

## EFFECT OF MULTIPATH ON SYNTHETIC APERTURE SONAR

A. Bellettini<sup>†,\*</sup>, M. Pinto<sup>†</sup>, L. Wang<sup>†</sup><sup>†</sup> NATO Undersea Research Centre, La Spezia, Italy

\*Email: bellettini@saclantc.nato.int

**Abstract**

The performance of real or synthetic aperture sonar (SAS) in shallow waters is degraded by multipath, which leads to ghost targets and reduced image contrast. This loss of image contrast fills in acoustic shadows and is therefore an important limitation for high resolution SAS applications such as minehunting, where target recognition exploits the shape and size of the shadow in addition to the echo structure. Experimental data from a 100 kHz sonar array mounted vertically on a tower in 20 m water depth show the importance of second order multipath. A specific SAS design with optimized transmit and receive beam characteristics in elevation is therefore required to achieve high SNR at large range to waterdepth ratios.

**Introduction**

As well known, synthetic aperture sonar (SAS) has the potential to provide very high cross-track resolution at long ranges. In practice, however, multipath interference can be a dominant cause of performance degradation, especially in shallow water. Multipath, besides the well known effect of ghost targets, leads to loss of image contrast (with consequent filling in of shadows) and degrades the quality of bathymetric estimates when interferometry is used. These effects, which are not SAS-specific, have nonetheless enhanced relevance in synthetic aperture imaging, since SAS aims naturally to extend the range of a sonar to fully exploit the gain in cross range resolution.

In addition, multipath affects specifically SAS performance because of the influence on the data-driven methods, as the Displaced Phase Centre Array (DPCA) micronavigation, used to estimate the platform trajectory. The DPCA technique makes use of the correlation of the sea bottom direct backscatter to estimate the displacement of the SAS between pings, and depends critically [1] on a generalized signal to noise ratio (SNR), where the signal is the seafloor backscatter coming from the direct path, while the noise consists of background noise of the sea, system noise, surface and volume reverberation and, last but not least, multipath interference of various orders.

We will adopt the convention of naming a multipath by the a combination of letters 'b' (for bot-

tom) and 's' (for surface), with a lower letter indicating a specular bouncing and a capital letter indicating a non-specular scattering. In Figs. 1 and 2 various first and second order multipaths from bottom and surface scattering are shown.

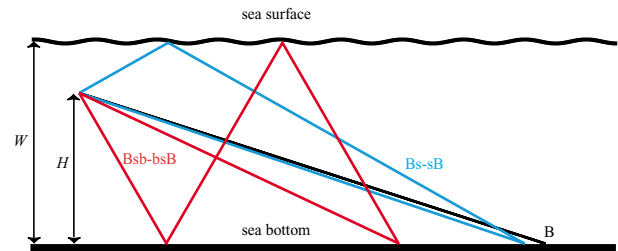


Figure 1: Multipath from bottom backscatter.

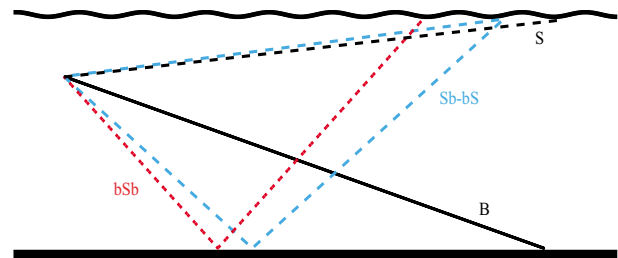


Figure 2: Multipath from surface backscatter.

Note that these plots show the trajectories for the same arrival time, and not, as it is more usual, for multiple returns from the same target. The focus will be, unlike in [2], on the multipath effects on the sea bottom direct backscatter, i.e., on the generalized SNR at a given range, which has direct implications on the DPCA technique and, at certain conditions, on the shadow contrast. In other words, this paper will investigate how multipath affects SAS even in the absence of targets.

