Sensitivity of Series 6000-6100 Direction Finders

A Technical Application Note from Doppler Systems

April 8, 2003

1.0 Introduction

This application note discusses the sensitivity of the 6000/6100 series direction finders in various signal detection modes – "continuous, pulsed, gated or synchronized pulse". A major change was made in the bearing detection algorithms used in version 4.19 which affects the signal detection of continuous and pulsed type signals.

2.0 Continuous Signal Detection Prior to V4.19

The DF processor samples the audio signal every 10 milliseconds and determines whether a signal is present every ½ second. (This interval may be changed using the serial commands). The determination is made by calculating the relative stability of the audio signal in relation to its average value. Both the variation from the average and the average itself are treated as vectors. That is, both the magnitude of the audio signal and its phase are used to determine these values.

The method permits the receiver to be used either squelched or unsquelched. Unsquelched operation generally provides higher sensitivity. Because the metric used to determine signal presence is a ratio, the setting of the audio volume control does not affect the sensitivity . The ratio is compared with a parameter called SNR in the firmware which may be changed by external serial command.

If a bearing is detected based on this statistic, it is assumed to have been present over the entire ½ second interval, and the angle is calculated. However, the sensitivity of detection during the first ½ second that the signal is present depends on the signal strength because the direction finder calculation interval is not synchronized to the signal. In general, this mode requires that a signal be present for at least ½ second for detection, but if the signal occurs midway through the direction finder interval, it is possible that it may be missed entirely if it is only ½ second long, because half the signal will be in one interval and half in the next.

The direction finder reverses antenna rotation every consecutive ½ second, and it is best to average at least two readings to get a bearing that is independent of RF signal strength and frequency offset. Therefore, the signal must be at least 1 second long to span two ½ second intervals, or considering the fact that it is not synchronized to the direction finder, it should ideally be at least 1.5 seconds long. Statistically, the sensitivity of the DF increases with the length of the signal, and in the measurements presented later in this report, the signal was continuous over the entire data-taking interval of 1000 seconds. For this reason, the data is labeled >>0.5 seconds.

3.0 Pulse Mode Signal Detection Prior to V4.19

The previous pulse mode performed a correlation detection over each ½ second interval looking for a pulse of 150 milliseconds duration. The algorithm did not require any synchronism to the direction finder ½ second interval, but it did require that the signal was on for 150 and off for 350 ms and that this pattern repeat continuously. Both the 150 ms on interval and the 500 ms repetition interval can be changed using external serial commands in order to match the correlator to the a-priori characteristics of a specific pulse train.

Antenna rotation direction reverses every ½ second (or whatever the repetition interval is set for) and the number of averages should be set for at least 2 to obtain insensitivity of the bearing to RF signal strength and frequency offset.

The sensitivity of this technique drops as either the ON or OFF interval departs from the correlation values. In the measurement data shown later, the repetition interval is fixed at 0.5+ seconds and the ON time was set at 100, 150, 200 and 250 msec to show this dependency.

4.0 Continuous and Pulsed Signal Detection in V4.19 and Later

The audio signal is still sampled every 10 msec, but in this algorithm, the phase stability of the signal is examined. Phase stability is compared to a threshold value which may be changed by external serial command and if the stability (variation) is less than the threshold, a signal is considered to be present. Since the comparison is made on the basis of phase and not amplitude, the audio volume control setting does not affect the process. (as long as it is above the threshold). Therefore this method also can be used with the receiver squelched or unsquelched for maximum sensitivity.

One advantage in using phase stability rather than vector stability as used in previous versions, is that the sensitivity is higher under "picket fence" conditions. The latter phenomena typically reduced the sensitivity of V4.18 in the 800-900 MHz band when either the direction finder or the transmitter was moving, and required lowering the SNR threshold (which increased the "false alarm" rate).

The test is performed every 10 msec using data retained from the previous 8 samples, so a strong signal can be detected that is only 80 msec long. Of course, the longer the signal, the better the stability and the more sensitive the detection. Bearings are still calculated and updated every ½ second but the update interval begins when the 8 sample test passes.

