RTCM SC-127
Maritime eLoran Receiver Minimum Performance Standards

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Effort Supported by FAA Loran Evaluation Program, Mitch Narins, Manager

Outline

- Receiver testing
- Cycle integrity algorithm
- Status & way forward

Table 2-6, Loran Signal Test Conditions from TSO-C60B (1986)

Test Case	Test Subject	GRI	Groundwave Noise S_m	S_x	S_y	S_n	T_{sw}*	S_{sw}*	ECD_m	ECD_x	ECD_y	CRI S_{cr}	F_1	S_1	CWI F_2	S_2
1	Dyn.	4990	110	30	30	30			+3.5	0	–2.4					
2	Range	—	40	40	40	46	35	46	0	0	0	110	88.0	80	76.3	80
3	ECD	↑	40	40	40	46	37.5	50	0	–2.4	0	40	119.85	80	124	80
4	Skywave	|	40	40	40	56	40	50	0	–2.4	–2.4		76.3	80	113	80
**5	CWI	|	40	40	40	56	42.5	55	0	0	0		48.5	110	214	110
6	CRI 3/	|	40	40	40	56	45	60	0	0	0					
7	4/	|	40	40	40	56	50	60	0	0	0					
8	ECD	|	40	40	40	56	55	65	0	0	0					
9		btwn	40	40	40	56	35	46	0	0	0					
10		7980	40	40	40	56	37.5	50	0	0	0					
11		and	40	40	40	56	40	50	0	0	0					
12		9990	40	40	40	56	42.5	55	–2.4	–2.4	–2.4					
13		|	40	40	40	56	45	60	–2.4	–2.4	–2.4					
14		|	40	40	40	56	50	60	–2.4	–2.4	–2.4					
15		|	40	40	40	56	55	65	–2.4	–2.4	–2.4					
16		|	40	40	40	56			–2.4	–2.4	–2.4					
17		|	40	40	40	56			–2.4	–2.4	–2.4					
18		|	40	40	40	56			–2.4	–2.4	–2.4					
19		|	60	60	60	60			0	0	0					
20		|	60	60	60	60			0	0	0					
21		|	60	60	60	60			0	0	0					
22		↓	50	50	50	50			0	0	0					
23		—	80	50	50	50			+1.5	–2.4	–2.4					
24		7980	110	50	50	50			0	–2.4	–2.4					
25		7930	40	40	40	40			0	0	0					
26		4990	30	110	30	30			–2.4	+3.5	0					

Receiver testing

- Things to test
  - Sensitivity
  - Dynamic Range
  - Acquisition, accuracy, cycle integrity, LDC demodulation, & off air/blink detection with
    - Cross Rate
    - Skywaves
    - CWI
    - Impulse Noise
    - Dynamics
  - TD & heading accuracy with H field Antenna rotation
  - Application of differential corrections & ASF grid
- How to test
  - Live signals
  - RF simulator generated fields in anechoic chamber
  - RF simulator via coax to RF input on receiver (via box to simulate frequency response & gain of antenna)
- Other considerations
  - Data files??
  - If magnetic or inertial sensors used to aid dynamic performance, how do we test?

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Millington Method chart for both Groundwave & Skywave amplitudes

