Technical Note: TN032

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Subject: Optimizing Your ADCP Setup

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By Peter Spain

Teledyne RDI's Acoustic Doppler Current Profilers (ADCPs) measure time series of speed and direction of water flow at many depths. Because they use a broad bandwidth signaling method, Teledyne RDI's ADCPs provide more information in less time. As a result, the BroadBand data are much clearer and cleaner than the original ADCP method. And there are several ways you can take advantage of these superior measurements—making decisions sooner, recording more accurate results, or seeing more of what is going on.

The automatic setup for the ADCP covers a wide range of operating situations. It works for many users in many applications. Yet, you always have the option to make your own setup choices. This note describes setting up ADCPs using Teledyne RDI's BroadBand method to optimize your results. The ADCP-setup trade-offs involve 3 R's—*resolution, range, and random noise*—that are interdependent. In this note, we present some simple rules-of-thumb that permit you to anticipate and balance the trade-offs—achieving optimized ADCP results.

ADCP setup

Teledyne RDI's ADCPs are configured automatically at power-on to support a wide range of current profiling situations. This allows many users to acquire high quality results without altering the ADCP's setup. Some users, however, seek more control of ADCP performance or have to operate in more demanding environments.

When operating an ADCP, you have the option to specify several aspects of how the data will be collected

- ✓ Depth range of measurements
- ✓ Spacing between measurements: in depth, time
- ✓ Desired precision of data
- ✓ Deployment duration

Although these choices are interdependent, some simple rules-of-thumb permit you to anticipate the trade-offs.

In addition, if the water speeds and depths you anticipate seeing are slow and/or shallow, you can take advantage of the ADCP's flexibility and choose an operating mode better matched for these conditions.

Teledyne RDI's ADCP design anticipated these occasional needs by providing an upgrade path that includes operating modes optimized for specialized conditions. This arrangement is similar to gears in an automobile or bicycle where the operator can cruise, for the most part, with standard operation yet select a specific gear for demanding situations (e.g. starting on an icy surface). This flexibility enables you to be more productive, using the same ADCP for both deep and shallow sites.

Operating Modes

For modest-to-higher speeds and depths, most ADCP users will stay with Mode 1, the operating mode set automatically at power-on. For shallower waters moving more than 1 m/s, or for improved velocity precision in non-dynamic situations, the choice is Mode 12. For slower speeds and shallower depths, we recommend Mode 11. Operating bounds for this mode are (water + boat) speed x depth < 1 m^2/s.

How these modes are inter-related is described in Tech Note TN031. Here we focus on their roles in optimizing your ADCP setup.

For collecting velocity data with a clear signal, we recommend choosing an ADCP setup that ensures standard deviation (random noise) < 1/6 typical water speed. This results in modest velocity signals not being lost in the peak-to-peak variation in random noise (see Fig. 3).

For measuring fast flows, this working rule is not very restrictive on setup choices. But if the flow speed you expect is 10 cm/s, the working rule restricts standard deviation to < 2 cm/s. In this Note, we will clarify your setup options for achieving this goal.

Operating Mode	1	12	11
Profiling Range	Highest	Mode 1 or less with smaller cells	Limited
Advantage	Higher Speeds Robustness	Most Flexible Mode	High Resolution
Precision	Few cm/s	Better	Highest (mm/s)

BroadBand Benefits

The range of acoustic penetration of the ADCP is subdivided into a large number of depth cells—uniformly sized, vertical segments. More cells obviously provide more detail or resolution about how things vary through depth. An average water velocity is computed from the Doppler-shifted echoes heard from each depth cell. Considered together, these velocity data are called a profile and the combined depth of their cells is the profiling range.

ADCPs are used in a wide range of marine and inland waters. For working in shallower waters, maximizing the amount of detail or resolution of the data set is usually the primary setup objective. In deeper waters, longer profiling range becomes the priority. Common to both groups is the need for a viable signal-to-noise velocity ratio; hence, controlling random noise is a universal goal. Teledyne RDI's ADCPs using the BroadBand method provide unique capability to this end.

