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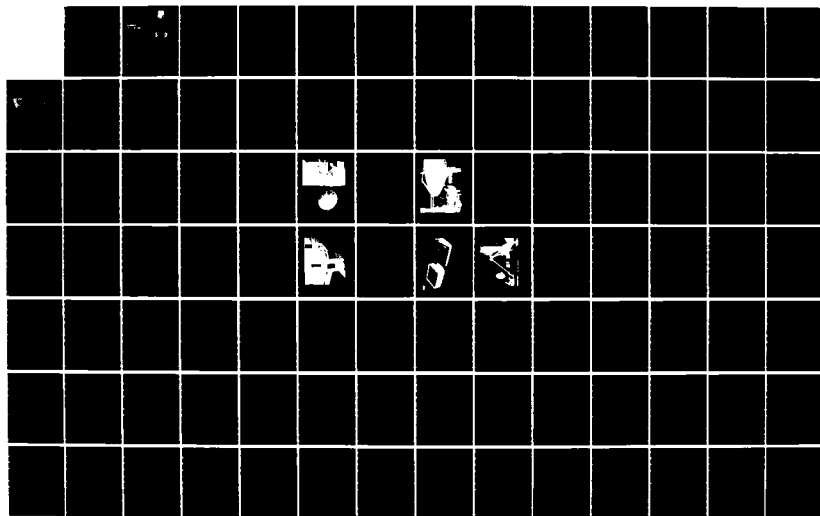
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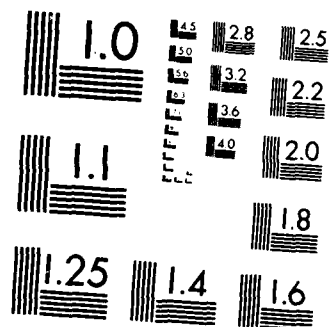
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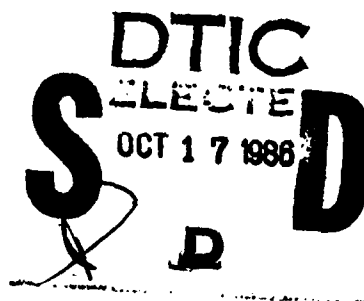
RADC-TR-86-96
In-House Report
July 1986



AD-A173 282

ALIGNMENT OF TACTICAL TRCPO ANTENNAS

Philip A. Bradley



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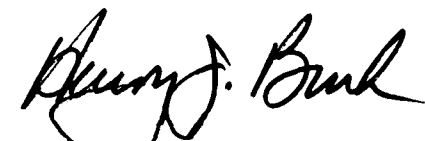
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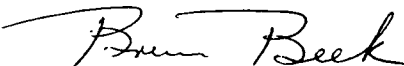
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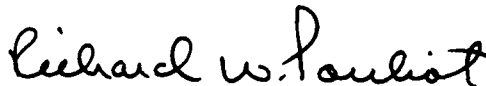
HENRY J. BUSH, Assistant Chief
Communications Transmission Branch
Communications Division

APPROVED:



BRUNO BEEK
Technical Director
Communications Division

FOR THE COMMANDER:



RICHARD W. POULIOT
Plans and Programs Division

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ABSTRACT

Alignment of tropospheric scatter radio antennas is often a difficult process. Problems of excessive alignment times and less than optimum alignments occur frequently. Tactical tropo, with requirements for rapid deployment, is severely stressed by antenna alignment problems.

This report outlines present alignment procedures and gives new insight as to why these procedures cannot always provide rapid and accurate alignment. Other techniques, previously developed by RADC, are also discussed.

A new technique of automatic antenna alignment has been successfully tested. The results are presented in this report. The technique features unambiguous and simultaneous azimuth alignment of the antennas of both terminals.



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SECTION 1

BACKGROUND

1.1 Need for Better Alignment Technique

The need for better alignment procedures has been reported by tactical tropo users. Excessive time to alignment, inaccurate alignment and degradation of alignment during operation are typical complaints.

All weather capability, night time operation and alignment under hazardous environmental conditions (chemical, radioactive, biological) are additional requirements. Alignment may also be required under jamming conditions.

1.1.1 Technical Order (T.O.) Antenna Alignment

Alignment is presently accomplished for the TRC-97A radio set by manual methods (complete T.O. procedures can be found in appendix C). A brief description of the installation and alignment process with a three man crew is given here.

Unpacking of antenna components and layout of desired antenna positions (by compass) is accomplished first. The radio set is positioned and two men assemble both antennas while the third man energizes and configures the radio van for the desired communications.

The 3 men erect both antennas and an initial azimuth alignment is given to each antenna by attaching a compass to the antenna mast and turning the antenna until the bearing specified in the operations plan is obtained. Elevation is set by bubble and scale (usually to a value 1/2 degree higher than specified in the operations plan). Contact with the far terminal is attempted without antenna adjustments for a specified period of time.

The transmit/receive antenna at one terminal is scanned in azimuth in period 2. If contact is not made, this antenna is raised one degree in elevation in period 3 and is then

scanned again in period 4. If contact has still not been achieved, the antenna is returned to its initial positions in azimuth and elevation in period 5. The far terminal transmit antenna is then scanned in period 6.

If no contact has been made at this point, then emergency procedures as outlined in the operations plan (the crew assignment sheet) are to be followed. This usually consists of offsetting the antenna of one terminal from its initial position and repeating the above process with the hope that the large initial azimuth misalignment is improved. Various offsets are attempted until communications is established.

If contact was established by any of the above procedures, then the senior crew chief coordinates a procedure of movement of the beams at both terminals in the same direction by 1/2 degree increments and recording the received signal level (RSL). This process is repeated for both directions until a peak in energy is observed. Both terminals then fix their antennas at this azimuth position.

At this time, one terminal optimizes elevation angle followed by the other terminal.

The second (or receive only) antenna at both terminals may now be aligned independently since the transmit antennas are now fixed.

1.1.2 Initial Elevation Misalignment

Initial setting of elevation is easy and unambiguous since a simple bubble and scale attached to the antenna provides reasonable accuracy compared to azimuth initial setting.

1.1.3 Initial Azimuth Misalignment

Inaccurate azimuth alignment and excessive time to final alignment are two complaints with the T.O. procedure. Possible reasons for large initial misalignments are:

1. bad compasses or operation near magnetic material
2. misreading the compasses
3. wrong locations
4. incorrectly reported coordinates

5. Confusion as to which bearing to use, magnetic north or true north
6. Antenna mechanical and electrical axes are not coincident

1.1.4 GREAT CIRCLE (GC) Ambiguity

Another factor, not commonly understood, is Great Circle ambiguity. Figure 1-1a illustrates the desired alignment of both antenna beams on the GC route between the two terminals. A plot of the RSL, obtained by scanning one terminal's antenna while the other terminal's antenna is fixed on GC, is shown in figure 1-1b. It shows a peak in energy as the beam passes GC. Figure 1-2, however, shows an antenna scanning a far antenna which is fixed at some angle off GC. Notice that, compared to figure 1-1b, the RSL has dropped, the pattern has widened somewhat and the apparent center of energy is not at GC but in the direction of the far beam misalignment.

This is GC ambiguity. A simple scan (as described above) by one antenna beam cannot determine the location of the GC path unless the far antenna beam is on GC.

The AN/TRC-97 T.O. attempts to eliminate the ambiguity by requiring that both terminals synchronously move their antenna beams equal amounts in the same direction and take further RSL readings. According to the T.O., RSL will be less if the beams have moved further away from G.C. and will strengthen as GC is approached.

1.1.5 Effect of Initial Misalignment

Small differences in the elevations of the terminals can cause changes in perceived azimuth angle of arrival when a site scans its antenna. The reason for this can be seen in figure 1-3. Figure 1-3a shows a side view of link AB with the terminal B ray (BC) having a significantly greater elevation than the terminal A ray (AC). Intersection of the rays at C occurs closer to the high angle terminal B. Figure 1-3b shows a top view of the same link with the GC path (AB) and also a skewed path (AEB). since elevation has not been changed, intersection of the skewed rays can only occur at the dotted line which was determined by the intersection of the GC rays. Note that for a given ray skew BAE at terminal A, the required skew ABE at terminal B for intersection is larger.

DESIRED GC ALIGNMENT

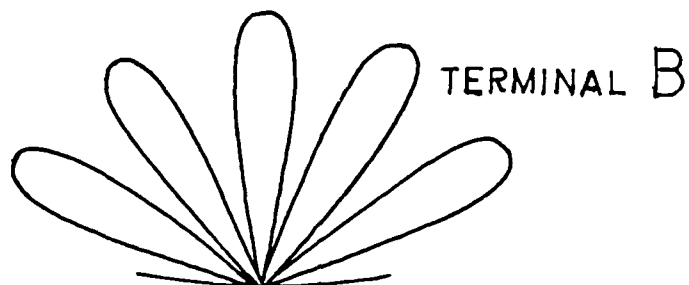
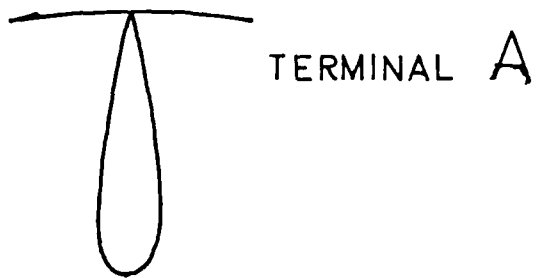