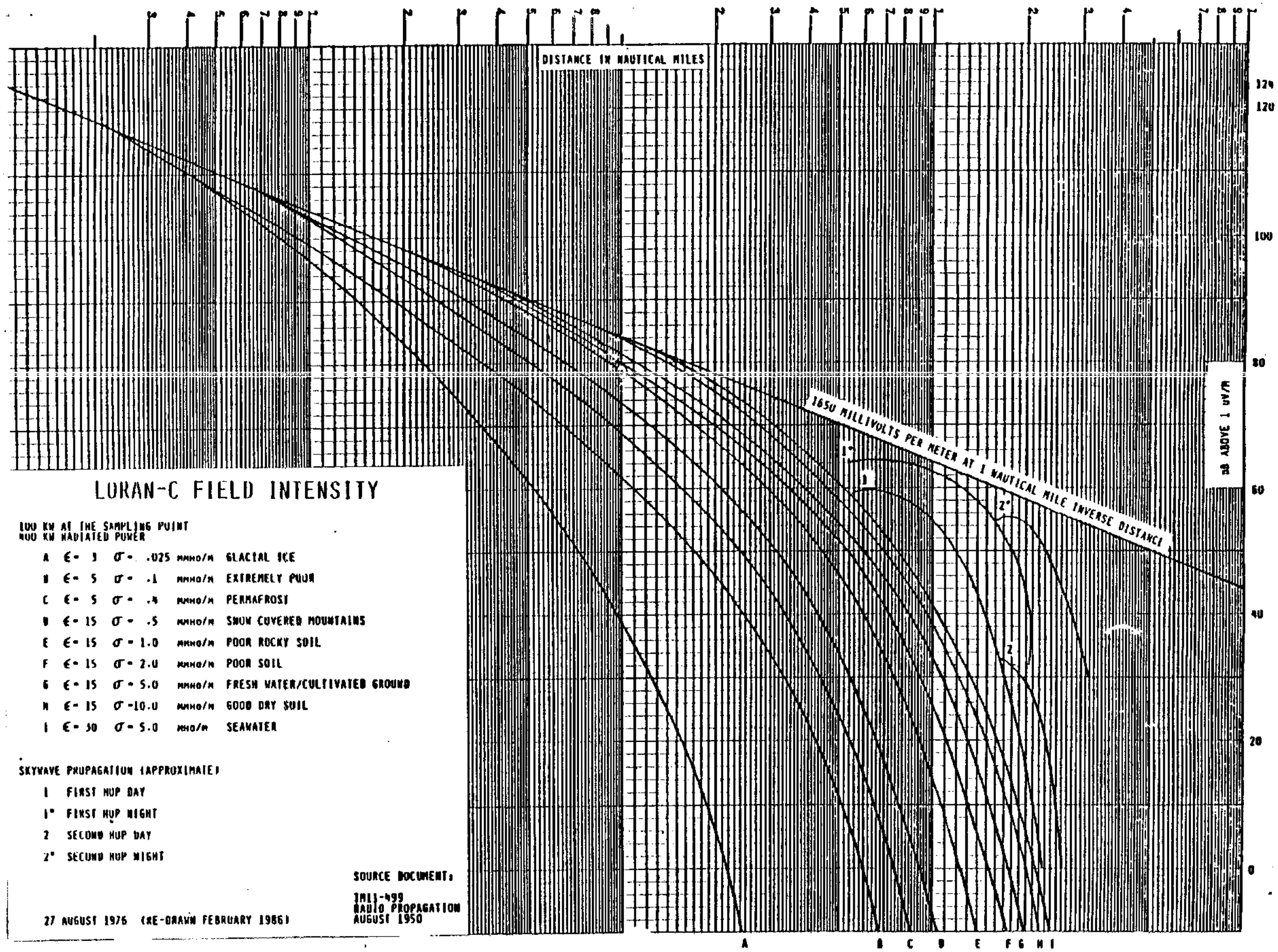


Figure 2 LORAN–C Field Strength vs. Distance

Entrance to Duluth, MN at Night
(combined CRI/nominal skywave test)

			Ground Wave (dB)	Distance in NM	Skywave (dB)	Skywave delay (us)
Caribou	5930M	9960W	26	985	67	100
Nantucket	5930X	9960X	33	1002	64	98
Cape Race	5930Y	7270W	NA	1579	55	74
Fox Harbor	5930Z	7270X	NA	1436	60	78
Williams L	5990M	8290Y	24	1217	61	86
Shoal Cove	5990X	7960Y	NA	1544	56	75
George	5990Y	9940W	36	1131	68	90
Port Hardy	5990Z		NA	1406	57	79
Malone	7980M	8970W	36	997	67	99
Grangevlle	7980W	9610Z	40	963	67	101
Raymondvll	7980X	9610Y	30	1244	62	85
Jupiter	7980Y		22	1310	59	82
Carolina B	7980Z	9960Y	34	994	65	99
Havre	8290M		47	733	65	125
Baudette	8290X	8970Y	78	152	63	357
Boise City	8970Z	9610M	48	784	68	118
Gillette	8290X	9610V	53	596	66	147
Dana	8970M	9960Z	57	458	64	181
Fallon	9940M		26	1244	61	85
Middletown	9940X		NA	1415	57	79
Searchlght	9610W	9940Y	28	1232	62	85
Las Cruces	9610X		33	1114	64	91
Seneca	8970X	9960M	50	689	68	131
Comfort Cv	7270M		NA	1483	54	76

Comments:

•Test would be in nominal conditions but in area of much CRI primarily due to night time skywaves.