In the original ADCP method, the data were inherently imprecise or *noisy*. A brute-force approach to noise suppression was implemented; a great many acoustic transmissions or *pings* had to be averaged together. This obviously became a controlling factor on the output rate of the ADCP or the time resolution of the data set. As we will see, there was an option for improving time resolution but it was generally unpalatable—sacrificing vertical resolution.

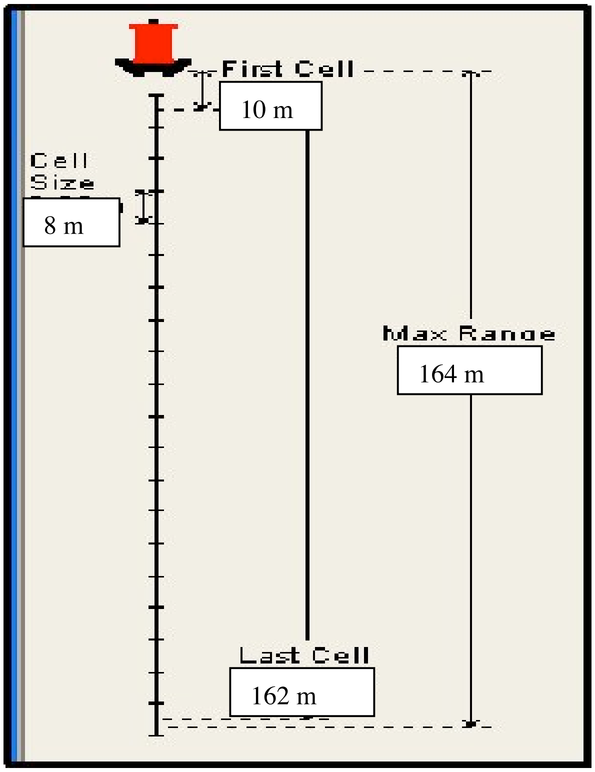


Figure 1. Velocity Profile Definitions. The relationship between depth cells and the profiling range is shown. Max range is the acoustic penetration determined with the SONAR equation. The mid-depth of the First Cell is marked.

BroadBand ADCPs provide users with much more flexibility by improving signal-to-noise velocity ratio in two innovative ways that are at work at the same time—for each acoustic transmission[1].

✓ *Using broad bandwidth signals*

This improves precision by collecting hundreds—rather than a few—independent samples from a water volume.

✓ *Measuring scatterer motion over longer time*

This is analogous to computing velocity by taking the difference between two position fixes. Waiting longer between the fixes reduces the uncertainty in velocity.

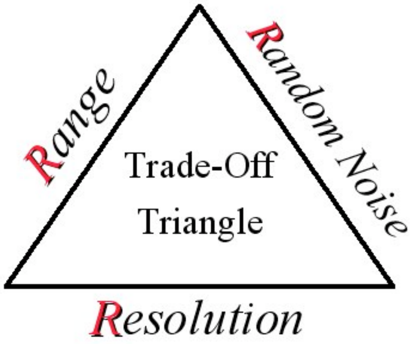
For the same setup as the original ADCP, the data returned by each BroadBand acoustic transmission is now inherently precise or *clean:* 50 x fewer transmissions are needed. You can take advantage of the BroadBand method to improve your measurement capability in three quite different ways—higher definition, longer profiling ranges, or lower noise.

Higher definition reveals to you more of what is going on—in time, through depth, or along a boat's path. This finer resolution has wide-ranging advantages. Second, your can double your profiling range for very high resolution profiling by using a lower frequency ADCP than was previously possible. Finally, having lower noise clarifies patterns in the data sooner so you spend less time waiting for results before making decisions.

