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DETERMINATION OF RANGE AND BEARING FROM LORAC LANE COUNTS

GRANT S. YEE

This memorandum describes the method for determining range and bearing between two ships at sea using LORAC as a navigational aid. This memorandum has been prepared because it is believed that the information may be useful to others working in an allied field at NEL. This memorandum should not be construed as a report since its only function is to present information on a small portion of the work on NEL Problem L1-5. Distribution outside the Laboratory is not contemplated.

I. INTRODUCTION

This memorandum will discuss a method for determining range and bearing between two ships, through the use of a Burroughs 220-Digital Computer, from the Red and Green lane counts obtained when using a LORAC[1] network. Previously, calculations of bearings and ranges were made using desk calculators. However, this was a long and tedious task which required the drawing of charts and the handling of voluminous numbers.

The present procedure is based on formulas supplied by the U. S. Navy Hydrographic Office. These formulas give the coordinates of a ship in Universal Transverse Mercator (U.T.M.) Coordinates when the LORAC red and green lane counts are known. The formulas were extended at NEL to determine range and bearing between ships in addition to the U.T.M. coordinates.

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[1] "Installation Techniques for AN/FQQ-1 (V) Navigational Aids" Sect. 3, NAVSHIPS 92963, March 11, 1957. (C)

II. PROCEDURE

This section will cover formulas used to convert LORAC lane coordinates to Universal Transverse Mercator (U.T.M.) Coordinates. These formulas were obtained from the U. S. Hydrographic Office, Washington, D. C.

Before going into the actual calculations, certain constants must be known. They are as follows:

1. X_m = U.T.M. Easting of Master
2. Y_m = U.T.M. Northing of Master
3. ψ_g = Angle of Rotation Counterclockwise; Green Axis into positive X-Axis
4. L_r = Red Lane Count
5. ΔA_r = 2/Number of Lanes in Red Base
6. K_r = Red Base length/$_2$
7. L_g = Green Lane Count
8. ΔA_g = 2/Number of Lanes in Green Base
9. K_g = Green Base length/$_2$
10. ω = Angle Counterclockwise between Red Base and Green Base
11. $\sin \omega$
12. $\cos \omega$

All the above mentioned constants, except L_r and L_g, were furnished by the U. S. Hydrographic Office during the planning and survey phases of the problem, upon receipt of the locations of the LORAC shore stations and the assigned LORAC radio frequency. Angles are in degrees and the distances are in meters. Refer to figure (1) for the meaning of terms not fully explained. With the above constants, and the Red and Green Lane counts obtained during sea operations from the LORAC receiving equipment, the solution to determine the U.T.M. coordinates is as follows:

$$A_r = 1 - \Delta A_r - L_r$$

$$A_g = 1 - \Delta A_g - L_g$$

$$K = K_r (1 - A_r^2) / K_g (1 - A_g^2)$$

$$\tan \phi = \sin \omega / K = \cos \omega$$

$$\cos (\theta_g - \phi) + \phi$$

$$R = K_g (1 - A_g^2) / A_g - \cos \theta_g$$

$$X_p = X_m + R \cos (\theta_g - \psi_g)$$

$$Y_p = Y_m + R \sin (\theta_g - \psi_g)$$

The final results obtained, X_p and Y_p, give the U.T.M. coordinates of the ship at sea.

III. DETERMINATION OF RANGE AND BEARING

A. Range - To solve for the range between two ships, with their respective values of X_p and Y_p, requires only plane geometry.

$$\text{Range} = (\Delta X^2 + \Delta Y^2)^{1/2}$$

where: ΔX = difference of the X_p of the two ships positions,

ΔY = difference of the Y_p of the two ships positions.

The range is in meters but can be converted to yards if so desired. The inaccuracies of the range determined on U.T.M. coordinates is negligible for most purposes (4 parts in 10,000).

B. Bearing - The bearing is obtained in the following manner:

$$\text{Bearing} = \text{Arctan} \frac{\Delta X}{\Delta Y}$$

There are four classes in which the bearing can fall.

