The Mystery of Phases

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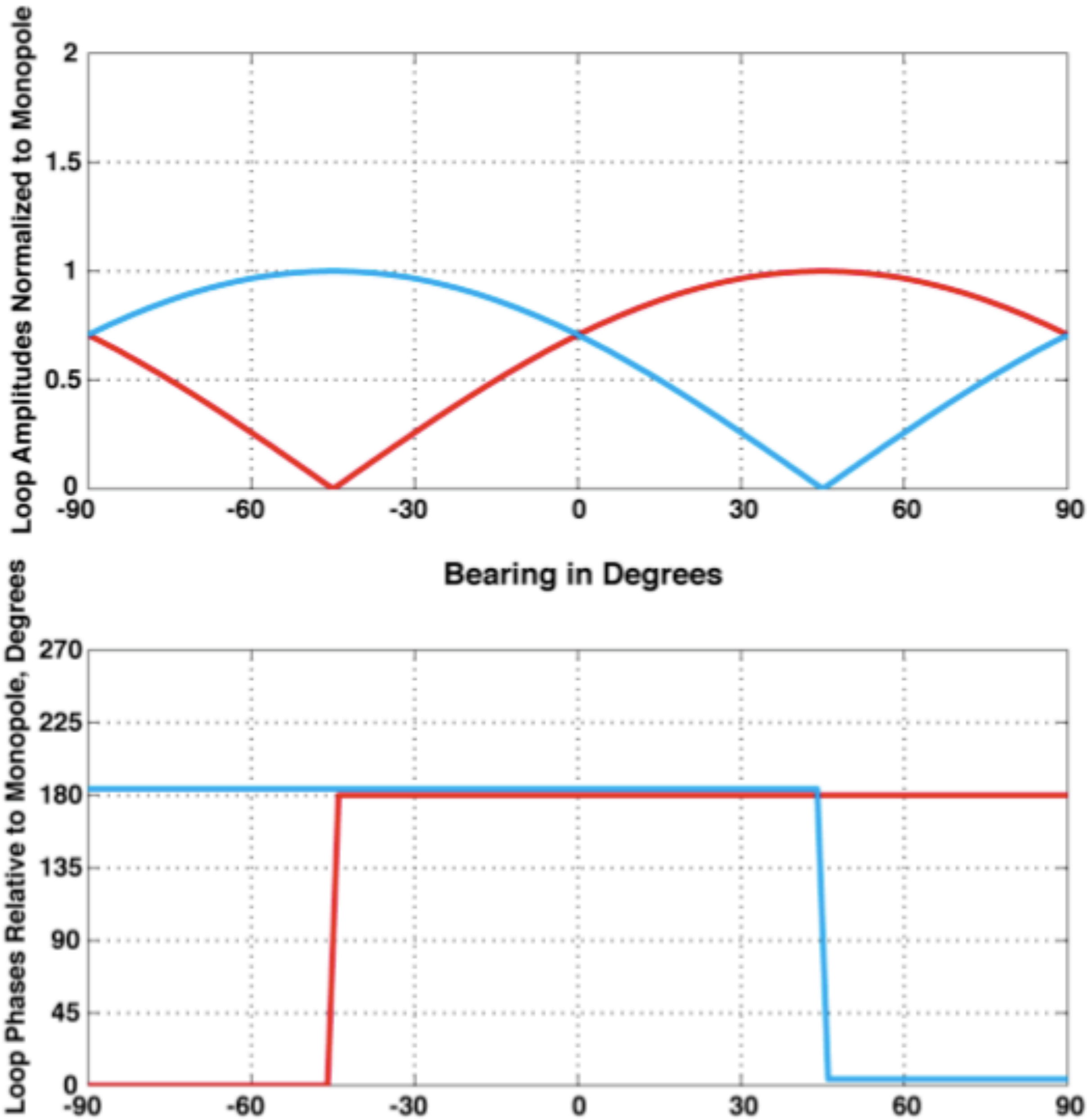
Nearly every SeaSonde operator has scratched his/her head uncomprehendingly as a Support staffer interpreted a "phase" plot of STAT files that looked totally noisy, and pronounced "the system is just fine, there is no phase problem". What is going on? Where do they get that conclusion? What does it all mean?