Trade-off Triangle

For understanding ADCP performance, it is useful to consider the interplay between 3 R's—resolution, range, and random noise. These variables are interdependent; changing one affects the other two, hence they form a trade-off triangle. Some simple rules-of-thumb permit you to anticipate the trade-offs.

Acoustic frequency, which is the distinguishing attribute of any ADCP, affects all three R's. Lower frequency permits greater profiling range at the cost of either coarser resolution and/or noisier data.



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[1] SEE TECH NOTE TN031

Trade-off Tables

A. BETTER RESOLUTION (depth, time, along-track) and/or REDUCED RANDOM NOISE

ADCP Setup: Use profiling mode intended for higher resolution and/or improved precision

Option	**Effect**
Improved 2-3 times: Mode 12	Not limited by higher speeds but anticipate need for less dynamic environment
Improved 10-100 times: Mode 11 for (water speed x depth) < 1 m^2/s	Expect short profiling range AND limited max. speed**

**Apparent speed seen by ADCP = (WATER + BOAT)

B. BETTER DEPTH RESOLUTION

ADCP Setup: Smaller depth cells

TRADE-OFF: More Random Noise, Some reduction in Profiling Range

Option to COUNTER-BALANCE Trade-off	**Effect**
Include more pings in the average *(Reduce RANDOM NOISE)*	Slows Profile update rate, fewer data points along boat's path
Switch on Narrower Bandwidth (*Regain RANGE)*	Many more pings will need to be included in the average; see box above.
Expert: Adjust WV command to be smaller to reduce Random Noise	Permitted max. speed** is reduced
General: Use a higher frequency ADCP	Profiling range reduced by 50%

C. REDUCED RANDOM NOISE

ADCP Setup: Larger depth cells

TRADE-OFF: Resolution (depth)

Option to COUNTER-BALANCE Trade-off	**Effect**
Include more pings in the average *(Reduce RESOLUTION in time, along track)*	Slows Profile update rate, fewer data points along boat's path
Expert: Adjust WV command to be smaller to reduce Random Noise	Permitted max. speed** is reduced
General: Use a higher frequency ADCP	Profiling range reduced by 50%

D. LONGER PROFILING RANGE

ADCP Setup: Narrower Bandwidth ON

TRADE-OFF: More Random Noise

Option to COUNTER-BALANCE Trade-off	**Effect**
Use Mode 12	Not limited by higher speeds but anticipate need for less dynamic environment
Include more pings in average *(Reduce RESOLUTION in time, along track)*	Slows profile update rate, fewer data points along boat's path
Use Larger depth cells to reduce random noise *(Reduce depth RESOLUTION)*	Fewer measurements top-to-bottom but will extend profiling range farther
Expert: Adjust WV command to be smaller to reduce Random Noise	Permitted max. speed** reduced
General: Use a lower frequency ADCP	Profiling range increased by 100%

Resolution

Teledyne RDI's first prototypes using broad bandwidth signaling were called High Resolution current profilers because their data sets provided unprecedented resolution. This connection between bandwidth and resolution is common in geophysics and arises because broader bandwidth signals permit higher sampling rates.

The resulting effect of BroadBand signaling is equivalent to having more scatterers in the water. Users can take advantage in two different ways:

- ✓ Improving resolution by reducing cell size and keeping the number of samples per cell the same
- ✓ Improving velocity precision and leaving resolution unchanged.

There are several types of data resolution important to users—in depth, in time, and along a boat's path. The last two are actually the same depending on whether the ADCP is fixed or moving.

By definition, cell size sets the depth resolution. This obviously sets the number of scattering targets included at each level of the profile. More targets will result in more echoes heard by the ADCP and hence more precise estimates of average velocity.

