paper on the lighter side of how this technology evolved over the years, borrowing on anecdotal recountings, recordings of on-the-air signal reception, and audio tapes of some of these famous pioneers. The current state-of-the-art is also overviewed, illustrating the use of PC and DSP technology. And a "CCW Compendium" is provided, referencing much of the technical background and theory of operation.

Introduction

This paper is the result of some discussions that started in early 1997 between us two authors when we happened to bump into each other on the QRP-L internet mail list, reminiscing of the "early days" in digital communications. George had posted a question to the list asking if anyone had heard of this thing called CCW and if it might be alive in any fashion these days. Among many other great responses (as always happens on that list), Peter had responded with more insight and involvement than the others seemed to have of those days in the early '70s. We chatted about the newsletters, the complicated digital circuits and frequency synchronization techniques used with the equipment, and the applicability it should have to low power amateur radio enthusiasts.

As it turned out, while George had only a passive technical interest in following the nascent years of CCW, Peter had been involved with some of this pioneering work and actually stayed in touch with some of those guys over the years. He's been able to dig through old boxes and archived material to rediscover original tape recordings of some early on-the-air CCW communications, audio tape recordings of presentations made by a few of the original pioneers, and recollections of humorous discussions he's had with these guys.

That's what this paper is about - a recounting of the early years of the technology leading up to some of today's advanced digital communication modes … ***and*** a technical overview of some of that current technology. We constructed, documented and review herein a relatively modern CCW system consisting of some low cost kits, a synthesized VFO, and various DSP/computer components.

We provide some excellent reference material for those wishing to dig further into the technology and techniques. An extensive bibliography is provided in the appendix which points to a website containing documents and discussions from the original authors from years ago. And although this paper describes the overall system operation, it isn't intended to be a construction guide for the individual modules - we provide useful references to the authors and resellers of those modules so the reader may research as needed to select and/or modify individual components.

Well, just what *IS* Coherent CW, anyway?

Before we go any further into ressurecting the past years or hopping into the current technology descriptions, we'd like to simply define and describe the basics of Coherent CW.

[Short section giving the simple overview of the technology:

- conventional CW filters, pass lots of QRM, high power often needed
- equivalent SNR gains by dramatically reducing the filter widths … 12 wpm, precise timing,
- if you know what you're looking for, you're more likely to find it
- technical challenge of aligning the transmit and receive windows to coincide over 100ms frame

blah blah blah]

In the Beginning … (Peter's Stuff)

This …

The Coherent CW Station

Our discussion of CCW technology and operation is based on a reference transceiver constructed specifically for this purpose. Normally any transceiver would do for a CCW station, as long as it had reasonable stability and the capability of being electronically adjusted in 1 Hertz steps. The Icom IC-706 is a popular transceiver currently used by a number of BPSK enthusiasts.

However by exercising the spirit of homebrewing we are able to control more facets of the system and thus better understand the principles and tune the operation with various technology components.

First, let's consider a simplified block diagram of the CCW station:

[INSERT FIGURE x HERE]

Figure x: CCW Station Block Diagram

Our simple CCW station consists of an HF transceiver, an analog-to-digital (A/D) converter and a laptop PC. The A/D is connected to the transceiver's audio output jack and continuously converts the received audio signal to a stream of 8-bit digital words sent to the PC via the RS-232C serial data link. The PC runs a program which inputs the stream of digitized audio, and performs digital signal processing on that data stream to properly align the 100ms processing window with the 100ms-spaced signal being received. When the DSP routines running in the PC determine that the received signal is drifting out of the processing window, it issues some pulses to the transceiver's frequency control to move the VFO up or down in 1 Hertz increments in order to keep the signal within the processing window. In this way the receiver is able to track the phase of the transmitted signal, thus accounting for a slow drifting transmitter or receiver.

When transmitting CCW, it is imperative to key the transmitter with precisely timed code at a rate of exactly 12 wpm. In this way the receiving station, which is expecting exactly 12 wpm rate, will be able to phase lock with the received signal and establish the correct processing windows. The operator types the desired message into the PC and the computer keys the transmitter by raising/lowering the RTS control line of the RS-232C serial data port at the specific rate.

Next, let's zoom in to detail the actual components being used:

[INSERT FIGURE x HERE]

Figure x: N2APB CCW Station

The transceiver is controlled by the DDS (Direct Digital Synthesis) VFO which provides a 7 MHz synthesized and filtered signal for the R2 receiver board and the T2 exciter board. The DDS VFO is a homebrew module comprised of an AD7008 DDS chip and a PIC microcontroller. Fairly conventional with several such synthesized VFOs on the homebrew scene these days, this design provides a front panel LCD display of frequency, keypad frequency entry and a shaft encoder for easy tuning. Details of this design are outside the bounds of this paper - see the schematic in Appendix B and contact the author for construction and programming details.