1. Bearing = Arctan $\frac{\Delta X}{\Delta Y}$ if $\Delta X = +, \Delta Y = +$,

2. Bearing = Arctan $\frac{\Delta X}{\Delta Y} + 90^\circ$ if $\Delta X = +, \Delta Y = -$,

3. Bearing = Arctan $\frac{\Delta X}{\Delta Y} + 180^\circ$ if $\Delta X = -, \Delta Y = -$,

4. Bearing = Arctan $\frac{\Delta X}{\Delta Y} + 270^\circ$ if $\Delta X = -, \Delta Y = +$.

IV. USING THE BURROUGHS 220

The formulas listed in the previous section have been programmed for the Burroughs 220 digital computer to accomplish rapid data reduction. Using a desk calculator several hours are required to compute the range and bearing between two ships. The Burroughs 220 program can accomplish the same thing in a few seconds, and is therefore useful when a number of these ranges or bearings are required.

The program in detail for determining range and bearing can be found in Appendix A and a flow chart of the program is shown in Figure 2. The program should be useful to others working with the same or other LORAC installations. The only additional data needed in the latter case are the constants determined by the shore installation positions and the assigned LORAC radio frequency. (See paragraph 2, section II.)

The set of Red and Green lanes, from which the range and bearing are to be determined, are punched on paper tape in the following manner:

Red Lane of Source (or Target)	aaa.aa
Green Lane of Source (or Target)	bbb.bb
Red Lane of Receiver	aaa.aa
Green Lane of Receiver	bbb.bb

Notice that the lane counts are carried out to 2 decimal places. The decimal point is not punched onto the paper tape and is shown above only for clarity. A roll of paper tape may contain many sets of lane counts. The computer program interprets the lane counts in groups of four: i.e., the first two as the target ship lane count and the next two as the receiving ship lane count.

The bearing and range, as determined by the computer, are printed on the flexowriter on line with the Burroughs 220. The bearing in degrees and range in yards are in floating point notation. As an illustration, the output for lane counts of 354.36 (red) and 495.60 (green) for the target and 327.66 (red and 396.08 (green) for the receiver would appear thusly:

Target

Red Lane. 35436

Green Lane. 49560

Receiver

Red Lane. 32766

Green Lane. 39608

True LORAC Bearing. . .5323492400

Range in Yards. 5549589760

For those who are not familiar with floating point notation, the first two digits from the left, denote the number of places to the right of the succeeding digits, with 50 meaning zero places, to put the decimal point. In other words, 5549589760 is the same as 49589.760.

Although the program is written in the language of the Burroughs 220, there is no reason why this same program cannot be implemented for use on any other digital computer such as the CDC 1604 or the NTDS unit-computer.

The author is greatly indebted to C. A. Tapella, Code 2243, Computer Branch, for the use of his sub-routine programs incorporated into the final range and bearing program.

APPENDIX A

BURROUGHS 220 PROGRAM for DETERMINING RANGE AND BEARING from LORAC RED AND GREEN LANES

LOCATION	INSTRUCTION	REMARKS
950	0 6341 59 4745	950-975 special for SPO
951	0 6316 59 4544	
952	0 0053 41 5545	
953	0 0000 00 0000	Insert Red Lane
954	0 4759 45 4555	
955	0 0053 41 5545	
956	0 0000 00 0000	Insert Green Lane
957	0 5945 43 4549	
958	0 6545 59 0000	
959	0 0016 59 4544	
960	0 0053 41 5545	
961	0 0000 00 0000	Insert Red Lane
962	0 4759 45 4555	
963	0 0053 41 5545	
964	0 0000 00 0000	Insert Green Lane
965	0 0000 00 0016	
966	0 5945 53 4163	
967	0 4965 45 0042	
968	0 4541 59 4955	
969	0 4700 00 0000	

970	0 0000 00 0000	Insert Bearing
971	0 5941 55 4745	
972	0 0049 55 0068	
973	0 4159 44 6200	
974	0 0000 00 0000	Insert Range
975	0 1616 16 1616	Advance paper
976		
977		
978	30 0986 BUN	
979	25	Constant
980	42 0979 LDB	Load B Register with 25
981	1 0000 10 0950 CAD	
982	2 43 0000 LSA	Load sign with 2
983	1 0000 40 0950 STA	Store
984	1 21 0981 DBB	Decrease B register and recycle
985	30 1160 BUN	To start of computations
986	10 1010 CAD	Get lane count
987	40 0953 STA	
988	10 1011 CAD	
989	40 0956 STA	
990	0 0070 09 0950 SPO	Write on SPO
991	30 1118 BUN	Read 2 lanes
992	10 1010 CAD	
993	40 0961 STA	
994	10 1010 CAD	
995	40 0964 STA	