FIG. 1A

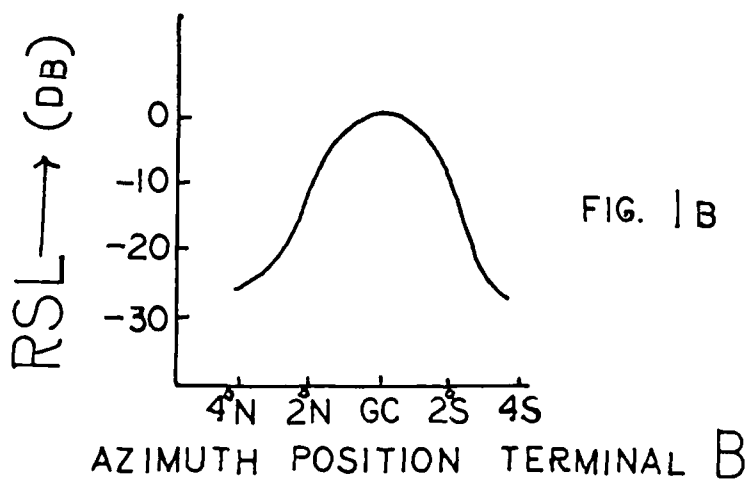


FIG. 1B

Figure 1-1

AZIMUTH MISALIGNMENT PROCESS

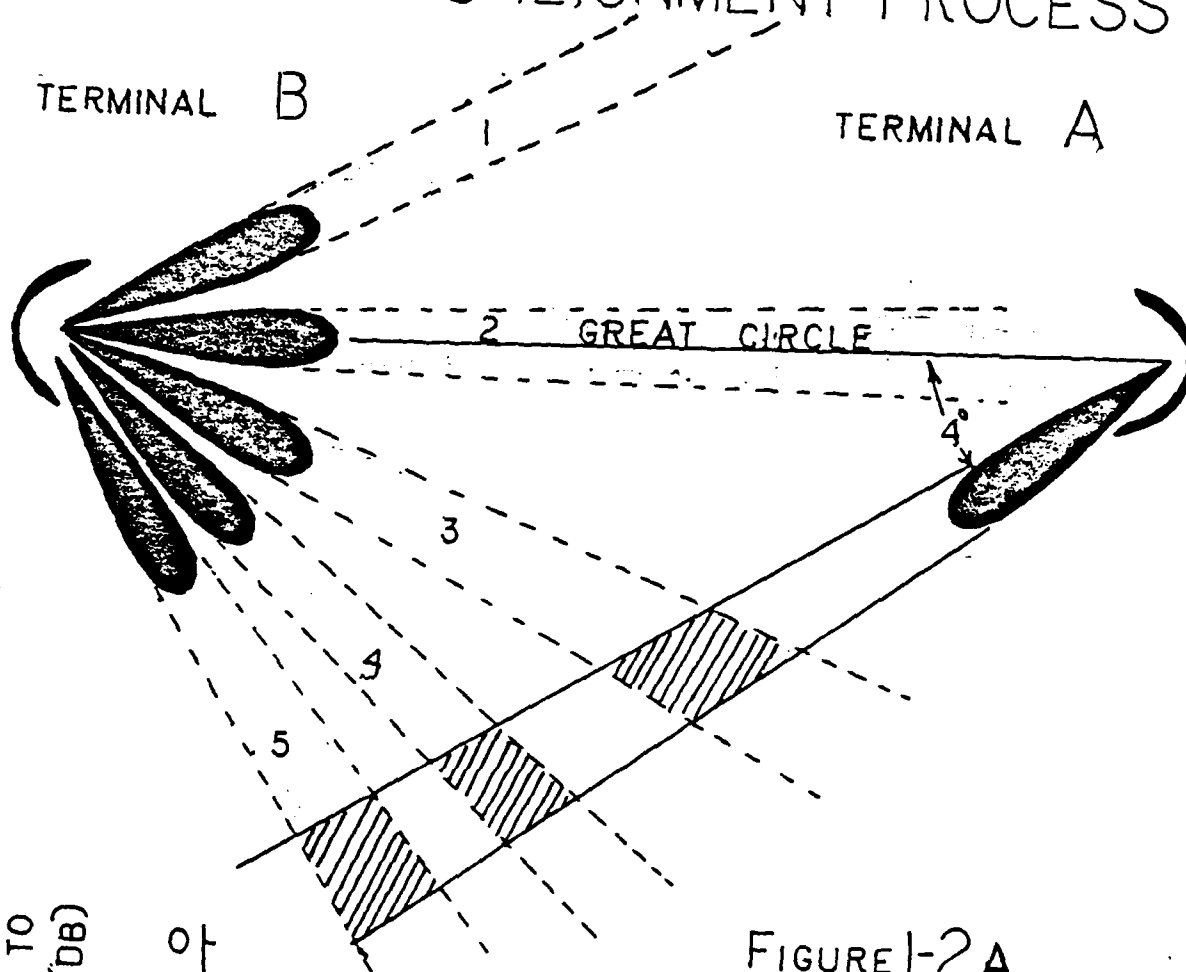


FIGURE 1-2A

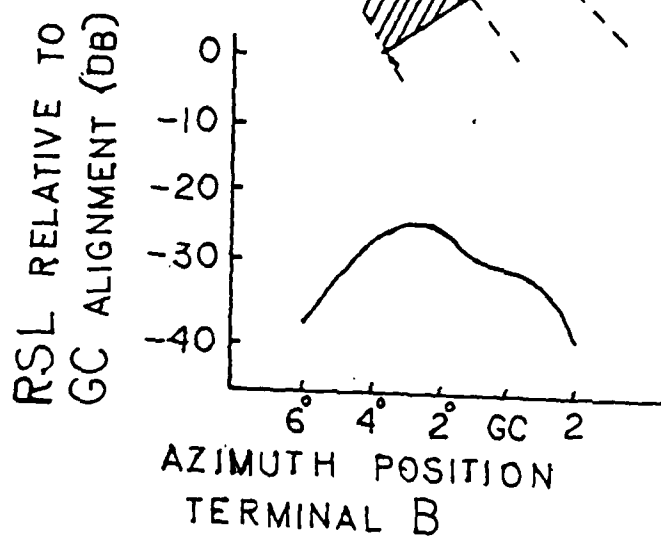


FIGURE 1-2B

Figure 1-2

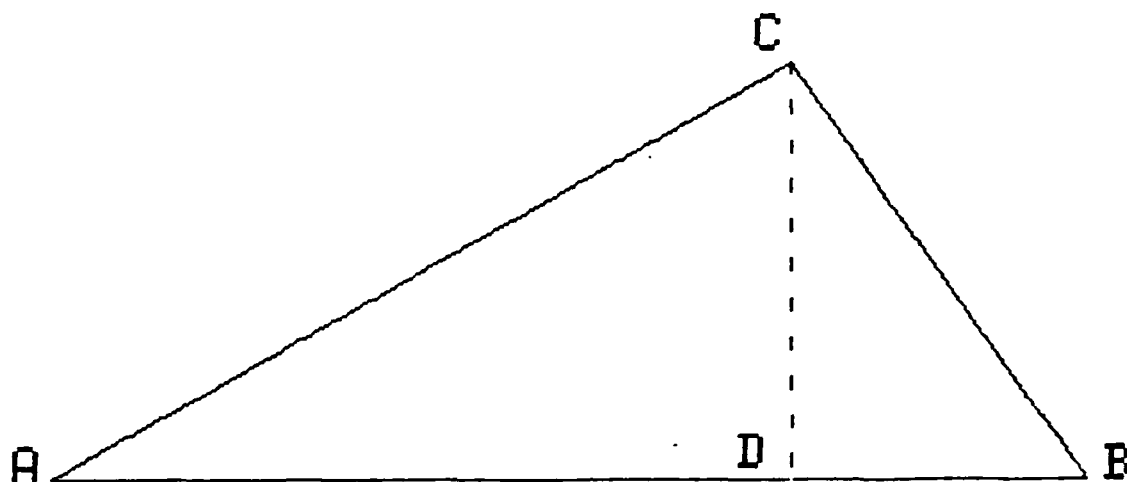


Figure 1-3a

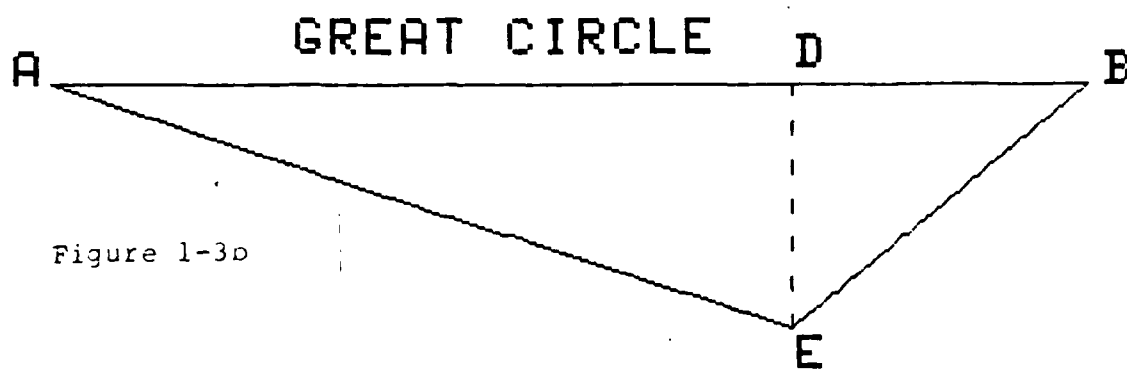


Figure 1-3b

Figure 1-3

The situation for skewed rays is three dimensional as opposed to the two-dimensional problem of rays intersecting on GC. Any attempt to change elevation at either terminal (after an azimuth scan has produced intersection) will eliminate the intersection.

Actually, the antennas do have finite beamwidths and scatter loss is less for those ray intersections with smaller scatter angle. Therefore, an azimuth scan will produce a pointing angle somewhat closer to GC than single ray analysis would suggest. Similarly, an elevation alignment may produce some reduction in elevation as well.

The synchronous scanning technique required by the T.O. assumes that any intersection of skewed beams will be symmetrical, that is, equal azimuth skews will be experienced by both of the terminals. That this is not generally true can be attributed to path asymmetry due to unequal take-off angles and the weighting effect of smaller losses for angles nearer GC on finite beamwidth antennas.

An example is given in Figures 1-4, 1-5 and 1-6 for a 50 mile link using 15 foot antennas. In figure 1-4, a terminal with a low take off angle of 1/2 degree scans a far, transmitted beam which has a 1.5 degree take off angle and a 4 degree azimuth skew. A computer simulation of the scan gives an RSL peak not at 4 degrees but at 1.9 degrees. The two terminals now perform a T.O. synchronous alignment from these positions. In figure 1-5, RSL does not continuously increase as GC is approached, but produces peaks at 0.9 degree for the low terminal and at 3.0 degree skew for the high terminal. Individual elevation alignments in figure 1-6 (zero degrees assumed optimum) do not continuously increase RSL as zero degrees is approached. Peaks are produced, instead, at take off angles of .15 degree and 1.3 degrees. A final misalignment loss of 25 dB is present but the T.O. considers the alignment complete.

Figures 1-7, 1-8 and 1-9 show the T.O. alignment process of the above situation using 8 foot antennas. Beam elevations end up at optimum zero degree takeoff angles for both terminals, but azimuths end at -.55 and +2.05 degrees. The larger beamwidth of the eight foot antenna is more forgiving but the loss in RSL due to misalignment is still over 12 dB.

TROPO LOSS--AZIMUTH MISALIGNMENT

LOW ANGLE TERMINAL

50 MILE PATH

TAKE OFF ANGLES 0.50 AND 1.50 DEG. XMIT + 4 DEG.