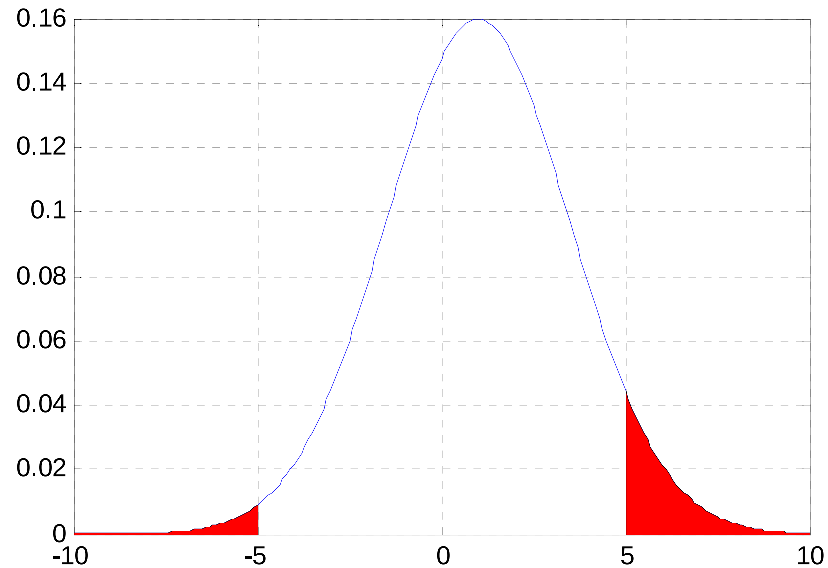
•To include all signals with 1st hop skywave of 56 dB re 1 uv/m we need 10 rates

Loran Cycle Integrity vs GPS RAIM

- In GPS RAIM, algorithm determines if a pseudorange error exists that causes position error to exceed some bound
  - Therefore algorithms focus on mapping (based on geometry) between the residual vector and position error
- In Loran
  - A range error a small as 50 ns or less can result in a position error > 25 m alarm limit
    - We have no hope of detecting errors this small with RAIM, other methods (monitors) must eliminate these errors.
  - A cycle error (3 km) or skywave error (>>3 km) will result in a position error >25 m even for signals with very small weighting & must be detected
  - Therefore, unlike GPS RAIM we need relationship (again based on geometry) between range errors & residuals, not position errors and residuals.

Previous Cycle Integrity Process (from LORIPP report)

Calculation of Probability of cycle error (P_{IC})



P_{IC} = red areas under curve

= normcdf(-5, ECDbias, σ) + normcdf(-5,- ECDbias, σ)

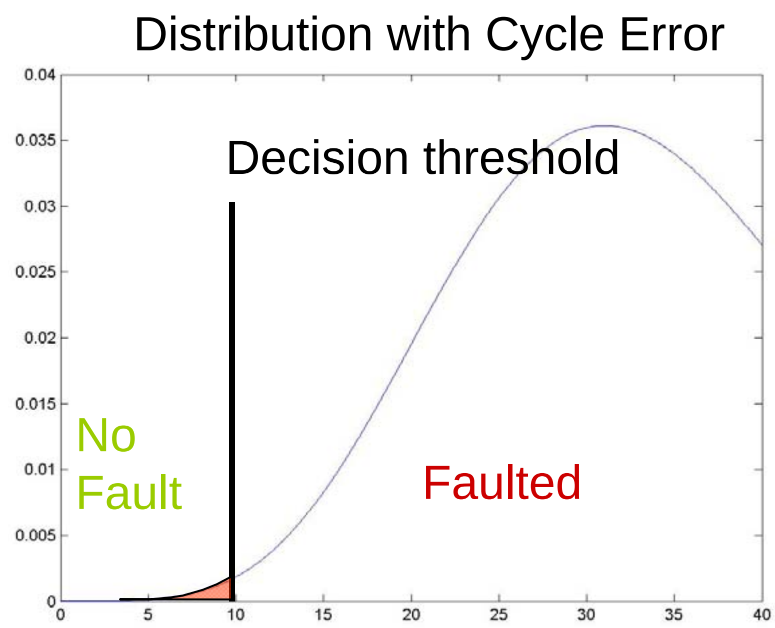
Where:

σ = K/sqrt(N * SNR), K = 42 usec for Austron 5000 method, present technology may be 3dB or more better

N = number of pulses averaged, 1000 is used

ECDbias = bound on constant errors such as propagation uncertainty, receiver calibration, & transmitter offset

Calculation of Probability of missed detection cycle error (P_{MD})



