## Do Pulsed FMCW Signals Create More Interference Potential Than Pure CW?

**Don Barrick January 2009**

<u>**Background**</u>**:** A question has been raised about the interference potential to other users of the HF spectrum, resulting from different transmitted waveforms. Specifically, all systems sold today use a frequency-modulated continuous wave signal (FMCW), where the frequency is swept linearly over periods from 1/4 to one-second repetition interval.

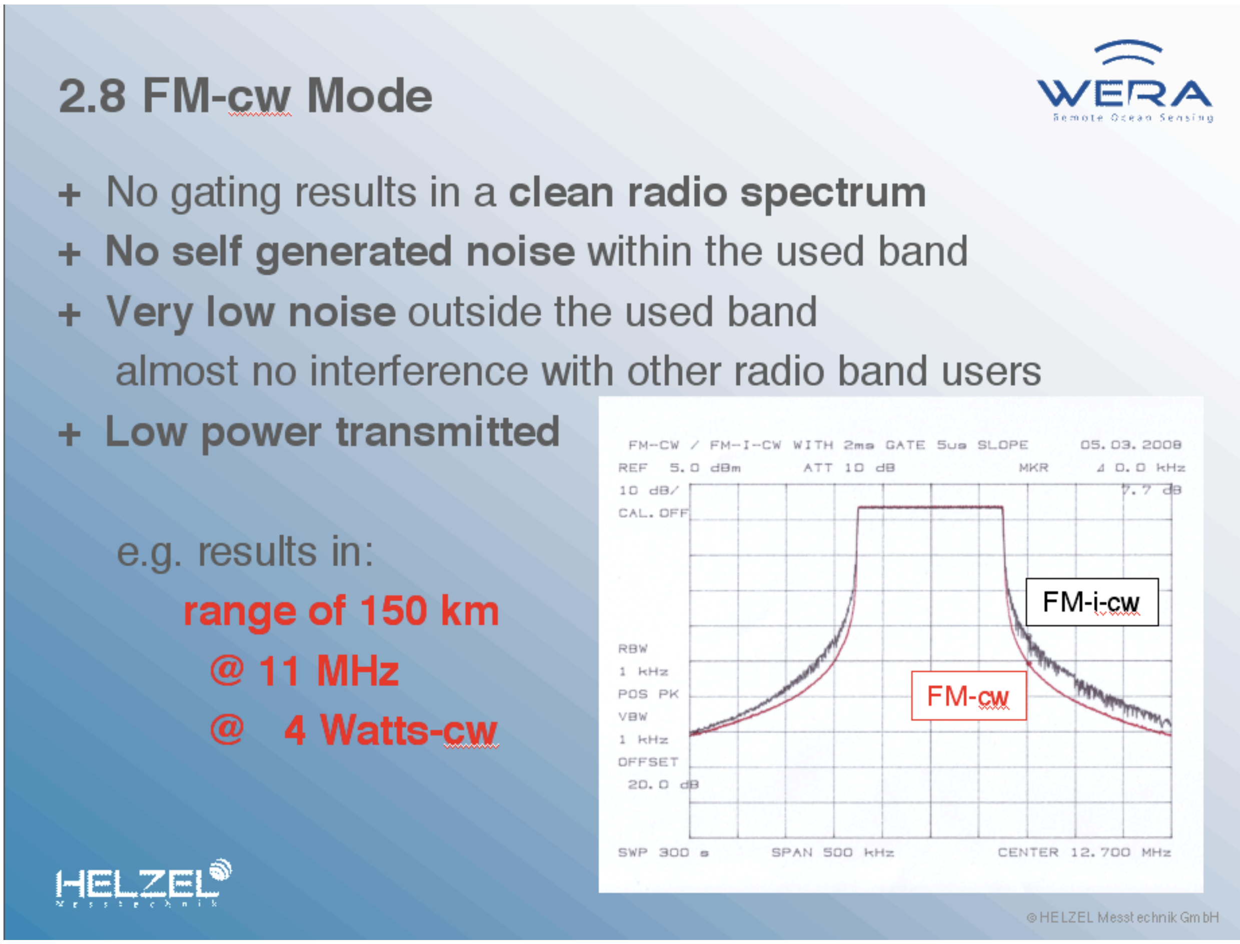
The difference is that some systems (a vast majority) pulse the signal at a more rapid rate in addition to the sweeping. This is done to suppress reception of the intense direct signal and strong early-range echoes that result from transmitting while receiving -- the pulsing and gating simply turns off the receiver while transmitting. This eliminates undesired consequences -- including false echoes at more distant ranges and elevated noise levels due to slight antenna vibrations in stronger winds. These problems both require other measures to deal with the stressed dynamic range, and often are never 100% effective. This is the only reason that nearly everyone applies pulsing/gating to the same FMCW signals -- it has nothing to do with range resolution.

