THE RAYMONDVILLE GHOST
Loran-C Signal Reflections

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ABSTRACT

In 1979, eight months after declaring the new Southeast U. S. (7980) chain operational, the U. S. Coast Guard issued a Notice to Mariners message warning of a low-level unidentified interference source affecting Loran-C navigation in the Port Isabel/Brownsville, Texas area. Receivers from several manufacturers acquired the interference signal in place of the Raymondville (7980X) groundwave. The interference was in the form of low-level signal bursts with Loran-C characteristics delayed by about 1500 microseconds from the Raymondville secondary signal and became known as the Raymondville Ghost. This paper characterizes the interference signal, recounts the search for the cause of the interference, describes the interference source, and identifies in the coverage area of the new Mid-Continent transmitters some potential signal reflectors with characteristics similar to the Sierra Madre Oriental escarpments that are the source of the Raymondville Ghost.

INTRODUCTION

The Southeast U. S. Chain (7980) was declared operational in October, 1978. The Loran-C signal interference problem, here called the Raymondville Ghost, was first noticed by shrimp fleet captains in the area of the Brownsville ship channel and the Port Isabel area in southern Texas, on the coast of the Gulf of Mexico [Figure 1]. The Loran-C receivers of several manufacturers attempted to lock on to (and in some cases tracked) a low-level interference signal delayed in time by some 1500 microseconds after the arrival of the Raymondville secondary signal. The result was improper acquisition and in some cases position errors of hundreds of kilometers.

In December of 1978 a major manufacturer reported the problem to the Coast Guard Chain Commander of the Atlantic Area [Reference 1]. An unsuccessful search for the interference source was conducted by both manufacturers and U. S. Coast Guard personnel. In 1979 a team was contracted by the Coast Guard to locate the source of the signal. The source was finally located in Mexico. Manufacturers made modifications to eliminate the problem, but the Raymondville Ghost signal still exists.

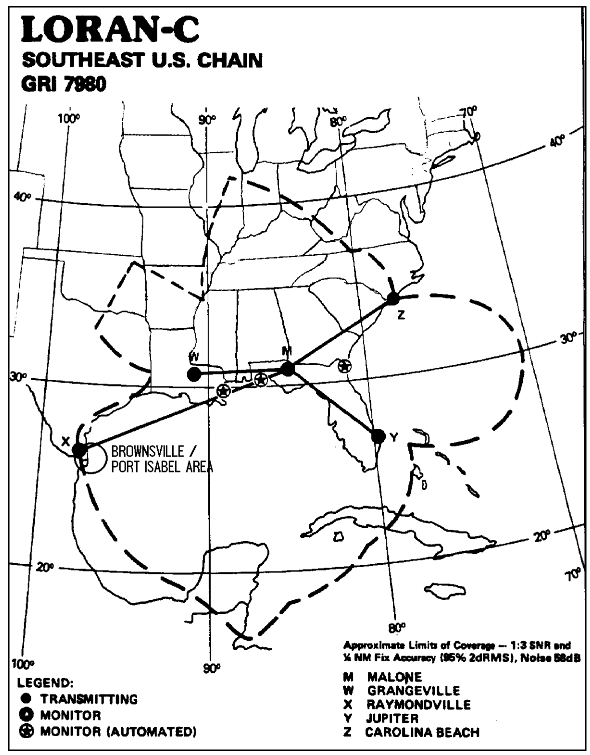

Figure 1. Southeast U.S. Chain

The Southern Mid-Continent Chain, using the Raymondville transmitter on another rate, may increase the use of the Raymondville signals, particularly in avionics receivers. New Mid-Continent Chain transmitters are coming on the air and some are located in places where similar "Ghost" signals could occur.

The purpose of this paper is to record the history of the Raymondville Ghost, to suggest that other Ghosts may occur, and to remind a new generation of Loran-C designers that some of the best acquisition schemes of major manufacturers were spoofed by the Raymondville Ghost.

THE INTERFERENCE PROBLEM

The Raymondville Ghost signal was often acquired, and in sometimes tracked, by some Loran-C receivers in the South Texas Gulf of Mexico area. The problem was of serious concern in early 1979.

The shrimp boat fleets were then the largest user of Loran-C sets in the area. These boats used Loran-C, particularly for its repeatable accuracy, to locate hazards and fishing areas. The Ghost signal caused the receivers to occasionally report time differences (TDs) with 1500 microsecond errors on the Raymondville 7980X secondary signal. While this most often occurred during initial acquisition in port, making the problem noticeable, it was not a simple matter to force correct acquisition by any other method than to continuously re-acquire until the TD was correct. In addition to the noticeable, in port, acquisition, boats entering the Raymondville service area from other areas of the Gulf of Mexico could unknowingly acquire the Ghost signal, introducing large position errors (200-300km) in receivers tracking three stations, and smaller, less noticeable errors in multiple station receivers.

This was a period in which the expansion of the Loran-C system with the installation of the Southeast U. S. Chain was accompanied by the introduction of new and inexpensive (then <$1,000.00) receivers. The appearance of the Ghost caused both an operational problem for users and a serious product image problem for several manufacturers attempting to make large numbers of sales in the area. In addition, the phasing out of Loran-A transmitters was being met with criticism from the same fleet owners that were having these Loran-C problems.

