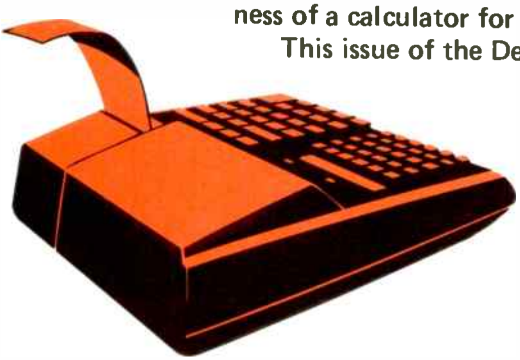
GTE LENKURT
DEMODULATOR
MARCH/APRIL 1979

Path Profiling with a Programmable Calculator

The time consuming effort of hand calculations and the inherent inaccuracies involved in using slide rules have been virtually eliminated by electronic calculators. The inclusion of a programmable memory increases the usefulness of a calculator for engineering applications. This issue of the Demodulator describes one of these applications.



The terrain and physical objects separating two antennas affects the transmission of microwave energy between them. When a microwave path is to be established between two points, maps are used to make a preliminary selection of a suitable path. Then, a profile of this path is plotted to determine what antenna heights are required to overcome the effects of terrain and physical objects. If the area is particularly rugged, partial profiling as well as map inspection may be needed for preliminary path selection.

A programmable calculator is a useful tool for reducing the time and effort required to prepare a path profile. Two programs for path profiling are presented at the end of this article. The programs are for the Hewlett Packard type 97 calculator but they can be easily adapted to other types of programmable calculators.

Microwave Transmission Characteristics

The curvature of the earth and the slight bending of the microwave beam as it is refracted downward by the earth's atmosphere are two factors that must be considered when constructing microwave path profiles. The earth's curvature and microwave beam refraction are commonly combined to form an equivalent earth radius factor, "K". This factor "K", multiplied by the true earth radius, is the radius of a fictitious earth curve for a microwave beam traveling in a straight line. As different atmospheric conditions change the amount of beam refraction, the value for "K" also changes.

Values for "K" during standard atmospheric conditions range from 1.2 in dry elevated areas to 2 or 3 in humid coastal areas, with 4/3 being typical of inland areas. Unusual propagation conditions, encountered a small percentage of time, can produce values of "K" ranging from 1/2 during substandard propagation to negative values during superstandard propagation. Figure 1 shows graphically how the refraction and earth's radius can be shown for a profile over flat terrain. It is convenient to plot the profile on rectangular graph paper to show both the refraction of the microwave beam and the earth curvature as a bending of

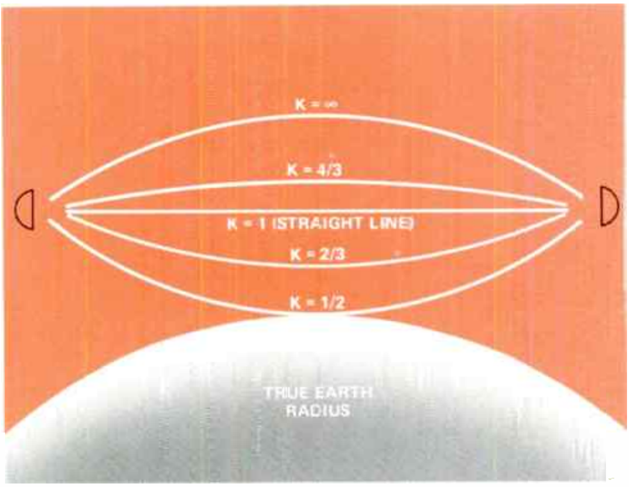


Figure 1. Beam refraction for true earth radius.

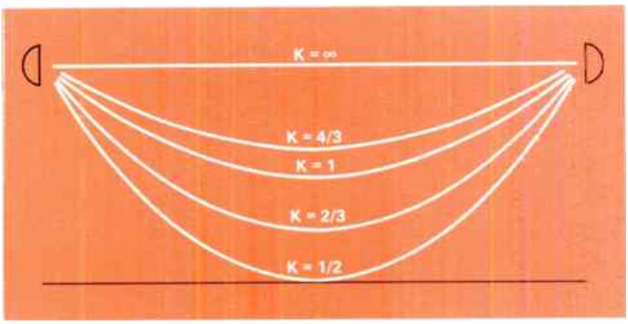


Figure 2. Relative beam curvatures for a flat earth.

the microwave beam, as depicted in Figure 2.

Another factor that must be considered in the construction of microwave path profiles is the influence of terrain and physical objects on the microwave beam. As a microwave beam passes close to an object some energy is redirected by the object, causing a variation in the receive signal level on the microwave path, as shown in Figure 3. The microwave frequency, the distance from the center of the microwave beam and the distance to the ends of the path determine where nulls and peaks in the signal will occur. The type of object and its physical shape determine the magnitude of the variations.

The distance from the microwave beam's center is commonly measured in units of Fresnel zones, to take into account both frequency and distance. The first Fresnel zone (1.0 F_1) is the surface of points along which the total distance to the ends of the path is exactly one-half a wavelength longer than the direct end-to-end microwave path.

Any object within the first Fresnel zone will diffract the microwave beam. In this diffraction zone, distances from the center of the microwave beam are measured in fractions of the first Fresnel zone.

It is important to note that a clearance of at least six tenths (0.6) of the first Fresnel zone is required to

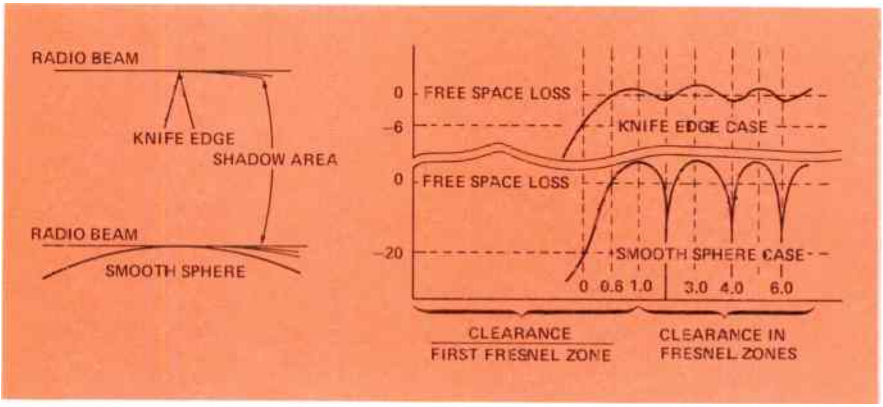


Figure 3. Diffractions caused by objects of different shapes.

maintain free space loss from end-to-end on a microwave path. When less than six tenths clearance is present, the microwave beam is considered to be obstructed.