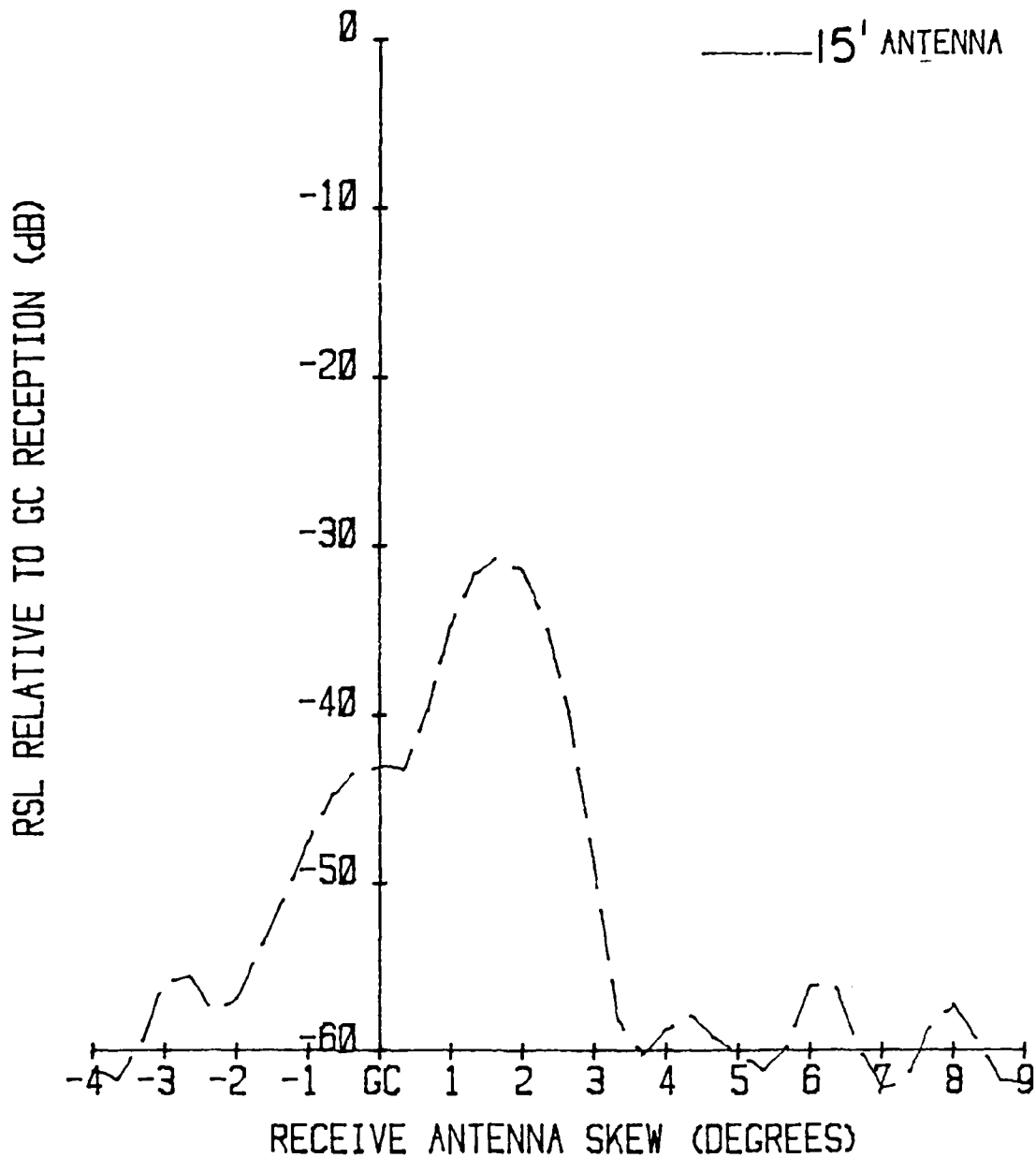


Figure 1-4

TROPO LOSS SYNCHRONOUS SCAN

15' ANTENNA 50 MILE PATH

TAKE OFF ANGLES 0.50 AND 1.50 DEG.

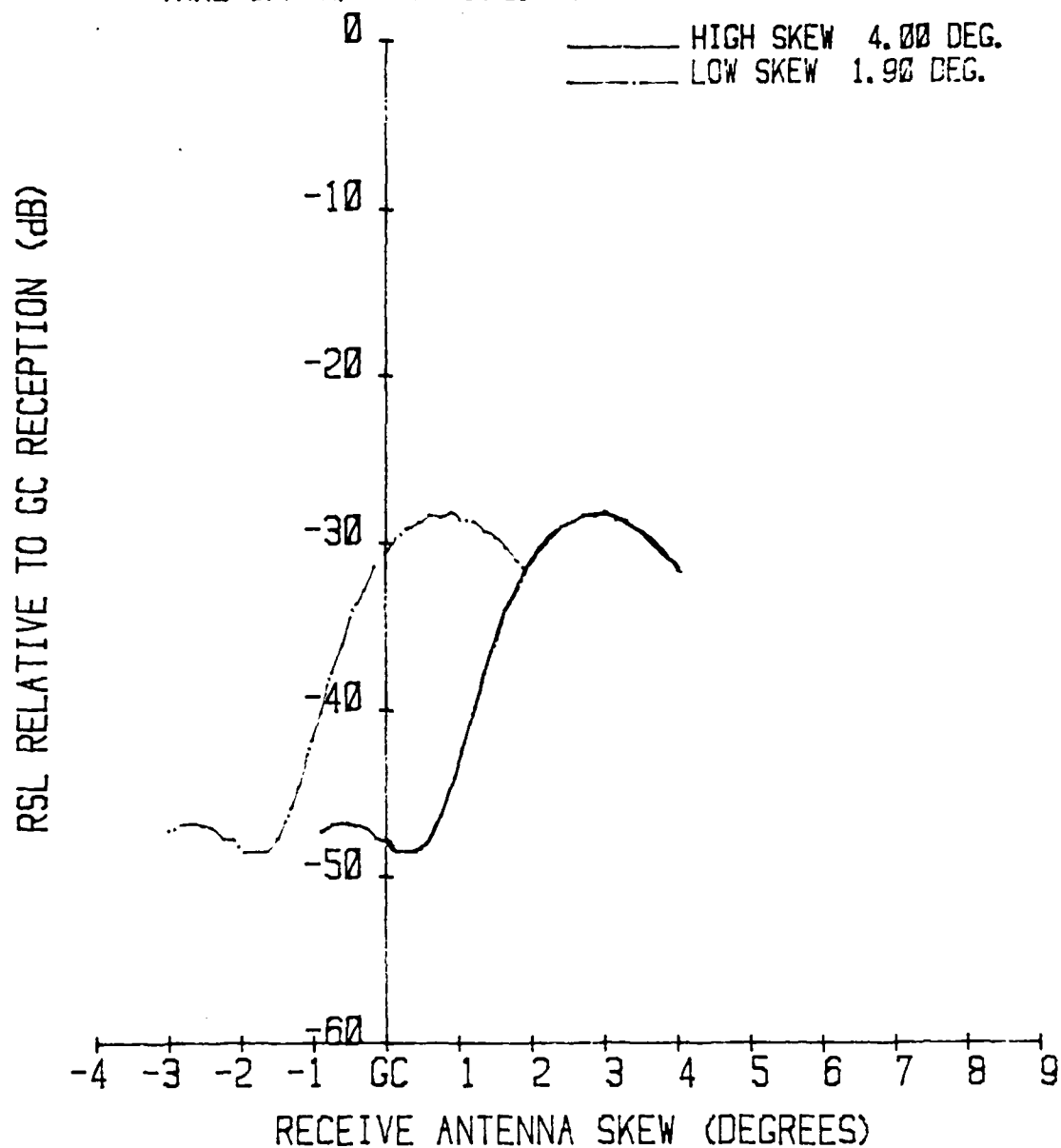


Figure 1-5

ELEVATION SCAN---AZIMUTH SKEW

15' ANTENNA 50 MILE PATH;
TAKE OFF ANGLES 0.50 AND 1.50 DEG.
AZIMUTH ANGLES 0.90 AND 3.00 DEG
---•--- LOW TERMINAL SCAN
--- HIGH TERMINAL SCAN

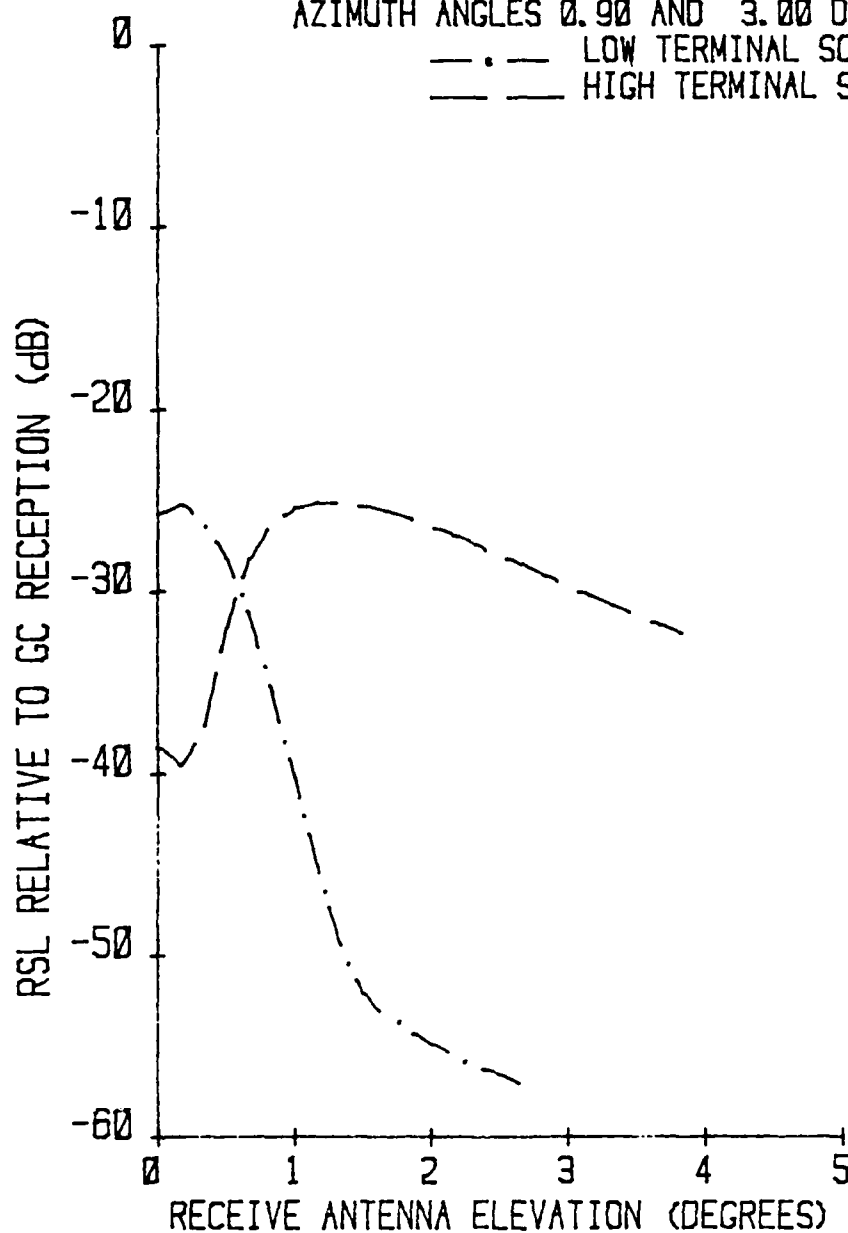


Figure 1-6

TROPO LOSS--AZIMUTH MISALIGNMENT

LOW ANGLE TERMINAL

80 MILE PATH

TAKE OFF ANGLES 0.50 AND 1.50 DEG. XMIT + 4 DEG.

