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POSITION DETERMINATION WITH LORAN-C TRIPLETS AND THE TEXAS INST--ETC(U)
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POSITION DETERMINATION WITH
LORAN-C TRIPLETS AND THE TEXAS INSTRUMENTS
TI-59 PROGRAMMABLE CALCULATOR

by

R. H. Shudde

May 1980

Approved for public release; distribution unlimited.

Prepared for:

Naval Postgraduate School
Monterey, Ca. 93940

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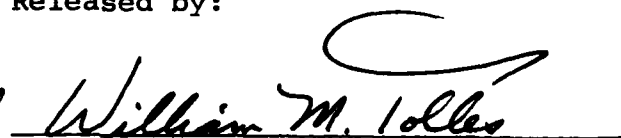
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ABSTRACT

This report presents an algorithm and TI-59 programs for position determination with Loran-C chains. Operational data cards are prepared in advance for Loran-C triplets. Position determination can be performed by using a single program card and an appropriate operational data card,

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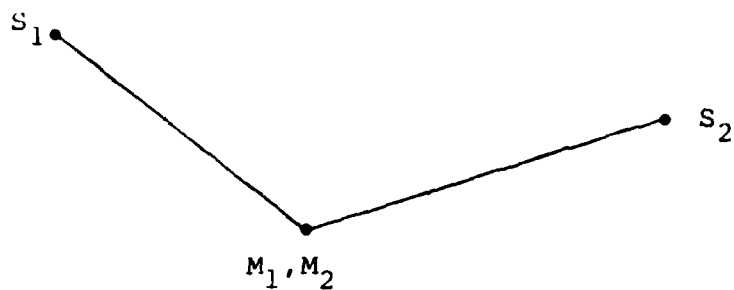
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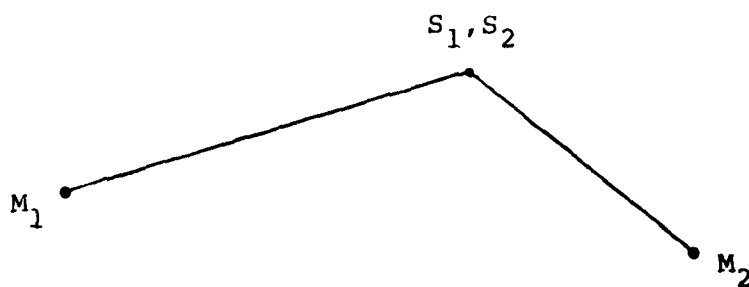
A. Introduction

The Loran system is a radio aid to navigation which utilizes the principle of hyperbolic fixing. The locus of points for which the difference in arrival time of synchronized signals from a pair of transmitters is constant determines a hyperbolic line of positions (LOP). The intersection of two hyperbolic lines of position from two pairs of transmitters (stations) determines a position estimate (a fix). That two lines of position and hence two pairs of stations are required for a fix does not necessarily mean that four separated stations are required, since one station of one pair may be colocated with one station of the other pair. In this case, a *Loran triplet* is formed (Figure 1). Triplets may be joined "end-to-end" by station colocation to form a *Loran chain* (Figure 2). Loran chains are common on both the East and West Coasts of the North American continent.

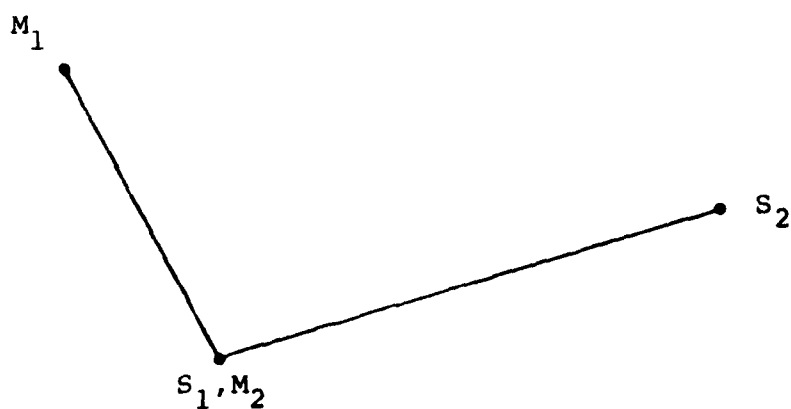
"Standard Loran" or "Loran-A" operates at a frequency just below 2 MHz and is now only used in the Pacific area. "Loran-C" operates at 100-kHz and is used both by ships and aircraft world wide. The computational algorithm and programs described herein can be used for position determination with Loran-C triplets. Further information on the history, development and operation of the Loran systems may be found in References 1 and 2.



(a) Colocated Master Stations



(b) Colocated Slave Stations



(c) Colocated Master and Slave

Figure 1. Loran Triplets.

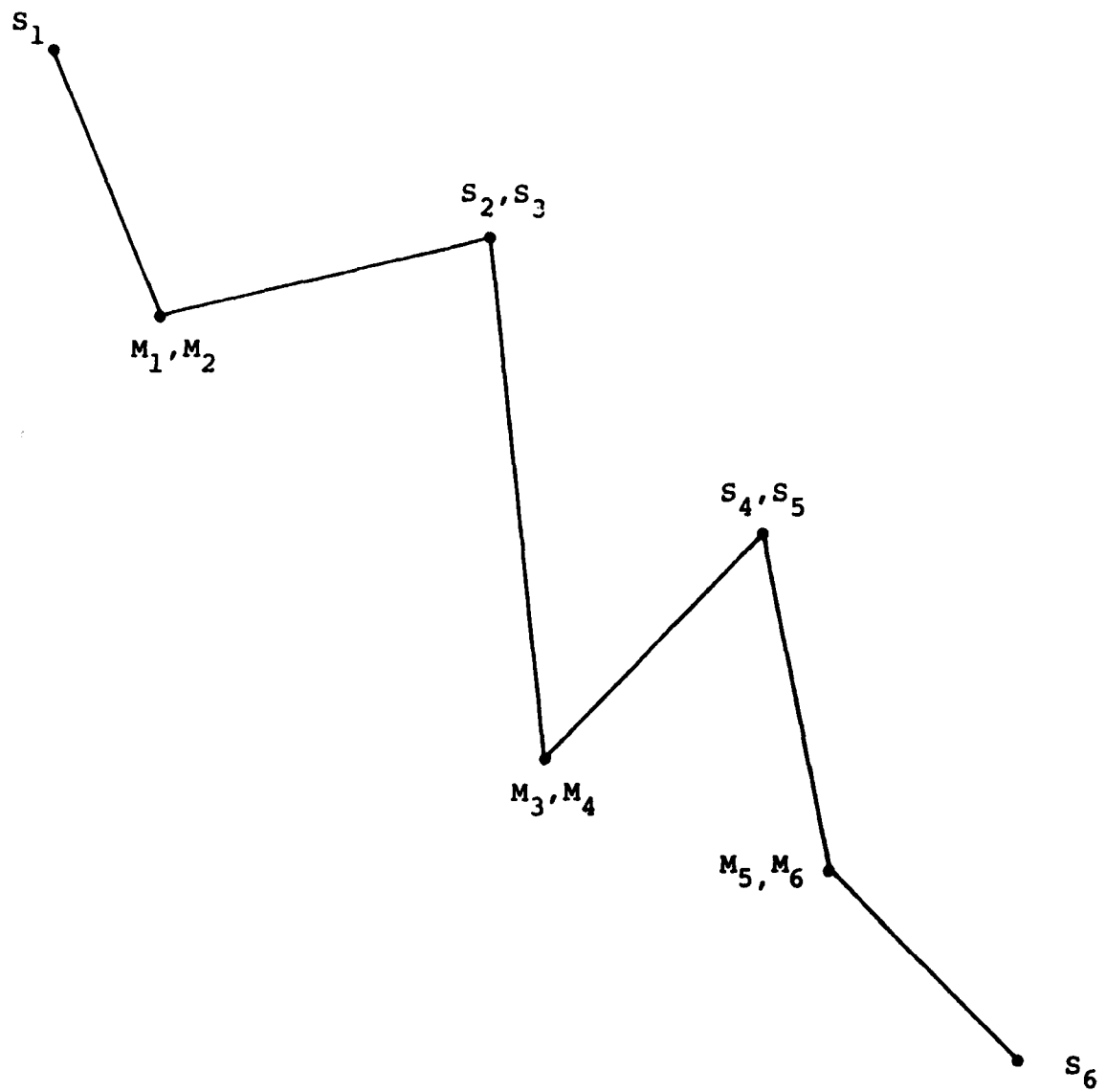


Figure 2. Loran Chain of Five Loran Triplets.