If an object is at or outside the first Fresnel zone, the distance from the object to the center of the microwave beam is measured in actual Fresnel zones. Figure 4 presents the formulas used to calculate various Fresnel zones.

Reflections

For very shallow angles of reflections, a 180° ($\lambda/2$) phase delay occurs at the reflection. The phase delay of the reflected signal, plus the $\lambda/2$ difference in the path length of the first Fresnel zone, will produce an in-phase addition of the direct and reflected beams at the receive antennas. This addition can give up to 6 dB increase in received signal level, depending on how well the signal is reflected. If the reflection point falls on an even Fresnel zone, a null in the receive signal can occur due to an out of phase addition of the direct and reflected signals.

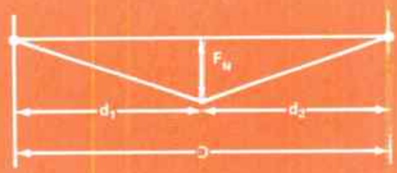
Microwave paths with strong reflections are usually designed to take advantage of odd Fresnel zone reflections. When even order reflections cannot be avoided, space diversity systems are normally used. These systems are designed so that only one of the space diversity antennas encounters an even Fresnel zone reflection at any single value of K.

Path Clearance Criteria

Earth curvature, microwave beam refraction and Fresnel zone clearance are combined into clearance criteria for a microwave path. Two basic sets of criteria, heavy route and light route, are in common use for microwave communication systems. Each set of criteria should be maintained along the entire microwave path. Earth bulge and Fresnel zone radii vary in a different way along the path and often one criterion is controlling near the center of the path and the other is controlling near the path ends.

- Heavy Route Clearance:

At least $0.3F_1$ at K=2/3 and $1.0F_1$ at K=4/3, whichever is greater. In cases of very difficult propagation, grazing at K=1/2 may be added to this criteria to assure adequate



IMPERIAL FORMULA

$$F_N = 72.1\sqrt{\frac{Nd_1\, d_2}{F_{GHz} D}}$$

F_N IN FEET

d AND D IN MILES

METRIC FORMULA

$$F_N = 17.3\sqrt{\frac{Nd_1\, d_2}{F_{GHz} D}}$$

F_N IN METERS

d AND D IN KILOMETERS

Figure 4. Fresnel zone formulas.

clearance. (For 2 GHz paths longer than 36 miles substitute 0.6F at K=1.0).

- Light Route:

At least $0.6F_1$ at K=1.0 plus 10 feet.

At points quite near the ends of the paths, the Fresnel zones and earth bulge become vanishingly small. However, it is still necessary to maintain a minimum of 15 to 20 feet clearance from all obstacles.

Sources of Terrain Information

Maps that accurately show physical objects and terrain contours are required for the path profile. In the United States 7-1/2 or 15 minute maps are used for the detailed information required in path profiling. Indexes and maps are available from the United States Geological Survey, Branch of Distribution. For areas east of the Mississippi River, the address is 1200 South Ends Street, Arlington, Virginia 22202. For areas west of the Mississippi River including Louisiana, the address is Box 25286 Federal Center, Denver, Colorado 80225.

The indexes list state, government and private locations where maps are for sale. After maps are obtained, preliminary path selection can be started.

Preliminary Path Selection

It is sometimes difficult to determine a useful microwave path over rugged terrain by inspection only. In these cases, at least part of the path is usually profiled. Programmable printing calculators can greatly speed up the process of selecting paths, in rugged terrain, by eliminating the necessity for plotting partial path profiles. To maintain proper clearance, the calculator program produces a profile of elevation points which the actual terrain, including obstructions, should not exceed. To use the "Profile Program" for path selection:

1) Establish possible antenna centerline elevation by adding reasonable tower heights to the ground elevations of the selected end-points.
2) Run the "Clearance Elevation at Incremental Distances" part of the "Profile" program, for the desired Fresnel zone clearance and earth curvature criteria, incrementing the program at even distance incre-

ments approximately 1/20 of the end-to-end path distance (for example 0.5. mi, 1.0 mi. or 2 mi.).

3) Check map elevations for the required path clearance, as shown in Figure 5. Trees and buildings located along the path will increase the map elevations of the path profile and must be taken into account. Any time the elevation exceeds the elevation given by the calculator output, additional tower height will be required at one or both ends of the microwave path. Terrain high-points that occur between calculator increments can be checked by interpolating between successive increments.

If the comparison of the calculator output and the map elevation look reasonable, a detailed path profile can be made of the microwave path.

Detailed Path Profile

In profiling a microwave path, the terrain contour heights found on the maps are entered on the profile graph paper. Enough points should be plotted so that high, low and relatively flat areas of contour are shown. Regular