996		10 1012 CAD	
997		40 1115	
998	0 0090	09 0957 SPO	Write on SPO
999		30 1020 BUN	To compute second set
1000	0 5665	53 6849	UTM Easting of Master Xm
1001	0 5739	48 2663	UTM Northing of Master Ym
1002	0 5090	00 6860	Angle of Green Lane into X-axis
1003	0 4822	90 7238	ΔA_r 2 + number of lanes in red base
1004	0 5528	74 1878	K_r 1/2 red base length
1005	0 4814	58 0896	ΔA_g 2 + number of lanes in green base
1006	0 5543	61 2485	K_g 1/2 green base length
1007	0 5317	95 2955	ω angle between red and green baseline
1008	0 4882	10 8000	Sine ω
1009	1 5099	99 7000	Cos ω
1010	0 0000	00 0000	Red Lane
1011	0 0000	00 0000	Green Lane
1012		01 0000	NOP
1013	0 5110	93 6111	Conversion of meters to yards
1014	0 5110	00 0000	Constant of 1
1015	0 0000	00 0000	
1016	0 5257	29 5779	Radians to degrees
1017	0 0000	00 0002	
1018	0 5290	00 0000	90 Degrees
1019	0 0000	00 0000	
1020		10 1010 CAD	Red lane L_r
1021		41 1017 LDR	Fixed to Floating point routine

1022	44 4600 STP	
1023	30 4601 BUN	
1024	24 1003 FMU	Floating multiply by ΔA_r
1025	40 2000 STA	$(L_r \Delta A_r)$ to (2000)
1026	10 1014 CAD	1
1027	23 2000 FSU	$1 - (L_r \Delta A_r)$
1028	40 2000 STA	
1029	10 1011 CAD	Green Lane L_g
1030	41 1017 STP	
1031	44 4600 LDR	
1032	30 4601 BUN	
1033	24 1005 FMU	$L_g \Delta A_g$
1034	40 2001 STA	
1035	10 1014 CAD	1
1036	23 2001 FSU	$1 - (L_g \Delta A_g)$
1037	40 4001 STA	
1038	10 2000 CAD	A_r
1039	24 2000 FMU	A_r^2
1040	40 2050 STA	
1041	10 1014 CAD	1
1042	23 2050 FSU	$1 - A_r^2$
1043	24 1004 FMU	$K_r (1 - A_r^2)$
1044	40 2002 STA	
1045	10 2001 CAD	A_g
1046	24 2001 FMU	A_g^2
1047	40 2051 STA	

1048	10 1014 CAD	1
1049	23 2051 FSU	$1 - A_g^2$
1050	24 1006 FMU	$K_g (1 - A_g^2)$
1051	40 2003 STA	
1052	10 2002 CAD	$K_r (1 - A_r^2)$
1053	25 2003 FDV	$K_r (1 - A_r^2) \div K_g (1 - A_g^2)$ K
1054	40 2004 STA	
1055	23 1009 FSU	K - Cos ω
1056	40 2005 STA	
1057	10 1008 CAD	Sine ω
1058	25 2005 FDV	Sine ω/K - cos ω Tan θ
1059	2 45 000 CLR	
1060	44 4360 STP	Arctan routine
1061	30 4361 BUN	
1062	40 2006 STA	
1063	44 4000 STP	Sine routine
1064	30 4002 BUN	
1065	40 2007 STA	
1066	2 45 0000 CLR	
1067	10 2004 CAD	K
1068	24 2001 FMU	K A_g
1069	23 2000 FSU	K $A_g - A_r$
1070	40 2008 STA	
1071	2 45 0000 CLR	
1072	10 2007 CAD	Sine ϕ

1073	25 1008 FDV	Sine ϕ / Sine ω
1074	24 2008 FMU	Cos $(\theta_g - \phi)$
1075	44 4820 STP	Arctan routine
1076	30 4821 BUN	
1077	40 1019 STA	
1078	10 1018 CAD	90 Degrees
1079	25 1016 FDV	Radians
1080	2 45 0000 CLR	
1081	23 1019 FSU	Arccos $(\theta_g - \phi)$
1082	1 43 0000 LSA	Make negative
1083	40 2009 STA	
1084	22 2006 FAD	
1085	40 2010 STA	
1086	44 4000 STP	Cosine routine
1087	30 4001 BUN	
1088	40 2012 STA	
1089	10 2001 CAD	A_g
1090	23 2012 FSU	$A_g - \cos \theta_g$
1091	40 2013 STA	
1092	2 45 0000 CLR	
1093	10 2003 CAD	$K_g (1 - A_g^2)$
1094	25 2013 FDV	R in meters
1095	40 2014 STA	
1096	10 2010 CAD	θ_g
1097	23 1002 FSU	
1098	40 2015 STA	

