ITERATIVE SPECTRUM ANALYSIS: NEW METHOD FOR DATA PROCESSING AND ANALYSIS

Klaus Bibl (1) **and George P. Cheney**(2)

(1)University of Massachusetts-Lowell, Center for Atmospheric Research
600 Suffolk St.,
LOWELL, MA 01854 USA
k.bibl@verizon.net

(2)As (1) above, but E-mail: George_Cheney@uml.edu

Abstract

From standard spectrum analysis (e.g. FFT) the exact frequency, amplitude, and phase of the largest spectral line can be determined by a simple process. In the time domain, the respective sine function can be subtracted from the data, but stored if the information is useful. This process can be repeated as often as necessary until a sufficient signal-to-noise ratio is established and a sufficient amount of wanted signals are detected or a sufficient number of interferers are eliminated. Applications are unlimited: the precise determination of specific frequencies in a spectrum, elimination of large interferers in broadband communications, and increase of the dynamic range in special codes and non-linear spectrum analysis.

Introduction

Iterative Spectrum Analysis was invented for improving the dynamic range and signal-to-noise of data processed by Non-Linear Spectrum Analysis. Even in standard spectrum analysis, the exact frequency of the largest signal in a spectrum can be determined by comparing the complex amplitudes of two adjacent spectral lines. From that it determines (and stores) the exact amplitude and phase by a simple process and eliminates the respective trigonometric function *in the time domain*. This is different from the frequently used and patented method [1] of "punching out" the largest signal in the frequency domain and avoids the cumbersome matrix inversion of "Music" [3] and other programs. None of the many available filtering programs [2] to minimize the side-lobes of spectral lines are necessary; they only diminish the signal-to-noise ratio and the accuracy of the spectral line measurement. The method can be used repeatedly on the same spectrum and is self-healing if the data are compromised by noise and interference from other spectral lines.

Soon it became obvious that Iterative Spectrum Analysis can be useful in any spectrum analysis program. Several completely different applications are discussed in this report. Substantial progress in Digital Data Processing makes the use of this method possible for real-time processing in most cases.

Precise Measurement of Amplitude and Phase in Spectrum Analyzers and other Equipment

Even in the most sophisticated Spectrum Analyzer equipment there is often a substantial limitation in spectral resolution because of the processing time of a very long spectrum. But the presented method (for which a patent has been applied) could be used to improve the resolution by a factor of ten or even one hundred, depending on the signal-to -noise conditions for the larger spectral lines when they are selected by the cross hair of the instrument. Thus the amplitudes and phases of the harmonics could be measured accurately in respect to the basic frequencies. This might be important for many applications.

Elimination of Narrow-band Interference in Pulse Radar and Other Wide-band Signals.

Ionosondes and Coherent Radars are often affected by narrow-band interference (fig.1), which can be 40 dB above the pulse signal. Even "Blue-Tooth" can be disabled by single frequency microwave ovens. All the intra-pulse and pulse sequence coding does not help in those cases. Iterative Spectrum Analysis can eliminate up to 100 spectral lines of carriers and narrow modulation lines sequentially if 512 or more data samples are available after each transmitter pulse from the 30 kHz wide-band receivers.