INTERFERENCE PARAMETERS

The Raymondville Ghost signal is a low-level set of eight Loran-C like pulses that occur at one millisecond intervals, delayed (in the problem area) by some 1500 microseconds from the Raymondville groundwave. Early investigations by manufacturers resulted in some characterizations of the Ghost.

Signal Characteristics

The Ghost signal can be seen in the area on an oscilloscope. Figure 2 shows the first five groundwave pulses and the first three Ghost pulses. In addition to the groundwave and main Ghost pulses, other interference bursts can be seen.

The Problem Area

The Raymondville Ghost problem area appears to be a local one, with the interference problem only noticeable in the Southeast Texas area.

Phase Code

The signal maintains the secondary phase code of the Raymondville groundwave signal.

Time Differences

The relative time difference between the Master (at Malone, Florida) and the Raymondville groundwave changes from location to location. This is an indication that the Ghost is not present on the signal when transmitted by the Raymondville antenna.

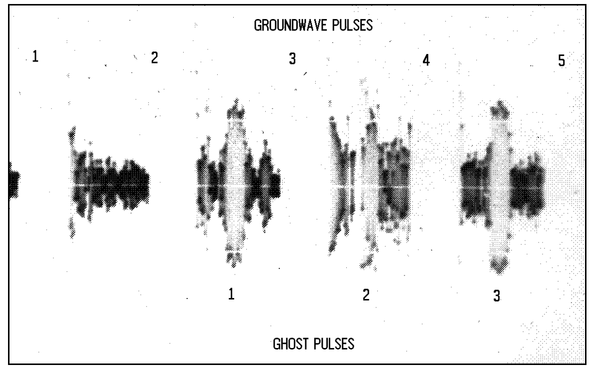

Figure 2. Raymondville Ghost: First Three Pulses

Amplitudes

The amplitude of the Ghost signal often changes by more than 10db over a short distance (<20km) while the amplitude of the Raymondville groundwave changes by less than one decibel (db) over the same distance. The Ghost signal varies in amplitude relative to the Raymondville groundwave from -40 to -55db [Reference 2].

Receiver Effects

Several well-known manufacturers, using different receiver techniques, experienced similar problems in acquisition and tracking of the Ghost. It seemed unlikely that similar interference was caused by different receivers.

Skywave

In the locations affected by the Ghost, the range to the Raymondville transmitter is around 80 kilometers. Multiple-hop skywaves can be detected out to around 900 microseconds, but none appear between the end of the second groundwave pulse and the start of the Ghost. Early efforts [Reference 1] showed that while these skywave pulses shifted amplitude and delay during the diurnal shift, the Ghost amplitude and phase remained relatively constant.

Early attempts at source location

Initial attempts to locate the source of the Ghost signal were based on the assumption that the source was in the Brownsville/Port Isabel area. Both manufacturers and the Coast Guard made field strength measurements in the area. In every case the largest amplitude readings were observed at the eastern end of the Brownsville ship channel near Port Isabel. Coast Guard personnel made initial attempts to locate the source with a loop antenna and a Loran-C timing receiver. The measured bearings showed a tendency to point parallel with the ship channel, but no conclusive results were obtained.

Many theories were advanced. Power line retransmission, power line carrier interference, retransmission from satellite television systems or decommissioned Loran-A transmitters, and even buried rail lines were suspected as possible sources.

COAST GUARD SPONSORED INVESTIGATION

The Broadcast Warning appeared in the June 23, 1979 Notice To Mariners [Reference 3]. In December of 1979, a team from Austron Navigation, Inc. was contracted by the Coast Guard to find the source of the Raymondville Ghost.

First measurement trip

The first Austron measurement trip to the area was in February, 1980. The Austron Navigation, Inc. measurement van was equipped with a three-kilowatt generator, an Austron 5000M Loran-C Monitor (an eight-station, four-chain receiver), both whip and loop antennas, an Austron 1250 Crystal Frequency Standard and an Austron 6030 Loran Assist Device (latitude, longitude converter).

Tracking the Ghost

All of the reported characteristics of the Ghost signal were confirmed during the first few hours in the area.

During acquisition the 5000M searches over several seconds for Loran-C energy occurring at the Group Repetition Interval (GRI). A table is constructed with approximate arrival times of phase coded 100kHz energy. To track the Ghost, the 5000M was manually instructed to track the interference signal after its approximate time of arrival was found following the Raymondville groundwave in the acquisition table.

Tracking points were selected at approximate delays of 500, 1500, and 2500 microseconds after the Raymondville groundwave signal. Phase code errors occurred at both the 500 and 2500 microsecond delays. The 5000M would occasionally attempt to lock onto the Ghost signal if the receiver happened to start looking for Loran-C energy at the Ghost position in the acquisition table.

The shape of the signal was difficult to characterize. The 5000M did not automatically track the signal because no envelope shape was found that satisfied the criteria for third-cycle tagging.

Measurement Sites

During this first trip, an attempt to locate the source was conducted using field strength and bearing measurements. Measurement sites were chosen for convenience and proximity to intersections that could be located on U. S. Geodetic Survey (USGS) 7.5 minute quadrangles. Positions were located to an accuracy of about one second (about 30 meters).

Field Strength Measurements

Field strength was measured in db above one microvolt per meter using the 5000M signal strength parameter. Because this parameter assumes a specific envelope shape, the reading can vary by six db with different manually selected tracking points near the start of the Ghost pulse.