The allegation has been made that pulsing the signal causes unacceptable out-of-band interference. This could alarm frequency approval authorities who may not probe deeply enough to find out the truth. Although mathematical analysis suggests that -- worst case -- a square-wave modulation on a signal causes classic "Sine(X)/X" processing side lobes that die out very slowly, many factors mitigate and eliminate this out of band radiation. Filters always band-limit signals (both specifically designed and the natural narrow-band transmit-antenna responses). Pulse shaping (i.e., rounding the sharp corners of the square wave transmit signal) is used to further suppress spurious radiation. These techniques have been known and used for decades.

<u>Summary</u>: **Bottom line is: pulsed FMCW waveforms do not create unacceptable out-of-band interference to other users.**

<u>**Explanation and Discussion**</u>**:** As evidence, I show a measured spectrum analyzer plot -- not done by CODAR -- but done by Helzel on the un-pulsed WERA signal and a pulsed version of the same FMCW signal. This figure is part of WERA marketing materials that circulates among the HF radar community.

This plot is presented as evidence to denigrate the pulsed signals of other vendors, such as CODAR in Helzel's advertising. However, look at the results! The pulsed signal (FM-i-cw) is at worst about 5 dB higher than the pure CW signal (FM-cw), far down on the sides; **such minimal differences would be barely detectable. But when you go down about 60 dB, the two are equal again. Not much of a case here that one is acceptable and the other is not. Furthermore, no pulse shaping nor special filtering was employed on the FM-i-cw signal, as is common among the users of this modulation.**




<u>**Don't Forget the FFT Window:**</u> There is a more important, over-riding issue not addressed in the above plot. **If you follow my argument in this paragraph, it proves that a pure un-pulsed waveform actually demands quite a bit more spectral bandwidth than the pulsed version.** The frequency sweep width in any radar is the first step in determining its range resolution. If a user wants a range resolution of 1 km, for example, he should consider a 150 kHz sweep (following the universal law between signal bandwidth and range resolution for **all** radars), in the absence of further processing windows. The above plot shows a 150 kHz sweep, as measured across the flat plateau at the top. However, because of the dynamic range issue of a pure FMCW

signal (i.e., receiving strong signal while transmitting), Gurgel and WERA wisely employ a four-term Blackman-Harris window on the time-series digital data stream before extracting range. This indeed does suppress the smearing and false echoes generated in the digital part of the processing, **but at the expense of broadening the range-cell size by exactly a factor of two!** ["On the use of windows for harmonic analysis with discrete Fourier transform", F.J. Harris, *Proceedings of IEEE, vol. 76*, pp. 51-83, 1978] Taking this into account, a sweep bandwidth of 300 kHz is needed (instead of the 150 kHz often cited) in order to achieve the 1 km cell size. Pulsed systems also require a window, but much less severe, usually a Hamming or Blackman-Tukey, which broadens the cell by a factor between 1.15 and 1.3. Thus to achieve the same range resolution, **an un-pulsed signal with a proper time-series window to suppress frequency sidelobes requires 50% - 80% more bandwidth**, a significant encroachment on other-user HF channels that goes unmentioned when castigating those who pulse.

**Motivation:** My arguments are not an attempt to show that one system is inherently superior to another due to the waveform used. We should avoid such divisive tactics. Any of us can operate our FMCW systems in an un-pulsed mode, if we choose. CODAR does this for stand-alone bistatic transmitters. If we are seeking universal approvals for HF radar primary allocations, we should emphasize what we have in common, in an attempt to persuade the approval authorities in Geneva to allow primary bands for HF radar operation for everyone, rather than trying to exclude competitors based on bogus signal interference claims. Bringing this up will divide the community, by resorting to arguments that are wrong and/or misleading, as I have shown above. This could lead to rejection of approval requests for everyone, or years of delay.

**The Record:** For the record, those countries/vendors presently using pulsed FMCW signals comprise about 90% - 92% of the world share of HFSWRs in use for current/wave monitoring. They comprise: U.S./CODAR; Japan/NJRC & Mitsubishi; China/FanGu. Only Germany/Helzel-WERA employ un-pulsed signals.