P_{MD} = red areas under curve
= $CDF\chi^2_{ncp,dof}$(threshold)
Where:
ncp = non centrality parameter $$ncp = b^T M b$$
worst case (smallest ncp) used
dof = degrees of freedom (stations – 3)
b = bias vector (including assumed fault)

$$M = W\left(I - P\right) \qquad P = G\left(G^T W G\right)^{-1} G^T W$$

Calculation of Probability of undetected cycle error

$$P_{WC} = \sum P_{MD_i} P_{IC_i} + \sum P_{MD_{ij}} P_{IC_i} P_{IC\,j} + \sum P_{MD_{jki}} P_{IC_i} P_{ICj} P_{IC\,k} + \ldots$$

- P_{ICi} = probability of incorrect cycle tracking on signal i
  - This is nominal performance - no checks
- P_{MDi} = probability of missed detection of incorrect cycle tracking on signal i
  - Missed detection probability of cycle fault detection algorithm
  - Depends on decision threshold selected
- P_{WC} = probability of having one or more undetected incorrect cycle

Issues with prior approach

- Complexity
  - Required cumulative distribution functions of chi squared distribution w/ & w/o non centrality parameter
    - Even then could not accurately model distribution of sum of bias and noise
  - Required precise definition of SNR & measurement of envelope as function of SNR
- Performance
  - Because of large variation is SNR among stations, weak signals weighted out of WSSE and cycle errors on these most vulnerable signals became undetectable

Simplifying Cycle Integrity for Loran

- Calculate standard n x 3 matrix of direction cosines

$$G = \begin{pmatrix} \cos(Az_1) & \sin(Az_1) & 1 \\ \cos(Az_2) & \sin(Az_2) & 1 \\ \ldots & \ldots & \ldots \\ \cos(Az_n) & \sin(Az_n) & 1 \end{pmatrix}$$