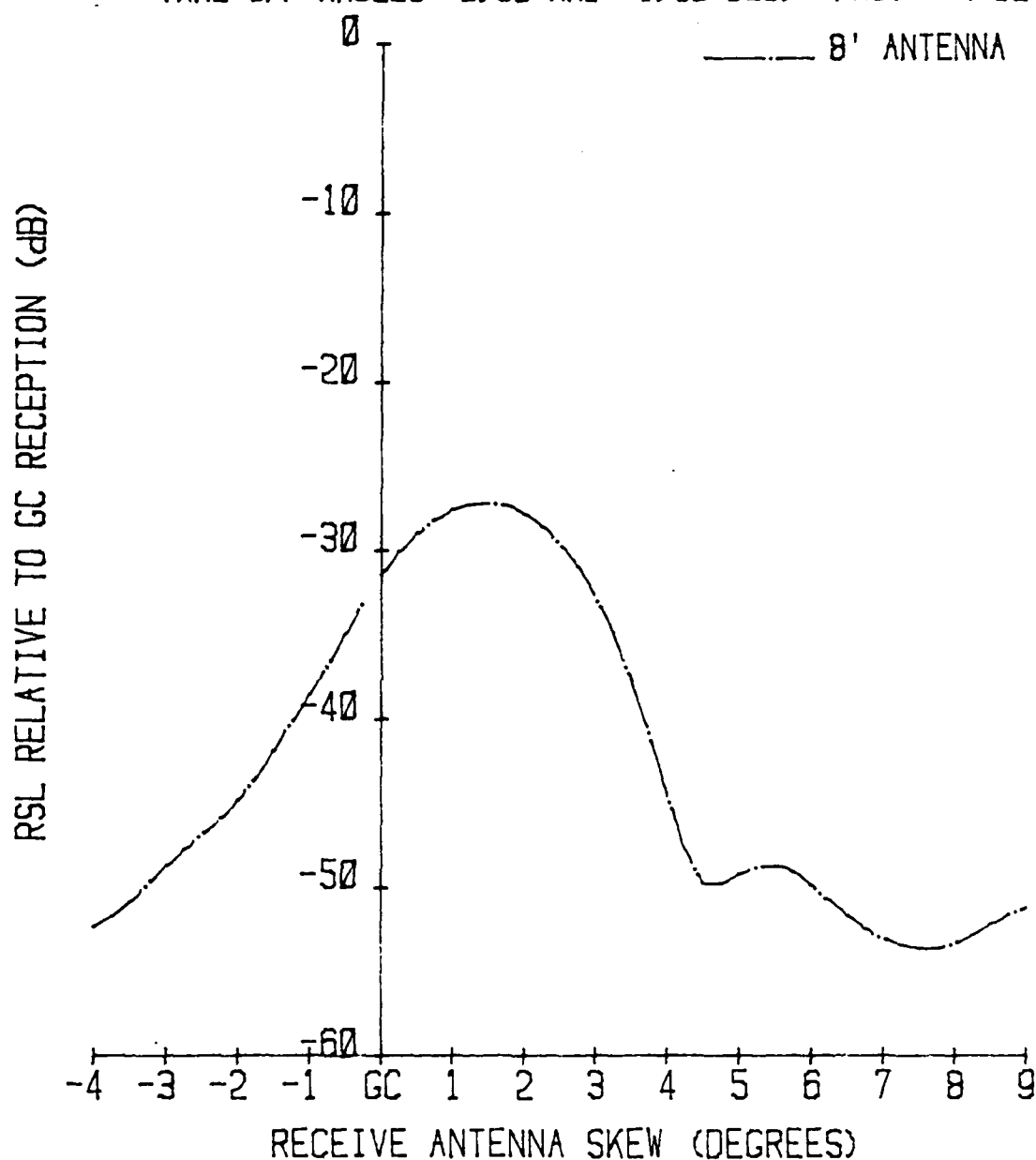


Figure 1-7

TROPO LOSS SYNCHRONOUS SCAN

8' ANTENNA 50 MILE PATH

TAKE OFF ANGLES 0.50 AND 1.50 DEG.

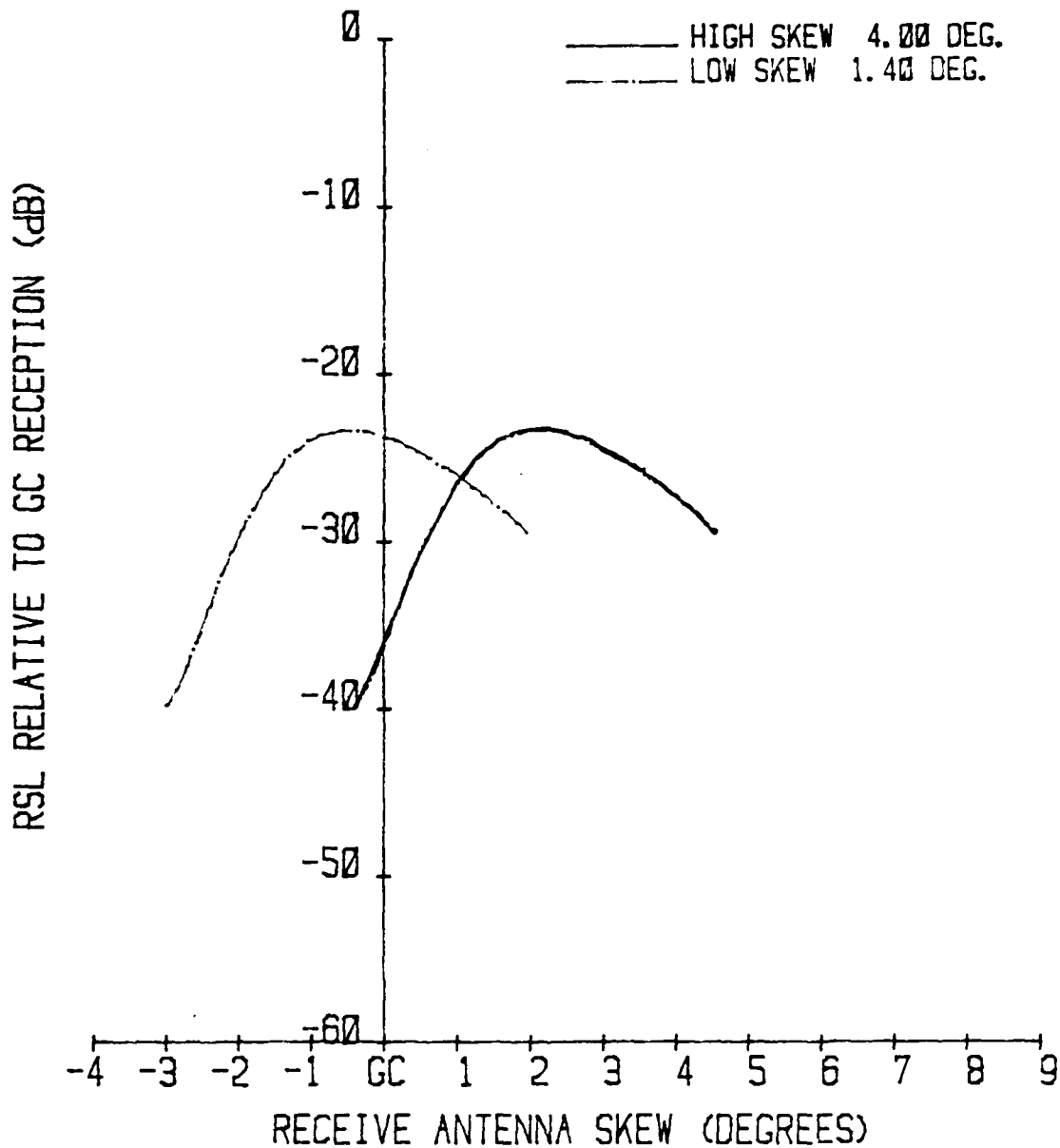


Figure 1-3

ELEVATION SCAN---AZIMUTH SKEW

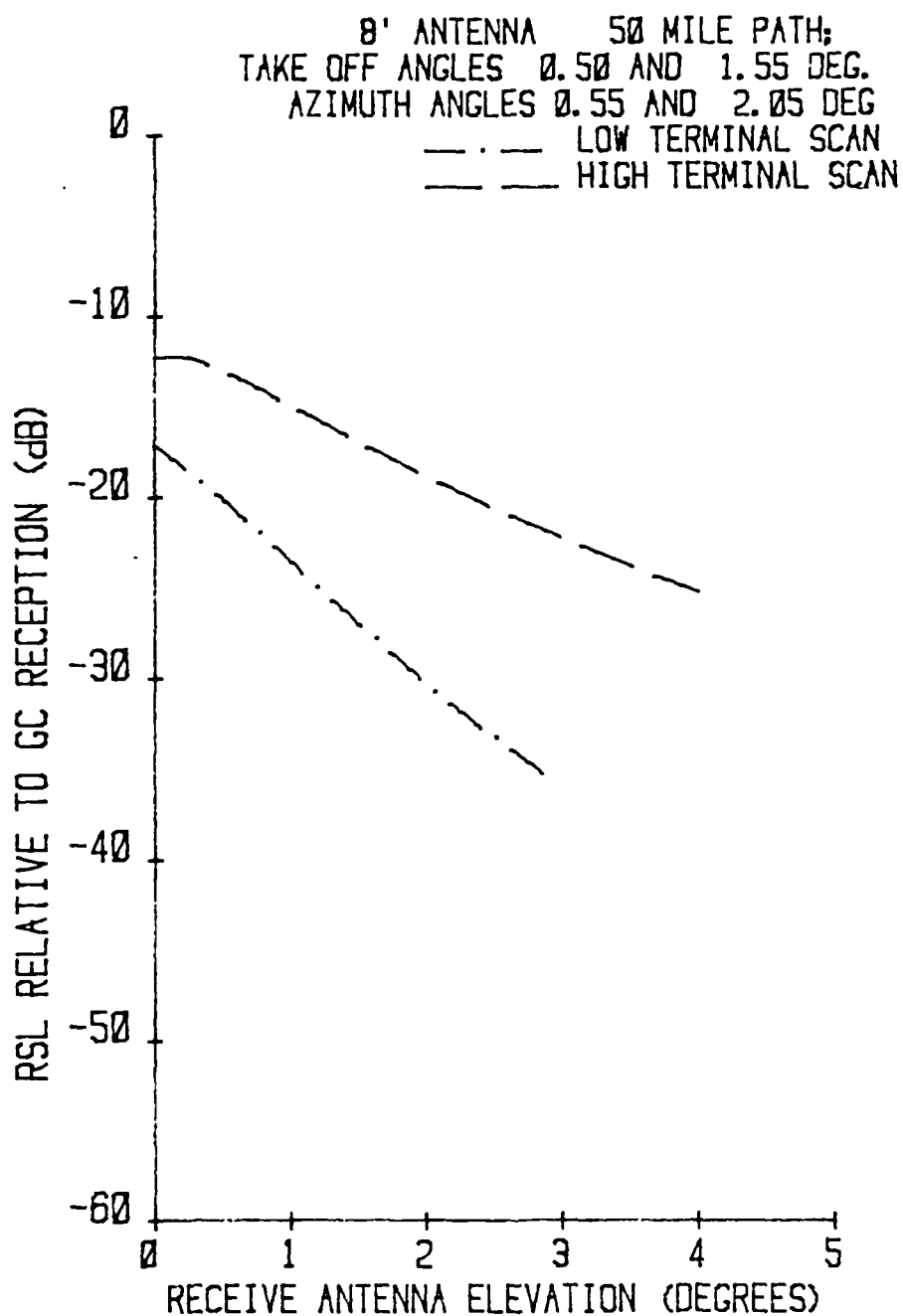


Figure 1-9

1.1.6 Further Misalignment

It may be that sufficient system margin is available initially for acceptable communications with skew alignment losses. However, changes in refractivity of the atmosphere or further misalignment caused by ground movement of wind conditions can rapidly make communications unacceptable. The effects of further azimuth misalignment for the above scenarios are illustrated in figures 1-10 and 1-11. Only one antenna has moved and the zero azimuth position represents the final azimuth from the T.O. alignment.