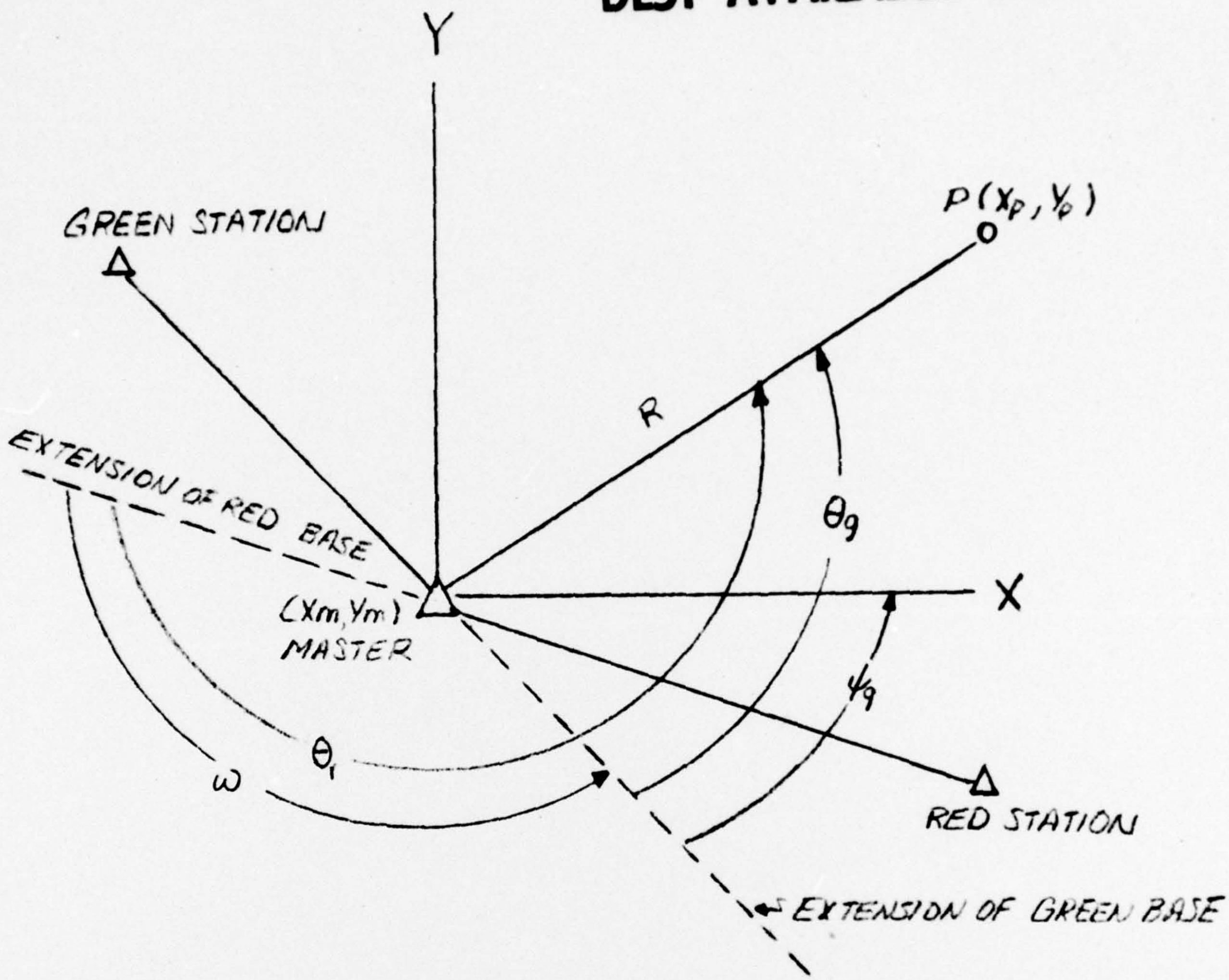
1099		44 4000 STP	Sine routine
1100		30 4002 BUN	
1101		01 0000 NOP	
1102		40 2017 STA	
1103		10 2015 CAD	
1104		44 4000 STP	Cosine routine
1105		30 4001 BUN	
1106		01 0000 NOP	
1107		40 2018 STA	
1108		24 2014 FMU	
1109		22 1000 FAD	X_p
1110		40 2019 STA	
1111		10 2017 CAD	
1112		24 2014 FMU	
1113		22 1001 FAD	Y_p
1114		40 2022 STA	
1115		30 0986 BUN	
1116			
1117			
1118	0 1020	03 1010 PTR	Read 2 more lanes
1119		10 1139 CAD	To modify 1117
1120		40 1117 STA	
1121		01 0000 NOP	
1122		10 2019 CAD	Relocate T_x
1123		40 2020 STA	
1124		10 2020 CAD	Relocate T_y