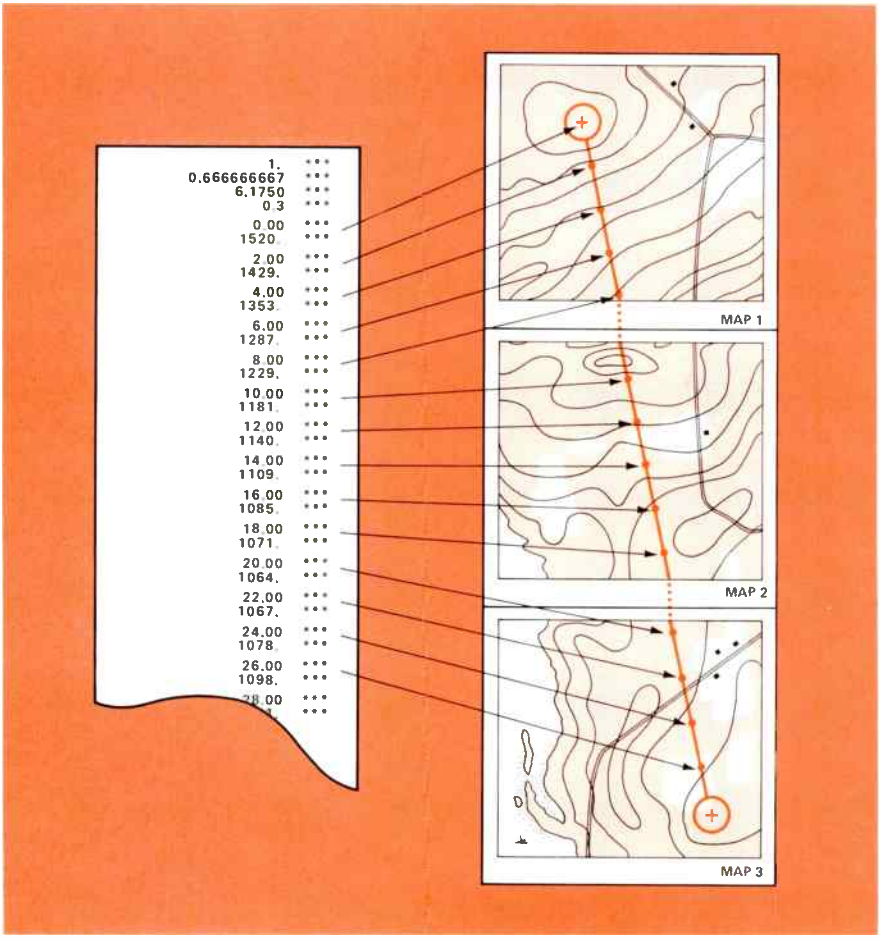


Figure 5. Checking map terrain against calculator generated output.

rectangular graph paper is used for this profile so that several values of K can be more easily shown on the final product.

When the profile contour has been completed, the desired Fresnel zone clearance is calculated for the profile high points, utilizing the "Calculate Fresnel zone Radius" portion of the "Profile" calculator program. The values of Fresnel zone clearances are then entered on the profile as shown in Figure 6.

Profiles drawn on rectangular graph paper use K=∞ as a reference. Because of this reference, the difference between K=∞ and the desired earth clearance K is next calculated for the high points utilizing the "Elevation at a Specific Distance" portion of the calculator program. Zero should be entered for the H_X and H_Y end-point elevations. The program will then give a negative value for the desired clearance. This value should be added to the desired Fresnel zone clearance on the profile. Figure 7 shows the placement of these points.

The antenna center-line heights can now be established by drawing a straight line (K=∞) through or above the K clearance dots between the ends of the path. Once the antenna mounting heights are established, the antenna center-line elevation above mean sea level (AMSL) can be entered into the program for H_X and H_Y. Then the "Path Profile Elevation at Incremental Distances" section of the program can be run for the locus of point elevations describing several K lines, as shown in Figure 8.

Reflection Point Analysis

If areas of water, swamps of flat ground exist along the microwave

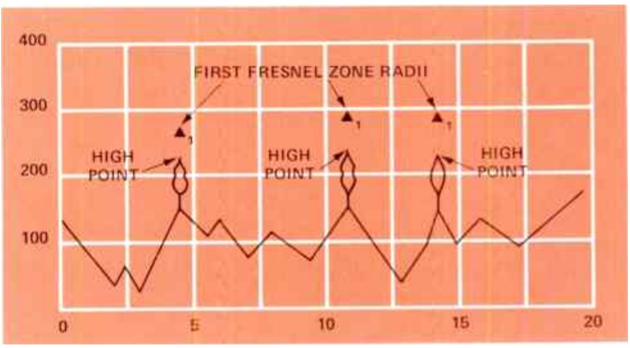


Figure 6. Fresnel zone clearance points.

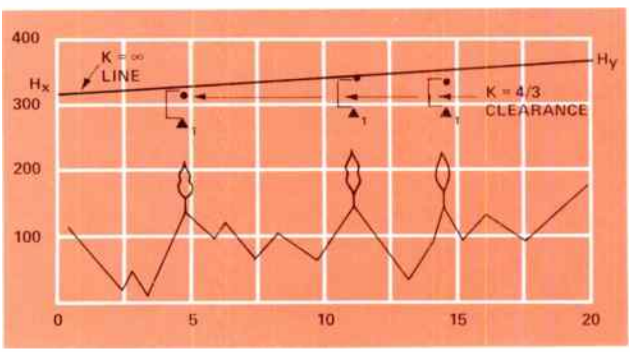
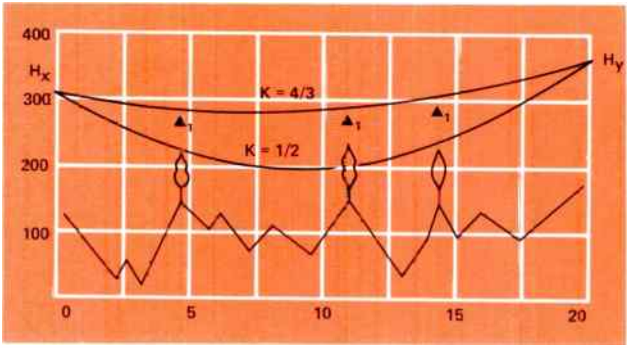


Figure 7. Addition of elevations at specific distances.

Figure 8. Profile elevations for different K values.



path, reflections can occur and affect the receive signal level. The Reflection Program can be used to calculate reflection points when the reflection point is level. Reflection points caused by sloping or rolling terrain can be adequately defined only by path tests.

The reflection point program calculates the distance at which reflections will be encountered for a given reflection point elevation. Figure 9 shows a set of reflection point calculations and the profile of a typical path.

In this example, the mounting height of the antenna at point B was specifically chosen to create a reflection path that is obstructed by land at point C. The use of a calculator allows an engineer to try mounting heights until the proper one to produce the desired obstruction is found.

After the profile is completed, it is field checked to accurately establish any map elevations that may be questionable. Tree and structure heights along the path are measured and enter-

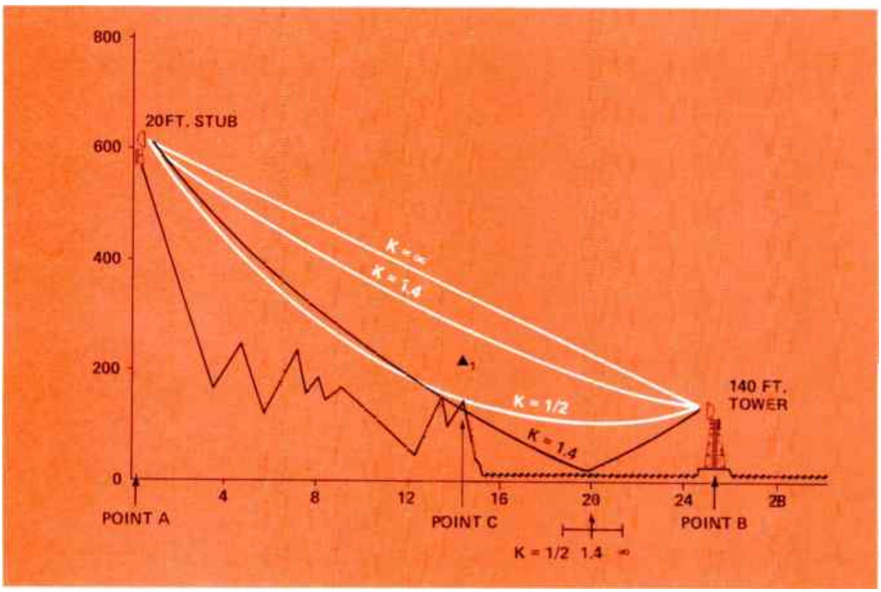


Figure 9. Obstructed reflection path.

ed on the profile. Potential reflection points along the path are visited to see if these points are adequately blocked by local obstructions.