In the case of the 15 foot antenna, shifts of the low elevation beam from zero cause rapid degradation in RSL. The narrow beamwidth and difference in beam elevations are factors in the narrower pattern here. In the case of the 3-foot antenna, it is obvious that the beams were not optimally intersecting after the T.O. alignment since a movement in one direction increases RSL. The wider pattern can be attributed to wider beamwidth and equal beam elevations.

A similar simulation could be done for further misalignment in elevation at one terminal. It must be remembered, however, that the problem is three dimensional. Any change in either elevation or azimuth will modify the scan in the other parameter.

1.1.7 Realignment Need

Tactical tropo antennas must be capable of frequent and rapid set-up and operation on unstable soil. All weather operation is also required. Accurate alignments can be degraded in a matter of minutes because of weather or soil conditions. A means of realignment or station keeping is needed as well as a means of initial alignment. Since traffic is being passed, realignment procedures must be structured to retain communications. This implies small azimuth and elevation movements and alignment bandwidths equal to the information band.

1.2 Methods of Alignment

A number of alignment techniques were developed and tested over a period of years in an effort to obtain faster and more accurate antenna alignment.

FURTHER AZIMUTH MISALIGNMENT

HIGH ANGLE TERMINAL; 50 MILE PATH 15' ANTENNA
TAKE OFF ANGLES 0.15 AND 1.30 DEG.
HIGH SKEW 3.00 DEG. LOW SKEW 0.90 DEG.

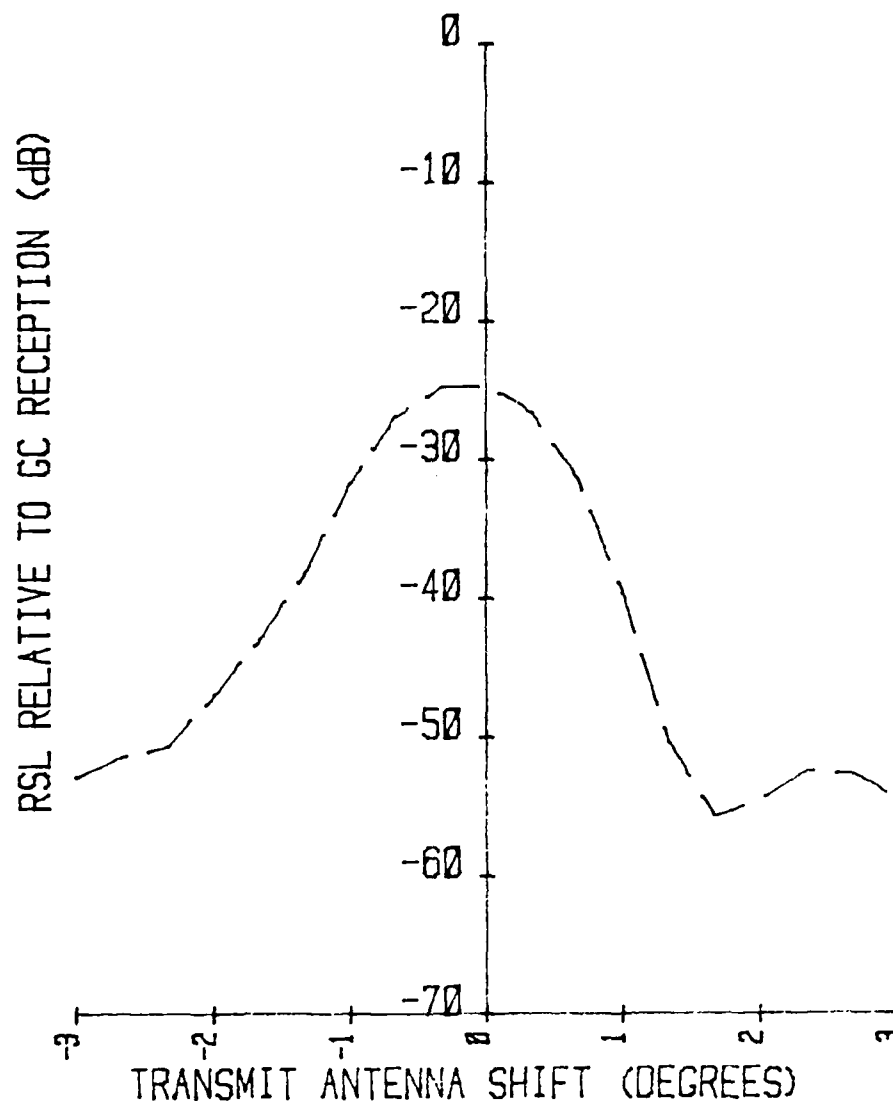


Figure 1-10

FURTHER AZIMUTH MISALIGNMENT

HIGH ANGLE TERMINAL; 50 MILE PATH 8' ANTENNA
TAKE OFF ANGLES 0.00 AND 0.00 DEG.
HIGH SKEW 2.05 DEG. LOW SKEW-0.55 DEG.

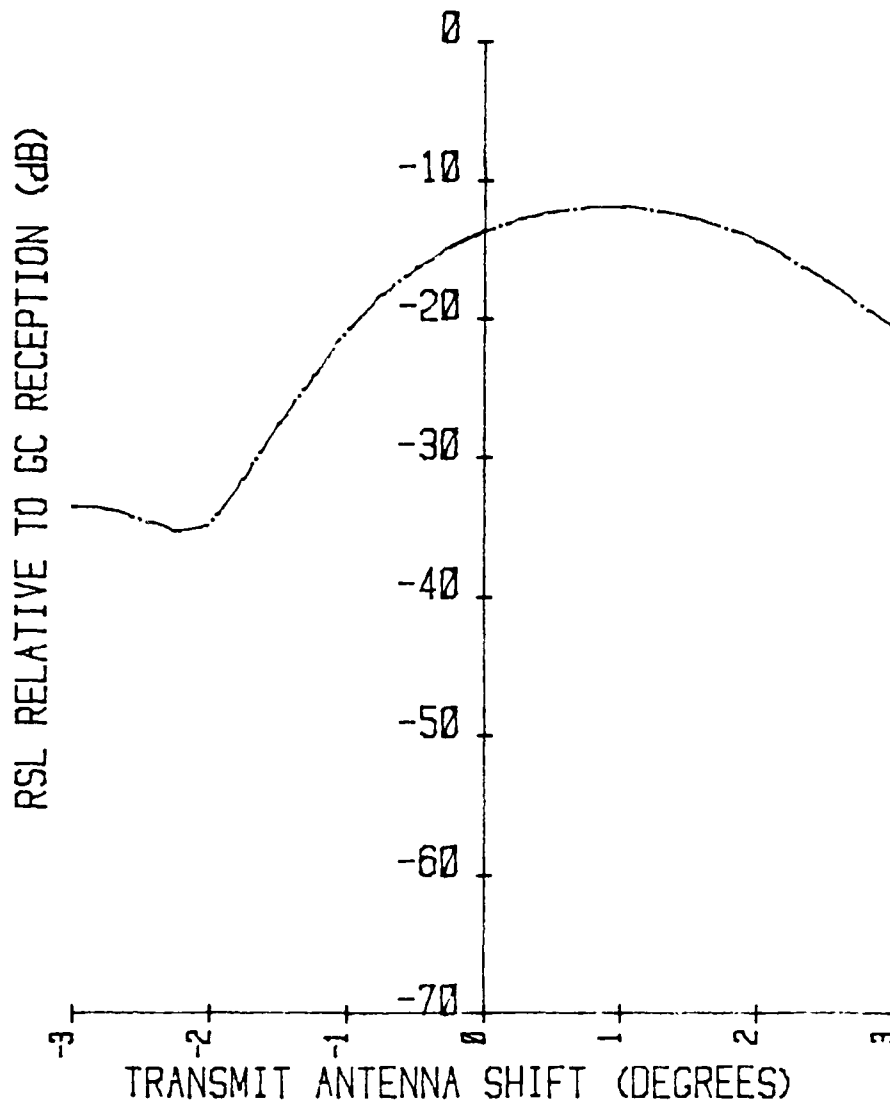


Figure 1-11

1.2.1 Birkmeir Method

A technique sponsored by RADC was developed by Birkmeir of the University of Wisconsin. It is based upon the fact that cross path components of wind in the tropo common volume account for doppler in RSL. If both antennas are fixed on GC, then equal doppler on each side of the carrier frequency is present and the long term doppler average is zero. If the aligning antenna scans a far beam fixed on GC, then the average doppler value is symmetrical on either side of GC and crosses zero at GC. Thus average doppler or a measure of the symmetry of the doppler curve (3rd moment or skew) can be used to indicate GC.

When both beams are initially aligned off the GC, then alignment to the same point in space presents the same symmetry as above. This condition can be made evident by defocussing one of the antennas which destroys the beam symmetry. Azimuth corrections can be made in the fixed beam until symmetry is again evident in the scan at which time both beams are on GC.

The magnitude of the doppler is small, ranging from 0.1 Hz to 5 Hz. The transmitted tropo continuous wave (CW) carrier and receiver local oscillator must be accurate and stable to within a few parts in 10 to the 10th. This requires that a more stable clock be provided to the TRC-97 radios (TRC-170 sets have stable clocks as standard equipment). In addition, data taken with aircraft in the common volume must be eliminated because of the additional doppler produced. Most observable aircraft doppler is above 20 Hz and easily removed by filtering.

RADC tested this technique extensively over an 87 mile link and was not able to achieve reliable alignment results. The cause is presumed to be the presence of large numbers of aircraft in the main beam and sidelobe common volumes. Syracuse Airport is close to the path GC as can be seen in figure 1.12. Motion of aircraft along the GC route frequently occurs. Low frequency doppler from the aircraft is possible in this situation.