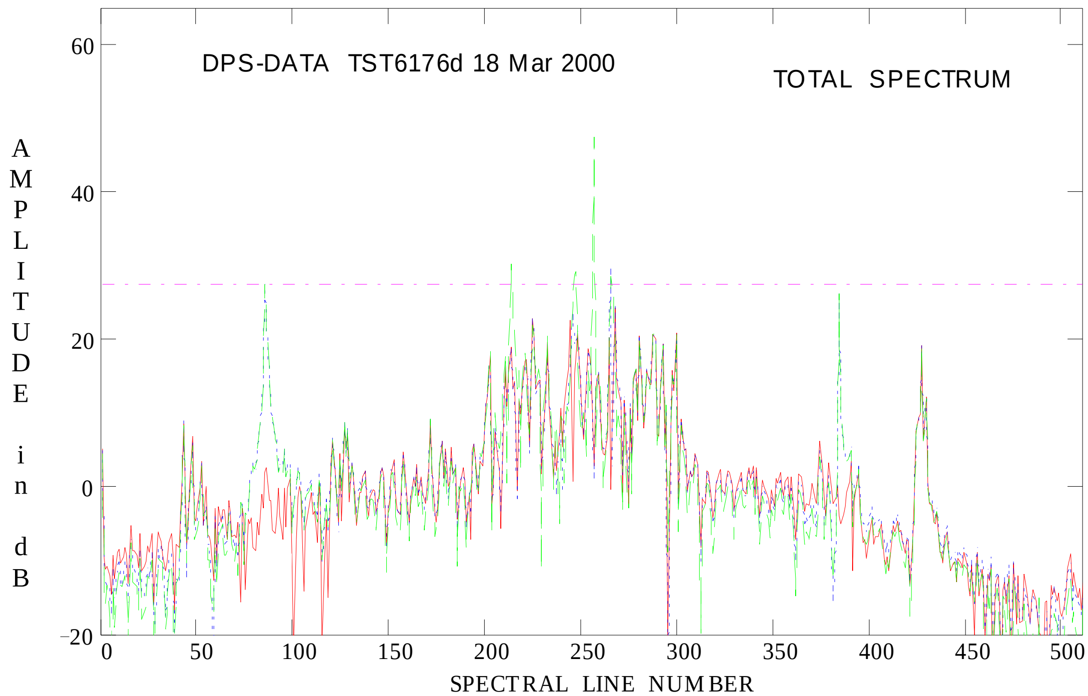

Figure 1: Spectrum Before (Green) and After (Red) Removal of Six Spectral Lines

This procedure does not affect the amplitude and the phase of the pulse signals. On the contrary, as presented ionogram data show (fig.2), the wanted data were invisible without that method. Pre-cleaning takes place in real time before data compression and narrow-band spectrum analysis of the pulse signal, which is performed in each delay range independently.