If Re is pseudorange error vector, Least Squares position error vector (Pe) is

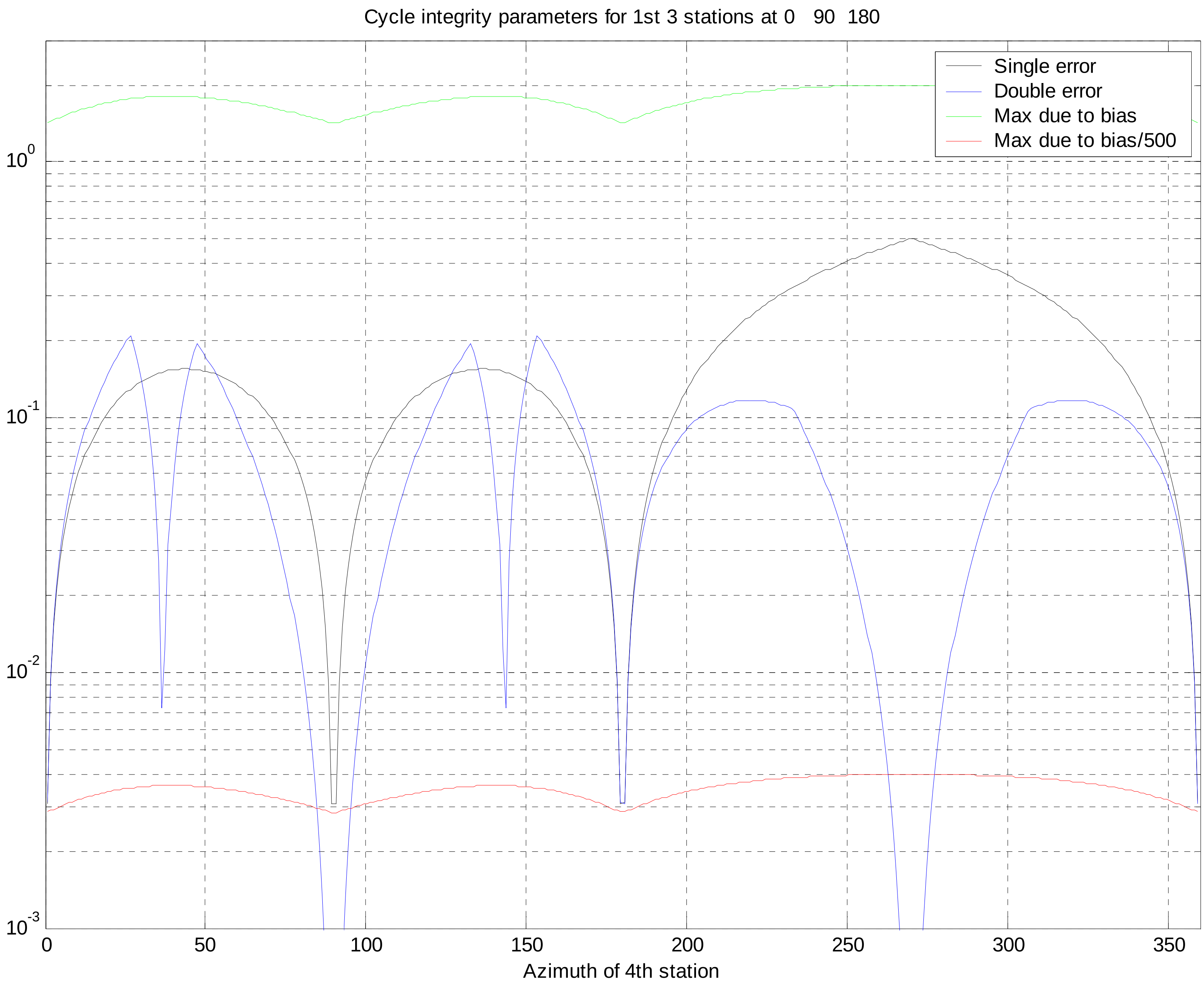
$$Pe = inv(G^T G)\, G^T\, Re$$

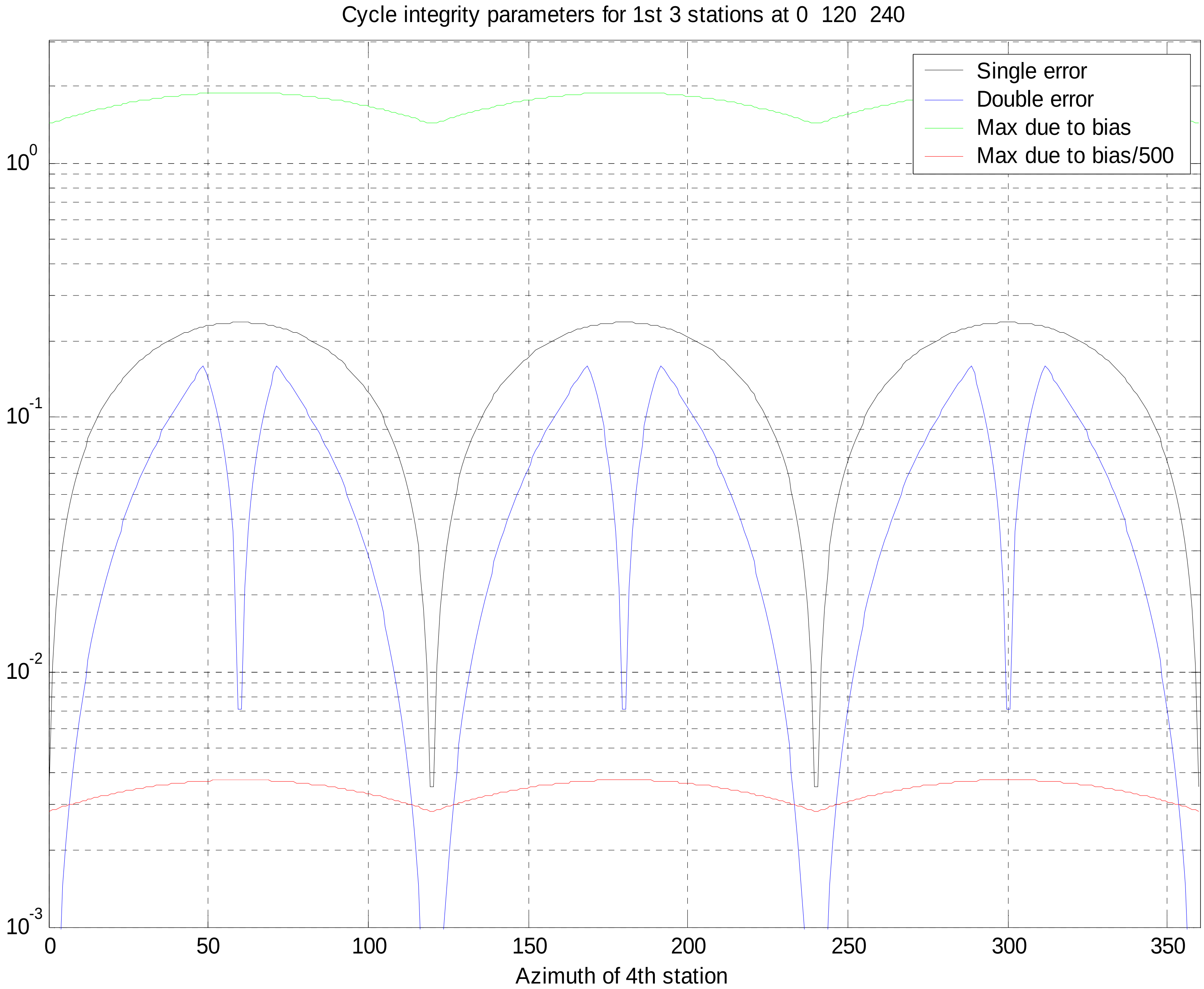
The residual vector (R) is given by

$$R = Re - G\, Pe = (I - G\, inv(G^T G)\, G^T)\, Re = A\, Re$$

Simplifying Cycle Integrity for Loran - 2

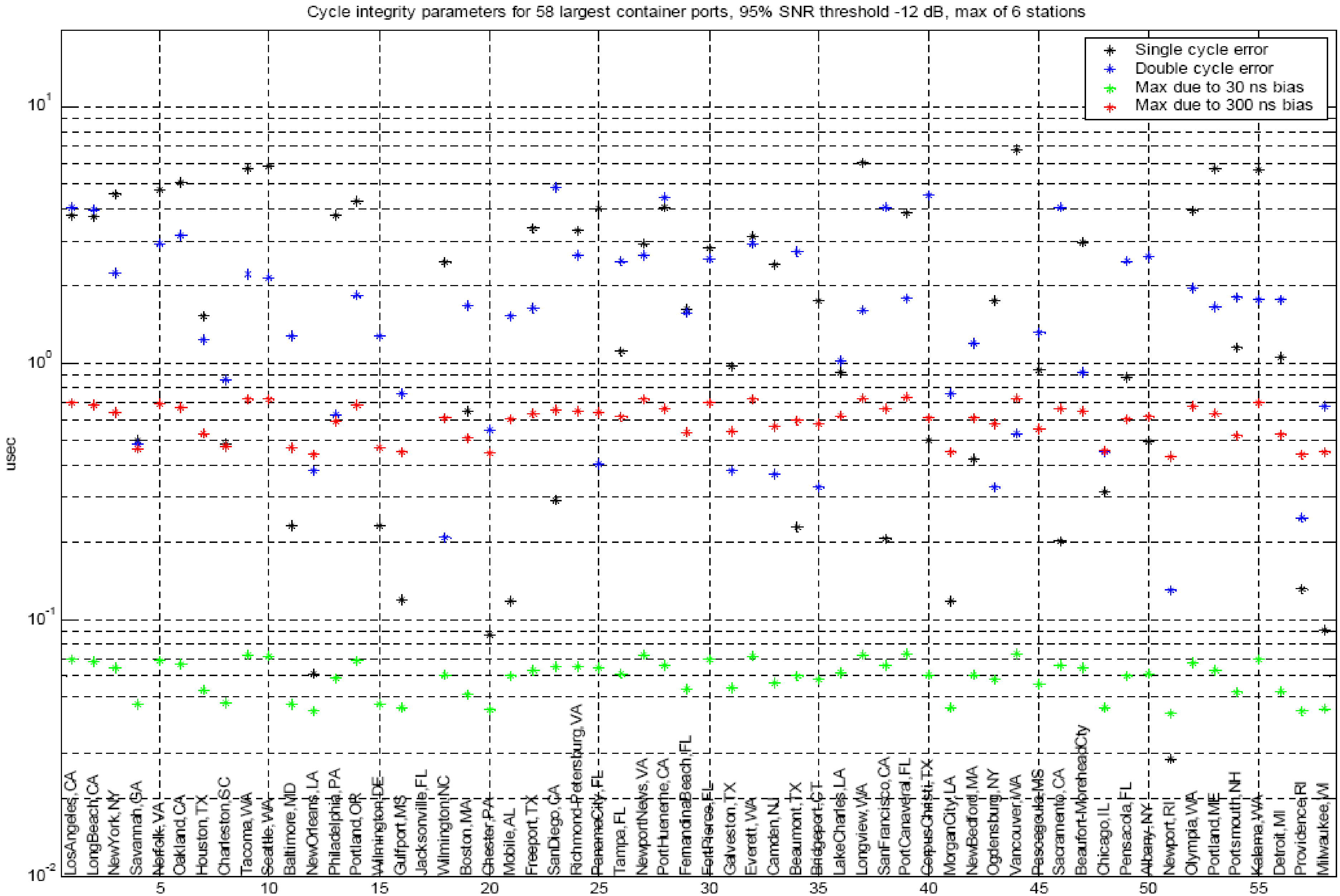
- Observability matrix $A = I – G\ inv(G^TG)G^T$
  - Is the desired mapping from range error to residuals
  - Is a function of only geometry
  - Will tell us
    - Which geometries will or won’t allow us to detect a single cycle or larger (i.e. skywave) error
    - Which individual errors are detectable & which aren’t
    - Which geometries will or won’t allow us to detect double cycle errors
    - Which combinations of 2 errors are detectable and which aren’t