1125	40 2022 STA	
1126	30 0992 BUN	To compute second set of points
1127	10 2021 CAD	Target X_p
1128	23 2019 FSU	Target X_p minus Receiver X_p
1129	1 33 1154 BSA	
1130	40 2023 STA	
1131	10 2022 CAD	Target Y_p
1132	23 2020 FSU	Target Y_p minus Receiver Y_p
1133	1 33 1146 BSA	
1134	40 2024 STA	
1135	44 1200 STP	To Bearing sub-routine
1136	30 1201 BUN	
1137	01 0000 NOP	
1138	30 1140 BUN	
1139	30 1127 BUN	No instruction
1140	0 0100 09 0966 SPO	Write range and bearing
1141	10 1012 CAD	
1142	40 1117 STA	
1143	10 0978 CAD	
1144	40 1115 STA	
1145	30 1160 BUN	
1146	43 0000 LSA	Routine if 90 - 180 degrees
1147	40 2024 STA	
1148	44 1180 STP	To bearing routine
1149	30 1181 BUN	
1150	10 0970 CAD	

1151		22 1018 FAD	
1152		40 0970 STA	
1153		30 1140 BUN	
1154		43 0000 LSA	
1155		40 2023 STA	
1156		10 2022 CAD	Target Y_p
1157		30 1162 BUN	
1158	0 5327	00 0000	270 degrees
1159	0 5318	00 0000	180 degrees
1160	0 1020	03 1010 PTR	Read 2 more lanes
1161		30 1020 BUN	To start of program
1162		23 2020 FSU	
1163		1 33 1171 BSA	
1164		40 2024 STA	
1165		44 1180 STP	To bearing routine
1166		30 1181 BUN	
1167		10 0970 CAD	
1168		22 1158 FAD	
1169		40 0970 STA	
1170		30 1140 BUN	To print-out
1171		43 0000 LSA	
1172		40 2024 STA	
1173		44 1200 STP	To bearing routine
1174		30 1201 BUN	
1175		10 0970 CAD	
1176		22 1159 FAD	
1177		40 0970 STA	

1178	30 1140	BUN	To print-out
1179			
1180	30 0000	BUN	To re-enter main program
1181	10 2024	CAD	ΔY
1182	25 2023	FDV	$\Delta Y / \Delta X$
1183	44 4360	STP	Arctan routine
1184	30 4361	BUN	
1185	40 2025	STA	
1186	24 1016	FMU	
1187	40 2026	STA	
1188	40 0970	STA	
1189	10 2025	CAD	
1190	44 4000	STP	To sine routine
1191	30 4002	BUN	
1192	40 2030	STA	
1193	10 2024	CAD	
1194	25 2030	FDV	Range in meters
1195	40 2027	STA	
1196	25 1013	FDV	Range in yards
1197	40 2028	STA	
1198	40 0974	STA	
1199	30 1180	BUN	EXIT
1200	30 0000	BUN	Re-entry to main program
1201	10 2023	CAD	
1202	25 2024	FDV	
1203	44 4360	STP	Arctan routine

1204	30 4361 BUN	
1205	40 2025 STA	
1206	24 1016 FMU	Bearing in degrees
1207	40 2026 STA	
1208	40 0970 STA	
1209	10 2025 CAD	
1210	44 4000 STP	To sine routine
1211	30 4002 BUN	
1212	40 2030 STA	
1213	10 2023 CAD	
1214	25 2030 FDV	Range in meters
1215	40 2027 STA	
1216	25 1013 FDV	Range in yards
1217	40 2028 STA	
1218	40 0974 STA	
1219	30 1200 BUN	EXIT