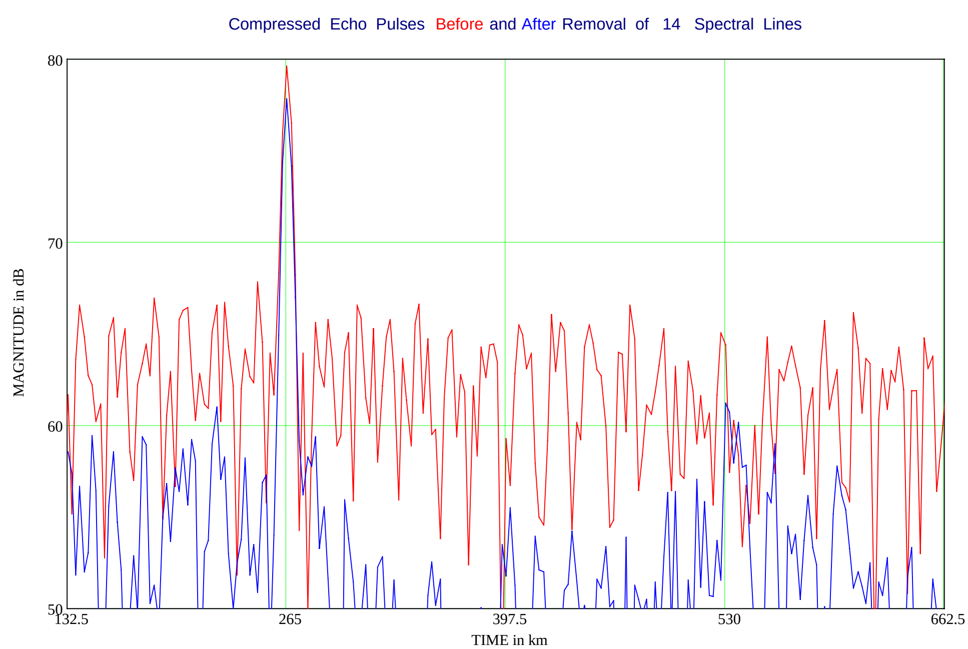

Figure 2: Double Echo Becomes Visible After Cleaning of Interference

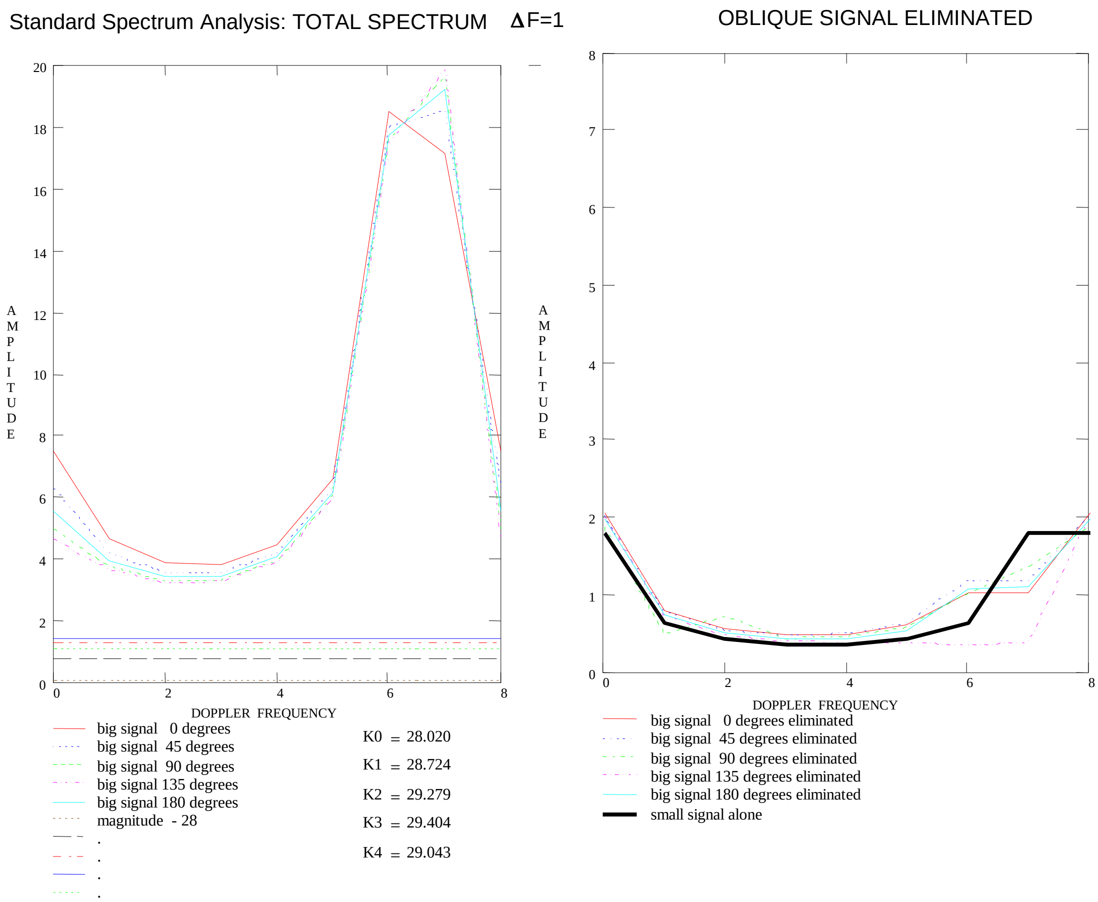

Figure 3: Cleaning of Interfering Signal from 20 dB Smaller Wanted Signal

Iterative Spectrum Analysis Increases the Dynamic Range for Unevenly Spaced Samples

In monostatic pulse sounding there is often the need to measure long-range echoes, which have large Doppler frequencies due to the fast movement of the reflector. If, in addition, echoes from short ranges can occur simultaneously, phase coded pulse sequences (like complementary pulse or even Barker codes) cannot be used for pulse compression to increase the number of samples for noise reduction. Both codes are sensitive to large Doppler shifts and large coherent interference