Figure 3 shows the measured field strengths at measurement sites from this first trip. These measurements confirmed the earlier reports of high signal strength near the east end of the ship channel.

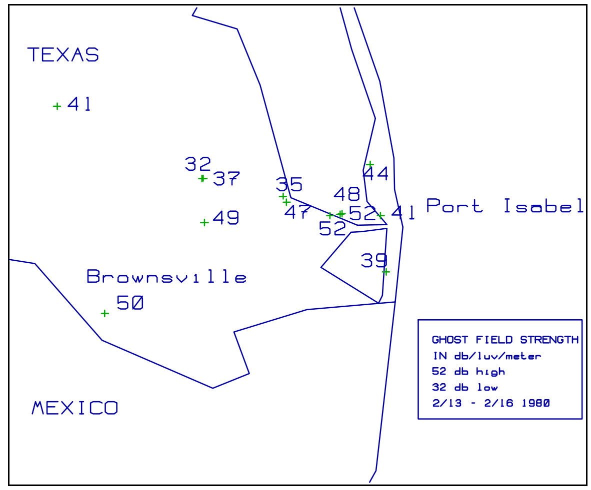

Figure 3. Local Area Ghost Field Strengths

Bearing Measurements

Bearings to the source were measured by adjusting a loop antenna until a minimum Ghost field strength was measured. The bearing were adjusted by the local magnetic variation and for the 90 degree offset in null measurements. The resulting bearings and their reciprocals were plotted [Figure 4].

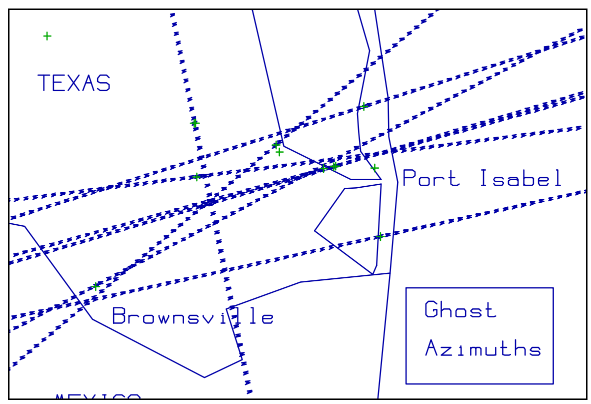

Figure 4. Local Area Ghost Bearings

Time Difference Measurements

Ghost time differences were recorded at each site. Because no attempt was made to maintain cycle lock between measurement sites, the TDs are only approximate indicators of Ghost arrival times with respect to the Master. Table 1 shows the first trip measurements.

First Trip Results

The results of this first trip, other than to confirm the existence of the Ghost and to verify the measurements made by previous investigators, were inconclusive. The source was not located.

Table 1. Trip One Data

#	Date	Time	Name	Lat	Long	á	db	TD
1	2/13	1720	FCC Monitor	27:28:00	97:51:30	218	40	25030.0
2	2/14	1013	PI Marina	26:04:30	97:12:47	254	48	25053.0
3	2/14	1045	San Roman	26:03:56	97:23:53	263	49	24947.7
4	2/14	1120	100 & 510	26:05:37	97:17:09		47	25012.0
5	2/14	1112	48 & 100	26:04:24	97:13:37		52	25044.0
6	2/14	1132	2480 & 510	26:07:43	97:23:55		37	24952.0
7	2/14	1340	802 & 281	25:56:17	97:32:07	243	50	24826.0
8	2/14	1529	Boca Chica	25:59:47	97:09:07	258	39	25066.0
9	2/15	1300	Wright's	26:04:34	97:12:39	255	52	25085.3
10	2/15	1400	Padre South	26:04:22	97:09:29		41	25116.2
11	2/15	1555	Laguna Vista	26:06:07	97:17:26	231	35	25034.0
12	2/15	1800	Andy Bowie	26:08:43	97:10:17	253	44	25094.0
13	2/16	1330	Bay View	26:07:42	97:24:01	348	32	24969.9
14	2/16	1500	1420 & 508	26:13:59	97:35:48		41	24873.3

Second Measurement Trip

A second field trip was made from June 23 to June 28 of 1980. Plans were made for a second trip to attempt source location by time of arrival phase tracking measurements and to test the power line carrier theory.

Power Line Carrier

Several people had suggested that Power Line Carrier (PLC) might be related to the Ghost interference. Power Line Carrier is the generic name for communications equipment that is used by power companies to send data and control information over power lines using low frequency transmitters and receivers. Much of this equipment transmits at 100kHz. One theory proposed that a PLC system might receive and retransmit the Raymondville signal, accounting for the 1500 microsecond delay by transmission over a 450km round-trip path length.

With the assistance of an official of the local Central Power and Light Company, the 100kHz PLC equipment was shut down for 25 minutes at noon on June 24. Prior to the shut-down the 5000M was set up to track the Ghost using the loop antenna adjusted for maximum gain. No change in amplitude or signal phase was notice during the shutdown so the PLC interference source theory was rejected.

Time of Arrival Measurements

The other planned measurements were time of arrival (TOA) measurements. By phase locking to an arbitrary cycle of the Ghost signal, traveling slowly along the roads, avoiding power lines and urban areas,
it was possible to maintain phase lock on the Ghost signal. By returning to the starting point and observing time difference measurements within one microsecond of those measured at the start, phase lock was confirmed. Two sets of phase-locked time of arrival data were measured.