It will be argued that the second order multipath 'bsB' and its reciprocal 'Bsb' constitute a major obstacle for obtaining high generalized SNR at large range to waterdepth ratios, both for physical and synthetic aperture imaging. Note that, because of the different spatial correlation properties, no SNR gain due to synthetic aperture processing of the kind described in [2] for targets is expected in the case of sea bottom backscatter, except when the SAS is oversampled.

### Experimental setting

To investigate the importance of higher order multipaths for SAS performance, an experiment was conducted in June 2002 by the NATO Under-sea Research Centre. A 100 kHz sonar was deployed vertically on a fixed tower at a height  $H$  of 10.7 m and in a waterdepth  $W$  of about 20 m, in the vicinity of La Spezia. In Figure 3 the arrival angle in function of arrival time (expressed in terms of slant range of the direct bottom return) is plotted for this geometry, assuming a flat bottom. The seafloor was hard mud and the sea was calm

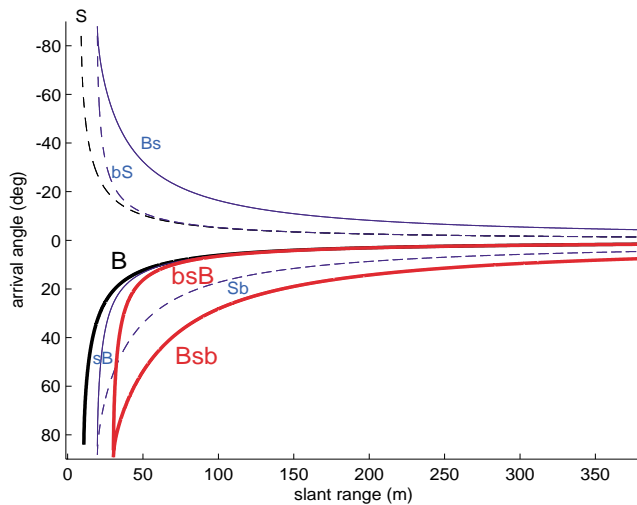


Figure 3: Direct and multipath returns as a function of range and arrival angle at the sonar, for the geometry of the experiment.

during the experiment. No targets were deployed. The sonar array consisted of 256 receiver elements spaced at 7.5 mm to form an aperture of 1.92 m. When the sonar mounted in vertical configuration, the vertical and horizontal beamwidths of the elements are about 40 deg and 100 deg respectively. The 64 channels at the center of the array form a fully programmable transmitter, allowing different vertical transmission beampatterns to be synthesized (see Fig. 4). The waveform used was a 95-105 kHz 10 ms chirp. A previous experiment [3] with the same sonar deployed vertically had been conducted in 2001, but unlike this experiment, no tower was used, the sonar being lowered with ropes from the R/V Alliance. Therefore, the sonar moved horizontally too much to allow studying the ping-to-ping correlation of the data, since the horizontal beamwidth of 100 deg gives in fact a spatial correlation length of only 0.8 cm.

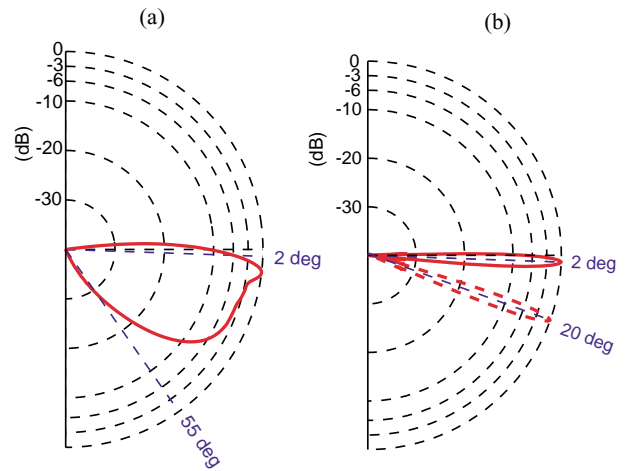


Figure 4: Vertical transmission beampatterns used in the experiment.