This article is an attempt to painlessly remove some of the "black magic" from the "black box" that some may think of as a CODAR system. Here are some digestible bullet-size factoids to help clear up the mysteries. More technical detail is involved the further you read, so you can decide when you've "had enough".

- There are two phases we refer to, but these are based on three antennas. They are obtained from the ratio of each loop signal divided by the monopole signal response. These three signals are complex numbers, and so their ratio is also complex.

- A complex ratio like this can be expressed as an amplitude and phase. If one plots the amplitude, a **perfect** loop/monopole pattern in polar form, it is the familiar "figure-8" pattern representing the absolute value of the cosine function of bearing angle.

- The phase in this complex ratio is actually the difference between loop and monopole phases. For the **perfect** loop/monopole ratio, the cosine function representing the pattern is positive over 180° of bearing angle, and negative over the other 180°. Perfect amplitude and phase patterns are shown below plotted in rectangular/Cartesian form for comparison, rather than polar form.



- This means the phase is constant over half of bearing space for perfect patterns, and then jumps suddenly by 180° when the cosine goes negative and remains constant at that value over this negative lobe. We define the phase "sense" with respect to the positive lobe for each loop.

- Although we refer to it and plot it as "Loop 1 phase", or "Loop 2 phase", you can see from the above definitions that it includes the effect of the monopole as well; both antennas are equally important in the process.

And **in practice**, phase is neither 0° or 180° -- nor is it even constant -- over each lobe.

- Even with patterns distorted by the local environment, phases should appear *reasonably* flat and then change rapidly by nearly 180° when passing through the null between loop lobes. If they do not have this appearance, then the patterns are badly distorted.

- Proper phase calibration is important in any radar antenna system, be it SeaSonde crossed loops or phased arrays. If these phase differences are not known, or if they change significantly with time for any reason, then bearing errors will result.

- These phases are best measured as part of the antenna pattern calibration process. With careful interpretation, they can sometimes be inferred directly from sea-echo calculations.

- Phases determined as part of calibration and set properly in "SeaSondeRadialSetup" (i.e. the Phases.txt file in your RadialConfigs) **are** used for wave extraction, as they also are for current extraction when ideal patterns (rather than measured) are employed.

- If antenna patterns have been measured -- and are being used for radial current processing -- then the phases stored in your Phases.txt file in your Radialconfigs **are not** used. The measured pattern contains all of the phase information needed.

- The phases extracted from the sea echo every ten minutes are not used in real time processing for either currents or waves. However, they are archived to a log of STAT files for reference.

- Phases measured from sea echo are often consulted so that radial currents can be outputted immediately after setup, before an antenna pattern can be measured. To do this, average values from the STAT files are estimated and set in the phase boxes of "SeaSondeRadialSetup" GUI. In this case, ideal patterns are assumed. If it's a new system the file's default values will be 0 and 0. If the system has been moved the phase values will have changed. In both cases the values will be wrong, and the radial current pattern will be in error if these values are not updated.

- Starting with the perfect textbook patterns shown in the above figure, nature deals us a hand of cards that is always less than ideal. Both the amplitudes and phases are distorted by the local environment near the antenna from those shown. Not only the shapes of the patterns are different from those in the figure, the levels will not generally be as shown, i.e., unity for amplitudes and 0°/180° for phases.

- What produces undesirable phase changes after setup? Actually, a lot fewer things cause phases to change than is true for amplitude factors -- that's a relief! For this reason, we have found it unwise to allow on-the-fly sea-echo-derived phases to be used for real-time calibration -- different from our policy for amplitudes.