➩ *Tip #1: RESOLUTION (DEPTH) vs. RANDOM NOISE*
*2 x more depth cells top-to-bottom will double** the standard deviation of the random noise, and vice versa (v.v.).*
***For cell sizes larger than about 15 cm*

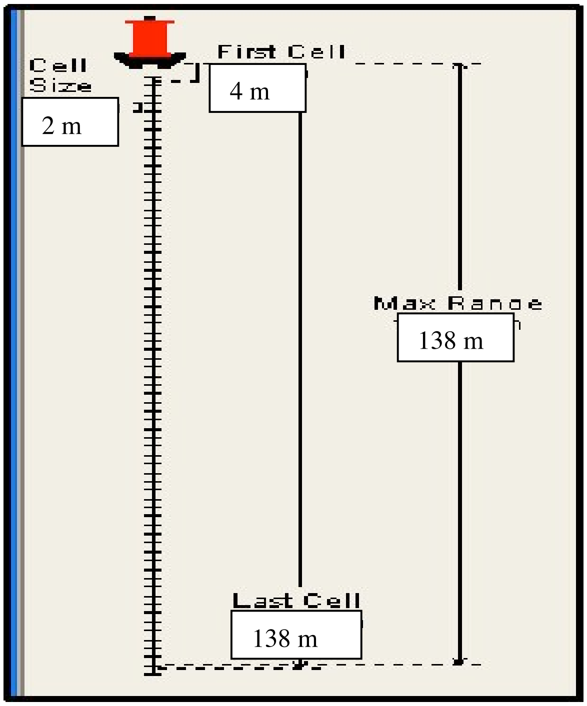

Figure 2. Velocity Profile with smaller-sized depth cells. Compared with Fig. 2, the maximum range, number of depth cells, and distance to mid-depth of First Cell are much changed.

The careful reader will realize this implies 1/4 x as many echoes are being heard. The explanation is that, by default, the length of the transmitted signal is set equal to depth cell size. As a result, when depth cell size is halved, the ADCP takes 1/2 x as many samples from 1/2 x as many targets and v.v.

Satisfying a required data precision can limit the ADCP's time resolution or output rate. Per the last paragraph, depth cell size and time resolution (between velocity profiles) are usually related by an inverse square law (for the same signal-to-noise velocity ratio).

➩ *Tip #2: RESOLUTION: DEPTH vs. TIME*
Doubling depth resolution (2 x cells)—without increasing the random noise—will require 4 x the measuring period and v.v. (For perspective, this is still 12 x fewer transmissions than the original ADCP method.)

Notice that this trade-off has an important implication re power consumption. Although an individual transmission will consume half as much energy, 4 x the number of transmissions are required for the same signal-to-noise velocity ratio.

➩ *Tip #3: RESOLUTION vs. DEPLOYMENT LENGTH*
Improving the depth resolution by doubling the number of depth cells top-to-bottom doubles the power consumption.

Range

The velocity profile ends at a range where acoustic energy density drops below a signal-to-noise threshold. Factors internal and external to the ADCP affect the profiling range by changing the signal-to-noise ratio of the acoustic energy.

(1) Internal Factors. We will consider four factors. First, frequency is the dominant control of profiling range. Energy at lower frequencies is absorbed less and therefore penetrates farther.

➩ *Tip #4: RANGE vs. FREQUENCY*
An approximate rule is that twice the acoustic frequency will reach about half as far.

Second, ADCP beam angle affects range in two ways.

1. Energy in beams angled closer to the vertical reaches deeper—8% farther for 20 cf. 30 degrees.
2. When a boundary is within acoustic range, the extent of useful data is trimmed, more for larger beam angles: beams at 20 cf. 30 degrees are trimmed 6% cf. 15% respectively

Why? Bottom echoes from acoustic energy emitted through sidelobes return with Doppler shifts irrelevant to the water motion. These returns interfere with the Doppler-shifted echoes from the main beam that is measuring the water motion. As a result, measurements from a layer near the boundary are biased and are generally discarded.

Third, when setting up ADCPs, the most common choice affecting range is the size of the depth cells.

