

Lecture #11: Background

This lecture is a bit of a potpourri of topics, but reasonably important ones, especially given our brief format.

The first topic is a “rehash” of rays as interfering modes (from section 3.4.2 KPL), which is just the Tindle result in different notation. There is a bit of extra discussion here that is worth reading, but otherwise it’s a repeat showing different notation.

The second topic is modes as interfering rays, the flip side of the first topic (section 3.4.3 KPL). Not surprisingly, the condition that neighboring eigenrays add in phase is the key here, and one obtains the mode eigenvalue equation directly from the rays!

The third topic, distinguishing between ray and mode arrivals in real data, is of great practical importance. Given a time series of (broadband) arrivals, is what I see a ray or a mode arrival? What should I use to model it numerically? More important ly, perhaps; how do I design a signal so that it produces useful, reasonable arrivals? This is treated in detail in KPL 3.4.4, which concentrates on the time-bandwidth criteria from Munk and Wunsch’s paper, but also takes that paper’s deep water discussion and puts it into the context of a shallow water waveguide. This discussion naturally leads to one asking what resolution one gets with receiver arrays, which use wavenumber processing, as opposed to frequency. That is treated next.

Before getting into the array “filtration” of ray and modes, there is a one page reminder of basic useful equations. These should be “meh” material to most readers.

The next section is actually a very important one, taken from C&M appendix A9. It shows how one can use arrays to filter out normal modes from a CW, $p(r,t)$ signal. This is the way one can extract a coupled modal picture from the PE, or the mode arrivals used for inversion from an otherwise unresolved time series. As a historical note, Clarence Clay (co-author of C&M) was the person who first showed how to do mode filtration using amplitude shaded vertical arrays and steered horizontal arrays, which are the topics in A9. The math in this section is easy, and the physics can be encapsulated by saying: the vertical array uses the mode orthogonality integral and the horizontal array relies on the array beamwidth discrimination of modes. C&M also look at a “matched array” with finite SNR, which is a useful addition to the previous “infinite SNR” discussion.

The next section, using section 8.4 of KPL, adds more discussion of mode filtration, with additional detail. Of interest here is the list of “warts and wrinkles” in mode filtration techniques (hey, nobody’s perfect), and also some nice examples. The subsection on “mode separation using steered and focused arrays” has a very nice, practice oriented, discussion of how one causes such arrays. (As a small note, resolution of modes with focused array was one of my early contributions, which was independently derived in Russian around the same time, in the early 80’s). The “horizontal steered array” section following has a good discussion of the angular orientation of horizontal array relative to the source, and the ambiguity it creates if this angle is unknown. Farther into this section, there is a rather curious figure, 8.13, which shows the author (left) and colleague Art Newhall (right) deploying an AUV with a horizontal array

attached. (Ignore how clunkily we did this, with an attached receiver pressure case – this was a prototype from 12 years ago, and things have greatly improved!). Using AUV’s with acoustic arrays is part of the present and future of this mode filtration technology, and works well as Figures 8.14 and 8.15 can attest. Section 8.4 ends with a bit more discussion of focused and combined vertical array/travel time filtration. Figs. 8.19 and 8.20 again show that these techniques work very well in practice!

Given large, capable computers, and fast, accurate numerical models, it was inevitable that the next technique we will discuss, matched field processing (MFP), would arise. MFP is (originally) a source localization beamforming technique that works like this: 1) put an array in the ocean and measure the acoustic field across it (and any array will do – though some are better or worse), 2) use your monster computer and fast codes to calculate the field at your array (using a perfectly known ocean, of course) from every possible source position of interest (e.g. out to a certain range R), 3) cross correlate the calculated (replica) and measured fields for all source positions, and 4) make a map of the cross correlation peak magnitude versus source position, called the “ambiguity diagram.” The real source position will have the highest peak. Moreover, the more complex the ocean, the better MFP identifies the peak. All these simple forms of MFP are easy to implement. Sounds ideal, right? Well, yes and no, as we will see.

In section 8.2 of KPL, MFP in shallow water is discussed. Shallow water fields are easy to calculate, and the size of the “source space” is small, so it makes a good MFP test bed. Also, since we don’t usually have real array data for sources all over the ocean waveguide, we often look at synthetic data studies of MFP. (Real experiments exist of course, with limited source positions – but real data analysis is a bigger scale project.)

Section 8.2.1 starts out with the simplest case, the (modal) projection of the replica field onto the measured field, shown in matrix form in Eq. 8.4.3. This is called the Bartlett beamformer. The “resolution kernel” for the beamformer is shown in Eq. 8.47, and is useful in determining mainlobe and sidelobe widths.

In section 8.2.2, a simple example of parameter estimation (for source angle) is given, and the Bartlett’s angular resolution is examined. Another important example is the performance of the Bartlett beamformer in noise (finite SNR), which is also discussed clearly in this section. The bottom line of these examples is that the Bartlett MFP beamformer is noise tolerant, but has low resolution and high sidelobes. Something better seems to be needed ...

The “better” solution for MFP commonly seen is the maximum likelihood (ML) beamformer, discussed in section 8.2.3 of KPL. This form has a much sharper peak, and explicitly includes the noise, as seen in Eq. (8.66). However, it needs high SNR to work well.

One problem that is not discussed in the notes is that of environmental mismatch. In doing MFP, we assumed a “perfectly known” ocean and seabed, which is, of course, perfect nonsense. But MFP localization, and particularly ML, is very sensitive to such mismatch, and can produce gloriously inaccurate results due to routine errors in the environmental input. Much effort has been expended in making MFP robust to such error, but that is beyond the scope of the notes.

The last topic in our “potpourri” lecture is the “time reversal” of acoustic signals received by an array. (This is phase conjugation for CW signals). The idea is an old one in physics, and reasonably old even in ocean acoustics (Parvelescu & Clay, 1965). Basically, if you take an impulsive sound created at a point (say a hand clap in a hallway or a sharp ping in the ocean), record it on an array (or even a single microphone/hydrophone for broadband), and then transmit the recording backwards in time, you will hear the sharp impulse reproduced at the source position! The physical trick here is that the time reversed signal reverses the dispersion curve (including scattering!) imposed on the original signal by the hallway or ocean waveguide. When it gets back to the original source position, it is entirely undispersed. Only two (important) things ruin this nice effect: 1) Attenuation in the medium, which is not time reversible, and 2) changes in the waveguide one transmits through (in time or space). The latter effect involves the stationarity time of the medium, which largely is due to the time variation of the oceanography in ocean acoustics. Last note – try this on your computer with a microphone using a hand clap - it’s simple and works well!

MIT OpenCourseWare
<http://ocw.mit.edu>

2.682 Acoustical Oceanography
Spring 2012

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.