Since alignment systems may be required to operate with large numbers of aircraft within the transmission path, and this system does not align elevation, the technique was rejected.

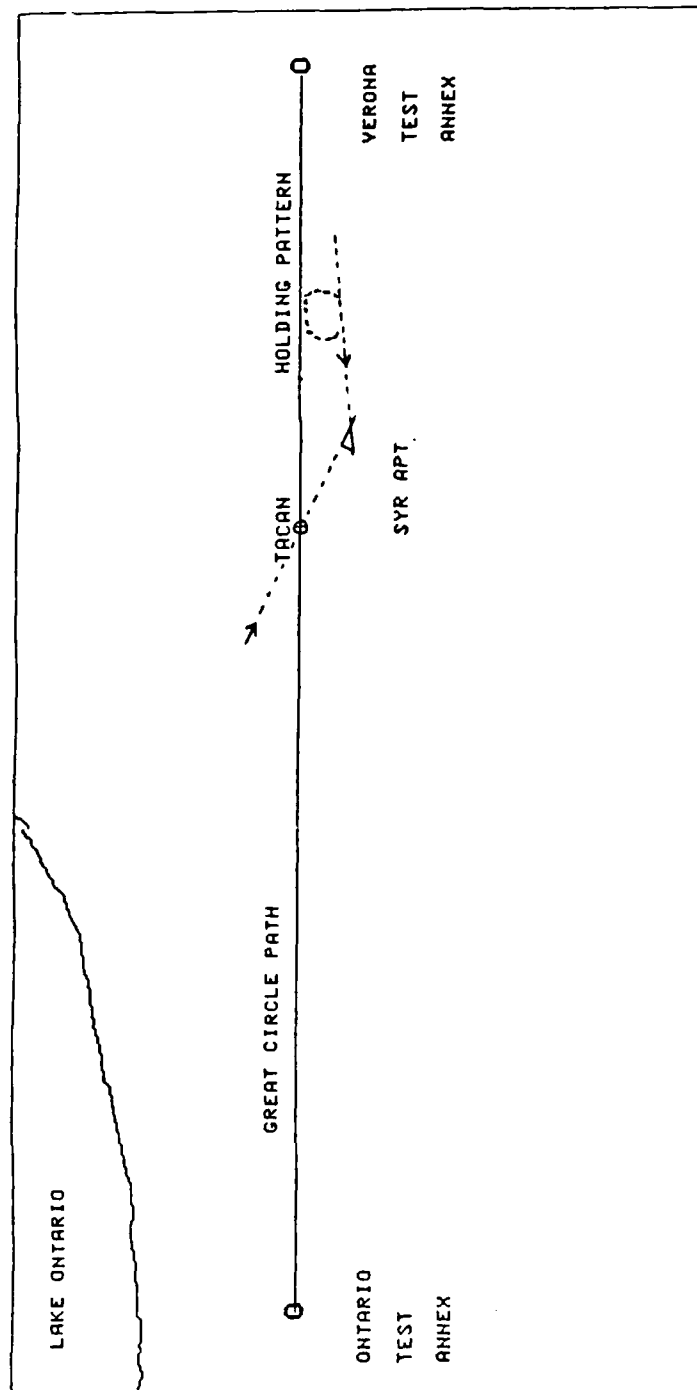


Figure 1-12

1.2.2 Northfinder

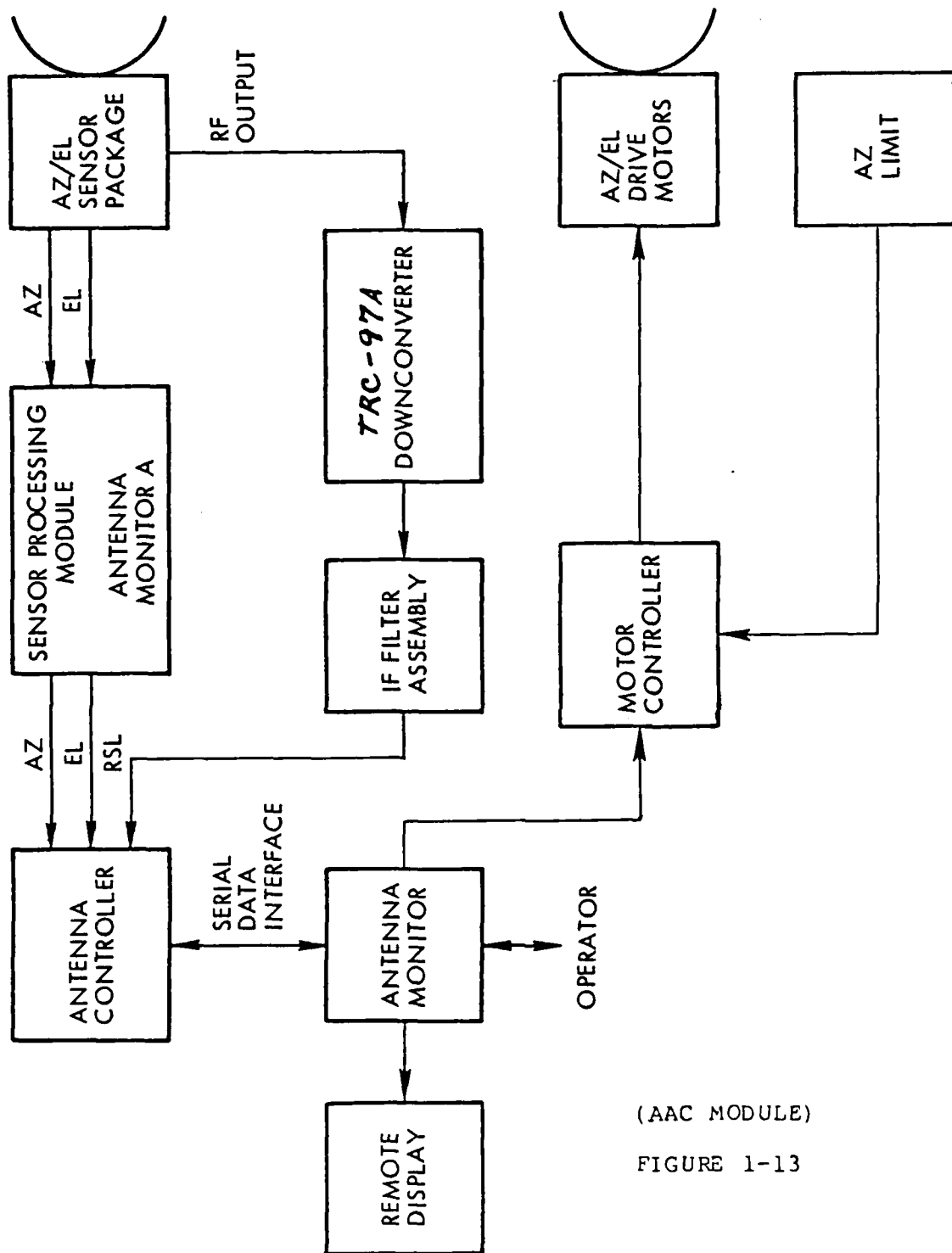
A replacement for the magnetic compass duty in initial alignment was tested. An automatic north-seeking gyrocompass made by the Sperry Corporation was mounted to the mast of the TRC-97 eight-foot antenna. The gyrocompass (called the Northfinder) can determine the angle of its axis to true north in 2 minutes with an accuracy of 0.1 degree. If the Northfinder is accurately mounted to align with the mechanical axis of the antenna and the electrical axis of the beam is the same as the mechanical axis, then the Northfinder can align the antenna in just over two minutes.

In tests, the practice of mounting the unit to the mast produced unreliable results at wind speeds above 5 miles per hour. A system would have to be devised to separate the Northfinder from the antenna to a more stable platform (perhaps a tripod).

This technique cannot correct for such errors as choosing the wrong locations or misprinting of bearings in operations plans. Also, since tactical antennas are rather frequently assembled and disassembled, it is likely that feedhorn offset errors and other mechanical axis to electrical axis errors could accumulate to more than 1 degree. Therefore, an electrical alignment must still be performed. Finally, a cost in excess of \$10,000 per Northfinder should remove this technique from further consideration.

1.2.3 Raytheon Aligner

An antenna alignment system was obtained by RADC from the Raytheon Company under Air Force contract F30602-81-C-080. The equipment provides motorized control of an 8-foot TRC-97 parabolic reflector antenna, azimuth and elevation position sensors, and a microprocessor and associated circuitry. Figure 13 is a block diagram of the system. The electronics is packaged in 3 boxes. Figure 1-14 shows the front panel of the antenna controller box containing the sensor processing module, IF filter assembly and the antenna controller. The antenna monitor box which interfaces with the operator can be seen in Figure 1-15. The motor controller box contains high power relays for distribution of power to the antenna actuators. The necessary interface between the alignment system and the TRC-



(AAC MODULE)