The antenna rotation direction reverses every ½ second, and it is best to average at least two consecutive measurements to eliminate the effect of RF signal strength or frequency offset on the calculation. In the measurement data shown later in this report, the pulsed signal repeated every 0.5 seconds, but it was not synchronized to the direction finder. Data is shown for ON times of 100, 150, 200, 300 and 500 msec (continuous).

5.0 Sensitivity Test Measurement Setup

Measurements were made using the same DDF6001 display processor and DDF6244B 4-input 2-phase RF summer. All testing used a frequency of 161.230 MHz which is a quiet one (no interference). Sweep rate was 1200 Hz and averaging was set to 2.

For bench testing, the HP8657D signal generator drove a 4-way splitter with VHF antenna simulator cables. Measured loss through the cables, splitter and connectors was 7.4 dB. For pulse testing, an HP8012A gated the signal generator. An R8500 receiver was used with 12 KHz bandwidth NBFM detection.

5.1 Thresholds

The old V4.18 threshold is a SNR parameter and the default value of 1.2 was used. For the new V4.19 firmware, the threshold corresponds to an angle. The default value of 0.3 radians was used. In both cases, the number of "false alarms" or bearing displayed when no signal was present, is very low (less than one per hour).

5.2 Data Collection

Data was collected using a data collection program running on a PC connected to the direction finder’s serial port. A total of 1000 bearings or 1000 seconds, which ever comes first, was recorded at each signal strength level. The program computes the probability of detection, average bearing and standard deviation of the bearing. The abscissa "RF Input" is the signal generator output minus the loss through the antenna simulator (7.4 dB).

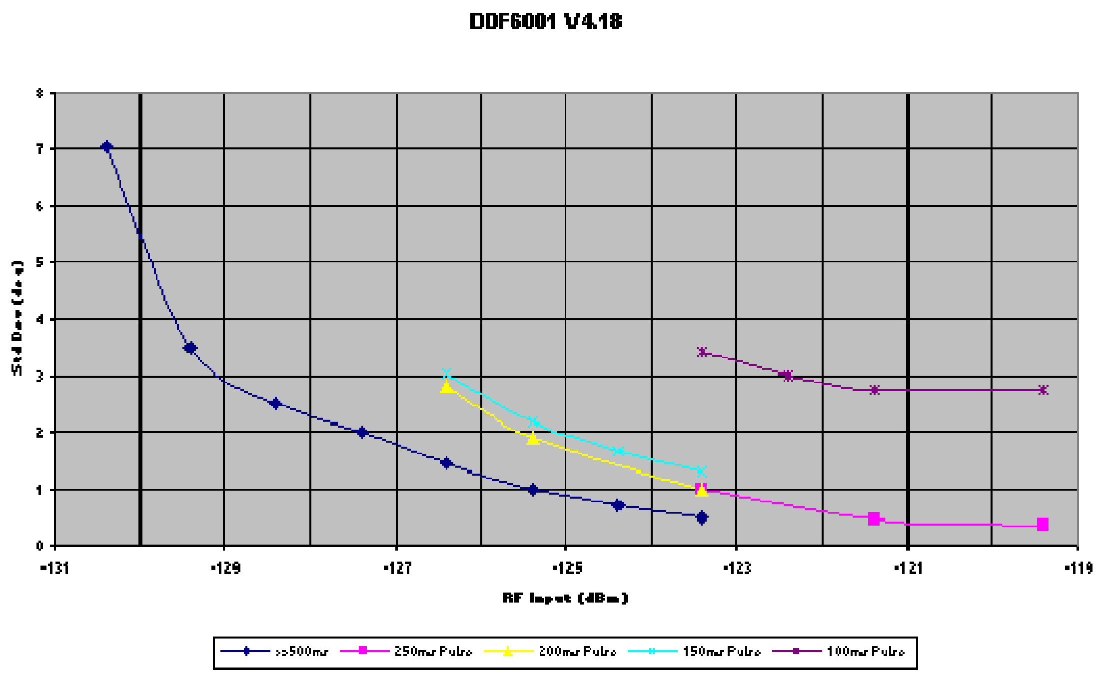
The average bearing in all cases was essentially the same (within 1/2 degree), and it is therefore not plotted.