B. Program Description

The Position Determination Program requires operational data cards (described below) for on-location position determination from Loran triplet time-difference measurements. Two programs are used to prepare an operational data card. Operational data cards should be prepared and validated prior to on-location navigational use. Then, although three programs are used in total, only one program is required for position determination, the remaining two programs are used to prepare operational data cards.

The programs are:

Master Data Card Program: This program is used to prepare *master data cards*. A master data card requires the following information for a master (M) station/slave (S) station pair (a list of current station parameters is in the appendix):

1. A M/S pair identification number.
2. The quantity Δt which is the sum of the coding delay plus the one way base line time in microseconds.
3. The latitude and longitude of the master station.
4. The latitude and longitude of the slave station.

Some preprocessing of these data is performed before the master data card is generated. The data generated require only one side of a TI-59 magnetic card for each M/S pair, thus a second M/S pair may be placed on side 2 of a master data card. A master data card should be prepared in advance for each M/S pair that might be used within an area of operation.

Operational Data Card Program: This program is used to prepare an *operational data card* for each Loran triplet that might be used within an area of operation. Each operational data card contains data merged from two master data cards that contain the M/S pair information for each pair of a triplet. These merged data are validity checked, colocation of master or slave determined and encoded.

The inputs required to generate an operational data card for a Loran triplet using this program are those contained in the two master data cards that are associated with the triplet. It is possible to prepare and store operational data cards rather than master data cards. This may be desirable if there is no scarcity of cards and storage space, however the number of possible Loran triplets is considerably larger than the number of M/S pairs.

Position Determination Program: This program is used for position determination. The required inputs for the program are the indicated time differences T for the two M/S pairs of the triplet and the data contained in the operational data card associated with the triplet. The outputs of the program are the computed latitude and longitude of the Loran fix. Note: Every Loran determination gives two solutions: the proper solution and the spurious solution.

The spurious solution can almost always be rejected by inspection. However, if the stations of the Loran triplet are nearly aligned this may not be the case, and additional information will be required to determine the proper solution.

C. TI-59 Calculator Programs

1. User Instructions

Master Data Card Program (MDCP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the MDCP program card.			
2.	Press CLR and then read side 2 of the MDCP program.		CLR	
3.	Input a unique ID number for the Loran pair. See Note a.	ID	2nd,A'	ID
4.	Input the coding delay Δt .	Δt	2nd,B'	Δt
5.	Input the master station latitude. See Note b.	ϕ_M	A	0
6.	Input the master station longitude. See Note b.	λ_M	B	0
7.	Input the slave station latitude.	ϕ_S	C	0
8.	Input the slave station longitude.	λ_S	D	0
9.	Run. When the calculations are complete, 4 will appear in the display; then the display will blank. After the display has blanked, enter a card in the read/write slot to record the master data card for the Loran pair. When the recording is complete, 4 will reappear in the display. See Note c.		E	

Notes: a. Loran pairs are coded on the navigation maps using designators such as 9930X, 9930Y, 9930Z and 9930W. It is suggested that the ID's for these pairs be coded as 9930.1, 9930.2, 9930.3 and 9930.4 respectively. However, any consistent scheme is acceptable.

- b. The format for latitude and longitude data input is of the form: DDD.MMSSFF, where

DDD denotes degrees
MMM denotes minutes
SS denotes seconds
FF denotes hundredths of a second.

A minus sign (-) denotes South latitude and West longitude. See the Appendix with regard to the latter sign convention.

- c. When the display has blanked after 4 has been displayed, the calculator is prepared to write a card side with the information (data) contained in bank 4. When a card is inserted, it will be recorded. Do not restrict the cards motion once the card has been grasped by the read/write mechanism. When recording is complete, the card will stop and 4 will reappear in the display. The card can then be removed.

Operational Data Card Program (ODCP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the ODCP program card.			
2.	Press CLR and then read side 2 of the ODCP program card.		CLR	
3.	Press CLR and then read a master data card containing the first pair of a Loran triplet.		CLR	
4.	Press A.		A	
5.	Press CLR and then read a master data card containing the second pair of a Loran triplet.		CLR	
6.	Press B. See Note a.		B	
7.	Run. When the calculations are complete, 4 will appear in the display; then the display will blank. After the display has blanked, enter a card in the read/write slot to record an operational data card. When recording is complete, 4 will reappear in the display. See Note b.		E	

Notes: a. Should the display flash, then the two master data cards do not correspond to a Loran triplet. Both the latitude and longitude of the colocated stations must be identical on both master data cards in order to successfully produce an operational data card.

b. When the display has blanked after 4 has been displayed, the calculator is prepared to write a card side with the information (data) contained in bank 4; and, when a card is inserted, it will be recorded. Do not restrict the cards motion once the card has been grasped by the read/write mechanism. When recording is complete, the card will stop and 4 will reappear in the display. The card can then be removed.

Position Determination Program (PDP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, then turn it off, then on to initialize it.			
1.	Read side 1 of the PDP program card.			
2.	Press CLR and then read side 2 of the PDP program card.		CLR	
3.	Press C to initialize, and then read the operational data card for a Loran triplet that you are receiving. See Note a below.		C	
4.	Input the observed time delay from the first Loran pair.	T_1	A	T_1
5.	Input the observed time delay from the second Loran pair.	T_2	B	T_2
6.	Compute the 1st solution latitude.		D	Latitude
7.	Compute the 1st solution longitude.		R/S	Longitude
8.	Compute the 2nd solution latitude.		E	Latitude
9.	Compute the 2nd solution longitude. See Note b.		R/S	Longitude
10.	To compute new solutions for new time delays, go to step 4. To compute new solutions for a new triplet, go to step 3.			

Note a. If the data card does not read (a flashing display results), press CLR and repeat the step. If the card does not read on the 2nd try, the card should be cleaned (see the TI-59 owners manual) or a new data card prepared.

Note b. Once the proper solution (solution 1 or solution 2) has been determined for a triplet, then only step 6 (for solution 1) or step 8 (for solution 2) need be repeated after inputting new time delays in step 4 and 5.