The DDS VFO feeds a phase splitter which produces a precise quadrature signal pair labeled "I" and "Q" to drive the respective inputs of the R2 receiver and the T2 exciter. We decided to use the Rick Campbell, KK7B design for two main reasons. Its simplicity and quality of single signal reception provides an outstanding signal to the ear, in a small, relatively straightforward and inexpensive kit. *(Footnote: Bill Kelsey N8___ is the US supplier of Kanga, and sells the R2/T2 kits. Bill helped lots in getting the right components together for us in this project.)* The R2 receiver was chosen as well as for its phasing method of demodulation which lends itself well to the use of digital signal processing, discussed a bit later.

The R2 audio output goes directly to a set of headphones and is also sampled and converted to a constant stream of 8-bit digital words by the Sigma-Delta (SD) A/D converter board. The SD board is a design and product of Bill de Carle, VE2IQ, described in a 1992 QST article and in the 1993 *Handbook (footnote)*. This board is an integral component of the CCW system in that it elegantly and inexpensively converts the audio baseband signal to digital form so the PC may process the signals in real time. The A/D converter provides 7200 samples per second to the PC over an RS-232C serial line running at 115,200 baud.

At the heart of the CCW system is a computer program called *Coherent*, also written and provided by Bill de Carle. Bill has been one of the major players in the CCW/BSPK experimentation over the years, and he has developed and refined this program to perform digital signal analysis on the received signal to determine if the transmitter has been keyed - within an effective 9 Hertz filter! The program estimates the amplitude of an 800 Hz sinusoid (i.e., the received signal with the sidetone set to 800 Hz) which is assumed to be unvarying throughout a 100 ms window and essentially determines if the signal is present or not. An audio sidetone is sounded in the following 100 ms window if the transmitted energy was detected. [For more detail on on *Coherent* operation, see sidebar.]

The *Coherent* program also has an auto-tune feature used to constantly adjust the receiver VFO in order to keep the incoming audio tone precisely at 800 Hz, thus keeping it centered within the filter's very narrow passband. If the frequency of the incoming signal varies by more than a half a hertz from the nominal 800 Hz value, *Coherent* issues a pulse on one of two control lines on the RS232C serial port to signal the VFO to move up or down in 1 Hz steps. This automatic tracking ability accommodates a drifting transmitter or receiver, thus overcoming most of the complexity of the earlier CCW designs needing very stable and precise frequnecy sources.

Coherent software has several other convenient features in addition to auto-tune. It has a fine tuning aid that measures the incoming 800 Hz audio signal (with 0.1 Hz resolution!), and a frame-phasing tracking loop that determines if the SNR would be better had the window ended 1 cycle (1.25 ms) earlier or 1 cycle later. The program adjusts the 100 ms processing frame slightly forward or backward depending on the trend of the signal over time. Thus, once synchronization has been established, *Coherent* is able to adjust the phasing as necessary to maximize the SNR, further reducing the need for rig stability and frequency standards. All that's necessary is a reasonably stable transceiver (or a DDS VFO, as in our case), the Sigma-Delta interface board and a computer.

The operator is able to send CCW by typing on the keyboard with Coherent providing a precisely-timed 12 wpm keying signal from the RTS control line in the RS232C serial port. Typed information is displayed in a window on the computer screen, as are numerous parameters giving the operator control over many aspects of the program's operation.

The keyed signal is delivered to the T2 transmitter board, a phasing modulator exciter providing xx mW output. (For CW operation with the T2, the keyed signal is injected to the final mixer stage, thus bypassing the phasing circuitry that is used for phone operation. The use of SSB will be discussed later when describing BPSK modulation techniques.)

The T2 exciter feeds a small 5W rf power amplifier to provide a full QRP gallon of transmitted power. A standard technique is provided to mute the receiver while transmitting.

Technology Enhancements … the Motorola DSP56002EVM

Once we had the basic system operational, it was time to add a very useful and powerful product of current technology: a single board digital signal processor from Motorola called the DSP56002 Evaluation Module. This is a low cost ($125), fast, and self-contained DSP subsystem

[ADD MORE 56K DESCRIPTION]

[INSERT FIG x HERE]

Figure x: Adding a DSP Card to the CCW System

The EVM card serves several purposes in our system: demodulation and filtering of the R2 audio processing chain, and replacement and ultimate simplification of the *Coherent* algorithm previously provided by the Sigma-Delta A/D board and PC. We'll talk about these functions separately.