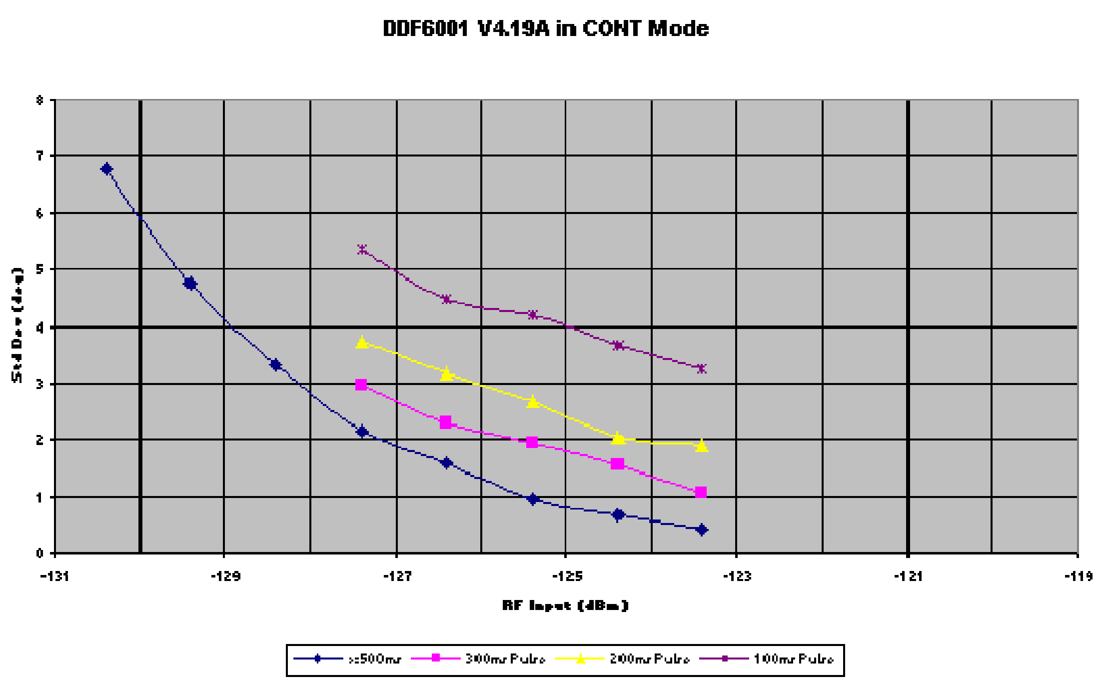
6.0 Standard Deviation Data

The following two figures plot the standard deviation of the two versions. In the case of V4.18, the direction finder is se5.1 t in the CONTINUOUS mode with a continuous signal and in the PULSE mode for the pulsed signals. For V4.19, the direction finder remains in the CONTINUOUS mode for both the continuous and pulsed signals tested.

Overall, the standard deviation is about the same for continuous signals and pulsed signals that are close to the 150 msec used in the V4.18 correlator. However, the signal strength required for V4.18 pulses that are much shorter (100 msec) or much longer (250 msec) is much higher because these signals no longer correlate and are therefore rejected.

Note also that the signal duration required for the continuous signal in V4.18 must be much longer than 500 msec, while it may be 500 msec or longer with V4.19.