2. Example Problem for Loran-C Pairs 9930X and 9930Y

An example use of the Master Data Card Program using coding delays and latitude and longitude values from the Appendix:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on. This assures that it will be in the correct initial state.			
1.	Read side 1 of the MDC program card.			
2.	Press CLR, then read side 2 of the MDC program card.		CLR	
3.	Input the ID for 9930X. Next press 2nd, then A.	9930.1	2nd,A'	9930.1
4.	Input the coding delay Δt for 9930X. Next press 2nd, then B.	36389.66	2nd,B'	36389.66
5.	Input the master station latitude, then press A.	34.034604	A	0
6.	Input the master station longitude and press +/- for West, then press B.	-77.544676	B	0
7.	Input the slave station latitude, then press C.	46.463218	C	0
8.	Input the slave station longitude and press +/- for West, then press D.	-53.102816	D	0
9.	Press E. After 4 has appeared in the display, enter an available card side in the read/write slot of the calculator. After recording is complete, 4 will reappear. Then remove the card and label the recorded side "9300X MASTER."		E	
10.	Input the ID for 9930Y, next press 2nd and then A.	9930.2	2nd,A'	9930.2

Step	Instructions	Input Data/Units	Keys	Output Data/Units
11.	Input the coding delay Δt for 9330Y, next press 2nd and then B.	52541.31	2nd,B'	52541.31
12.	Input the master station latitude, then press A.	34.034604	A	0
13.	Input the master station longitude and press +/- for West, then press B.	-77.544676	B	0
14.	Input the slave station latitude, then press C.	41.151193	C	0
15.	Input the slave station longitude, and press +/- for West, then press D.	-69.583909	D	0
16.	Press E. After 4 has appeared in the display, enter an available card side (for example the second side of the card used in Step 9) in the read/write slot of the calculator. After recording is complete, 4 will reappear in the display. Then remove the card and label the recorded side "9930Y MASTER." The recorded data cards (or card) will be used in the next example.		E	0

An example use of the Operational Data Card Program:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the ODCP program card.			
2.	Press CLR and then read side 2 of the ODCP Program Card.		CLR	
3.	Press CLR and then read the master data card for station 9330X.		CLR	
4.	Press A.		A	
5.	Press CLR and then read the master data card for station 9930Y.		CLR	
6.	Press B. See Note a of the ODCP instructions on page 9.		B	
7.	Press E. When the display has blanked after 4 has appeared, insert an available card side in the read/write slot. After recording is complete, 4 will reappear in the display. Label the recorded card side "9330X/9930Y OPERATIONAL DATA. Then, for identification, label the A key position on the card "9330X" and the B key position "9330Y". This card will be used as the data card in the Position Determination Program example. The key labeling relates to that program.		E	

An example use of the Position Determination Program:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
	You are in the North Atlantic and you are receiving 9930X and 9930Y and you wish to obtain a fix.			
0.	Turn the calculator on. If the calculator has been on, then turn it off, then on to initialize it.			
1.	Read side 1 of the PDP program card.			
2.	Press CLR and then read side 2 of the PDP program card.		CLR	
3.	Press C to initialize, and then read the operational data for the triplet 9930X/9930Y from the card side recorded in the ODCP example.		C	
4.	The indicated time delay is 28800 μ s from 9930X. Input the indicated time delay, then press A.	28800	A	28800
5.	The indicated time delay is 49400 μ s from 9930Y. Input the indicated time delay, then press B.	49400	B	49400
6.	Press D to obtain the 1st solution latitude.		D	42.4457
7.	Press R/S to obtain the 1st solution longitude. The first solution is: 42°44'57"N Latitude 41°07'32"W Longitude		R/S	-41.0732
8.	Press E to obtain the 2nd solution latitude.		E	-27.0007
9.	Press R/S to obtain the 2nd solution longitude. The 2nd solution is: 27°00'07"S Latitude 102°27'12"E Longitude		R/S	102.2712

3. Program Listings

Master Data Card Program

000	76	LBL	050	75	-	100	55	+
001	42	STD	051	02	2	101	02	2
002	72	ST+	052	09	9	102	95	=
003	00	00	053	08	9	103	42	STD
004	97	D82	054	93	.	104	01	01
005	00	00	055	02	2	105	43	RCL
006	42	STD	056	06	6	106	24	24
007	00	0	057	35	1/X	107	75	-
008	32	INV	058	42	STD	108	43	RCL
009	58	FIX	059	20	20	109	22	22
010	04	4	060	95	=	110	95	=
011	66	PAU	061	22	INV	111	42	STD
012	66	PAU	062	30	TAN	112	02	02
013	66	PAU	063	72	ST+	113	55	+
014	66	PAU	064	00	00	114	02	2
015	66	PAU	065	00	0	115	95	=
016	96	MRT	066	92	RTN	116	42	STD
017	92	RTN	067	76	LBL	117	03	03
018	76	LBL	068	12	B	118	38	SIN
019	17	B'	069	88	DMS	119	33	X ²
020	42	STD	070	42	STD	120	65	X
021	29	29	071	22	22	121	43	RCL
022	92	RTN	072	00	0	122	23	23
023	76	LBL	073	92	RTN	123	39	CD8
024	16	A'	074	76	LBL	124	65	X
025	42	STD	075	14	D	125	43	RCL
026	28	28	076	88	DMS	126	25	25
027	92	RTN	077	42	STD	127	39	CD8
028	76	LBL	078	24	24	128	85	+
029	11	A	079	00	0	129	43	RCL
030	32	X:T	080	92	RTN	130	01	01
031	02	2	081	76	LBL	131	38	SIN
032	03	3	082	15	E	132	33	X ²
033	61	GTD	083	13	RCL	133	95	=
034	85	+	084	23	23	134	42	STD
035	76	LBL	085	85	+	135	04	04
036	13	C	086	43	RCL	136	65	X
037	32	X:T	087	25	25	137	02	2
038	02	2	088	95	=	138	94	+/-
039	05	5	089	55	+	139	85	+
040	76	LBL	090	02	2	140	01	1
041	85	+	091	95	=	141	95	=
042	42	STD	092	42	STD	142	22	INV
043	00	00	093	00	00	143	39	CD8
044	32	X:T	094	43	RCL	144	42	STD
045	88	DMS	095	25	25	145	13	13
046	30	TAN	096	75	-	146	43	RCL
047	65	5	097	43	RCL	147	00	00
048	52	5	098	23	23	148	38	SIN
049	01	1	099	95	=	149	65	X

Master Data Card Program (continued)

150	43	RCL	200	43	RCL	250	65	-
151	01	01	201	13	13	251	53	-
152	39	COS	202	38	SIN	252	04	4
153	95	=	203	65	X	253	75	-
154	33	X ²	204	89	π	254	43	RCL
155	65	X	205	55	+	255	08	05
156	02	2	206	01	1	256	54	7
157	55	+	207	08	8	257	95	=
158	52	7	208	00	0	258	65	X
159	01	1	209	95	=	259	43	RCL
160	75	-	210	42	STD	260	20	20
161	43	RCL	211	05	05	261	65	X
162	04	04	212	65	X	262	43	RCL
163	95	=	213	43	RCL	263	05	05
164	42	STD	214	08	08	264	65	X
165	06	06	215	75	-	265	43	RCL
166	43	RCL	216	43	RCL	266	02	02
167	01	01	217	09	09	267	30	TAN
168	38	SIN	218	95	=	268	65	X
169	65	X	219	65	X	269	04	4
170	43	RCL	220	43	RCL	270	05	5
171	00	00	221	20	20	271	55	+
172	39	COS	222	55	+	272	89	π
173	95	=	223	04	4	273	94	+/-
174	33	X ²	224	95	=	274	65	+
175	65	X	225	42	STD	275	43	RCL
176	02	2	226	11	11	276	02	02
177	55	+	227	94	+/-	277	95	=
178	43	RCL	228	85	+	278	55	+
179	04	04	229	43	RCL	279	02	2
180	95	=	230	05	05	280	95	=
181	42	STD	231	95	=	281	42	STD
182	07	07	232	65	X	282	12	12
183	85	+	233	43	RCL	283	38	SIN
184	43	RCL	234	13	13	284	65	X
185	06	06	235	38	SIN	285	43	RCL
186	95	=	236	95	=	286	00	00
187	42	STD	237	42	STD	287	39	COS
188	08	08	238	26	26	288	95	=
189	43	RCL	239	43	RCL	289	32	X ¹ T
190	06	06	240	09	09	290	43	RCL
191	75	-	241	75	-	291	12	12
192	43	RCL	242	53	7	292	39	COS
193	07	07	243	01	1	293	65	X
194	35	=	244	75	-	294	43	RCL
195	42	STD	245	01	1	295	01	01
196	09	09	246	55	+	296	38	SIN
197	41	50L	247	17	00L	297	95	=
198	13	13	248	04	04	298	94	+/-
199	55	-	249	54	-	299	22	INV