Tip #5: RESOLUTION vs. RANGE
Doubling cell size injects 2 x more energy into the water—adding 10% to the profiling range and v.v. (This is an empirical relationship.)

Finally, another way to improve range is by setting a narrower bandwidth for the transmitted and received signals (at the cost of data precision). This reduces the amount of noise energy received thereby pushing out the range where the cutoff for the signal-to-noise energy ratio is reached.

(2) External Factors. We consider environmental and installation factors. Environmental factors can have a significant influence on profiling range. These factors include temperature, salinity, and the concentration of backscattering materials.

Tip #6: RANGE FACTORS. With some exceptions, profiling range is enhanced by colder and fresher water and by more suspended material.

On occasion, research cruises between extreme backscattering conditions have reported profiling range changing by a factor of 2.

Installation factors causing absorption and reflection of the transmitted acoustic energy can reduce profiling range. Examples beneath boats include bubble layers and protective acoustic windows.

These windows are used to protect ADCPs from biofouling and to isolate the transducer faces from hydrodynamic flow disturbances. If the latter are a significant noise source, the window can improve the signal-to-noise ratio, which aids profiling range.

Random Noise

The hallmark of BroadBand data is reduced random noise. Here we consider a variety of factors that affect/control the noise in the data. A theme in what follows is that having more information returned from a depth cell improves the precision of the average velocity.

Tip #7: RANDOM NOISE: CONTROLS
Precision improves by √Bandwidth x √No. Scatterers

(1) Transmitting a broader bandwidth signal extracts more information from a depth cell, producing *quieter* data. Teledyne RDI's BroadBand method transmits a very narrow pulse. This increased 50 x the number of independent samples per depth cell.

(2) A similar effect arises with more scattering targets. They result in more echoes heard by the ADCP and hence a more precise average velocity. Notice that greater numbers of scatterers produce not only longer range but quieter velocity data.

Tip #8: RANDOM NOISE vs. RESOLUTION
Velocity precision improves by √No. Pings x Depth Cell

(3) The traditional means for controlling random noise are either adding more *pings* to the average or using larger depth cells. Both include more scatterers in the average velocity so the random noise contributions tend to cancel each other.

(4) Teledyne RDI's BroadBand method also provides a second option to reduce random noise. The method sends a pair of narrow pulses separated by a time delay or lag. This lag separates Teledyne RDI's operating modes into two classes: short lag (Modes 1, 12) and long lag (Modes 11, 8, 5). Longer lags return more precise velocity data.