•• It would take a catastrophic failure of a receive antenna or channel to produce a phase change significant enough to matter. This is unlike amplitude changes, where corrosion or water in a cable would alter these.

•• An obvious cause of a phase change will occur if one of the three receive cables were cut and a section removed, making their lengths unequal.

•• A big change in operating frequency could possibly produce some differential phase change, especially if the cables are quite long.

•• If antenna, receiver, or cables are replaced, expect that phases might be changed.

•• If the antenna is moved, or if the environment very near the Rx antenna changes (e.g., a building or fence is erected a few feet away), then a phase change could be expected, because the antenna pattern is modified.

•• New systems now have their phases calibrated before leaving the manufacturer (CODAR). They should be equal to each other, but not necessarily zero (i.e., zero is the default setting found in the Phases.txt file).

• Then why do we care about or bother with phases from STAT files measured from the sea echo after setup/calibration, if they are not used in processing on-the-fly? Mainly they are referred to -- always along with other information in the STAT files -- to diagnose a major system failure problem and/or understand its nature.

• So how are phases in the STAT files measured from sea echo -- and why might they appear flaky/noisy -- even though the actual phases needed for calibrating the system are totally stable? Let's examine this quandary in bite-size pieces:

•• An ideal loop has a bipolar phase that flips 180° as the incoming signal moves through its null from its positive to its negative lobe, as shown in the previous figure. What we need for calibration is the phase of the loop in its positive lobe with respect to the monopole (which is omni-directional and should have constant phase over 360°) The value found in the Phases.txt file (in RadialConfigs) is subtracted from a loop channel to make it equal to the monopole phase, when patterns are ideal -- this is the calibration value.

•• To illustrate, assume a straight coastline and a loop whose positive lobe points straight offshore; this implies its negative lobe is back over land, where no sea echo signals are received. Then the phase difference (loop-to-monopole) between **all** sea echo signals (1st & 2nd order) from offshore should be a precise measure of the mismatch needed to make the loop and monopole phases equal (after adjustment). So this is a very stable measurement.

•• But for the example above, the other loop lobes point up and down the coast. One lobe has positive phase and one has negative phase. If the sea echo pattern is omni-directional, then phase will be completely indeterminate. That is, as many signals may be arriving in the positive lobe as in the negative, and -- referenced to monopole phase -- a time history will appear to be incredibly noisy, jumping states by 180° with slight shifts in short wind- wave directional distribution as it favors one lobe over the other.