Master Data Card Program (continued)

300	37	P/R
301	42	STD
302	21	21
303	42	STD
304	27	27
305	01	1
306	32	X/T
307	43	RCL
308	12	12
309	37	P/R
310	65	X
311	43	RCL
312	00	00
313	38	SIN
314	95	=
315	32	X/T
316	65	X
317	43	RCL
318	01	01
319	39	CDS
320	95	=
321	22	INV
322	37	P/R
323	44	SUM
324	21	21
325	22	INV
326	44	SUM
327	27	27
328	01	1
329	03	3
330	42	STD
331	00	00
332	00	0
333	61	GTD
334	42	STD
335	00	0
336	00	0
337	00	0
338	00	0
339	00	0
340	00	0
341	00	0
342	00	0

Operational Data Card Program

000	76	LBL	050	09	9	100	61	GTO
001	42	STD	051	42	STD	101	44	SUM
002	73	RC+	052	00	00	102	76	LBL
003	01	01	053	03	3	103	75	-
004	72	ST-	054	09	9	104	43	RCL
005	02	02	055	42	STD	105	22	22
006	69	DP	056	01	01	106	32	XIT
007	31	31	057	02	2	107	43	RCL
008	69	DP	058	09	9	108	14	14
009	32	32	059	42	STD	109	67	EQ
010	97	D82	060	02	02	110	65	X
011	00	00	061	71	SBR	111	43	RCL
012	42	STD	062	42	STD	112	23	23
013	92	RTN	063	43	RCL	113	32	XIT
014	76	LBL	064	22	22	114	43	RCL
015	11	A	065	32	XIT	115	15	15
016	09	9	066	43	RCL	116	22	INV
017	42	STD	067	12	12	117	67	EQ
018	00	00	068	22	INV	118	65	X
019	02	2	069	67	EQ	119	71	SBR
020	09	9	070	85	+	120	37	P/R
021	42	STD	071	43	RCL	121	61	GTO
022	01	01	072	23	23	122	44	SUM
023	03	3	073	32	XIT	123	76	LBL
024	09	9	074	43	RCL	124	65	X
025	42	STD	075	13	13	125	43	RCL
026	02	02	076	67	EQ	126	12	12
027	71	SBR	077	44	SUM	127	32	XIT
028	42	STD	078	76	LBL	128	43	RCL
029	00	0	079	85	+	129	24	24
030	92	RTN	080	43	RCL	130	22	INV
031	76	LBL	081	24	24	131	67	EQ
032	12	B	082	32	XIT	132	55	+
033	09	9	083	43	RCL	133	43	RCL
034	42	STD	084	14	14	134	13	13
035	00	00	085	22	INV	135	32	XIT
036	02	2	086	67	EQ	136	43	RCL
037	09	9	087	75	-	137	25	25
038	42	STD	088	43	RCL	138	22	INV
039	01	01	089	25	25	139	67	EQ
040	01	1	090	32	XIT	140	55	+
041	09	9	091	43	RCL	141	71	SBR
042	42	STD	092	15	15	142	32	XIT
043	02	02	093	22	INV	143	76	LBL
044	71	SBR	094	67	EQ	144	44	SUM
045	42	STD	095	75	-	145	00	0
046	00	0	096	71	SBR	146	42	STD
047	92	RTN	097	32	XIT	147	00	00
048	76	LBL	098	71	SBR	148	42	STD
049	15	E	099	37	P/R	149	01	01

Operational Data Program Card (continued)

150	42	STD	200	23	23	250	00	0
151	02	02	201	32	X:T	251	00	0
152	02	2	202	42	STD	252	00	0
153	01	1	203	25	25	253	00	0
154	02	2	204	43	RCL	254	00	0
155	09	9	205	28	28	255	00	0
156	05	5	206	94	+/-	256	00	0
157	93	.	207	42	STD	257	00	0
158	08	8	208	28	28	258	00	0
159	07	7	209	92	RTN	259	00	0
160	42	STD	210	76	LBL	260	00	0
161	10	10	211	37	P/R	261	00	0
162	22	INV	212	43	RCL			
163	58	FIX	213	11	11			
164	04	4	214	32	X:T			
165	66	PAU	215	43	RCL			
166	66	PAU	216	17	17			
167	66	PAU	217	42	STD			
168	66	PAU	218	11	11			
169	66	PAU	219	32	X:T			
170	96	WRT	220	42	STD			
171	92	RTN	221	17	17			
172	76	LBL	222	43	RCL			
173	32	X:T	223	12	12			
174	43	RCL	224	32	X:T			
175	21	21	225	43	RCL			
176	32	X:T	226	14	14			
177	43	RCL	227	42	STD			
178	27	27	228	12	12			
179	42	STD	229	32	X:T			
180	21	21	230	42	STD			
181	32	X:T	231	14	14			
182	42	STD	232	43	RCL			
183	27	27	233	23	23			
184	43	RCL	234	32	X:T			
185	22	22	235	43	RCL			
186	32	X:T	236	15	15			
187	43	RCL	237	42	STD			
188	24	24	238	13	13			
189	42	STD	239	32	X:T			
190	22	22	240	42	STD			
191	32	X:T	241	15	15			
192	42	STD	242	43	RCL			
193	24	24	243	18	18			
194	43	RCL	244	94	+/-			
195	23	23	245	42	STD			
196	32	X:T	246	18	18			
197	43	RCL	247	92	RTN			
198	25	25	248	76	LBL			
199	42	STD	249	55	+			

Position Determination Program

000	76	LBL	050	32	X:T	100	37	P/R
001	13	0	051	75	-	101	78	Z+
002	22	INV	052	01	1	102	43	RCL
003	58	FIX	053	32	X:T	103	14	14
004	00	0	054	69	DP	104	65	X
005	92	RTN	055	30	30	105	43	RCL
006	76	LBL	056	73	RC*	106	25	25
007	11	R	057	00	00	107	95	=
008	32	X:T	058	37	P/R	108	32	X:T
009	02	2	059	69	DP	109	43	RCL
010	09	9	060	30	30	110	21	21
011	61	GTO	061	72	ST*	111	37	P/R
012	85	+	062	00	00	112	22	INV
013	76	LBL	063	69	DP	113	78	Z+
014	12	B	064	30	30	114	43	RCL
015	32	X:T	065	32	X:T	115	04	04
016	01	1	066	95	=	116	32	X:T
017	09	9	067	72	ST*	117	43	RCL
018	76	LBL	068	00	00	118	01	01
019	85	+	069	43	RCL	119	22	INV
020	70	RAD	070	59	59	120	37	P/R
021	42	STD	071	92	RTN	121	42	STD
022	00	00	072	76	LBL	122	09	09
023	32	X:T	073	14	D	123	43	RCL
024	42	STD	074	86	STF	124	14	14
025	59	59	075	00	00	125	65	X
026	75	-	076	61	GTO	126	43	RCL
027	73	RC*	077	55	+	127	27	27
028	00	00	078	76	LBL	128	75	-
029	95	=	079	15	E	129	43	RCL
030	55	+	080	22	INV	130	17	17
031	43	RCL	081	86	STF	131	65	X
032	10	10	082	00	00	132	43	RCL
033	95	=	083	76	LBL	133	24	24
034	32	X:T	084	55	+	134	95	=
035	69	DP	085	00	0	135	55	+
036	30	30	086	42	STD	136	32	X:T
037	73	RC*	087	01	01	137	95	=
038	00	00	088	42	STD	138	22	INV
039	69	DP	089	04	04	139	39	COS
040	10	10	090	60	DEG	140	87	IFF
041	69	DP	091	43	RCL	141	00	00
042	30	30	092	24	24	142	75	-
043	72	ST+	093	65	X	143	94	+/-
044	00	00	094	43	RCL	144	76	LBL
045	01	1	095	15	15	145	75	-
046	32	X:T	096	95	=	146	44	SUM
047	37	P/R	097	32	X:T	147	09	09
048	64	PD+	098	43	RCL	148	43	RCL
049	00	00	099	11	11	149	09	09