The foregoing discussion briefly describes path profiling to provide a background for using the calculator programs presented below. The references listed in the bibliography describe path profiling in more detail and should be reviewed before preparing an actual path profile.

Calculator Programs

Two application programs are presented in the following pages. The first is called "Profile" and the second is called "Reflection". Each program is divided into three parts.

The first part, "Program Description" describes the programs purpose, lists the formulas on which it is based and states the program's operating limits. Warnings about common mistakes are also included in the Program Description.

The second part, "User Instructions" provides step by step instructions for using the calculator to perform the calculations specified in the instructions column of the User Instructions form.

The calculator must have the program listing stored in memory to perform the calculations.

The third part of each program is the "Program Listing". The Program Listing may be considered as a set of instructions to the calculator. It is keyed into the calculator memory before the calculations in the User Instructions are performed.

The HP 97 uses a magnetic card for permanent storage. The Program Listing may be stored on a magnetic card for future use. Instructions for using magnetic cards are contained in the HP 97 Instruction Manual.

BIBLIOGRAPHY

1. GTE Lenkurt Demodulator, *Profile Charts of Radio Link Routes*, Volume 2, No. 1, January 1953.

2. GTE Lenkurt Demodulator, *Microwave Transmission Engineering*, Parts One and Two, July and August 1972.

3. GTE Lenkurt Publication, *Engineering Considerations for Microwave Communication Systems.*

4. GTE Lenkurt Demodulator, *Anomalous Propagation Parts One and Two*, July and August 1975.

5. GTE Lenkurt Demodulator, *Antenna Decoupling*, March 1978.

6. *Economic and Technical Aspects of the Choice of Transmission Systems*, – Propagation appendix to Section B.IV.3. Published by the International Telecommunications Union, 1971.

7. Bell System Technical Journal, *Radio-Relay Antenna Pointing for Controlled Interference with Geostationary Satellites – Appendix A, Estimation of Antenna Elevation Angles*, December 1969.

Moving? When you notify the Demodulator, please include your old as well as your new address. An easy way to do this is to use the address label from your last copy. Send the information to the address on the back cover, attention: B552.

Program Description

Program Title PROFILE

Name John E. Hendricks, Jr., Staff Engineer **Date** 2/6/79

Address GTE Lenkurt 1105 County Road

City San Carlos State CA Zip Code 94070

Program Description, Equations, Variables, etc.

This program is designed to assist in preparing microwave path profiles. At the option of the user, the program can perform the calculations in imperial units (feet and miles) or metric units (meters and kilometers).

The program contains two subroutines; Fresnel zone radius calculations and beam center-line elevation calculations. The subroutines may be used separately or together as desired by the user. Print subroutines are also included at appropriate points to provide hard copy records of the calculations.

Any of the following calculations may be performed:

1. Calculate and print tne Fresnel zone radius at a specific distance.
2. Calculate and display the beam center-line elevation at a specific distance.
3. Calculate and print the beam center-line elevation at incremental distances.
4. Calculate and print the clearance elevation at incremental distances.
   Clearance elevation is the beam center-line elevation minus the desired Fresnel zone radius.

This program is referenced to the GTE Lenkurt publication, "Engineering Considerations for Microwave Communications Systems." The following formulas appear in that reference: Fresnel Zone Radius; Imperial page 38; Metric page B2; Earth Curvature; Imperial page 12; Metric page B1.

Path Slope:

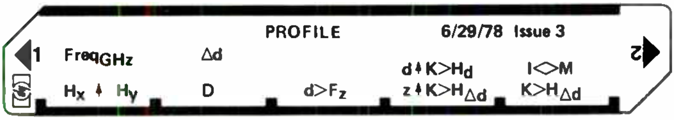
$H_s = H_x - \left(\frac{H_x - H_y}{D} * d\right)$ where: H_x = elevation of point x, H_y = elevation of point y, D = total path cistance, d = distance to desired slope location.

Operating Limits and Warnings There is much confusion regarding Fresnel Zone radius less than 1. This program uses the following convention:

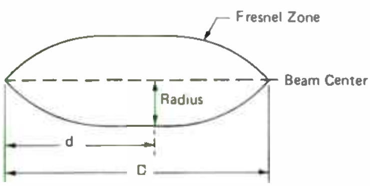
For Fresnel Zone radius less than 1 the program is always the value times the first Fresnel Zone radius (i.e., $0.6F_1$).

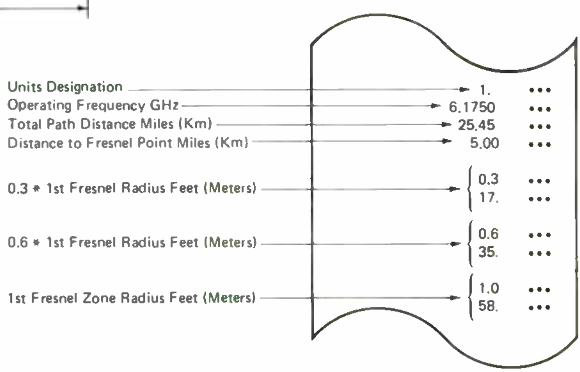
For Fresnel Zone radius greater than or equal to 1, the program always uses the square root of the value times the first Fresnel Zone (i.e., $\sqrt{N}F_1$).