Demodulation & Filtering with the DSP56002EVM

[TALK ABOUT ROB FROHNE'S EXPERIENCES AND ARTICLE]

[INSERT FIG x HERE]

Figure x: Use of the EVM in the R2 Receiver

Putting the *Coherent* CCW Algorithm into the DSP56002EVM

[TALK ABOUT JOHAN FORRER's EXPERIENCES AND ARTICLE]

[INSERT FIG x HERE]

Figure x: Use of the EVM for Coherent

The Next Step: Stand-Alone CCW with the DSP56002EVM

[TALK ABOUT ADDING PADDLE INPUT, CCW KEYING ALGORITHM AND INTERACTIVE SYSTEM MONITORING TO THE EVM, THUS ELIMINATING THE NEED FOR THE PC.

[INSERT FIG x HERE]

Figure x: Stand-Alone CCW with the EVM

Construction of the CCW Station

- diagram showing layout … and discussion
- close-up of the DDS VFO … pic & discussion
- close-up of the R2 … pic & discussion
- close-up of the T2 and rf amp … pic & discussion
- close-up of the DSP56002EVM … pic and discussion
- photos of chassis: top, front, rear panels

Operation

- frequencies & skeds

Peter Lumb (G3IRM) and Bill de Carle (VE2IQ) have a daily BPSK sked on 14.081 MHz (weekdays) at 1600z. The settings we use are MS25 (40 baud), ET1-enabled. Anyone with a SD board and the COHERENT software should be able to read the mail.

- groups
- beacons
- lack of people doing

So What's Happening Today? … BPSK!

As interesting as it is, the technology of Coherent CW is actually obsolete. The CCW concept of carefully aligning a processing window over the on/off received signal, and thus gaining significant SNR improvements over conventional CW, is able to be improve upon through use of a system of phase shifting a constant carrier. Within the last several years, the work of VE2IQ and Max Carter have evolved the techniques to focus on use of binary phase shift keying (BPSK) modulation techniques in some amateur experimentation circles.

According to Carter (Footnote: "Super Narrowband Techniques Equalilze Power Inequity on 1750 Meters", Communications Quarterly, November 1990), BPSK gives 6dB advantage over CCW when demodulated synchronously - in the case of true coherent demodulation. *Coherent* may not perform true coherent demodulation (due to needing more processing power in real time than an x86 processor can provide) but BPSK still gives advantage over other modulation schemes.

In BPSK modulation, the phase of the RF carrier is shifted 180 degrees depending on the binary bit pattern of the data being sent. The system uses an NRZ-M digital coding scheme whereby a "one" bit causes a phase transition in the middle of the bit period, while a "zero" bit does not produce a phase transition. This method provides independence from the polarity of the signal, where the phase of each bit is comparted to the phase of the preceding bit.

One LowFER reports that in playing around with various weak signal CW (& CCW) systems over the years on VLF, HF, VHF, and EME the problem always boiled down to the difficulty of determining what was going on when there was no signal present. That is, is the key up or did the signal just fade out?

Any type of bipolar keying has an advantage over CW techniques in that there is a signal present all the time, one to indicate both key down and key up if you think in terms of CW. Even RTTY has this advantage! I suppose you could FSK or PSK a carrier with CCW and obtain this advantage but on off keying definitely isn't the way to go for weak signal work as the detector has no signal at all to work with 50% of the time.

Another LOWfer reports that after many years of listening to weak signals off the moon he has developed a rather good narrow band 'organic' filter between his ears. He find extremely narrow band filters very hard on the nerves and ears and prefer the normal 2.1 Khz filter for most weak signal work, doing the narrow band processing in his head. He has no problem getting solid copy on a weak CW signal that is -17 to -20 db or so below the noise floor in a 2.1 KHz filter. The only problem with this built in filter is that it tires easily. After several hours of this extreme concentration he starts to hear signals that aren't there and has to resort to constantly varying the pitch of the receiver in order to make the signal stand out against the noise. A signal of this same strength (or even weaker!) is 100% solid copy on his BPSK setup and unlike the 'organic filter', the computer's brain never tires!

In addition toMax Carter's article in Communications Quartery, there is an excellent BPSK overview given by _____ on his website: http://______ .

And where's this all going?