Position Determination Program (continued)

150	75	-	200	94	+/-	250	65	X
151	43	RCL	201	85	+	251	43	RCL
152	21	21	202	01	1	252	08	08
153	95	=	203	75	-	253	38	SIN
154	39	CDS	204	43	RCL	254	65	X
155	65	X	205	02	02	255	02	2
156	43	RCL	206	65	X	256	65	X
157	25	25	207	43	RCL	257	43	RCL
158	85	+	208	00	00	258	03	03
159	43	RCL	209	95	=	259	65	X
160	27	27	210	35	1/X	260	43	RCL
161	95	=	211	49	PRD	261	05	05
162	32	XIT	212	03	03	262	65	X
163	43	RCL	213	49	PRD	263	01	1
164	24	24	214	08	08	264	08	8
165	22	INV	215	43	RCL	265	00	0
166	37	P/R	216	23	23	266	55	÷
167	42	STD	217	38	SIN	267	89	π
168	08	08	218	32	XIT	268	95	=
169	43	RCL	219	42	STD	269	22	INV
170	23	23	220	01	01	270	44	SUM
171	39	CDS	221	22	INV	271	08	08
172	32	XIT	222	37	P/R	272	43	RCL
173	43	RCL	223	75	-	273	23	23
174	09	09	224	43	RCL	274	38	SIN
175	37	P/R	225	08	08	275	65	X
176	42	STD	226	95	=	276	43	RCL
177	00	00	227	65	X	277	08	08
178	65	X	228	02	2	278	39	CDS
179	43	RCL	229	95	=	279	85	+
180	20	20	230	42	STD	280	43	RCL
181	95	=	231	04	04	281	01	01
182	42	STD	232	85	+	282	65	X
183	02	02	233	43	RCL	283	43	RCL
184	01	1	234	08	08	284	08	08
185	75	-	235	95	=	285	38	SIN
186	43	RCL	236	39	CDS	286	95	=
187	00	00	237	42	STD	287	42	STD
188	33	X²	238	05	05	288	07	07
189	95	=	239	01	1	289	01	1
190	55	÷	240	75	-	290	32	XIT
191	04	4	241	43	RCL	291	43	RCL
192	65	X	242	04	04	292	08	08
193	43	RCL	243	39	CDS	293	37	P/R
194	20	20	244	65	X	294	65	X
195	95	=	245	02	2	295	43	RCL
196	42	STD	246	65	X	296	23	23
197	03	03	247	43	RCL	297	38	SIN
198	65	X	248	03	03	298	94	+/-
199	02	2	249	95	=	299	85	+

Position Determination Program (continued)

300	43	RCL	350	08	08	400	22	INV
301	01	01	351	38	SIN	401	88	DMS
302	65	*	352	65	*	402	58	FIX
303	32	X:T	353	43	RCL	403	04	04
304	95	=	354	09	09	404	91	R/S
305	33	X²	355	38	SIN	405	32	X:T
306	85	+	356	95	=	406	91	R/S
307	43	RCL	357	22	INV	407	00	0
308	00	00	358	37	P/R	408	00	0
309	33	X²	359	75	-	409	00	0
310	95	=	360	43	RCL	410	00	0
311	34	FX	361	02	02	411	00	0
312	65	*	362	65	*	412	00	0
313	53	(	363	43	RCL	413	00	0
314	01	1	364	08	08	414	00	0
315	75	-	365	85	+	415	00	0
316	43	RCL	366	43	RCL	416	00	0
317	20	20	367	22	22	417	00	0
318	95	=	368	95	=	418	00	0
319	35	1/X	369	32	X:T	420	00	0
320	65	*	370	01	1	421	00	0
321	43	RCL	371	32	X:T	422	00	0
322	07	07	372	37	P/R	423	00	0
323	95	=	373	22	INV	424	00	0
324	22	INV	374	37	P/R	425	00	0
325	30	TAN	375	42	STD			
326	42	STD	376	06	06			
327	07	07	377	32	X:T			
328	43	RCL	378	01	1			
329	23	23	379	08	8			
330	39	COS	380	00	0			
331	65	*	381	77	GE			
332	43	RCL	382	65	*			
333	08	08	383	65	*			
334	39	COS	384	02	2			
335	75	-	385	94	+/-			
336	43	RCL	386	85	+			
337	23	23	387	32	X:T			
338	38	SIN	388	95	=			
339	65	*	389	42	STD			
340	43	RCL	390	06	06			
341	08	08	391	76	LBL			
342	38	SIN	392	65	*			
343	65	*	393	43	RCL			
344	43	RCL	394	06	06			
345	09	09	395	22	INV			
346	39	COS	396	88	DMS			
347	95	=	397	32	X:T			
348	32	X:T	398	43	RCL			
349	43	RCL	399	07	07			

D. Loran-C Fixing Algorithms

The development of the Loran fixing algorithms in this report is presented in more detail in a companion report [Ref. 3] and will not be repeated here.

The basic Loran-C equation [Ref. 4] can be written as

$$T = [T_S + p(T_S)] - [T_M + p(T_M)] + [T_B + p(T_B)] + \delta \quad (1)$$

where

T is the "indicated time difference" in microseconds,
 T_M, T_S is the distance, in microseconds, from the master and the slave to the receiver, respectively,
 T_B is the distance, in microseconds, between the master and the slave,
 δ is the assigned coding delay, in microseconds, and
 $p(T)$ is the secondary phase correction, in microseconds, for an all sea water path of length T .

The quantity

$$\Delta t = [T_B + p(T_B)] + \delta$$

is a constant for each master/slave pair. The following World Geodetic System 1972 (WGS 72) values have been adopted for Loran-C navigation [Ref. 4]:

$v_0 = 299792458$ meters/second is the velocity of light in free space,

$n = 1.000338$ is the index of refraction of the surface of the earth for standard atmosphere and 100kHz electromagnetic waves,

$a_e = 6378135.00$ meters is the equatorial radius of the earth, and

$f = 1/298.26$ is the flattening factor ($1 - b/a_e$, where b is the polar radius) of the earth.