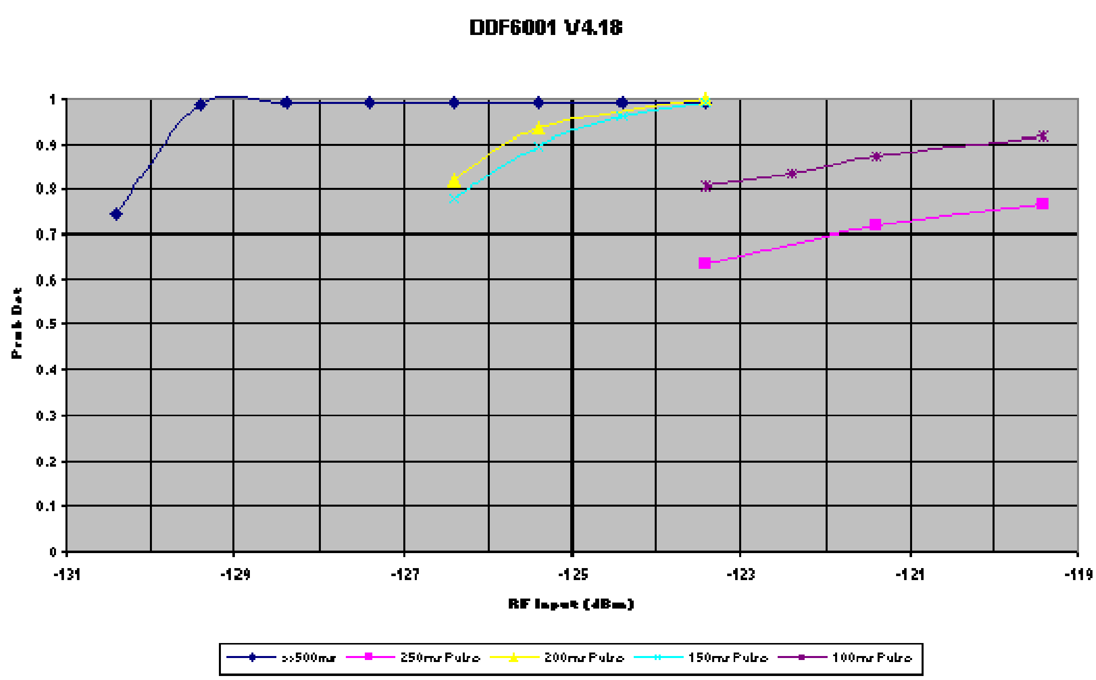


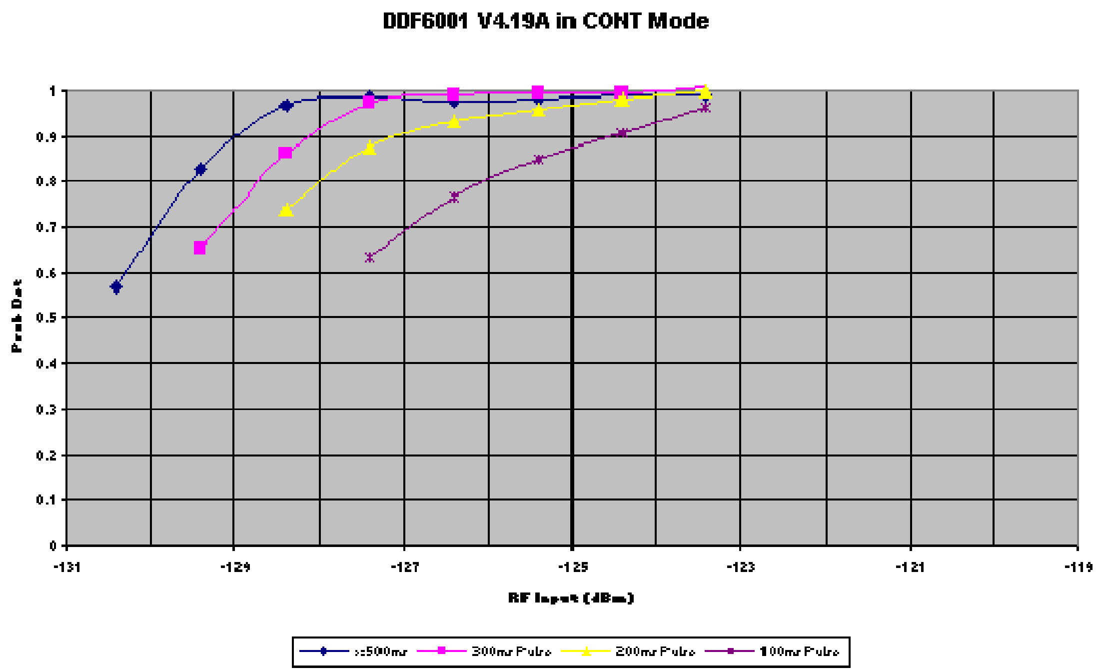
7.0 Probability of Detection

This is perhaps more important than the standard deviation since averaging can be used to reduce the standard deviation, but nothing can replace missing data.

V4.18 appears to be about 1 dB more sensitive with continuous signals than V4.19. However, this may be misleading because with V4.18, the signal must be much longer than the update interval (500 msec) to be considered continuous. V4.19 requires only that each signal be equal to or longer than 500 msec to be considered continuous. Note that the black curves are labeled differently (>>500ms and >=500ms) in the figures to reflect this.

As a rough demonstration of this fact, the pulse generator was set to produce 1000 msec long pulses, manually triggered. This causes the 1-second duration signal to be triggered randomly with respect to the 500 msec timer used in the direction finder (inV4.18). A total of 25 pulses were applied, all at a very low level of –127.4 dBm (RF input). Looking at the curves for continuous signals in the figures below, both V4.18 and V4.19 should produce 100% or 2x25 = 50 bearings at this signal level. In, fact, V4.18 produced only 40 while V4.19 got all 50.





8.0 Gated Pulse Detection

In V4.18 (and earlier), a gated pulse mode was provided that was enabled using serial command 978. In V4.19 this mode is also enabled by serial commands 978 or 13 or by pressing the PULSE button on the front panel.

The gated pulse mode depends entirely on the receiver or some other signal processor determining when the signal is present. A TTL level Gate signal is applied through the AUX INPUT jack on the rear panel and the direction finder samples the audio input every 10 msec as long as the signal is present, up to ½ second. The bearing is calculated at the end of the Gate pulse. DF sensitivity in this mode is much better, but of course the key is how sensitive the external processor is in determining the Gate pulse.