User Instructions



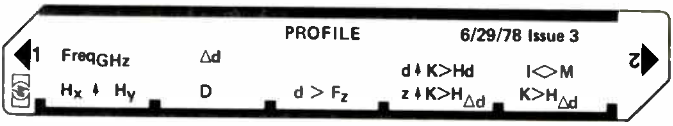
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	CALCULATE FRESNEL ZONE RADIUS				
1*	The program is set for Imperial units (feet & miles). If metric units				
	(meters & kilometers) are required or a change back to Imperial units				
	is required, the following is performed:				
	(units designation 1 = Imperial, 2 = metric)	None	f	e	units designation
2*	Operating frequency	Freq/GHz	f	a	
3*	Total Path Distance	D/Miles(Km)	B		
4	Distance from one end of the path to the location at which the				
	Fresnel Zone is to be calculated	d/Miles(Km)	C		See Below





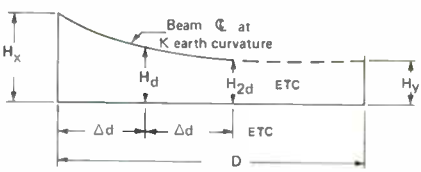
	*NOTE: If these entries remain unchanged from previous				
	calculations they do not need to be re-entered.				

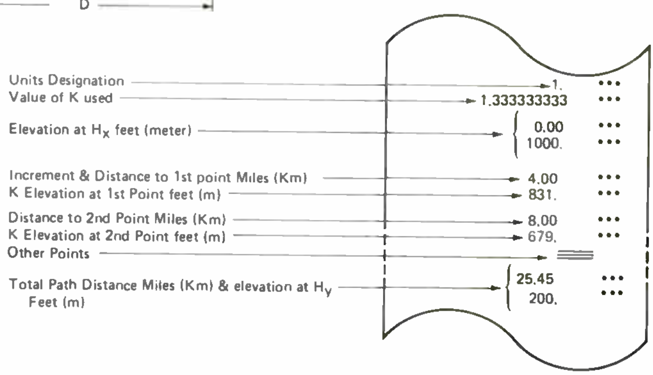
User Instructions



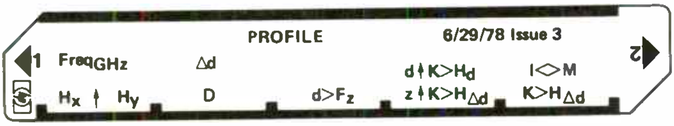
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	PATH PROFILE ELEVATION				
1*	The program is set for Imperial units (feet & miles). If metric units				
	(meters & kilometers) are required or a change back to Imperial				
	units is required, the following is performed:				
	(units designation 1 = Imperial, 2 = metric)	None	f	e	units designation
2*	Total Path Length	D/miles(Km)	B		
3*	Antenna center-line elevation AMSL at site X	H_x/feet (m)	↑		
	Antenna center-line elevation AMSL at site Y	H_y/feet (m)	A		H_x
	AT A SPECIFIC DISTANCE				
4	Distance to point of calculation	d/miles (Km)	↑		displayed output
5	Value of earth curvature	K	f	d	d/miles(Km)
	AT INCREMENTAL DISTANCES				
6*	Distance increment	Δd/miles(Km)	f	b	
7	Value of earth curvature	K	E		See Below

*NOTE: If these entries remain unchanged from previous calculations they do not need to be re-entered.

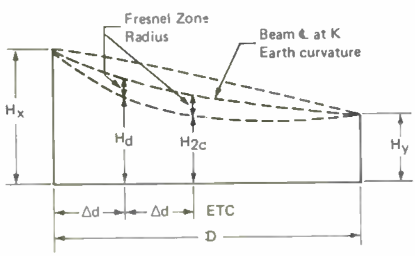


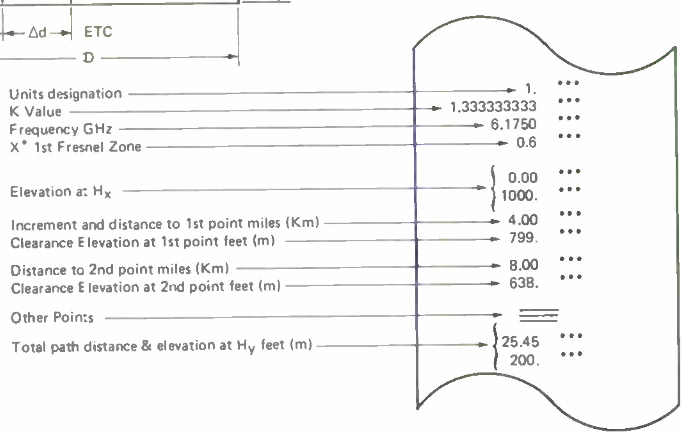


User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	CLEARANCE ELEVATION AT INCREMENTAL DISTANCES				
1*	The program is set for Imperial units (feet & miles). If metric units				
	(meters & kilometers) are required or a change back to Imperial				
	units is required, the following is performed:				
	(units designation 1 = Imperial, 2 = metric)	None	f	e	units designation
2*	Total Path Distance	D/miles (Km)	B		
3*	Antenna center-line elevation AMSL at site X	H_x/feet (m)	↑		
	Antenna center-line elevation AMSL at site Y	H_y/feet (m)	A		H_x
4*	Distance increment	Δd/miles (Km)	f	b	
5*	Operating Frequency	Freq/GHz	f	a	
6	Portion of first Fresnel Zone required**	F_z	↑		
	Value of earth curvature	K	D		See Below





	*NOTE: If these entries remain unchanged from previous calculations				
	they do not need to be re-entered.				
	**If a number greater than * is entered the program assumes that the				
	Nth Fresnel Zone is required (i.e., $\sqrt{N} \cdot F_1$).				