Accurate formulas for computing the secondary phase correction $p(T)$ are contained in Reference 4, but for use with the handheld calculator the following linear approximation [Ref. 3] will be used:

$$p(T) = a_1 + a_2 T ,$$

where

$$a_1 = -0.321,$$

and

$$a_2 = 0.000635.$$

Using this approximation, it is possible to solve Equation 1 for the quantity $T_S - T_M$. We find

$$T_S - T_M = (T - \Delta t)/(1 + a_2) . \quad (2)$$

On the surface of a sphere a hyperbolic line of position can be represented by the equation [Ref. 3, page 175]

$$\tan r = \frac{\cos 2a - \cos 2c}{\sin 2c \cos \omega + \zeta \sin 2a} \quad (3)$$

where the origin of the coordinate system is at the prime focus of the spherical hyperbola, $2c$ is the spherical arc joining the foci, $2a$ is a constant for any one LOP, and r and ω are the spherical coordinates of a point on the LOP. If the base line of the coordinate system is the arc joining the foci then ω is the spherical polar angle from the base line to a point P on the LOP and r is the spherical polar distance (or arc) from the prime focus to P . Using the Loran system we take $\zeta = +1$ if the prime focus is at a master station and we take $\zeta = -1$ if the prime focus is at a slave station.

If we take $v = v_0/\eta$ to be the velocity of 100kHz electromagnetic radiation of the earth's surface then

$$2a = v(T_S - T_M)/a_e ,$$

or, using Eq. (2),

$$2a = (T - \Delta t)/a_p , \quad (4)$$

where

$$a_p = \frac{a_e(1 + a_2)}{v_0/\eta} = 21295.87 \text{ } \mu\text{s} .$$

The baseline between master and slave can be obtained from

$$2c = v T_B/a_e . \quad (5)$$

Here $2c$ is computed by program card 1 (preparation of master data cards) using the algorithm in Section E.

Consider a Loran-C triplet with master stations colocated. Let ξ_1 and ξ_2 denote the azimuth angles of slave 1 (S_1) and slave 2 (S_2), respectively, measured from North toward the East from the master stations (M) (see Fig. 3). Further, let α and r denote the azimuth and spherical polar arc (distance) of the receiver (R) from M. For this geometry, Eq. (3) can be written as

$$\tan r_i = \frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i} \quad (6)$$

where

$$A_i = \ell_i \sin 2a_i$$

$$B_i = \cos 2a_i - \cos 2c_i$$

and

$$C_i = \sin 2c_i$$

for the i^{th} Loran pair, $i = 1, 2$. Since $r = r_1 = r_2$, $\tan r_i$ can be eliminated in Eq. (6). The resulting equation can be rewritten as

$$C \cos \alpha + S \sin \alpha = K, \quad (7)$$

where

$$C = B_1 C_2 \cos \xi_2 - B_2 C_1 \cos \xi_1,$$

$$S = B_1 C_2 \sin \xi_2 - B_2 C_1 \sin \xi_1,$$

and

$$K = B_2 A_1 - B_1 A_2.$$

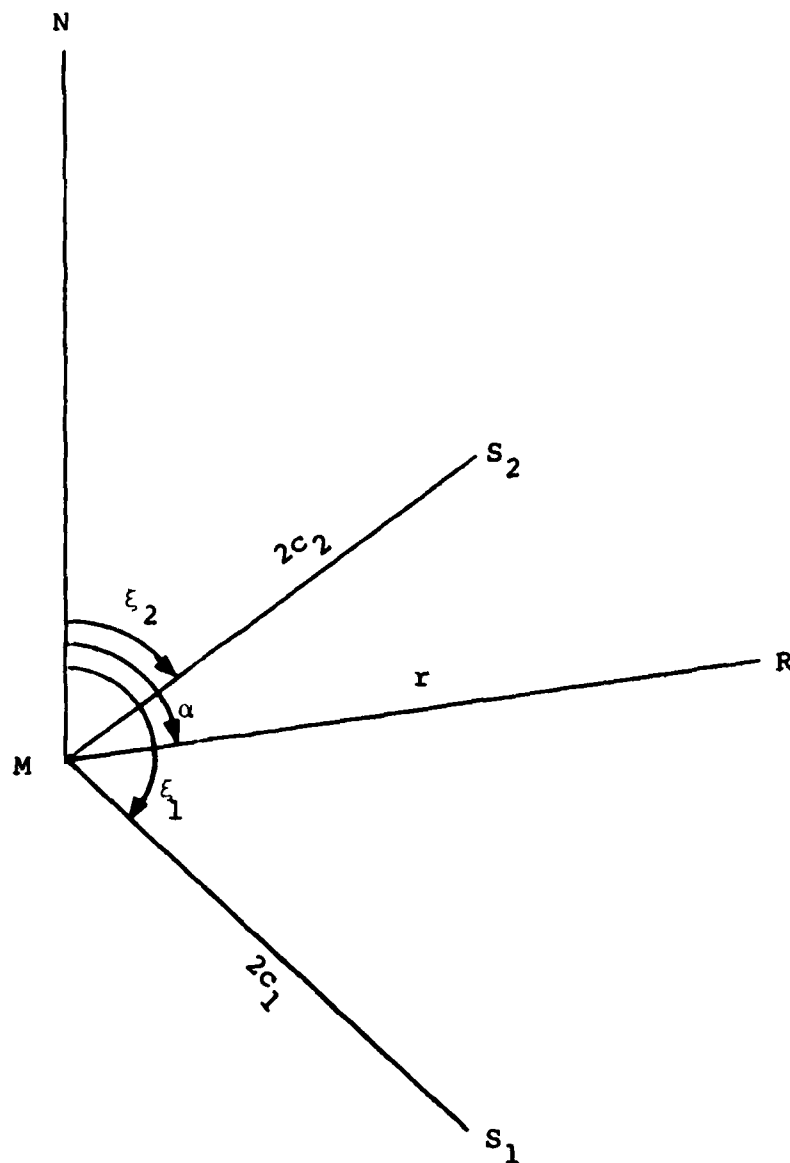


Figure 3. Geometry of a Loran Triplet and a Receiver.

If we define $\rho > 0$ and γ by the equations

$$\begin{aligned} \rho \cos \gamma &= C, \\ \rho \sin \gamma &= S, \end{aligned} \tag{8}$$

then

$$\rho = \sqrt{C^2 + S^2},$$

and

$$\gamma = \text{qatn}(S, C).$$

Here the function $\text{qatn}(y, x)$ is the arctangent of y/x adjusted for the proper quadrant according to the signs of x and y . A compact form of this function is

$$\text{qatn}(y, x) = \tan^{-1} \frac{y}{x + 10^{-9} t(x = 0?)} + \pi t(x < 0?)$$

where

$$t(z) = 1 \text{ when } z \text{ is true}$$

and

$$t(z) = 0 \text{ when } z \text{ is false.}$$

When convenient we will use the notation $\text{qatn}(y/x)$ interchangeably with $\text{qatn}(y, x)$. The qatn function is equivalent to the polar angle obtained using the rectangular to polar conversion function on the TI-59.

Now substitute Eq. (8) into Eq. (7) and solve for

$$\alpha = \gamma \pm \cos^{-1}(k/\rho) \tag{9}$$

to obtain the azimuth angle α of the two points of intersection of the LOP's. Finally we obtain a value for r by substituting each α into Eq. (5). We find that

$$r = \rho \arctan \left[\frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i} \right] \quad \text{for } i = 1 \text{ or } 2.$$

The distance and azimuth from M or the triplet vertex can be converted into the latitude and longitude of the two possible positions of R .

The fixing algorithm then uses α and r in the *direct* solution algorithm of spheroidal geodesy (Section F).