### Experimental Results

To begin, a broad transmission beam, shaped to ensonify a wide swath of the seafloor while avoiding surface direct ('S') and first order multipaths ('Sb', 'sB'), was synthesized using the flexibility of the programmable transmitter. The beam, shown in figure Fig. 4(a), captures the main features of present sonar design. In Fig. 5 the beamformed data are presented in function of slant range and arrival angle. A time variable gain has been applied to the data. A comparison with Fig. 3 indicates that it is impossible at long range to separate the arrival direction of the direct return 'B' from the second order multipath 'bsB'.

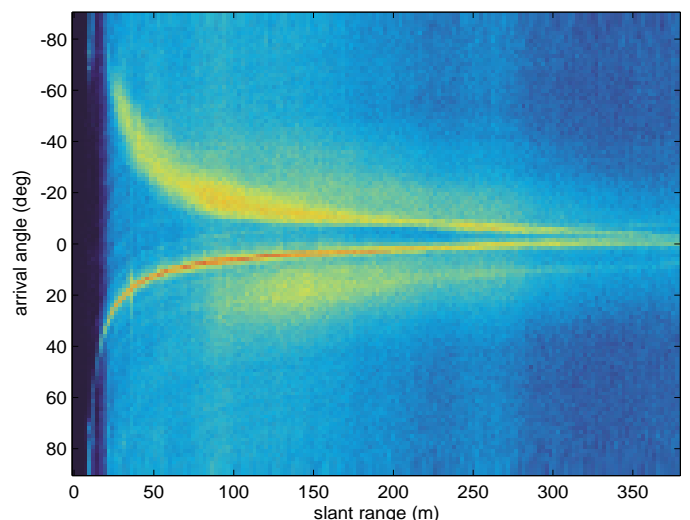


Figure 5: Direct and multipath returns for the transmission beam as in Fig. 4(a), as a function of slant range and arrival angle.

Then, a 7 deg vertical beam with -20 dB sidelobes is synthesized in reception. The SNR, derived from

the ping to ping correlation, is plotted in Fig. 6 for various depression angles of the receive beam. The white line represents the direct bottom return arrival.

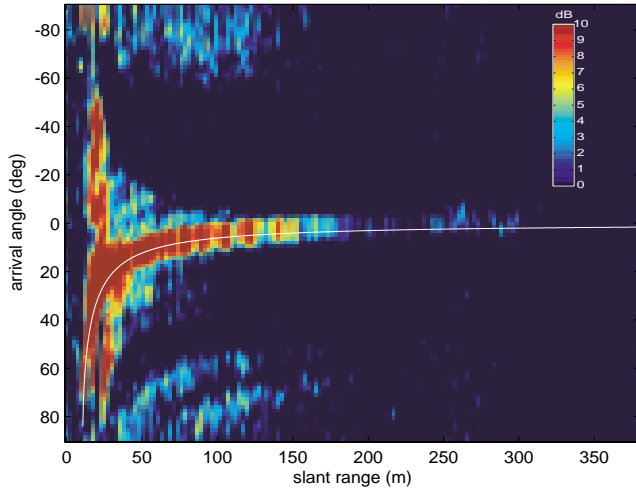


Figure 6: SNR measured at the output of a transmission beam as in Fig. 4(a) and a receive 7 deg beam, as a function of range and the depression angle of the receive beam.

The SNR is seen to fall off with range, well before the range where noise is dominant, indicating that there are other contributions than the direct seafloor return ‘B’.

The assumption is that the drop in SNR is due to high order multipath, excited at short range. To validate this assumption, a narrow transmission beam (3 deg at 3 dB) steered at close range (32 m) was synthesized (see Fig. 4(b) dashed line) and the corresponding data are plotted in Fig. 7. The ‘bsB’ multipath whose bottom specular reflection is at 32 m is clearly visible in the region around 145 m. Other multipath returns of first, second, third and fourth order are also visible (compare with Fig. 8), but the ‘bsB’ return is by far the most important, because its reception angle is nearly the same as that of the direct returns at far range. This explains the drop in correlation shown in Fig. 6 for the broad sector ensonification.