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBLA	21 11	Store End Heights H_x & H_y		STO4	35 04	Curvature with Fresnel Zones
	STO2	35 02			R↓	–31	
	R↓	–31			STO7	35 07	
	STO0	35 00		060	GSB9	23 09	
	RTN	24			RCL4	36 04	
	•LBLB	21 12	Store Total Distance D		DSP9	–63 09	
	STO1	35 01			PRTX	–14	
	RTN	24			RCL5	36 05	
	•LBLb	21 16 12	Store Incremental Distance Δd		DSP4	–63 04	
010	STO3	35 03			PRTX	–14	
	RTN	24			RCL7	36 07	
	•LBLa	21 16 11	Store Frequency f_{GHz}		DSP1	–63 01	
	STO5	35 05			PRTX	–14	
	RTN	24		070	SPC	16–11	
	•LBLe	21 16 15	Set or Reset Metric Flag F1 And Output Units Designator		0	00	
	F1?	16 23 01			STO6	35 06	
	GTO0	22 00			RCL0	36 00	
	SF1	16 21 01			•LBL3	21 03	
	2	02			GSB8	23 08	Print Subroutine
020	RTN	24			RCL6	36 06	
	•LBL0	21 00			RCL3	36 03	
	CF1	16 22 01			+	–55	
	1	01			STO6	35 06	Preset Distance
	RTN	24		080	RCL1	36 01	
	•LBLE	21 15	Earth Curvature		X≤Y?	16–35	
	STO4	35 04			GTO2	22 02	
	GSB9	23 09	Units Subroutine		GSB6	23 06	Fresnel Subroutine
	RCL4	36 04			1	01	If zone > 1
	DSP9	–63 09			RCL7	36 07	assume F_N If not,
030	PRTX	–14			X>Y?	16–34	assume N F_1
	SPC	16–11			√X	54	
	0	00			ST•8	35–35 08	
	STO6	35 06			GSB7	23 07	Earth curvature Sub
	RCL0	36 00		090	RCL8	36 08	
	•LBL1	21 01			–	–45	
	GSB8	23 08	Print Subroutine		GTO3	22 03	Calculate Elevation
	RCL6	36 06			•LBLC	21 13	Run Fresnel Zone
	RCL3	36 03			STO6	35 06	Store d
	+	–55			GSB9	23 09	Units Subroutine
040	STO6	35 06			RCL5	36 05	
	RCL1	36 01			DSP4	–63 04	
	X≤Y?	16–35			PRTX	–14	
	GTO2	22 02			RCL1	36 01	
	GSB7	23 07		100	DSP2	–63 02	
	GTO1	22 01			PRTX	–14	
	•LBL2	21 02	Finish Printout		RCL6	36 06	
	STO6	35 06			PRTX	–14	
	RCL2	36 02			SPC	16–11	
	GSB8	23 08	Print Subroutine		GSB6	23 06	Fresnel Subroutine
050	SPC	16–11			.	–62	
	SPC	16–11			3	03	
	SPC	16–11			DSP1	–63 01	
	DSP2	–63 02			PRTX	–14	
	CLX	–51		110	×	–35	
	RTN	24			DSP0	–63 00	
	•LBLD	21 14	Run Earth		PRTX	–14	= 0.3 F_1

REGISTERS

0	1	2	3	4	5	6	7	8	9
H_x	D	H_y	Δd	k	f_{GHz}	d	z	F_1 Zone	
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
← NOT USED →									

A	B	C	D	E	I

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
	SPC	16–11	
	RCLB	36 08	
	.	–62	
	6	06	
	DSP1	–63 01	
	PRTX	–14	
	X	–35	
120	DSP0	–63 00	
	PRTX	–14	= 0.6 F_1
	SPC	16–11	
	1	01	
	DSP1	–63 01	
	PRTX	–14	
	RCLB	36 08	
	DSP0	–63 00	
	PRTX	–14	= F_1
	SPC	16–11	
130	SPC	16–11	
	SPC	16–11	
	SPC	16–11	
	DSP2	–63 02	
	CLX	–51	
	RTN	24	
	•LBL6	21 06	Fresnel Subroutine
	RCL1	36 01	
	RCL6	36 06	
	–	–45	Imperial
140	RCL6	36 06	
	X	–35	$F_1 = 72.1 \sqrt{\frac{(D-d)d}{f_{GHz} D}}$
	RCL5	36 05	
	RCL1	36 01	
	X	–35	
	÷	–24	Metric
	√X	54	
	F1?	16 23 01	$F_1 = 17.3 \sqrt{\frac{(D-d)d}{f_{GHz} D}}$
	GTO0	22 00	
	7	07	
150	2	02	
	.	–62	
	1	01	
	•LBL4	21 04	
	X	–35	
	STOB	35 08	
	RTN	24	
	•LBL0	21 00	Metric Constant for Fresnel Subroutine
	1	01	
	7	07	
160	.	–62	
	3	03	
	GTO4	22 04	
	•LBL7	21 07	Earth Curvature Subroutine
	RCL0	36 00	
	RCL0	36 00	
	RCL2	36 02	Calculate Slope Elevation
	–	–45	
	RCL1	36 01	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	÷	–24	
170	RCL6	36 06	$H_s = H_x - \left(\frac{H_x - H_y}{D} d\right)$
	X	–35	
	–	–45	
	RCL1	36 01	Calculate Earth Curvature
	RCL6	36 06	
	–	–45	Imperial
	RCL6	36 06	
	X	–35	$H_k = \frac{(D-d)\ \ d}{k \cdot 1.5}$
	F1?	16 23 01	
	GTO0	22 00	
180	1	01	Metric
	.	–62	
	5	05	$H_k = \frac{(D-d)\ \ d}{k \cdot 12.75}$
	•LBL5	21 05	
	RCL4	36 04	
	X	–35	
	÷	–24	
	–	–45	
	RTN	24	$H_d = H_s - H_k$
	•LBL0	21 00	Metric Constant for Earth Curvature
190	1	01	
	2	02	
	.	–62	
	7	07	
	5	05	
	GTO5	22 05	
	•LBLB	21 08	Print Subroutine
	DSP2	–63 02	
	RCL6	36 06	
	PRTX	–14	Print Output Subroutine
200	R↓	–31	
	DSP0	–63 00	
	PRTX	–14	
	SPC	16–11	
	RTN	24	
	•LBL9	21 09	Print Units Designator
	SPC	16–11	
	1	01	1 = Imperial
	DSP0	–63 00	2 = Metric
	F1?	16 23 01	
210	2	02	
	PRTX	–14	
	RTN	24	
	•LBLd	21 16 14	Run Specific Earth Curvature
	STO4	35 04	
	R↓	–31	
	STO6	35 06	
	GSB7	23 07	
	RCL6	36 06	
	DSP2	–63 02	
220	PSE	16 51	
	R↓	–31	
	DSP0	–63 00	
	RTN	24	
	R/S	51	

LABELS

A 001	B 006	C 093	D 056	E 025
a 012	b 015	c	d 213	e
0 21,157,189	1 035	2 046	3 074	4 154
5 183	6 136	7 163	8 196	9 205

FLAGS

0	– – –
1	Imperial (Off) Metric (On)
2	– – –
3	– – –

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 2	

Program Description

Program Title	REFLECTION		
Name	John E. Hendricks, Jr., Staff Engineer	**Date**	2/6/79
Address	GTE Lenkurt, 1105 County Road		
City	San Carlos	State CA	Zip Code 94070

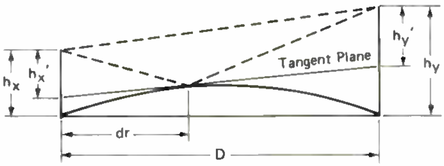
Program Description, Equations, Variables, etc.