Measurement Sites

Measurements were made at sites with positions that could be located on the 7.5 minute quadrangles, but because the van was moving continuously along the road, the accuracy of the positions may be in error by as much as 5 seconds of latitude and longitude (about 150 meters).

Clock Drift

The 5000M records both TDs and TOAs. Because the TOAs are measured with respect to the frequency standard driving the 5000M, an attempt was made to rate this clock. TOAs on the strong Raymondville groundwave were measured at the position that was used as the start and the end for the data sets. Multiple time and TOA measurements were made on this signal. Mean start time and start TOAs were subtracted from mean end times and TOAs to arrive at a linear oscillator drift estimate for the clock during the measurement period. The drift was then used to adjust each measured TOA to produce an adjusted TOA for each measurement site.

TOA Data Set 1

The first data set was taken in the primary problem area. Table 2 shows the first set of phase-locked data.

Table 2. Set A (Oscillator Drift= 0.002662μs/s)

	Time	Name	Lat	Lon	db	TD	TOA	Adj TOA
1	11:04:46	802 & 281	25:56:17	97:32:07	50	24815.8	31504.6	31504.6
2	11:13:02	1421 & 281	25:59:37	97:36:09	52	24801.8	31492.2	31490.9
3	11:34:16	Int & 4	25:54:03	97:29:14	39	24836.0	31523.8	31519.1
4	11:38:46	4 & 1419	25:54:37	97:28:27	39	24851.1	31531.8	31526.4
5	11:43:29	511 & 1419	25:53:25	97:26:15	38	24858.9	31533.0	31526.8
6	12:04:16	4 & 511	25:55:00	97:24:25	37	24888.2	31552.3	31542.8
7	12:07:09	802 & 511	25:56:19	97:24:25	37	24892.9	31552.6	31542.6
8	12:08:46	48 & 511	25:57:05	97:24:33	37	24893.3	31554.3	31544.0
9	12:28:09	100 & 48	26:04:24	97:13:38	55	25045.8	31632.4	31619.1
10	13:24:07	510 & 100	26:05:37	97:17:09	53	25013.6	31623.8	31601.5
11	13:41:27	1847 & 100	26:04:17	97:28:33	45	24889.9	31563.6	31538.6
12	13:46:16	1847 & 511	26:00:50	97:28:52	48	24871.7	31557.1	31531.3
13	13:52:03	1847 & 802	25:56:54	97:29:13	53	24848.8	31548.0	31521.2
14	11:51:46	3068 & 1419	25:51:57	97:24:27	38	24874.0	31543.3	31535.7

TOA Data Set 2

Because of the difficulty in maintaining phase lock for any distance, a second set of TOA data was taken in an area north and west of the Brownsville area. The data from that set is presented in Table 3.

Table 3. Set B. (Oscillator Drift= 0.001258μs/s)

#	Time	Name	Lat	Lon	TD	TOA	Adj TOA
1	14:54:20	Rest Area	26:29:59	99:04:09	24636.5	45844.1	45844.1
2	15:00:50	2098 & 83	26:31:55	99:05:22	24645.3	45853.5	45853.0
3	15:03:20	Power Line	26:32:49	99:06:31	24646.8	45859.9	45859.2
4	15:05:20	2098 & 46	26:33:54	99:07:30	24649.3	45865.9	45865.1
5	15:11:20	Falcon Dam	26:33:10	99:08:38	24636.9	45861.3	45860.1
6	15:19:50	Salinas Rd	26:31:40	99:05:19	24643.5	45855.4	45853.4
7	15:23:50	Salinas Sq	26:30:57	99:06:44	24629.9	45851.2	45849.0

Preliminary Data Analysis

The data from the second trip measurement sets were used to estimate the position of the Ghost source.

TOA Analysis

The times of arrival were interpreted as if the Ghost was a signal re-transmitted from a single point. A computer program was developed that used the relative arrival times from these two sets of sites to locate the probable position of the source.

The program used pairs of TOAs from each set of sites as lines of positions in a reverse navigation process. Several sets of data pairs were used and the results averaged to estimate the position of the source. The geometry of the measurement sites and the estimated measurement noise was used to predict the position error.

The program indicated a source at 25:22:10 North latitude and 99:20:50 West longitude, with a 48km circular error of position. This is a position south and east of Monterrey, in northern Mexico.

Bearing Analysis

When re-plotted at a smaller scale [Figure 5], the bearing data from the first field trip was now seen to support the possibility of this position as the source of the Ghost.

Flight Over Mexico

In July, 1980, the Austron team made a flight to Mexico in a twin-engine Cessna, equipped with an ONI 711 Loran-C avionics receiver and an oscilloscope. The Ghost did not appear on the screen until about 40km from Brownsville in the direction of the probable source position.

During the flight, the delay of the Ghost signal with respect to the Raymondville groundwave decreased. As the plane flew along the azimuth toward the predicted position the delay was reduced from about 1400 microseconds to a few hundred microseconds. As the interference signal delay went from 1200 to 1000 microseconds, it passed through the Raymondville groundwave second pulse and re-appeared with a delay of less than 1000 microseconds.