Thus, to achieve high SNR at very large relative ranges  $r = R/W$ , where  $R$  is the slant range, it is necessary not to ensonify the seafloor at short ranges, in order to avoid ‘bsB’ multipath whose arrival angle is impossible to separate in reception (similarly, a narrow receive beam is required to rule out the reciprocal ‘Bsb’ multipath).

To validate this assumption, the 3 deg transmission beam was steered at far range, as in the continuous line of Fig. 4(b). The corresponding SNR,

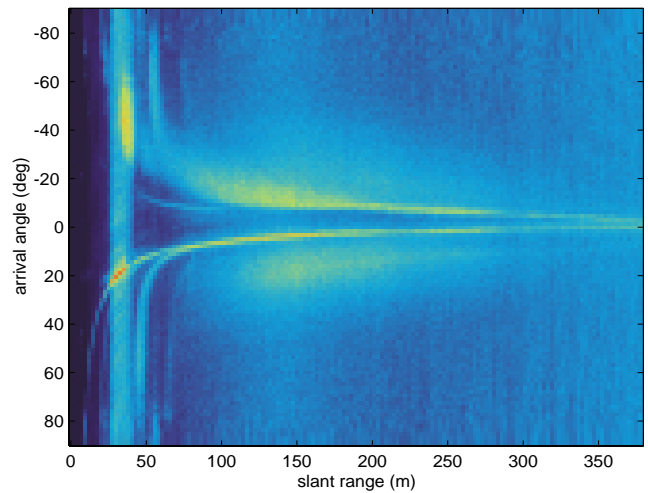


Figure 7: Direct and multipath returns for the transmission beam as in Fig. 4(b), steered at 20 degrees.

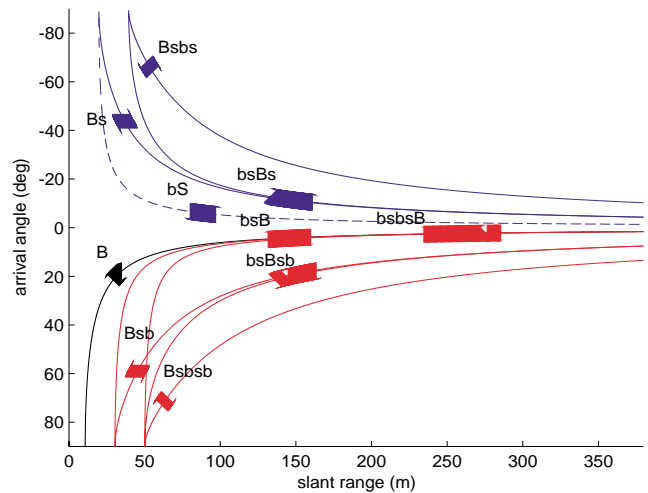


Figure 8: Multipath returns for the data of Fig. 7.

obtained as above, is plotted in Fig. 9. The increase in SNR at long ranges over Fig. 4 is evident.

### Consequences for sonar design

To design a sonar with high generalized SNR at long range a key parameter is therefore the difference between the angle of the direct signal and the second order multipath signals (‘Bsb’, ‘bsB’) arriving at the same time.

From geometry considerations, we have, for relative range  $r \gg 1$ ,

$$u_B - u_{Bsb} \cong 2/r. \tag{1}$$

where  $u_B$  and  $u_{Bsb}$  are the sines of the receive angles. This formula gives an important design criterion for the beamwidth necessary to achieve high SNR at long range. Given the narrowness of the