This program calculates the parameters normally used in designing microwave paths that contain reflection points. The user has the option of performing the calculations in imperial units (feet and miles) or metric units (meters and kilometers). The program uses a solution to the cubic equation derived from the following relationships:

$$\frac{h_x'}{dr} = \frac{h_y'}{D-dr}$$

$$hx' = h_x - \frac{dr^2}{1.5K}$$

$$hy' = hy - \frac{(D-dr)^2}{1.5K}$$



For metric units, substitute 12.75K for 1.5K. The solution for these equations is in steps 50 through 106 of the program listing. Additional equations come from the GTE Lenkurt publication, "Engineering Considerations for Microwave Communications Systems."

The following formulas appear in that publication:

Fresnel Zone radius — Imperial, page 38; metric, page B2.

Earth Curvature — Imperial, page 12; metric, page B1.

The reference for the reflection point angle is: Appendix A of "Radio Relay Antenna Pointing for Controlled Interference with Geostationary Satellites", Bell System Technical Journal, December 1963.

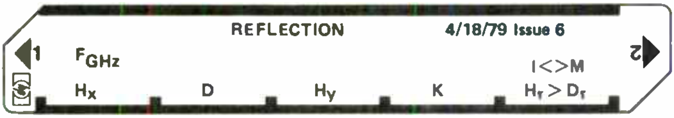
Operating Limits and Warnings There is much confusion regarding Fresnel Zone radius less than 1. This program uses the following convention:

For Fresnel Zone radius less than 1 the program is always the value times the first Fresnel Zone radius (i.e., 0.6 F_1).

For Fresnel Zone radius greater than or equal to 1, the program always uses the square root of the value times the first Fresnel Zone (i.e., $\sqrt{N}F_1$).

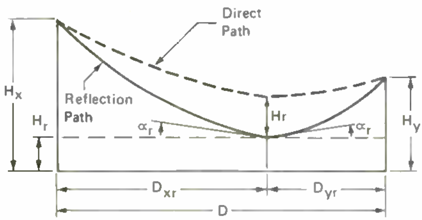
This program will not work for negative values of K or when the reflection point elevation exceeds either end point elevations. For K = ∞, use K = 9 X 10^{10}. Larger values than 9 X 10^{10} may give erroneous answers. Program is accurate to 0.01 miles (0.016 Km) and reflection point clearance of 0.1 ft (.003 meters) for total path distances to 100 miles (160 Km).

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	The program is pre-set for Imperial units (feet & miles).				
	If metric units (meters & kilometers) are required or if a change				
	back to Imperial units from metric units is required the following				
	step is performed:				
	(units designation 1 = Imperial, 2 = Metric)	None	f	e	units designation
2*	Antenna center-line elevation AMSL at site X	H_x/Feet (m)	A		H_x
3*	Total path length	D/miles(Km)	B		D
4*	Antenna center-line elevation AMSL at site Y	H_y/Feet (m)	C		H_y
5*	Value of earth curvature	K	D		K
6*	Operating frequency	Freq/GHz	f	a	Freq
7	Enter the elevation AMSL at the suspected reflection point	H_r/Feet (m)	E		See Below

*Note: If these entries remain unchanged from previous calculations they do not need to be re-entered.



Units Designation	1. ***
Elevation at H_x	2095.000000 ***
Elevation at Reflection H_r	2015.000000 ***
Total Path Length	25.68000000 ***
Elevation at H_y	2400.000000 ***
Value of K used for calculations	1.333333333 ***
Distance from H_x to Reflection Point D_{xr}	6.15 ***
Distance from H_y to Reflection Point $-D_{yr}$	−19.53 ***
Clearance of main beam at Reflection Point H_r	92.97 ***
Operating Frequency**	6.1750 ***
Fresnel Zone at Reflection Point**	2.20 ***
Angle of beam at the Reflection Point α_r**	0.11 ***

**Note: When the path is obstructed due to the height of the reflection point, these items are not printed.

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
	STO0	35 00	Store H_x
	RTN	24	
	*LBLE	21 12	
	STO1	35 01	Store D_{TOTAL}
	RTN	24	
	*LBLC	21 13	
	STO2	35 02	Store H_y
	RTN	24	
010	*LBLD	21 14	
	STO3	35 03	Store K
	RTN	24	
	*LBLa	21 16 11	
	STO5	35 05	Store Frequency
	RTN	24	
	*LBLe	21 16 15	Set Units Designation
	F0?	16 23 00	
	GTOe	22 16 15	
	SF0	16 21 00	Set Metric
020	2	02	
	RTN	24	
	*LBLe	21 16 15	
	CF0	16 22 00	Set Imperial
	1	01	
	RTN	24	
	*LBLE	21 15	Run Program
	STO4	35 04	
	DSP0	–63 00	
	1	01	
030	F0?	16 23 00	
	2	02	
	PRTX	–14	Print Units Designation
	DSP9	–63 09	
	RCL0	36 00	
	PRTX	–14	Print H_x
	RCL4	36 04	
	PRTX	–14	Print H_r
	–	–45	
	STOA	35 11	
040	RCL2	36 02	
	RCL4	36 04	
	–	–45	
	STOB	35 12	
	+	–55	
	RCL3	36 03	
	X	–35	
	F0?	16 23 00	
	GSB4	23 04	
	RCL1	36 01	
050	PRTX	–14	Print Total Distance
	X^2	53	
	3	03	$q = \sqrt{\dfrac{(H_A+H_B)*K+\dfrac{D^2}{3}}{4}}$
	÷	–24	
	+	–55	
	4	04	
	÷	–24	Metric K = K*8.5