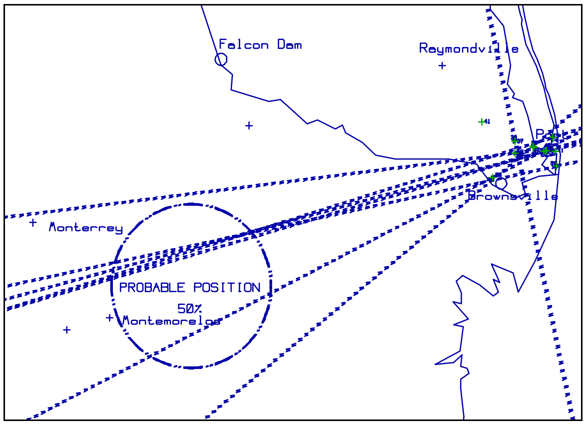

Figure 5. Probable Ghost Position and Bearings

When the aircraft reached the predicted area there was still a delay of around 300 microseconds. At the predicted point the Ghost amplitude was large, with an amplitude of -30db with respect to the groundwave. While continuing to fly along the predicted azimuth, the signal delay decreased and was still just visible behind the groundwave at the town of Montemorelos. Beyond Montemorelos, the eastern escarpments of the Sierra Madre Oriental climb from an elevation of a few hundred meters to almost 3000 meters in a short distance. As the aircraft approached the steep face of these mountains the Ghost signal disappeared into the groundwave pulse. The Ghost signal did not reappear west of the ridge.

Investigation Results (1980)

It seemed possible that the Ghost signal was the Raymondville groundwave reflecting off the face of the steep escarpment of the Sierra Madre. If the mountain ridge near Montemorelos was modeled as a flat reflector, an incident ray path angle from Raymondville would result in an equal angle of reflection toward Brownsville [Figure 6]. Field strength magnitudes could be explained by the 450km path from Raymondville to Montemorelos and back to Brownsville, and a directed beam could account for the high field strength readings directly in the center of the beam at Port Isabel.

A report [Reference 4] was issued to the Coast Guard in July, 1980 and was circulated by Coast Guard Headquarters to interested parties. No further action was taken by the Coast Guard because the Ghost was seen as primarily a receiver problem. Careful design can reduce the chance of locking up on a signal some 1500 microseconds late and with a -40db field strength relative to the desired signal. Manufacturers were quick to change their acquisition techniques (rumor has it that one manufacturer installed "Texas Mod" software). The operational problem disappeared with receiver re-design, but the Raymondville Ghost signal is still there.

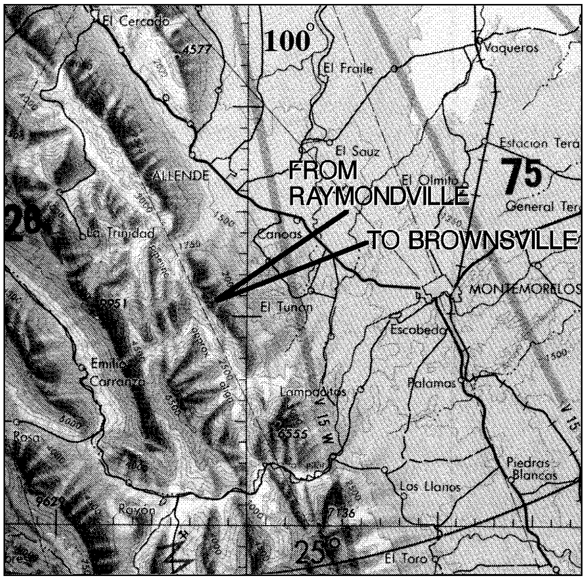

Figure 6. Sierra Madre Oriental Near Montemorelos

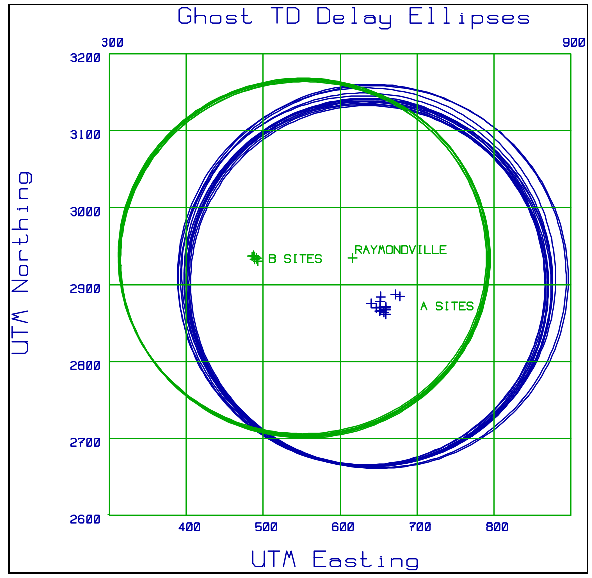

Figure 7. TD Delay Ellipses

GHOST SIGNAL REFLECTION ANALYSIS (1990)

The Raymondville Ghost continues to exist. The Raymondville transmitter has been dual rated for the new South Central Chain. The Ghost now is being transmitted on two GRIs. New avionic receivers are being designed and additional areas of the country will soon be within the coverage area of the new Mid-Continent Chains.

Because some of the new transmitters will be located near the eastern edge of the Rocky Mountains, and the Raymondville transmitter will be utilized in areas not previously covered with good Loran-C, a new look at the Ghost source in Mexico is appropriate.

TD and TOA Analysis

The data presented in Tables 2 and 3 can be used in several ways to point to the Ghost source.