FIGURE 1-13

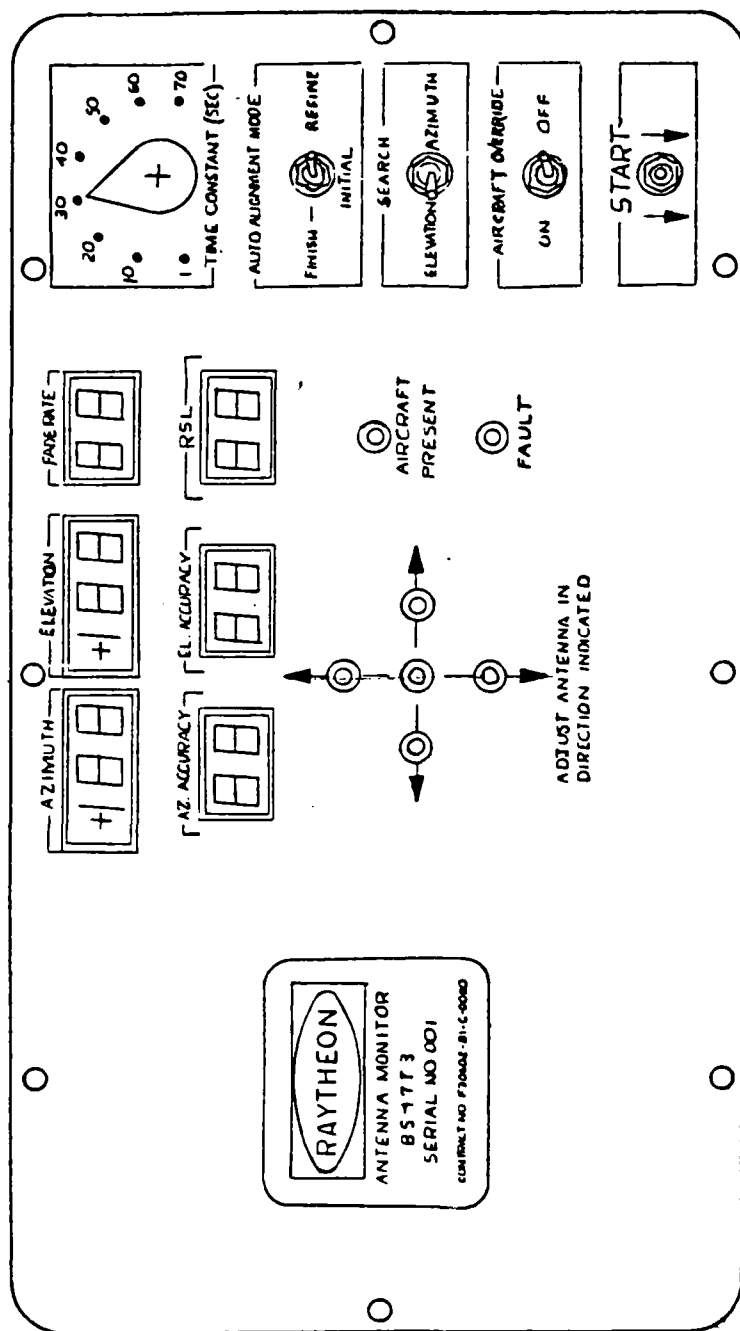


FIGURE 1-15
ANTENNA MONITOR

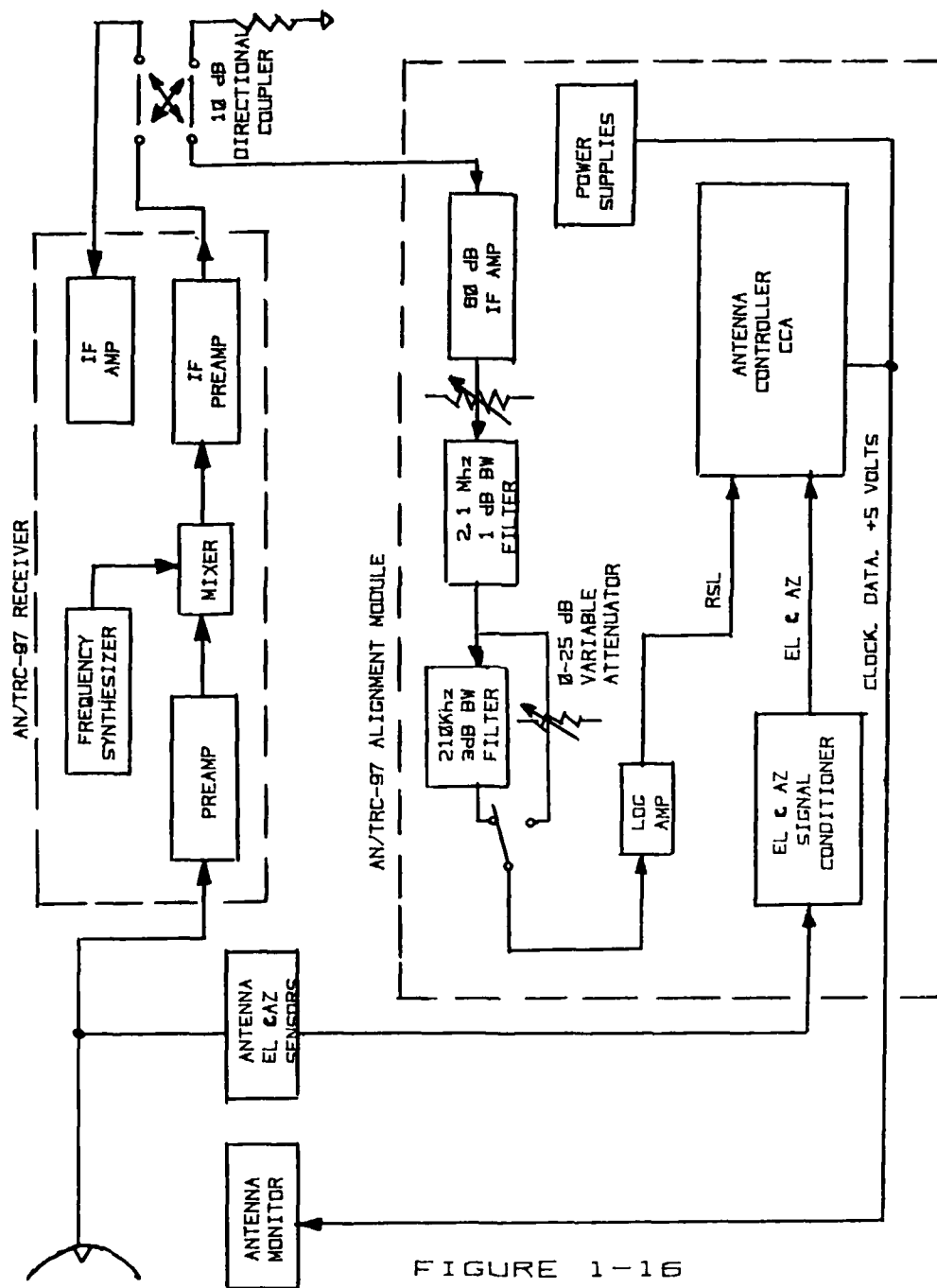


FIGURE 1-16

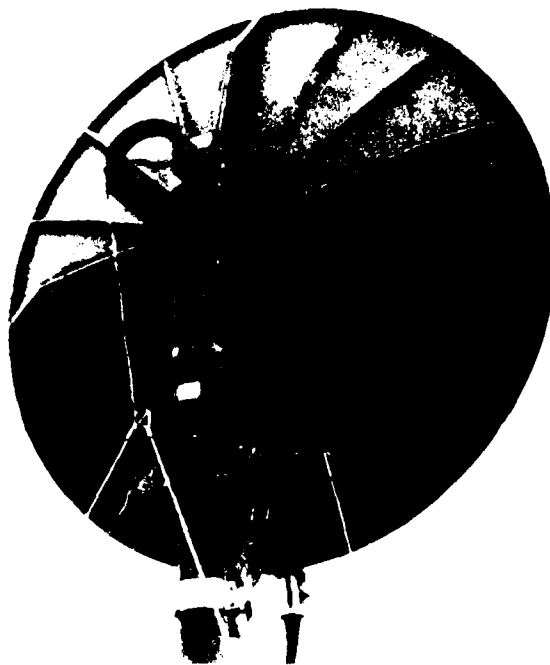


Figure 1-17

TRC-97A EIGHT FOOT ANTENNA

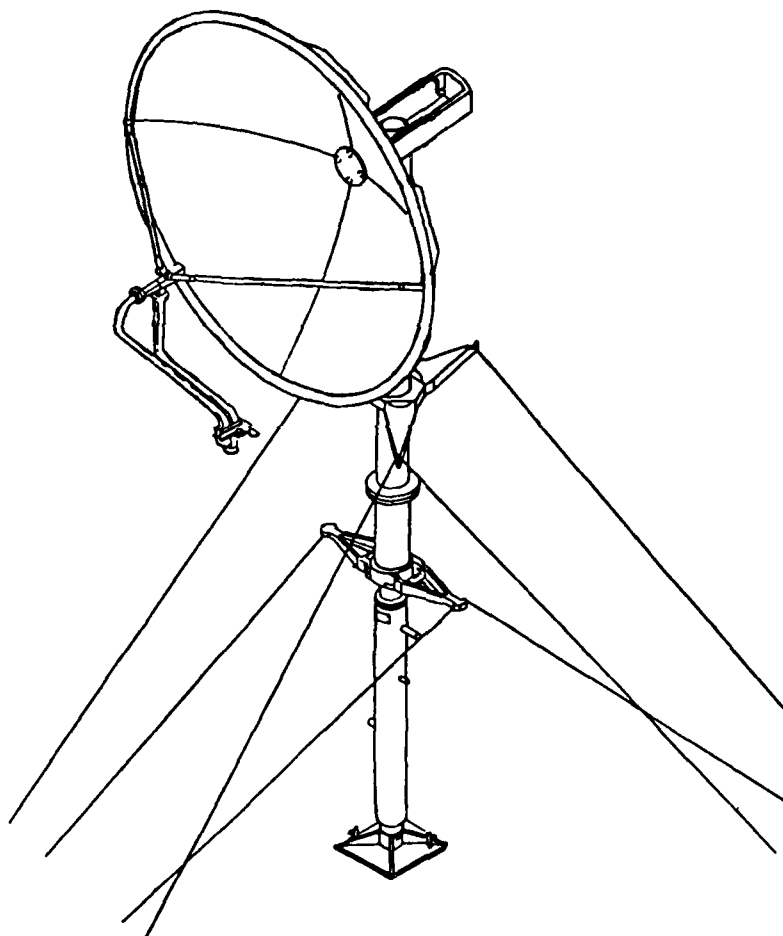


Figure 1-18



Figure 1-19

97 radios is shown in figure 1-16. Figure 1-17 shows the system in operation and figures 1-18 and 1-19 show unmodified and modified 8 foot antennas respectively.

The technique provides a multistep scan of the antenna to determine the angle of arrival of maximum energy from a fixed, far end transmit antenna. Operation is asynchronous, that is, only one antenna moves at a time. Either elevation or azimuth may be aligned.

A TRC-170 sensor package which includes a pendulum potentiometer for elevation sensor and an earth field magnetic azimuth sensor is used. Both sensors can be calibrated to give absolute values of their parameters.

The system uses a five step scan to make a decision at the "first accuracy". Time for this to occur is 5 minutes. If the equipment is left running, a second process occurs. The system will attempt to better the first GC estimate by taking further RSL data near the first accuracy estimate. Data points with successively smaller step sizes are taken until a peak in RSL is obtained. This process takes an additional 2 minutes. The antenna now moves to this second estimate called "second accuracy". The operator now has the choice of running the alignment again from this new position or accepting the position for use by putting the system into the "finish" mode. In this mode, the sensors are continually monitored. If the antenna moves for any reason from its stored values of azimuth or elevation, the system will move the antenna back to the original values. In this way the system keeps station despite wind loading, soil movements or crew attempts at tightening guy wires.

1.2.3.1 Test Results

Figure 1-20 shows accuracy of alignment when a local eight foot antenna was aligned to a distant eight foot antenna (aligned along GC) using this system. An alignment accuracy within 1 degree ($1/2$ beamwidth) was achieved 90 per cent of the time for first accuracy. Second accuracy achieved a 90 percentile of 0.8 degree.