Antenna rotation direction is also controlled externally using serial commands 941 and 942.

In the older model direction finders (DDF6000A, 6000B and 6100B), there was no Aux Input jack, and in these models the Gate signal is applied through the S-meter input.

In models DDF6000C and 6100C, there is no internal pull-up on the Aux Input, so the high level input must be asserted. The same is true of course when using the S-meter input on the DDF6000A, 6000B and 6100B.

In models DDF6000D, 6100D, 6001E/F and 6002E/F, there is an internal pull-up on the Aux Input, and the Aux Input is normally open circuit, so the direction finder treats the PULSE mode as a continuously gated signal if nothing is plugged into the Aux Input jack. That is, the direction finder will "free run".

9.0 Sync Pulse Detection

This is a special version of the gated pulse input in which the pulse signal is a short duration pulse (typically 100 msec) that sets an internal timer in the direction finder which takes 500 msec of bearing data with clockwise antenna rotation followed by 500 msec of bearing data with counter clockwise antenna rotation. In both V4.18 and V4.19, this mode is initiated using either serial command 977 or by pressing the PULSE button when the CAL light is ON.

In the older model direction finders (DDF6000A, 6000B and 6100B), there was no Aux Input jack, and in these models the Gate signal is applied through the S-meter input.

In models DDF6000C and 6100C, there is no internal pull-up on the Aux Input, so the high level input must be asserted. The same is true of course when using the S-meter input on the DDF6000A, 6000B and 6100B.

In models DDF6000D, 6100D, 6001E/F and 6002E/F, there is an internal pull-up on the Aux Input, and the Aux Input is normally open circuit, so the direction finder treats the PULSE mode as a continuously gated signal if nothing is plugged into the Aux Input jack. That is, the direction finder will "free run". In addition, some minor circuit changes must be made on the logic board of the DDF6000D and 6100D by the factory to utilize this mode.