Delta TD Ellipses

Each measured TD from the Ghost signal can be converted to delays from measured or predicted Raymondville groundwave TDs. These delta TDs can be interpreted as ranges over the path from the transmitter, to the Ghost source, and back to the measurement site. For both sets of phase-locked TD measurements the ellipses can be plotted on a grid representing the possible Ghost source locations. Figure 7 shows these ellipses plotted in Universal Transverse Mercator (UTM) Northing and Easting. Because the entire area covers only a few hundred kilometers, all of the analysis assumes that ranges and bearings computed from UTM coordinates are close enough to ellipsoidal earth computations that the differences are far less than the noise in the initial measurements. The datum for this UTM system is the North American Datum of 1927.

The Ghost signal, if it were a single source, would be located near the area in which the ellipses intersect.

Function Minimization

For this report, a program was written that iteratively solves for a single source position, minimizing the residuals between the predicted and observed TOAs for both set of sites. The directional derivatives for TOA errors from the two sets of sites are used together by assuming two different clock bias offsets for the two sets of sites. Equation 1 shows the method used to move a predicted position to a minimum residual error point. The program, imprecise because of the poor geometry (GDOP>22), measurement noise (around 2ìs), and the dubious assumption of a single point source, predicts a source location at 25:23:42N latitude and 99:15:53W longitude (473375 East, 2808546 North).

$$\Delta Easting, \Delta Northing, and\ range$$
$$from\ predicted\ position\ to\ each\ measurement\ site$$
$$A = \begin{vmatrix} (\Delta Easting/range & \Delta Northing/range & -1.0 & 0.0\ )_{TOA\,SET\ 1_i} \\ (\Delta Easting/range & \Delta Northing/range & 0.0 & -1.0\ )_{TOA\,SET\ 2_i} \end{vmatrix}$$
$$\Delta\ TOAs = measured\ TOA - predicted\ TOA$$
$$\Delta\ position = (\ A^T * A\ )^{-1}\ A^T * \Delta\ TOA$$
$$new\ position = predicted\ position + \Delta\ position$$

(1) Iterative Source Prediction from Two TOA Sets

Grid Correlation

Another way to look at the TOA data is to compute TOA residuals at 10km grid points over the area. A residual grid was produced for each set of TOAs. By multiplying the grids together, a new grid is formed that graphically displays the correlation between residuals from both data sets [Figure 8]. The minimum contours center on the area in which the source should be found.

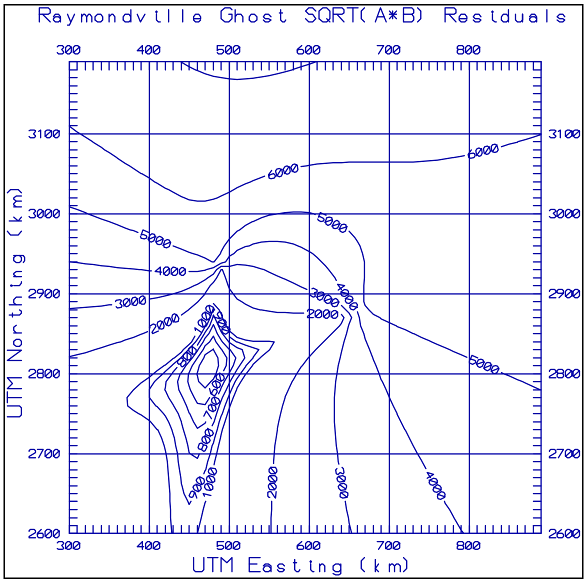

Figure 8. Correlation of Both TOA Residual Sets

Reflection Source

The Sierra Madre Oriental is a thrust fault, with limestone layers from the Lower Cretaceous period standing on edge [Reference 5]. A digital terrain model [Figure 9] of part of the ridge near Montemorelos was produced from topographic maps [Reference 6]. Viewed from the direction of the Raymondville transmitter, the mountains present a considerable reflecting surface. The cross section through the ridge center shows the steepness of the slope, shown with a vertical exaggeration of five.

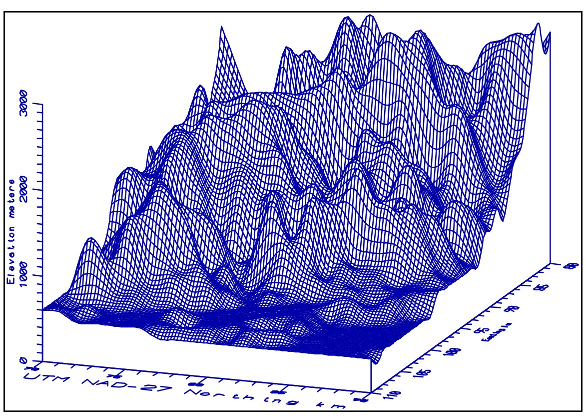

Figure 9. Montemorelos Area Sierra Madre Ridge

Ground Reflections

Loran-C ground reflections are usually associated with the ground reflections of multiple-hop skywaves. The skywave ground reflection coefficient is related to ground conductivity and incidence angle [Reference 7]. For the skywave case where a vertically polarized signal reflects from a surface perpendicular to the plane of polarization, the effect of incidence angle on both attenuation (3 to 15db) and phase shift (10 to 180 degrees) is significant.

The case here, in which a vertically polarized signal is reflected from a surface in the same plane as the polarization, the incidence angle has a minimal effect on both attenuation (<3db) and phase shift (<10 degrees) [Reference 8].