In speaking with VE2IQ, Bill states that he doesn't expect BPSK to be obsolete any time soon. It is optimum under conditions of additive Gaussian white noise. But he has been looking into adding an MSK mode to *Coherent*. The same hardware can be used, and some new software is all that's needed. Theoretically, BPSK is still better on HF under most conditions, but MSK has a slight edge over BPSK under certain conditions like those most likely to be encountered on LF. Apparently MSK has a slight advantage when the noise is predominantly impulse-type. For some LF users MSK might be better.

Summary

So what does all this mean for the average homebrewer, QRPer, or communications experimenter?

Well to us it means that the spark is still alive in the amateur ranks! In fact, some in our field are pushing the envelope with newer, state-of-the-art technology like Digital Signal Processing and powerful embedded microcontrollers to accomplish more than what analog components have been able to do in years past.

It's hoped that this paper serves to inspire others to experiment with CCW and BPSK communication modes. Neither of us authors are expert in the fields reported on here - we're just technically savvy, inquisitive homebrewers who are standing on the shoulders of legendary giants, combining/extending their work to experiment with innovative communications systems.

Anybody want to do a CCW or BPSK sked with us?!

Acknowledgements

There are so many people we'd like to thank in helping us bring this paper and our CCW technology demonstration system together.

First and foremost, our appreciation goes out to the many pioneers in this field of specialized communication techniques. Countless hours of homebrewing, experimentation and on the air tests have given us all a solid foundation leading to today's capabilities. Ray Petit, Peter Lumb, Charles "Woody" Woodson and Ade Weiss have all left their indellible mark on the evolution of this field.

Next, some of the leading experimenters of today were very willing to help us out with our every question. Specioal thanks are extended to Johan Forrer, Bill de Carle and Rob Frohne for their tireless explanation of the principles used in their respective projects which we so readily and shamelessly adopted in constructing our system.

Bill Kelsey of Kanga Systems helped us out with quick response on supply of some of the components (R2T2 kits) used in our system and with the networking contacts for others doijng similar work in this area. Friend and neighbor Clark Fishman, WA2UNN provided key technical assist in getting the RF components of the system in tuned, working order.

And last but not least, our sincere appreciation and thanks go to our families for putting up with the many long hours of construction, operating time and word processing necessary in our publishing this work. It's amazing what all our ham families put up with sometimes!

Footnotes

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12) lkjlkjl

13) llkjl

14)

References

[Peter's]

The BPSK reflector

To get on the BSPK reflector, send a message to majordomo@qth.net with "subscribe bpsk" in the body of the message.

The McClune website

The NJ-QRP website

The New Jersey QRP Club website contains the

DDS VFO Module:

The DDS VFO is an original design by N2APB, likely to be discussed separately in a follow-on paper. Regardless, the schematic is shown in Appendix C, and the software for the microcontroller is available on the NJ-QRP website: http://www.njqrp.org/memberprojects/dds_vfo .

DSP56002EVM Module: references

R2T2 Modules: references

The

RF Amplifier module: references

Sigma-Delta A/D Module

For HF use, people should really use both the Sogma-Delta board and the SD-DAC board. The original SD board (kit of all parts is still available from VE2IQ and the cost is still US$49) plus the new SD-DAC board (kit is also available from VE2IQ, cost US$39). Bill can ship both kits in one parcel for the same postage cost, which is US$5. So to order both kits at the same time, send $93 US to: Bill de Carle, 29 Sommet Vert, St-Adolphe d'Howard, Qc, J0T 2B0. The SD-DAC board generates a nice, shaped-pulse waveform that does not produce excessive interference to other users on the band. We have found by experience that people who try to homebrew a BPSK modulator for HF generally end up with very wide signals that draw complaints from other users.

The Rob Frohne article

Rob Frohne, KL7NA, "A High-Performance, Single-Signal, Direct-Conversion Receiver with DSP Filtering," QST, April 1998, pp 40-45.

The Max Carter article

Max Carter, "Super Narrowband Techniques Equalize Power Inequity on 1750 Meters," Communications Quarterly, November 1990, pp 99-113.

The Johan Forrer article

Johan Forrer, KC7WW, "Using the Motorola DSP56002EVM for Amateur Radio DSP Projects," QEX, August 1995.

The VE2IQ Articles

Bill de Carle, VE2IQ, "A Receiver Spectral Display Using DSP," QST, January 1992, pp 23-29.

Bill de Carle, VE2IQ, "A DSP Version of Coherent-CW (CCW)," QEX, February 1994, pp 25-30.

Appendix A

[A full set of files, descriptions, locations for all the CCW literary works published in the past. Use Pete's list.]

Appendix B

[Schematic of the VE2IQ Sigma-Delta Board]

Appendix C

[Schematic of the N2APB DDS VFO]

Appendix D

[Schematic of RF Amplifier]