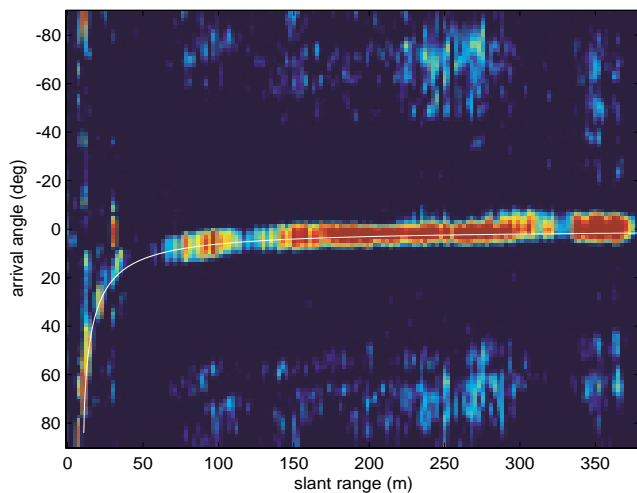


Figure 9: SNR measured at the output of a transmission beam as in Fig. 4(b), steered at 2 degrees, and a receive 7 deg beam.

beams required at large  $r$  and the need to maintain a full swath imaging, a sonar design allowing different beamwidths at different ranges seems attractive. The performance of this type of sonar

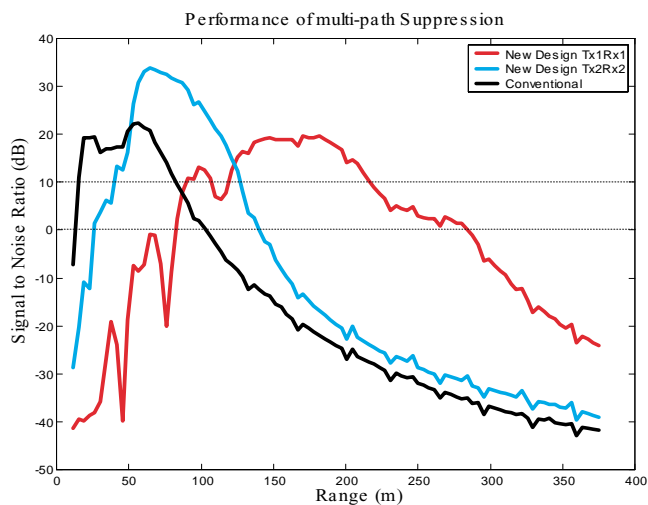


Figure 10: Performance prediction of the sonar design.

was assessed using the sonar performance prediction tool ESPRESSO developed by Gary Davies at NATO Undersea Research Centre (Fig. 10). In this example the water depth was 20 m and the sonar altitude was 15 m. The multipath suppression is achieved by transmitting two beams, a wide one steered at short range and a narrow one steered at long range, with two different frequency bands to be transmitted simultaneously. Similarly, two different receive beams with different depression angle are used. A SNR in excess of 10 dB is obtained out of at least one of the two beams up to 225 m range

in 20 m water depth. The SNR which corresponds to a vertical beampattern similar to Fig. 3(a) is shown for comparison.

## Conclusions

Experimental evidence for the importance of (second order) multipath in degrading the SNR at large range to waterdepth ratios has been provided. This suggests that, in shallow water, it is not enough to shape the beams in such a way to reject signal coming from the surface, and that a narrow beam pointing at long range can provide significant improvement. Full swath imaging could still be obtained transmitting two beams, a wide one steered at short range and a narrow one steered at long range, with two different frequency bands to be transmitted simultaneously.

## References

- [1] A. Bellettini and M. A. Pinto, "Theoretical accuracy of synthetic aperture sonar micronavigation using a displaced phase centre antenna," *IEEE J. Oceanic Eng.*, vol. 27, n. 4, pp. 780–789, 2002.
- [2] B. Davis, P. Gough and B. Hunt, "Sea surface simulator for testing a synthetic aperture sonar," in *Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance*, ed. by N.G.Pace and F.B.Jensen, pp. 473-480, Kluwer Acad. Publ., 2002.
- [3] L. Wang, G. Davies, A. Bellettini and M. Pinto, "Multipath effect on DPCA micronavigation of a synthetic aperture sonar," in *Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance*, ed. by N.G.Pace and F.B.Jensen, pp. 465-472, Kluwer Acad. Publ., 2002.