E. The Reverse (Inverse) Solution Algorithm

This *reverse* solution algorithm is a modification of the first order in flattening (*f*) algorithm given by Thomas [Ref. 5, pp. 8-10]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The *q*uth function is defined in Section D. West longitudes (λ) and South latitudes (ϕ) are negative. We are given the points $P_1(\phi_1, \lambda_1)$, $P_2(\phi_2, \lambda_2)$ on the spheroid and are to find the distance S between the points and the forward and back azimuths, α_{12} and α_{21} . Given quantities are $\phi_1, \lambda_1, \phi_2$ and λ_2 . No assumptions about the relative location of P_1 and P_2 are required. The modified *reverse* solution algorithm is:

$$\theta_i = \tan^{-1}[(1-f) \tan \phi_i], \quad i = 1, 2,$$

$$\theta_m = (\theta_1 + \theta_2)/2, \quad \Delta\theta_m = (\theta_2 - \theta_1)/2, \quad \Delta\lambda = \lambda_2 - \lambda_1,$$

$$\Delta\lambda_m = \Delta\lambda/2, \quad H = \cos^2 \Delta\theta_m - \sin^2 \theta_m = \cos^2 \theta_m - \sin^2 \Delta\theta_m = \cos \theta_1 \cos \theta_2,$$

$$L = \sin^2 \Delta\theta_m + H \sin^2 \Delta\lambda_m = \sin^2(d/2), \quad 1 - L = \cos^2(d/2),$$

$$d = \cos^{-1}(1 - 2L), \quad U = 2 \sin^2 \theta_m \cos^2 \Delta\theta_m / (1 - L),$$

$$V = 2 \sin^2 \Delta\theta_m \cos^2 \theta_m / L, \quad X = U + V, \quad Y = U - V,$$

$$T = d/\sin d, \quad \delta_1 d = f(TX - Y)/4, \quad S = a_e(T - \delta_1 d) \sin d,$$

$$F = 2[Y - (1 - 2f)(4 - X)], \quad G = fT/2,$$

$$Q = -(FG \tan \Delta\lambda)/4, \quad \Delta\lambda'_m = (\Delta\lambda + Q)/2$$

$$t_1 = \text{qatn}(-\sin \Delta\theta_m \cos \Delta\lambda_m', \cos \theta_m \sin \Delta\lambda_m'),$$

$$t_2 = \text{qatn}(\cos \Delta\theta_m \cos \Delta\lambda_m', \sin \theta_m \sin \Delta\lambda_m'),$$

$$u_{12} = t_1 + t_2, \quad u_{21} = t_1 - t_2.$$

This reverse solution algorithm is used by program card 1 (preparation of master data cards) to compute the baseline distance $2c$ and the azimuths ξ_{MS} and ξ_{SM} between the master and slave stations of a Loran pair.

Details of the modifications made to Thomas' algorithm are contained in Reference 3.

F. The Direct Solution Algorithm

This *direct* solution algorithm is a modification of the first order in flattening (f) algorithm given by Thomas [Ref. 5, pp. 7-8]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The *qatn* function is defined in Section D. West longitudes and South latitudes are negative. We are given the point $P_1(\phi_1, \lambda_1)$ on the spherioid, where ϕ_1, λ_1 are the geodetic latitude and longitude (geographic coordinates); the forward azimuth α_{12} and the distance S to a second point $P_2(\phi_2, \lambda_2)$; and from these we are to find the geographic coordinates ϕ_2, λ_2 and the back azimuth α_{21} . The given quantities are $\phi_1, \lambda_1, \alpha_{12}$ and S . No assumptions about the relative location of P_1 and P_2 are required. The modified *direct* solution algorithm is:

$$\theta_1 = \tan^{-1}[(1-f) \tan \phi_1], \quad M = \cos \theta_1 \sin \alpha_{12}$$

$$N = \cos \theta_1 \cos \alpha_{12}, \quad c_1 = fM, \quad c_2 = f(1 - M^2)/4,$$

$$D = 1 - 2c_2 - c_1M, \quad P = c_2/D, \quad \sigma_1 = \text{qatn}(N, \sin \theta_1)$$

$$d = S/(a_e D), \quad u = 2(\sigma_1 - d), \quad W = 1 - 2P \cos u,$$

$$V = \cos(u + d), \quad Y = 2PVW \sin d, \quad \Delta\sigma = d - Y,$$

$$\alpha_{21} = \text{qatn}[-M, -(N \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma)],$$

$$K = (1-f) [M^2 + (N \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma)^2]^{1/2},$$

$$\phi_2 = \tan^{-1}[(\sin \theta_1 \cos \Delta\sigma + N \sin \Delta\sigma)/K],$$

$$\Delta\eta = \text{qatn}(\sin \Delta\sigma \sin \alpha_{12}, \cos \theta_1 \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma \cos \alpha_{12}),$$

$$H = c_1 \Delta\sigma, \quad \Delta\lambda = \Delta\eta - H, \quad \lambda_2 = \lambda_1 + \Delta\lambda.$$

This direct solution algorithm is used by program card 3 (improved fix program) to compute the latitude and longitude of the receiver using the azimuth and range of the receiver from the Loran triplet vertex.

Details of the modifications made to Thomas' algorithm are contained in Reference 3.

G. Some Results

The following procedure was used to test the fixing algorithm: A more accurate version of the reverse solution algorithm (see Reference 3) was used to compute time delays at selected positions from Loran-C pairs. These computed time delays do not depend upon a fixing algorithm. The fixing algorithm was tested by determining the distance between the fix and the positions used to compute the time delays. Typical results are presented in Tables I through IV. As can be seen, all differences (Δ) are within 1 n.mi. The greatest difference ($\Delta = 0.92$ n.mi. in Table IV) was obtained at a position located 2270 n.mi. from the triplet vertex.

Table I. 9940X/9940Y

Position		Calculated Time Delay		TI-59 Fix		Δ n.mi
Lat	Long	9940X	9940Y	Lat (N)	Long (W)	
24°N	122°W	27726.19	40912.76	23°59'55"	122°00'01"	0.08
26	122	27715.97	40998.39	25°59'57"	122°00'01"	0.05
28	122	27702.41	41117.84	28°00'00"	122°00'00"	0.00
30	122	27683.53	41291.85	29°59'59"	122°00'00"	0.02
32	122	27655.47	41555.46	32°00'00"	122°00'00"	0.00
34	122	27609.63	41959.57	34°00'00"	122°00'00"	0.00
36	122	27523.56	42544.11	36°00'00"	121°59'59"	0.01
38	122	27334.61	43248.22	38°00'00"	122°59'59"	0.01

Table II. 9940Y/9940W

Position		Calculated Time Delay		TI-59 Fix		Δ n.mi
Lat	Long	9940Y	9940W	Lat (N)	Long (W)	
37°N	122°W	42892.86	16257.23	36°59'59"	122°01'01"	0.02
37	125	43056.68	15765.13	37°00'00"	125°00'00"	0.00
37	128	43137.78	15327.12	37°00'00"	128°00'00"	0.00
37	131	43191.10	14970.77	37°00'00"	131°00'00"	0.00
37	134	43232.38	14683.74	37°00'00"	134°00'00"	0.00
37	137	43267.42	14449.40	37°00'00"	137°00'00"	0.00
37	140	43298.80	14254.02	37°00'00"	140°00'00"	0.01
37	143	43327.85	14087.43	37°00'01"	142°59'59"	0.02

Table III. 7930Z/9930X*

Position		Calculated Time Delay		TI-59 Fix		Δ n.mi
Lat	Long	7930Z	9930X	Lat (N)	Long (W)	
60°N	30°W	52437.86	28451.72	60°00'03"	29°59'32"	0.24
58	35	51960.93	28391.50	58°00'00"	34°59'48"	0.09
56	40	50992.37	28359.15	55°59'59"	39°59'54"	0.06
54	45	49292.46	28370.85	53°59'59"	44°59'57"	0.03
52	50	47165.60	28490.64	52°00'00"	49°59'57"	0.01
50	55	45236.59	29070.48	50°00'00"	55°00'00"	0.00
48	60	44505.60	30991.94	48°00'00"	60°00'00"	0.00
46	65	44475.70	33697.14	46°00'00"	65°00'00"	0.00
44	70	44588.91	36567.42	43°59'59"	69°59'59"	0.02