Although the method of unevenly spaced pulses, called the Staggered Pulse Code, is a known alternative, it has not been used much because of its limited dynamic range of amplitudes. A staggered pulse code has been found and modified for a minimum number of transmitter pulses. At any transmitted frequency, it distinguishes up to 256 Doppler frequencies in the time period given by four consecutive equally spaced pulses covering 256 height ranges. There are 1024 timing units, called chips. From those 1024 chips, transmitter pulses occupy 204 chips, organized as 108 groups of one, two, or three pulses per group. To give the tuned antenna and the receiver time to recover from the transmitter pulse, 108 chips at the end of each transmitter group are also excluded from sampling. Thus 712 chips are available for reception where sine and cosine samples are taken. The code allows the detection of very large Doppler shifts. Short and large ranges can be optimally sampled with a minimum of 128 and a maximum of 152 samples in any delay range, except the first.

There are two independent reasons for the limited dynamic range for staggered pulse codes:

1.) the substantial background of unwanted Doppler lines less than 20 dB down for the spectrum of a perfectly sinusoidal signal and

2.) cross-talk between the ranges.

Although a phase code for the pulse sequence is applied, it is impossible to optimize the phase code for all delay ranges at all possible Doppler frequencies. This leads to a substantial leakage of the largest signal into other delay ranges.

Thus, the new method of Iterative Spectrum Analysis comes to the rescue. Coherent interference spectral lines are extracted first in the time-domain data, as explained in the preceding section. Then the remaining data is sequentially treated by applying the individual phase code for each delay range and finding the largest Doppler amplitude of all ranges. The exact frequency, amplitude and phase will be stored and the respective values of a sine wave will be removed from the specific samples of the time-domain data. This method overcomes the limited dynamic range of the staggered pulse code scheme.

Elimination of Unwanted Signals by Iterative Spectrum Analysis in Top-Side Sounding

Iterative Spectrum Analysis finds an important application in Top-Side Sounding. It is possible that oblique echoes have a much larger amplitude, due to focusing or polarization, than the wanted vertical echo. In many cases, the oblique echo will have a very large Doppler shift and can be separated by spectrum analysis. But in cases where the oblique signal is substantially larger, it will completely obscure the vertical echo because of the limited number of available frequency channels. For topside sounding with 8- or 16-chip pulses, the number of available samples and Doppler frequencies is normally limited to 8.

Therefore mathematical examples have been constructed with Doppler separations of four to one units, an oblique signal 10 or 20 dB higher than the vertical signal, and a Doppler frequency for both signals exactly between the measured channels. The Doppler spectra show the following:

With standard analysis the smaller signal is completely drowned within the bigger signal. But, after Iterative Spectrum Analysis removed the bigger signal, the amplitudes of the smaller signal are within a fraction of 1dB of its correct value and the phase errors are less than +/- 1 degree. An exception is the case of separation by one unit where the errors are larger when the amplitude ratio is 20 dB, the frequencies of both signals are exactly halfway in between spectral lines, and the frequency separation is only one spectral line. Even in this case the smaller signal is still clearly distinguished after the larger signal is removed. Thus, the frequency of the smaller, but wanted, signal and its amplitude and phase can be measured (even under bad conditions) by Iterative Spectrum Analysis, as fig. 3 shows:

Conclusion

Iterative Spectrum Analysis can be used successfully to determine the exact frequency, amplitude, and phase of many signals in a spectrum, to improve the dynamic range of a spectrum, and to eliminate unwanted signals and interferers from any spectrum, small or wide.

References

[1] R. R. Kurth and A. Gabel, "Narrowband Interference Suppression Systems", US Patent No. 04613978 06/1986.

[2] R. W. Hamming, "Digital Filters", 3rd Edition (1989) Prentice Hall, Signal Processing Series.

[3] S. M. Kay, "Modern Spectral Estimation", (1998) Englewood Cliffs, NJ.