Cycle integrity parameters for 1st 3 stations at 0 90 180
Single error
Double error
Max due to bias
Max due to bias/500
10^0
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
350
Azimuth of 4th station

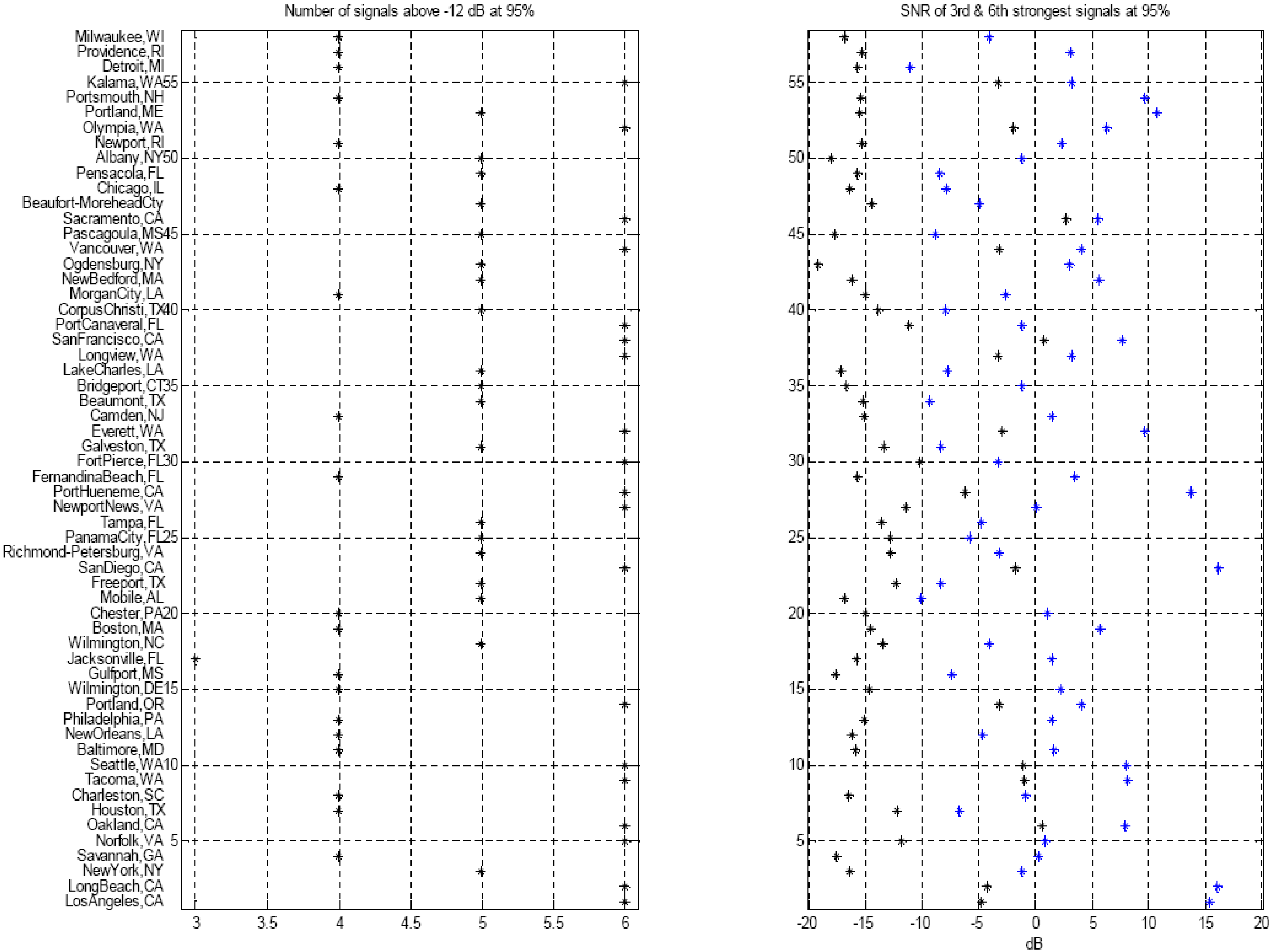

Cycle integrity parameters for 1st 3 stations at 0 120 240
Single error
Double error
Max due to bias
Max due to bias/500
10^0
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
350
Azimuth of 4th station

List of Ports

- 73 largest container ports from MARAD web site
- Eliminate Hawaii, Puerto Rico, & South Florida
- Eliminate some duplicates (multiple terminals in NYC area, etc.)
- Left with 58



Note: SNR on this and on following slides is pre-clipping or other non-linearity, post clipping SNR may be 8-12 dB better.


Number of signals above -12 dB at 95%
Milwaukee,WI
Providence,RI
Detroit,MI
Kalama,WA
Portsmouth,NH
Portland,ME
Olympia,WA
Newport,RI
Albany,NY
Pensacola,FL
Chicago,IL
Beaufort-MoreheadCty
Sacramento,CA
Pascagoula,MS
Vancouver,WA
Ogdensburg,NY
NewBedford,MA
MorganCity,LA
CorpusChristi,TX
PortCanaveral,FL
SanFrancisco,CA
Longview,WA
LakeCharles,LA
Bridgeport,CT
Beaumont,TX
Camden,NJ
Everett,WA
Galveston,TX
FortPierce,FL
FernandinaBeach,FL
PortHueneme,CA
NewportNews,VA
Tampa,FL
PanamaCity,FL
Richmond-Petersburg,VA
SanDiego,CA
Freeport,TX
Mobile,AL
Chester,PA
Boston,MA
Wilmington,NC
Jacksonville,FL
Gulfport,MS
Wilmington,DE
Portland,OR
Philadelphia,PA
NewOrleans,LA
Baltimore,MD
Seattle,WA
Tacoma,WA
Charleston,SC
Houston,TX
Oakland,CA
Norfolk,VA
Savannah,GA
NewYork,NY
LongBeach,CA
LosAngeles,CA
55
50
45
40
35
30
25
20
15
10
5
3
3.5
4
4.5
5
5.5
6
SNR of 3rd & 6th strongest signals at 95%
55
50
45
40
35
30
25
20
15
10
5
-20
-15
-10
-5
0
5
10
15
20
dB

Implementation Issues & Recommendations

- For fault free measurements, assume sum of bias and noise has bound to some required number of 9's (i.e. 5, 6 etc.)