Table IV. 9930W/9930X*

Position		Calculated Time Delay		TI-59 Fix		Δ n.mi
Lat	Long	9930W	9930X	Lat (N)	Long (W)	
9°N	47°W	13058.04	36466.46	8°59'59"	46°59'22"	0.92
12	52	12984.71	37288.35	11°59'34"	51°59'37"	0.57
15	57	12898.73	38267.58	14°59'45"	56°59'47"	0.28
18	62	12793.91	39431.32	17°59'52"	61°59'54"	0.16
21	67	12656.52	40794.36	20°59'56"	66°59'57"	0.08
24	72	12451.30	42330.55	23°59'59"	71°59'59"	0.02
27	77	12097.12	43876.62	27°00'01"	77°00'00"	0.02
30	82	12973.95	44768.53	30°00'01"	82°00'06"	0.09

*The 9930 system was disestablished 30 September 1979. It is included here for illustration only.

H. References

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2. G. Hefley, *The Development of Loran-C Navigation and Timing*, National Bureau of Standards Monograph 129, U. S. Department of Commerce, U. S. Government Printing Office, Washington, D. C. 20402, October 1972.
3. R. H. Shudde, "An Algorithm for Position Determination Using Loran-C Triplets with a BASIC Program for the Commodore 2001 Microcomputer," Technical Report NPS55-80-009, March 1980, Naval Postgraduate School, Monterey, CA 93940.
4. *LORAN HYPERBOLIC LOP FORMULAS AND GENERAL SPECIFICATIONS FOR LORAN-C* (20 June 1949) were obtained from G. R. Young, Acting Chief, Navigation Department, Defense Mapping Agency, Hydrographic/Topographic Center, Washington, D.C. by private communication, 5 March 1980.
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6. R. H. Shudde, "Position Determination with Loran-C Triplets and the Hewlett-Packard HP-67/97 Programmable Calculators," Technical Report NPS55-80-010, March 1980, Naval Postgraduate School, Monterey, CA 93940.

APPENDIX. Loran-C Station Parameters

The following list contains the pertinent parameters for each Loran-C station pair. This list was compiled from data in Reference 4. Each row contains the following information:

1. The Loran-C station pair designator
2. Δt , the sum of the coding delay plus one way baseline time, including the secondary phase correction for an all seawater path, in microseconds.
3. The master station latitude.
4. The master station longitude.
5. The slave station latitude.
6. The slave station longitude.

In this report, the convention that a minus (-) sign denotes South latitudes and West longitudes has been followed throughout. Some users may wish to reverse the longitude convention so that (-) longitudes are East rather than West. This may be accomplished by consistently changing the sign of the longitude *everywhere* that it is required for data input; no program modifications are required. If the sign convention for longitude is reversed, care should be taken that the signs of all longitudes in the list are reversed. In columns 3 through 6 the latitudes and longitudes appear to be in decimal form, but the actual format is DDD.MMSSFF where

DDD designates degrees,
MM designates minutes,
SS designates seconds, and
FF designates hundredths of seconds.

4990X, 15972.23, 16.444395, -169.303120, 20.144916, -155.530970
 4990Y, 34253.13, 16.444395, -169.303120, 28.234177, -178.173020
 5990X, 13131.88, 46.482720, -067.553771, 41.151193, -069.583909
 5990Y, 28755.02, 46.482720, -067.553771, 46.463218, -053.102816
 5990Z, 13343.50, 51.575878, -122.220224, 55.262085, -131.151965
 5990Y, 28927.36, 51.575878, -122.220224, 47.034799, -119.443953
 5990Z, 42266.63, 51.575878, -122.220224, 50.362972, -127.212935
 7990W, 15068.02, 59.591727, -045.102747, 64.542658, -023.552175
 7990X, 27803.77, 59.591727, -045.102747, 62.175968, -007.042671
 7990Z, 48212.20, 59.591727, -045.102747, 46.463218, -053.102816
 7990Y, 13804.45, 63.194281, -142.483190, 57.262021, -152.221122
 7990Y, 39651.14, 63.194281, -142.483190, 55.262085, -131.151965
 7970W, 30065.64, 62.175968, -007.042671, 54.482980, +008.173633
 7970X, 15048.10, 62.175968, -007.042671, 68.380615, +014.274700
 7970Y, 48944.53, 62.175968, -007.042671, 64.542658, -023.552175
 7970Z, 63216.30, 62.175968, -007.042671, 70.545261, -008.435869
 7980W, 12809.54, 30.593874, -085.100930, 30.433302, -090.494360
 7980X, 27442.38, 30.593874, -085.100930, 26.315501, -097.500009
 7980Y, 45201.30, 30.593874, -085.100930, 27.015849, -080.065352
 7980Z, 61542.72, 30.593874, -085.100930, 34.034604, -077.544676
 7990X, 12755.97, 38.522061, 016.430596, 35.312088, 012.312996
 7990Y, 32273.30, 38.522061, 016.430596, 40.582095, 027.520152
 7990Z, 50999.69, 38.522061, 016.430596, 42.033649, 003.121590
 8970W, 14355.11, 39.510754, -087.291214, 30.593874, -085.100930
 8970X, 31162.06, 39.510754, -087.291214, 42.425060, -076.493386
 8970Y, 47753.74, 39.510754, -087.291214, 48.364984, -094.331847
 9930W, 13635.51, 34.034604, -077.544676, 27.015849, -080.065352
 9930X, 36389.66, 34.034604, -077.544676, 46.463218, -053.102816
 9930Y, 52541.31, 34.034604, -077.544676, 41.151193, -069.583909
 9930Z, 68560.72, 34.034604, -077.544676, 39.510754, -087.291214
 9940W, 13796.90, 39.330662, -118.495637, 47.034799, -119.443953
 9940X, 28094.50, 39.330662, -118.495637, 38.465699, -122.294453
 9940Y, 41967.30, 39.330662, -118.495637, 35.191818, -114.481743
 9960W, 13797.20, 42.425060, -076.493386, 46.482720, -067.553771
 9960X, 26969.93, 42.425060, -076.493386, 41.151193, -069.583909
 9960Y, 42221.65, 42.425060, -076.493386, 34.034604, -077.544676
 9960Z, 57162.00, 42.425060, -076.493386, 39.510754, -087.291214
 9970W, 15283.94, 24.48041, 141.19290, 24.17077, 153.58515
 9970X, 36685.12, 24.48041, 141.19290, 42.443700, 143.430906
 9970Y, 59463.13, 24.48041, 141.19290, 26.362499, 128.085621
 9970Z, 80746.79, 24.48041, 141.19290, 09.324566, 138.095523
 9990X, 14875.22, 57.090988, -170.145981, 52.494505, +173.105231
 9990Y, 32069.09, 57.090988, -170.145981, 65.144012, -166.531447
 9990Z, 46590.10, 57.090988, -170.145981, 57.262021, -152.221122

Coverage of Loran-C Systems

<u>Station</u>	<u>Location</u>
4990	Central Pacific
5930	East Coast, Canada
5990	West Coast, Canada
7930	North Atlantic
7960	Gulf of Alaska
7970	Norwegian Sea
7980	Southeast U.S.A.
7990	Mediterranean Sea
8970	Great Lakes
9930	East Coast, U.S.A.
9940	West Coast, U.S.A.
9960	Northeast U.S.A.
9970	Northwest Pacific
9990	North Pacific

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