Roughness

The Rayleigh criteria [Reference 9] defines a surface as smooth if the height of surface features is less than the value given by Equation 2. It is not clear that this expression holds true for very large wavelengths such as the 3000 meter Loran-C wavelength. If the criteria is applicable, a ridge over an eighth of a wavelength high could reflect the groundwave and the surface of the ridge facing the incident ray (at 83 degrees) would have to have average surface variations of less than 378 meters. Both requirements are met by the uplifted-sedimentary layers of the Sierra Madre Oriental near Montemorelos.

$$h < \frac{l}{8 * \sin(g)}$$

$$\text{where } h = \text{surface relief height}$$
$$l = \text{wavelength}$$
$$g = \text{angle of incidence}$$

(2) Rayleigh Smoothness Criteria

Models of the Ghost

It seems reasonable to assume that although the Montemorelos area ridge is a prime candidate for the source of the Ghost, many reflections from other ridges along the escarpment may combine to form complex interference patterns in the South Texas area. The following simplified models can assist in an understanding of the Raymondville Ghost.

Beam Forming

Antenna beam forming techniques can be used to model the reflection pattern from the ridge. Figure 10 shows the result of applying Equation 3 [Reference 10] to a ridge 30 kilometers long, centered at 390km Easting, 2780km Northing, and angled at the 152.24 degree azimuth of the Montemorelos ridge. This pattern was generated by assuming 30 antenna elements at one kilometer spacing along the ridge. Phase shifts at each element are computed from the range to the Raymondville transmitter. The resulting narrow beam is directed in the azimuth that points to the Brownsville/Port Isabel area.

$$E(\Theta) = a/n^e * \sum_{n=0}^{n=n_e} e^{(j*f_n - j*k*de*n*\mathrm{SIN}(\Theta))}$$

$$\text{where } E = \text{beam field}$$
$$\Theta = \text{azimuth}$$
$$a = \text{field strength of emitters}$$
$$n^e = \text{number of emitters}$$
$$f^n = \text{phase shift of emitter } n$$

(3) Antenna Beamforming Equation

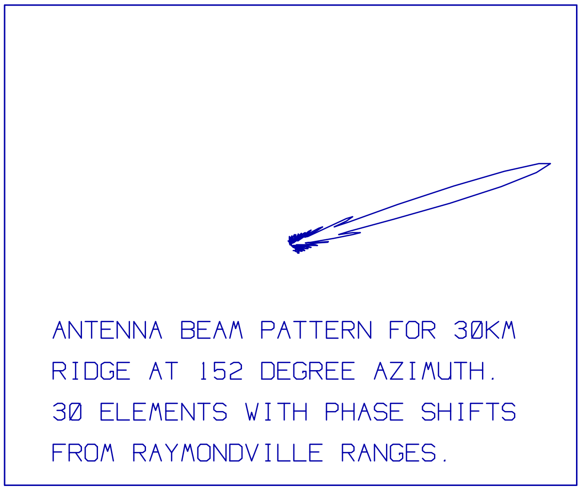

Figure 10. Antenna Beam Pattern

Ghost Simulation

The Ghost reflection pattern can also be modeled through a simulation. Figure 11 shows the results of a simulation in which the 30 source elements along the same ridge described above are used to compute at each grid point the phase and amplitude of the resulting signal. In this simulation, attenuation from ground conductivity is included in the computations. The resulting pattern matches the direction of the beam pattern, but includes predicted field strengths for the Ghost signal. When examined in the area of the field measurements, the pattern shows a remarkable ability to predict Ghost field strengths [Figure 12].