ω = ANGLE COUNTER-CLOCKWISE BETWEEN RED BASE AND GREEN BASE

ψ_g = ANGLE OF ROTATION COUNTER-CLOCKWISE, GREEN AXIS INTO POSITIVE X-AXIS

X_m = U.T.M. EASTING OF MASTER

Y_m = U.T.M NORTHING OF MASTER

FIGURE 1

CONVERSION OF LORAC LANE COUNTS TO U.T.M. COORDINATES.

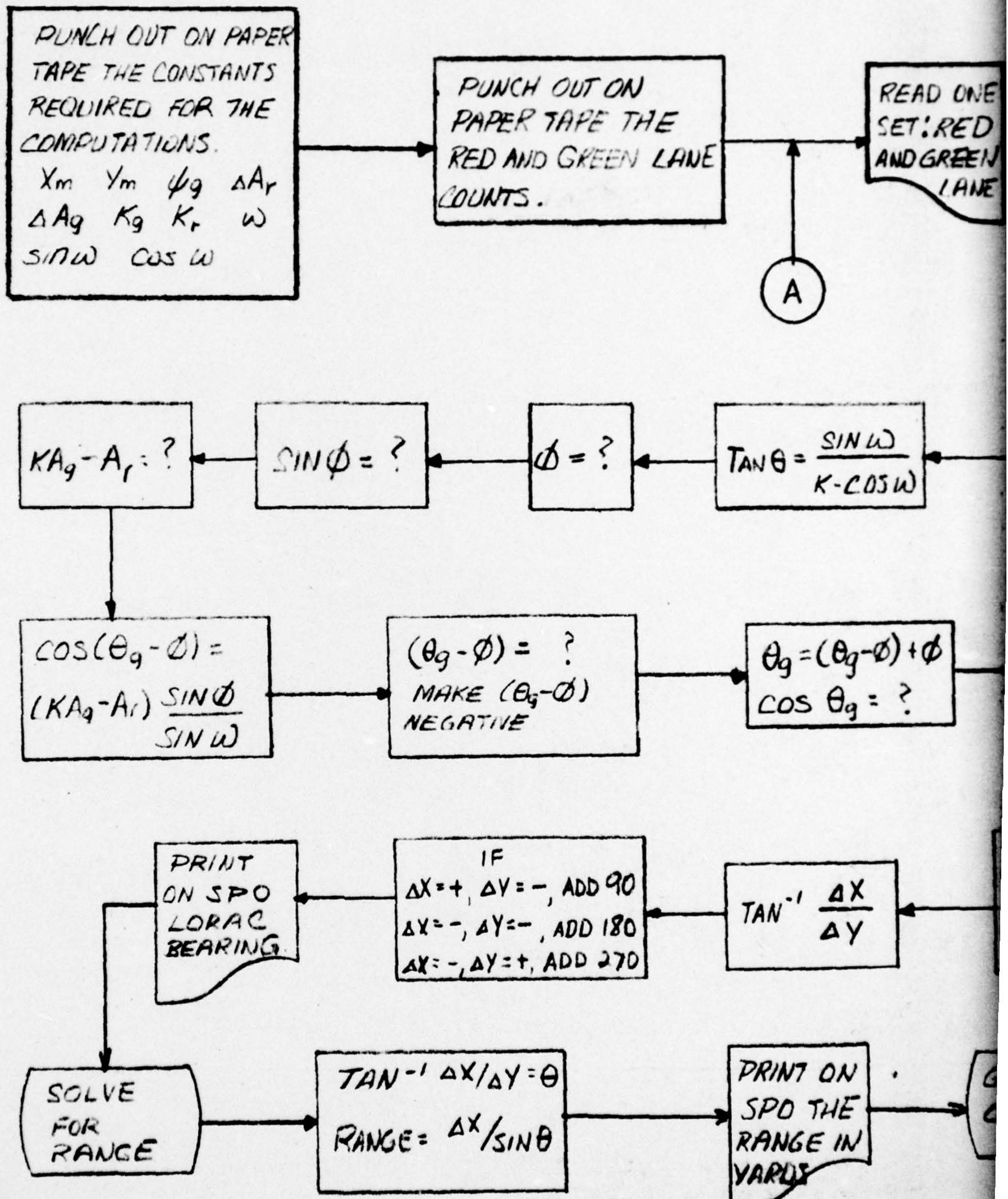
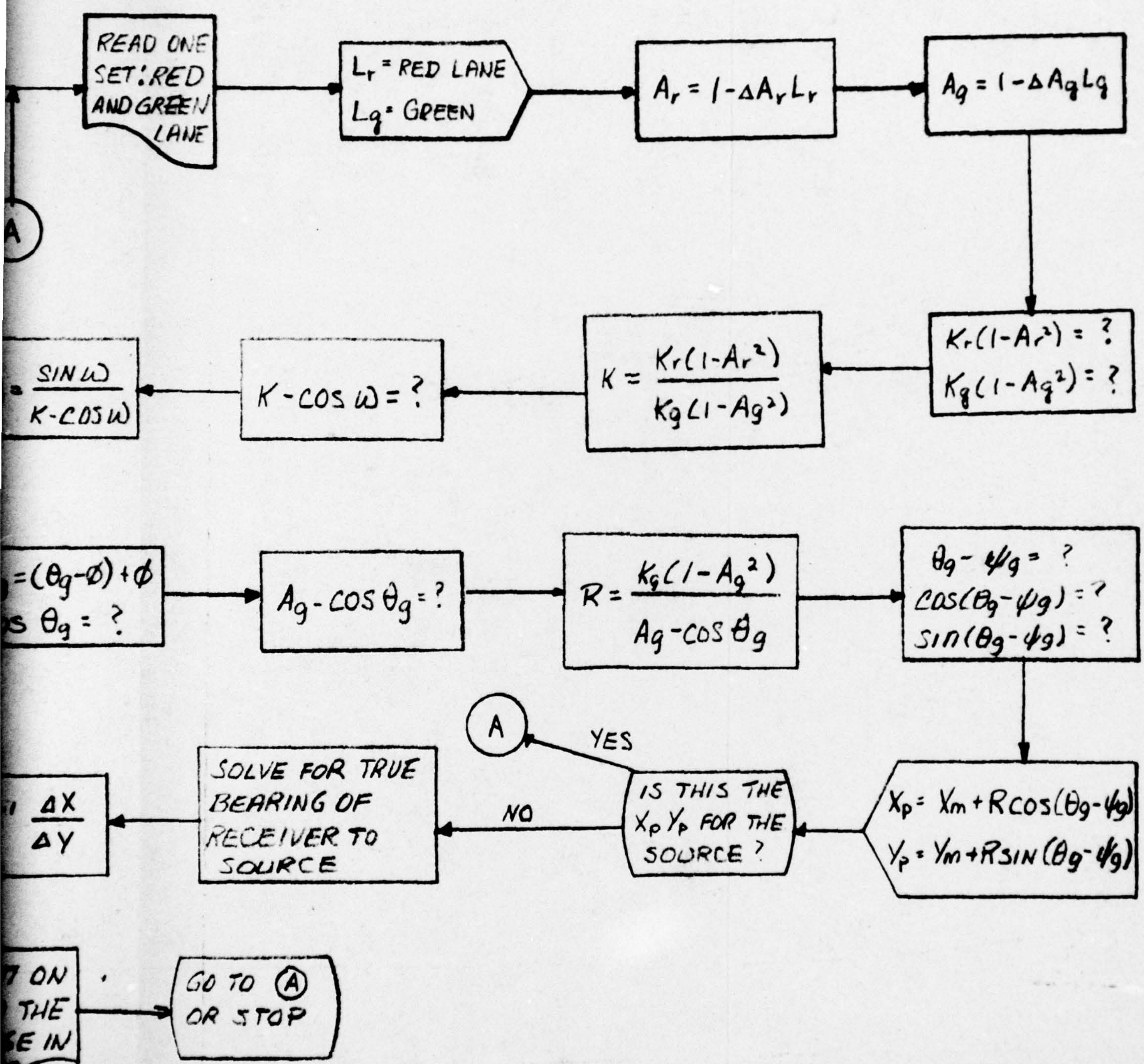


FIGURE 2. FLOW CHART
DETERMINAT



LOW CHART FOR BEARING AND RANGE
ETERMINATIONS USING BURROUGHS 220