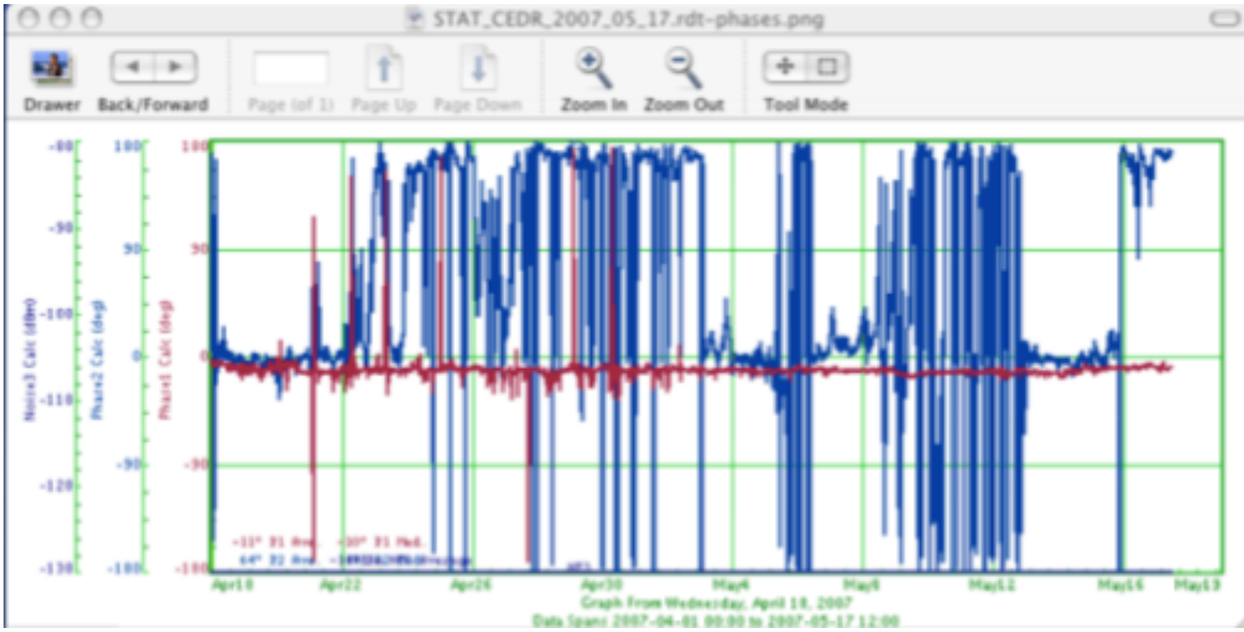
•• However, if one has measured the phase carefully and it does not change, then the antenna orientation as described above (one lobe straight out, the other along the coast) will work just as well as when they are cocked at ±45°, for current or wave extraction.

•• But if one wants to make use of continuously updated phase estimates from the sea echo, a preferred loop orientation would be ±45°. Then **most** of the positive lobes for both loops is over the sea, with only a tiny bit of each negative lobe over the sea.

•• This also explains why sea echo can never be used for phase estimation when sea surrounds it by 360°, as on an oil rig. Phase from the sea echo for **both** loops will be totally "pathologically bipolar", even though actual system phases may be rock solid and highly stable current/wave outputs are being produced.

•• Even with the antennas oriented ±45°, infrequently certain local coastline geometries and predominant wind/short-wave directions may cause one loop's phase to be "bipolar unstable". This merely means that as much echo energy is coming into the negative as the positive lobe, and slight changes will cause 180° flips. When this happens to one loop, the other loop's phase will always be rock solid.

• So now consider the "black magic" question again. How do the CODAR magicians know -- when they look at flipping phases on one loop -- that it's OK, the actual system phases -- the ones that matter -- probably aren't changing. We'll explain what we are seeing -- and what we want you to also glean from the data. As an example, take a look at actual sea-echo phases recorded below in the STAT file from a 5-MHz NASA SeaSonde in Virginia.



•• What do you see? The red curve representing phase for Loop 1 is very stable over the month time period. The "median" estimator says it is -10°, which your eyeball would confirm. The phase for Loop 2 is "noisy", jumping all over the place. It's hard to believe that there's any useful information there. Probably the system is broken, right? Wrong -- read on!

•• What do we see? -- a different picture entirely. There are "stable" periods when the phase is close to 0°. During other times, the phase jumps
between 180° and -180°. However, -180° is really the same as +180°, isn't it? Therefore, Loop 2 phase is really jumping between 0° and 180°. This is a bipolar condition that reflects the fact that the short-period wind waves tend to overwhelm the negative lobe, even though very little of the negative lobe lies over the sea.

•• What would we recommend? Use a value of 0° for Loop 2 phase. Why? Since our choices are really 0° and 180°, in the absence of other information, 0° is the better guess because: systems leave CODAR with phases equalized. It would take a huge cable length difference among the three antennas (i.e., tens of meters) to cause a 180° mismatch. Note: differences of up to 30° in phase settings hardly matter in bearing determination, so do not worry about 5° or 10° phase estimation errors.

•• What we really recommend is: measure the actual antenna pattern as soon as possible to confirm the corrections needed so that the loop positive lobes will have the same phases as the monopole.