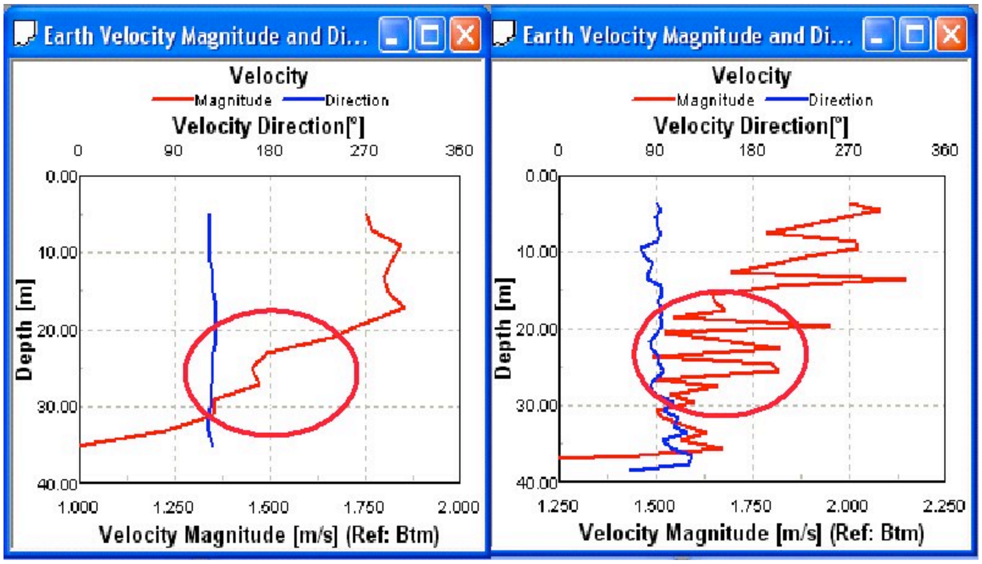

Figure 3. Random Noise on Velocity Profile. The size of the left-to-right wriggles in the red line indicates the size of the random noise. Profile at left (cf. right) has 2x cell size, 5 x pings included in average velocity.

↳ *Tip #9: RANDOM NOISE vs. OPERATING MODES Very low random noise (or very high resolution) can be achieved with Mode 11 (superceding Mode 5). The cost is limited profiling range and a lower cutoff for maximum velocity.*

(5) Highly dynamic conditions degrade velocity precision. Their common effect is to cause the echo to be more decorrelated. This makes evaluating the lag between the pulses in the echo less certain.

↳ *Tip #10: RANDOM NOISE: DYNAMIC CONDITIONS Velocity precision degrades due to more turbulence, greater change in velocity across a depth cell, higher boat and water speeds, or greater heave, pitch, and roll of the ADCP mounting.*

(6) The ADCP configuration is a factor in setting random noise in horizontal velocities. Using a higher frequency reduces random noise in the velocity profile, as does a more horizontal beam angle. Both trade off measurement ranges with the latter losing data near boundaries.

(7) Finally, there is a means to control random noise that is recommended for advanced ADCP users only. You can tune the performance of operating modes by adjusting the direct command WV. Setting WV smaller reduces the amount of random noise in velocity. The trade-off is a reduction in the maximum measurable speed, i.e. apparent (boat + water) velocity.

Conclusion

We have looked at setting up Teledyne RDI's ADCPs that use the BroadBand method. The automatic setup at power-on covers a wide range of operating situations. It works for many users in many applications. Yet, you always have the option to make your own setup choices. These choices unavoidably involve trade-offs.

For understanding ADCP performance, it is useful to consider the interplay between 3 R's—*resolution, range, and random noise*—that form a trade-off triangle. This note describes simple rules-of-thumb to clarify these trade-offs and to aid in optimizing your results.

Summary Table

FOR BETTER DEPTH RESOLUTION. Doubling the number of measurements top-to-bottom …

✓ Increases 2 x** the standard deviation of random noise, and vice versa (v.v.) (For cell sizes > about 10 cm)

✓ Requires measuring 4 x No. Pings to maintain velocity precision. And v.v.

✓ Cuts 10% off profiling range. And v.v. (This is an empirical relationship.)

✓ Increases 2 x power consumption. And v.v.

✓ Requires 2 x acoustic frequency for no sacrifice in velocity precision

FOR LONGER PROFILING RANGE. Profiling range can be enhanced by …

✓ 1.3 x by using Teledyne RDI's narrower bandwidth mode—at cost of 2 x velocity standard deviation

✓ 1.1 x by using 2 x depth cell size. And v.v. (Empirical relationship)

✓ Colder and fresher water and by more suspended material (with some exceptions, e.g. 1200 kHz)

✓ 2** x by using an acoustic frequency that is 2 x lower. And v.v.
** Very approximate rule

FOR IMPROVED VELOCITY PRECISION. Velocity standard deviation is reduced by …

✓ 2 x by using 2 x fewer depth cells top-to-bottom. And v.v. (For cell sizes > about 10 cm)

✓ √ Bandwidth of Signal x √No. of Pings

✓ √No. of Scattering targets

✓ Less turbulent waters, less velocity change between depth cell boundaries, slower boat and water speeds, less dynamic motions of the ADCP's mounting

✓ 2 x by using an acoustic frequency that is 2 x higher. And v.v.