STEP	KEY ENTRY	KEY CODE	COMMENTS
	$\sqrt{X}$	54	
	STO8	35 08	
	3	03	
060	Y^X	31	
	RCL0	36 00	
	RCL2	36 02	
	PRTX	–14	Print H_y
	–	–45	
	STO6	35 06	
	RCL1	36 01	
	X	–35	
	ABS	16 31	
	RCL3	36 03	
070	PRTX	–14	Print K
	SPC	16–11	
	X	–35	
	3	03	
	X	–35	
	1	01	
	6	06	
	÷	–24	
	F0?	16 23 00	
	GSB4	23 04	
080	X⇄Y	–41	
	÷	–24	
	COS^{-1}	16 42	
	3	03	
	÷	–24	Store 8 = $q * 2\ COS\left(240 + \frac{1}{3} COS^{-1} \frac{3\lvert H_x - H_y\rvert * D * K}{16 q^3}\right)$
	2	02	
	4	04	
	0	00	
	+	–55	
	COS	42	
090	2	02	
	X	–35	
	ST•B	35–35 0B	
	RCL1	36 01	
	2	02	
	÷	–24	
	ST+B	35–55 0B	
	RCL6	36 06	
	X<0?	16–45	
	GTO0	22 00	IF $H_x \geq H_y$
100	RCL1	36 01	$O_{xr} = \frac{D}{2}$ – Store B
	RCLB	36 08	
	–	–45	Else
	STOB	35 0B	
	*LBL0	21 00	$D_{xr} = \frac{D}{2}$ + Store B
	RCLB	36 08	
	DSP2	–63 02	
	PRTX	–14	Print D_{xr}
	RCL1	36 01	
	–	–45	
110	STO9	35 09	
	PRTX	–14	Print D_{yr}
	SPC	16–11	

REGISTERS

0	1	2	3	4	5	6	7	8	9
H_x	D_{TOTAL}	H_y	K	H_R	FREQ	L_R	Fresnel Zone	D_{xr}	D_{yr}
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
$H_x - H_r$	$H_y - H_r$	$D_{xr} * (-D_{yr})$			

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCLA	36 11	
	RCL6	36 06	
	RCL1	36 01	
	÷	–24	
	RCL8	36 08	
	X	–35	
	–	–45	
120	RCL8	36 08	
	STO6	35 06	
	RCL9	36 09	
	CHS	–22	
	X	–35	
	STOC	35 13	
	1	01	
	.	–62	
	5	05	
	F0?	16 23 00	
130	GSB4	23 04	
	÷	–24	
	RCL3	36 03	
	÷	–24	
	–	–45	
	PRTX	–14	Print Path Clearance
	X<0?	16–45	Stop Program
	RTN	24	IF Path Obstructed
	RCLC	36 13	
	RCL5	36 05	
140	DSP4	–63 04	
	PRTX	–14	Print Frequency
	DSP2	–63 02	
	÷	–24	
	RCL1	36 01	
	÷	–24	
	√X	54	
	F0?	16 23 00	
	GTO5	22 05	
	7	07	
150	2	02	
	.	–62	
	1	01	
	•LBL1	21 01	
	X	–35	
	÷	–24	
	1	01	
	X⇄Y	–41	
	X<Y?	16–34	
	X²	53	
160	STO7	35 07	
	PRTX	–14	Print Fresnel Zone
	RCLA	36 11	
	GSB7	23 07	
	F0?	16 23 00	
	GTO6	22 06	
	7	07	
	9	09	
	2	02	

$$\text{Path}_C = H_x - H_r - \frac{D_{xr}}{D}(H_x - H_y) - \left(\frac{D_{xr} \cdot (-D_{yr})}{1.5K}\right)$$

Metric K = 8.5 • K

PATH CLEARANCE

$$F_Z = \left(\begin{pmatrix}72.1\ \text{Imperial}\\ 17.3\ \text{Metric}\end{pmatrix}\sqrt{\frac{D_{xr} \cdot (-D_{yr})}{\text{frequency} \cdot D_{TOTAL}}}\right)^2$$

IF $F_Z >$ Then $F_Z = \sqrt{F_Z}$

STEP	KEY ENTRY	KEY CODE	COMMENTS
	0	00	
170	•LBL3	21 03	
	RCL3	36 03	
	X	–35	
	ST÷6	35–24 06	
	RCL0	36 00	
	RCL4	36 04	
	+	–55	
	GSB7	23 07	
	+	–55	
	RCL6	36 06	
180	R→D	16 46	
	TAN	43	
	X	–35	
	÷	–24	
	TAN⁻¹	16 43	
	RCL6	36 06	
	R→D	16 46	
	–	–45	
	PRTX	–14	
	STO6	35 06	
190	SPC	16–11	
	RTN	24	Print Reflection Angle
	•LBL4	21 04	Metric
	8	08	K Conversion
	.	–62	
	5	05	K Metric = K • 8.5
	X	–35	
	RTN	24	
	•LBL5	21 05	
	1	01	Metric
200	7	07	Fresnel Zone
	.	–62	Constant
	3	03	
	GTO1	22 01	
	•LBL6	21 06	Metric
	1	01	Earth
	2	02	Radius • 2
	7	07	
	4	04	
	6	06	
210	GTO3	22 03	
	•LBL7	21 07	
	F0?	16 23 00	
	GTO8	22 08	Convert
	5	05	Feet To
	2	02	Miles
	8	08	
	0	00	
	÷	–24	
	RTN	24	
220	•LBL8	21 08	
	EEX	–23	Convert
	3	03	Meters To
	÷	–24	Kilometers
	RTN	24	

$$L_R = \text{Tan}^{-1}\left[\frac{H_x - H_r}{\text{TAN}\left(\frac{D}{K_{2a}}\right)_{\text{radians}} \cdot (K_{2a} + H_r + H_r)}\right] - \frac{D}{K_{2a}}\ \text{radians}$$

LABELS

A 001	B 004	C 007	D 010	E 026
a 013	b	c	d	e
0 104	1 153	2	3 170	4 192
5 198	6 204	7 211	8 220	9

FLAGS

0	On=Metric
1	016/022
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

ADDRESS CORRECTION REQUESTED

Bulk Rate
U. S. Postage
PAID
San Carlos, CA
Permit No. 37

1

PIC00319C015
B J PICOU

319 CRAWFORD ST
LAFAYETTE LA 70501

EF&I

GTE Lenkurt's Engineer Furnish and Install service provides overall management of planning, engineering, construction, installation, testing and maintenance of GTE Lenkurt communications systems.

GTE Lenkurt personnel will plan a system in detail; conduct cost studies, obtain all necessary parts and equipment; arrange for construction of access roads; supervise installation; provide comprehensive project information and conduct on-the-job training for operating and maintenance personnel. Or, if the customer prefers, GTE Lenkurt will perform only specific portions of planning and installation.

GTE LENKURT

VIDEO, VOICE & DATA
TRANSMISSION SYSTEMS

The GTE Lenkurt Demodulator is circulated bimonthly to selected technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.