Computer Modeling of Loran-C Additional Secondary Factors

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BALOR Computer Program

- Models Loran-C propagation over ground.
- Computes field strength, ASF, and ECD.
- Considers terrain elevation and ground conductivity.
- Developed by Paul Williams and David Last, University of Wales, Bangor, UK.
- The name “BALOR” comes from BAngor LORan.
- The Avionics Engineering Center at Ohio University took over maintenance of the BALOR software in March 2005.
Factors Affecting Loran-C Propagation

- Primary Factor (PF) – accounts for the speed of propagation through the atmosphere, rather than through a vacuum.

- Secondary Factor (SF) – accounts for the time difference for a signal traveling over a spherical seawater surface, rather than through the atmosphere.

- Additional Secondary Factor (ASF) – accounts for the time difference for a signal path that is at least partly over terrain, rather than all seawater, as well as any other factors that may come into play.

- ASFs are affected by
  - Ground conductivity
  - Changes in terrain elevation
  - Receiver elevation
  - Temporal changes (seasons, time-of-day, local weather)
US Ground Conductivity Map

“M3 map” from CFR Radio and Television Rules (47 CFR 73.170)
Phase of attenuation in relation to conductivity

- $\sigma = 0.001$
- $\sigma = 0.002$
- $\sigma = 0.004$
- $\sigma = 0.008$
- $\sigma = 0.015$
- $\sigma = 0.030$
- $\sigma = 5.0$

Seawater = Loran secondary factor
Additional secondary factor in relation to conductivity
Sample BALOR plot of predicted ASFs

- BALOR predicts ASFs that are corrections to single-station TOA values.
- The transmitter here is Carolina Beach.
- Note how ASF values are very low over the ocean, but generally higher and more variable over land.
Effective earth radius

- Except at very low frequency, radio waves are refracted by the atmosphere to some extent.
- If we assume a linear vertical lapse rate, then this effect may be modeled by multiplying the actual earth radius by some factor, which we will call the effective earth radius factor (eerf).
- The traditional value for the eerf is 4/3, but the value should probably be smaller for lower frequencies such as the Loran frequency.
- (The inverse, the vertical lapse rate, is also commonly used. In this case, the traditional value is clearly 0.75.)
Effective Earth Radius Factor

Effect of effective earth radius on phase delay

- Blue line: $\varepsilon_{ef} = 1.0$
- Red line: $\varepsilon_{ef} = 1.14$
- Green line: $\varepsilon_{ef} = 4/3$

Phase Delay (microseconds)

Distance from Transmitter (km)

- Flat and sandy soil or rocky and steep hills
- Average soil
- Seawater
Height Gain Factor

- This factor comes into play in two ways:
  - First, it is part of the solution for irregular terrain – if a point is on a hill, it is as if it were a raised transmitter or receiver.
  - Second, if we are actually modeling an elevated receiver, say in an aircraft, then we need to apply the height gain factor again to the ground-based solution.

- The height gain factor is a complex function of height, distance, and ground conductivity.
Relative magnitude of attenuation vs. receiver height

$$a_e = 1.14a, \sigma = 5S/m, \epsilon = 80$$
Phase offset vs. receiver height

\[ a_e = 1.14a, \sigma = 5S/m, \epsilon = 80 \]
Relative magnitude of attenuation vs. receiver height

\(a_e = 1.14a, \sigma = 0.001\text{S/m}, \epsilon = 15\)
Phase offset vs. receiver height

$ae=1.14a$, $\sigma=0.001S/m$, $\epsilon=15$

![Phase Offset Graph](image)
“Worst Case Path” Examples
“Worst Case Path”

In their 1979 report, Burt Gambill and Kenneth Schwartz described a path along the radial from the Loran transmitter at Searchlight to Fort Cronkhite, near San Francisco Bay.

Because of the extremes in terrain along the path, they called it the “Worst Case Path”, or WCP.

It makes a nice example, so we will make use of this path as well.
Terrain Elevation over “Worst Case Path”
Ground Conductivity over “Worst Case Path”

Graph showing ground conductivity in S/m as a function of distance from the transmitter in km. The x-axis represents distance from the transmitter in kilometers, ranging from 0 to 800 km, with tick marks at 100 km intervals. The y-axis represents ground conductivity in S/m, ranging from 0.001 to 10 S/m, with tick marks at 0.01, 0.1, 1, and 10 S/m. The graph shows a step-like increase in conductivity, especially noticeable at 700 km.
Terrain Smoothing over “Worst Case Path”

Distance from Transmitter (km)

Terrain Elevation (m)

-1000
0
1000
2000
3000
4000
5000
6000
7000

0 100 200 300 400 500 600 700 800

Terrain Elevation (m)

+3000
+2000
+1000
Effect of Terrain Smoothing over WCP

- ASF (microseconds)
- Distance from Transmitter (km)

Lines represent:
- blue: no smoothing
- red: interval = 2km
- green: interval = 4km
- pink: interval = 8km
Effect of Receiver Altitude on ASFs over WCP
Effect of Receiver Altitude on ASFs over WCP

![Graph showing the effect of receiver altitude on ASFs. The y-axis represents ASF relative to a grounded receiver in microseconds, ranging from -0.3 to 0.3. The x-axis represents distance from the transmitter in kilometers, ranging from 0 to 800. The graph includes lines for different altitudes (alt = 5000m, 6000m, 10000m, and 12000m).]
Terrain Contributions to ASFs over WCP

![Graph showing terrain contributions to ASFs over WCP. The x-axis represents distance from the transmitter in km, and the y-axis represents ASF (microseconds). The graph includes lines for 'elevation only', 'conductivity only', 'sum of above', and 'original'.]
Reality Checks
Loran-C Correction Tables

- Published by NOAA
- Show ASF corrections to TD values for master-secondary pairs
- Cover US coastal confluence zones
- Data represents the results of a computer program, adjusted to fit measured data
Sample Loran-C correction table data
Terrain in the US West Coast region

Ground conductivity

Terrain elevation
Calculated ASFs for Fallon and Searchlight
Correction table data vs. BALOR results

Loran-C correction table data

Relative ASF data from BALOR
Flight path from Ohio toward Carolina Beach
transmitter is Carolina Beach; aircraft is King Air; 8/29/07

The plot at left shows flight path; the color represents ASFs. Terrain elevation and conductivity are shown above.
Comparison of measured and calculated ASFs for flight from Ohio toward Carolina Beach

![Graph showing comparison of measured and calculated ASFs](image-url)
Approach to Allaire Airport, Belmar/Farmingdale, NJ
transmitter is Carolina Beach, aircraft is King Air; 4/10/07

Flight Path Calculated Map of ASFs
Comparison of measured and calculated ASFs from Carolina Beach during approach to Allaire, NJ
Closing
Conclusions

- Further comparisons between BALOR and actual measured data are required.
- It may not be possible to obtain extremely accurate ASF predictions, due to lack of detail and possible bias in the conductivity database.
- Nevertheless, we should be able to eliminate any bias or scale errors from the BALOR model itself.
- Even in its current state, BALOR is a useful tool for large scale mapping of predicted ASFs.
- More accurate results could be produced by adjusting the BALOR maps to fit measured data points.
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Questions?