  - Eliminates calculation of chi square distributions
  - For dLoran & 25 m alarm limit, this bound has to be or order of 30-50 ns or less or fault free case will not meet requirement
  - Off-shore/non differential, this bound might be 300-500 ns
- Either external to user equipment

– Regulating agency uses algorithm to specify acceptable constellations for each port

- Or within user equipment; In order to use a signal or signals, 1 of 2 conditions must be met

– Signal either has sufficient SNR to be "trusted"

  - Necessitates specifying a method of determining (post-clipping, post averaging) probability of cycle error
  - Preserves ability to navigate on "trusted" triad

– or cycle error or errors on signals below this SNR threshold can be detected

Note: In both cases; Least Squares used for cycle integrity, after cycle integrity assured, other method such as Weighted Least Squares may be used

Conclusions

- Algorithm is very simple
- Both single and double errors can be detected in dLoran case
- Offshore, in some cases may only be able to detect single error

Way Forward

- Goal is to submit drafts to initiate IMO/IEC process within next few months while continuing to work receiver testing chapter.
  - To selected people external to SC-127 in mid Dec for comment. Comments due 22 Jan.
    - If you would like to receive draft for comment, send email to Tom Gunther (Gunther_Thomas@bah.com)
  - We will use these comments, revise draft & submit to UK government for IMO process in mid February.
- Next meetings (both @ Catamaran Hotel, San Diego)
  - Thursday, Jan. 28, 2010 (Day after ION-NTM)
  - Week of 17 May 2010 in conjunction with RTCM Assembly.

Contact Info/Disclaimer

For additional info:

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-Note-

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