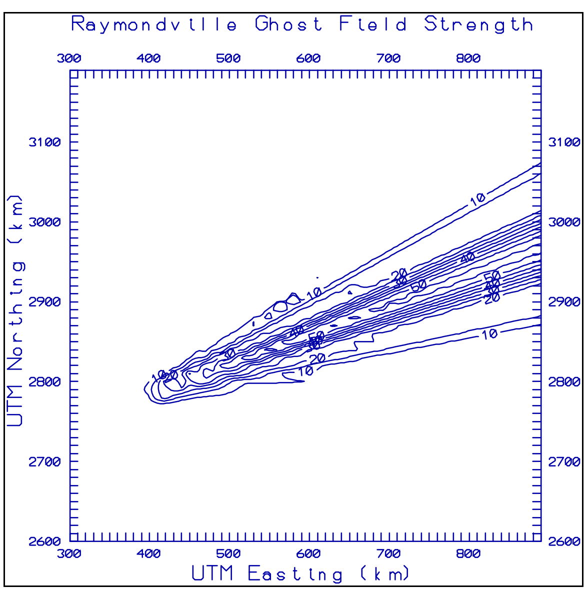

Figure 11. Ghost Field Strength Simulation

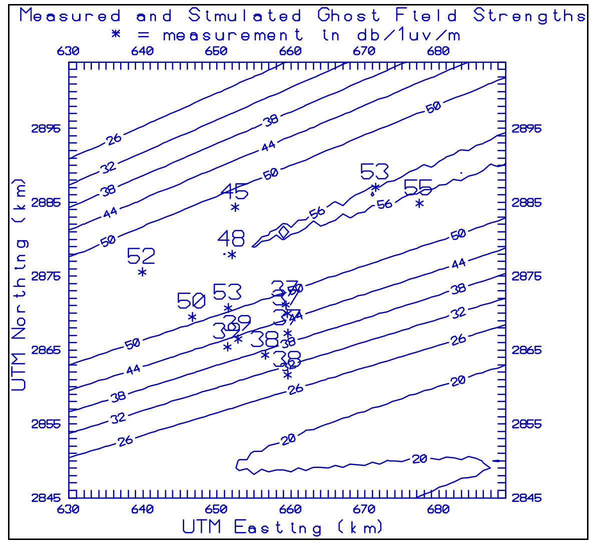

Figure 12. Brownsville Area Simulated and Measured Ghost Field Strengths

MID-CONTINENT CHAIN IMPLICATIONS

The new Mid-Continent Chains [Figure 13] will use the Raymondville signal on two GRIs. New transmitters are coming on-line east of the Rocky Mountains. In those areas where reflections might occur with sufficient amplitude to be seen by a receiver, careful receiver acquisition design and the ability of the Loran-C phase code to minimize tracking errors caused by one pulse (1ms) delays can solve most Ghost-like problems. But near reflectors where Ghost delays are small, errors in phase tracking of the groundwave can occur.

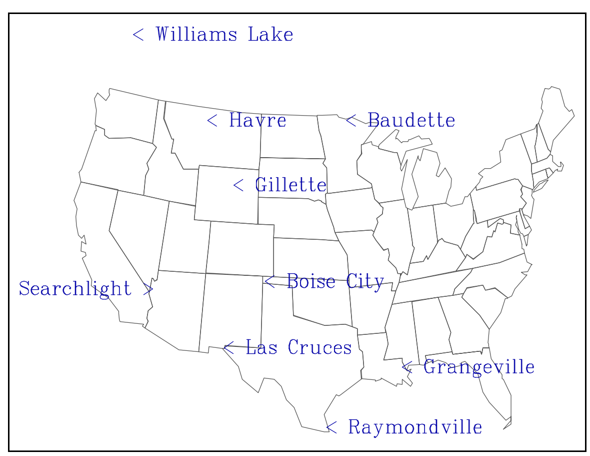

Figure 13. Mid-Continent Transmitters

Figure 14 is a view of the eastern edge of the Rocky Mountains, as seen from a vantage point just above the new transmitter at Boise City, Oklahoma. The ridges of the mountains east of Pueblo, Colorado share many of the characteristics of the Sierra Madre Oriental. For example the Greenhorn Mountain ridge is a sedimentary uplift, and has steep slopes rising to half wavelength heights above flat ground in the direction of a transmitter less than 200 kilometers away. While the particular geologic features of the Sierra Madre Oriental near Montemorelos may be unique, the possibility exists for new Ghosts along the eastern edge of the Rocky Mountains.

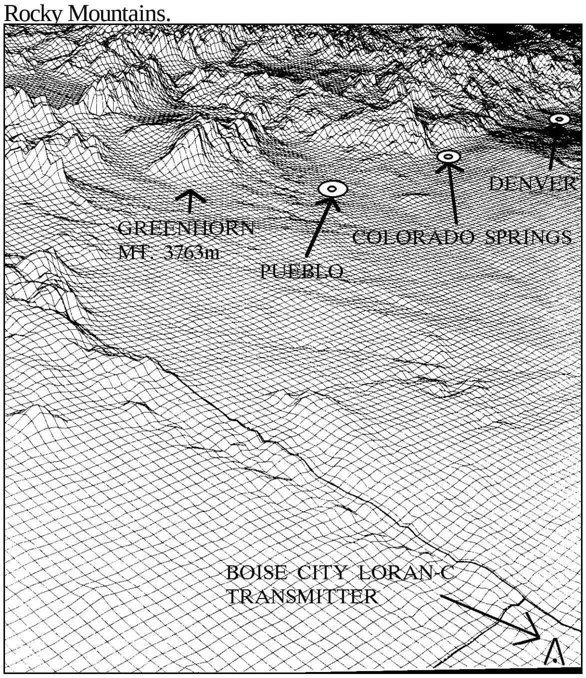

Figure 14. Eastern Edge of Rocky Mountains

[Adapted from "The Rockies, the High Plains and the Intermountain West" Computer Image copyright © Dynamic Graphics, Berkeley, CA.]

SUMMARY

The Raymondville Ghost caused problems in a small area of the Gulf of Mexico for both users and manufacturers when the Southeast U. S. Chain came on the air in the late 1970s. The signal interference source was identified as reflections from the escarpments of the Sierra Madre Oriental in Northern Mexico. Manufacturers implemented receiver changes to avoid the problem.

The Raymondville transmitter will soon be used in new areas as a dual-rated station in the Mid-Continent chain configurations. New transmitters are being constructed and brought on-line near the eastern edge of the Rocky Mountains. New avionics receivers are being designed and deployed in wide areas that may see a re-occurrence of the Raymondville Ghost. The possibility exists for new Ghosts, resulting from reflections of signals from the new transmitters.

Early identification of Ghost reflections and awareness of the potential for Ghosts in new receiver designs can prevent problems in the Loran-C avionics environment of the 1990s.

ACKNOWLEDGEMENTS

This paper draws on the Austron Navigation, Inc. report issued to the Coast Guard in 1980 [Reference 2]. Bill Schorr was helpful then and now with details about the Raymondville Ghost. Bruce Francis, then program manager for the Raymondville Interference Signal Investigation project, shared in all the field and office work but kept the difficult political and team management tasks for himself.

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