Figure 1-21 illustrates GC ambiguity by showing alignment with the far end beam skewed at various angles and directions

AZIMUTH ERROR DISTRIBUTION
RAYTHEON ALIGNER
8' ANTENNA

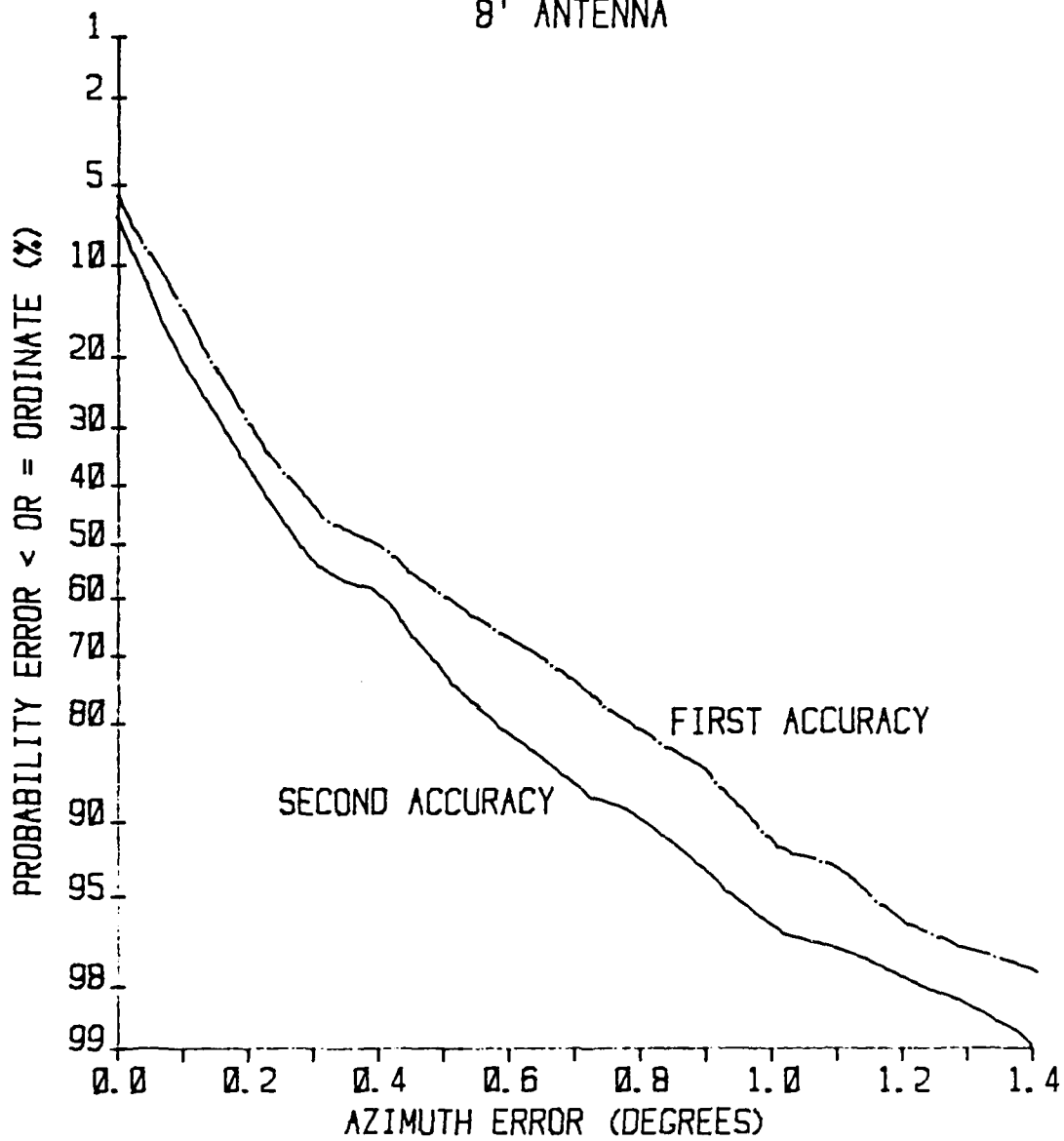


Figure 1-20

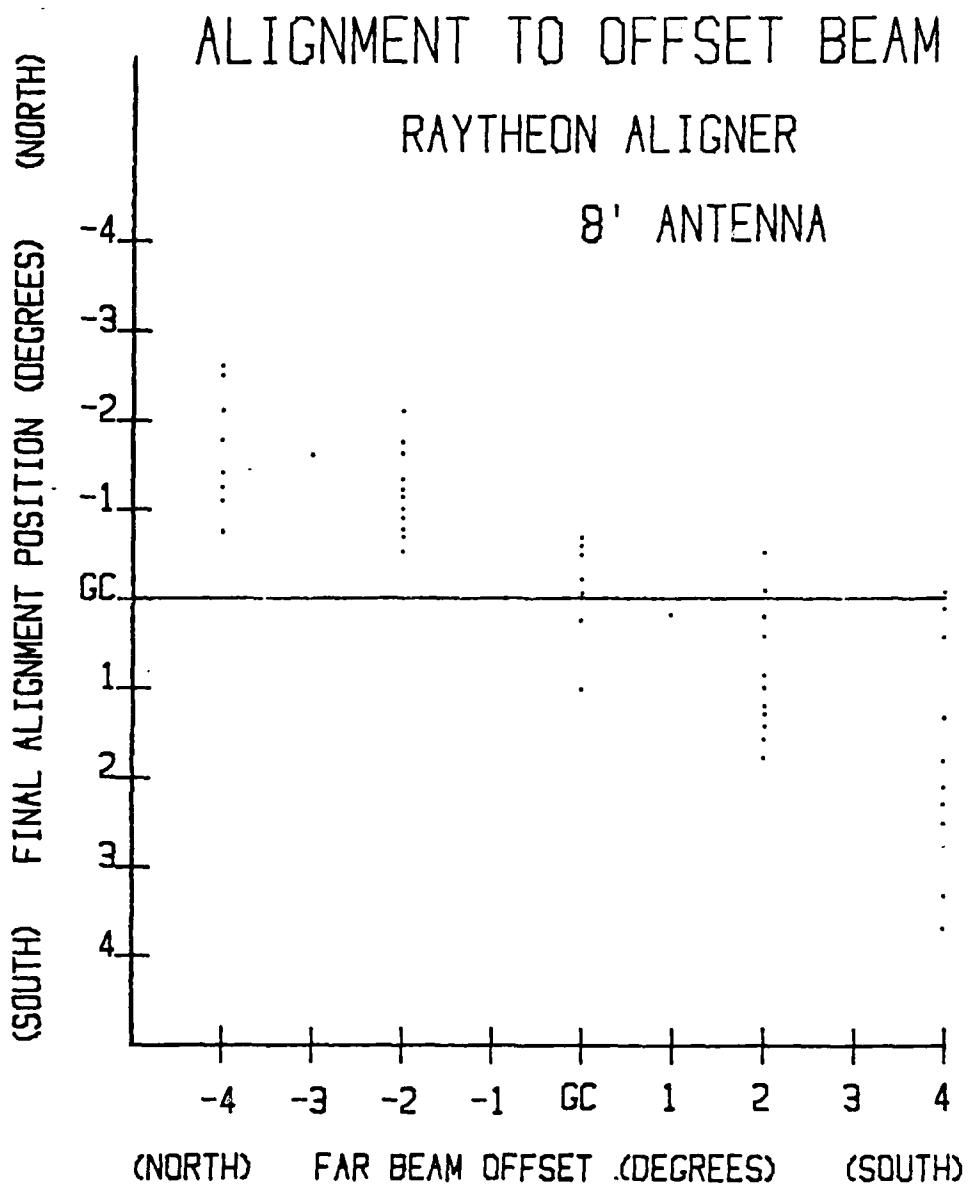


Figure 1-21

off GC. The scanning antenna aligns off GC in the same direction as the far beam. The spread in the data can be attributed to resolution of the aligner and variations in the scattering efficiency of the troposphere during the 5 week testing period.

1.2.3.2 Limiting Factors

The technique obviously automates only the first part of the T.O. alignment method. All the faults inherent in the manual alignment are still present in this system except that the crew gets some rest. Large initial misalignment would still create confusion. Synchronous alignment of the terminal antennas would have to be accomplished manually with coordination between the terminals by the senior crew chief.

The 8 foot antenna was originally modified with a drill on the worm gear for azimuth movement. This was not a good solution since the resolution obtainable by the system in a reasonable amount of time was about 1/2 degree. Raytheon therefore programmed a window of 1/2 degree into the system. It was not possible for RADC personnel to modify this figure after modifications to the antenna improved azimuth movement. Greater alignment accuracy would have been obtained by a smaller window size. A feature in the system was to have been a fine resolution scan with 0.3 degree step size. The 0.5 degree window prevented this mode from working.

1.3 Alternate Techniques Studied

RADC then studied the alignment problem in-house with the objective of eliminating the ambiguity question.

1.3.1 Automated T.O. Method

One approach would be to automate the complete T.O. technique. One terminal would be required to complete a simple multipoint asynchronous scan and then initiate a synchronous scan with the far terminal. It has previously been shown that this technique does not ensure GC alignment with one pass. Multiple passes would be necessary with errors reduced for each iteration. The system would have to be provided with a supervisory communications link for the computers in order to control the process. The link would be narrowband with a

protocol that enabled communications over a very noisy channel.

1.3.2 Synchronous Test Scan

An alternate solution studied involved synchronous, multiple azimuth movements of the antennas at each terminal. The aligner at each terminal would seek symmetry in the RSL scan data. With the antennas at both ends moving, complete symmetry is possible only when the midpoint of both terminal's scan is GC. The net effect of the algorithm is to drive both terminal's antennas toward GC with each pass.

The implementation of the technique required time of day clocks, one at each terminal, which were reasonably well synchronized to each other. The technique would not require auxiliary communications or operator intervention to achieve GC alignment. In addition, azimuth alignment of all four antennas could be achieved simultaneously.

Since all the necessary resources needed to implement this approach were available, an in-house effort to design and construct a system using one antenna at each end of an 87 mile link was initiated.

SECTION 2

RADC APPROACH

The RADC technique attempts to obtain RSL data that is symmetrical about central beam positions at both terminals. Since this central beam position corresponds to GC, the alignment process tends to drive the antennas closer to GC with each complete test. Path asymmetry due to unequal beam elevations will not affect RSL symmetry at each terminal and therefore will not affect alignment.

2.1 Technique Description

Both links are required to move their antennas in a synchronous manner so as to test the various positions of the far transmitted beam for angle of arrival. A matrix of 5 positions is assumed by each antenna at scheduled times under clock control.

One terminal is designated the slow scan site and moves to a new position every 1.5 minutes. The other terminal is designated the fast scan site and tests each position of the slow scan site with 5 movements each of 16 seconds duration. At the end of the test sequence both sites possess 5 sets of data each with 5 RSL readings. Each data set then can be considered to be a local antenna scan to test the angle of arrival of a particular far terminal beam position. The centroid and peak RSL of each test scan is computed and provides new data points for computing a new overall centroid which is the estimate of GC. If both terminals include the GC as part of the scan, then both final centroid estimates are likely to be close to GC. If the GC was not included in the scans of one or both of the terminals, the estimates move the antennas closer to GC. The next test cycle (one every 10 minutes) would likely contain GC within the scans.

Figure 2-1 illustrates the desired technique. If the far end antenna is allowed to move a predetermined amount from its initial position (2-1c), then the near end antenna can test each of its positions for RSL and angle of arrival. The step size used was 2 degrees. Thus the far end (slow scan) antenna

FAST SCAN ALIGNMENT

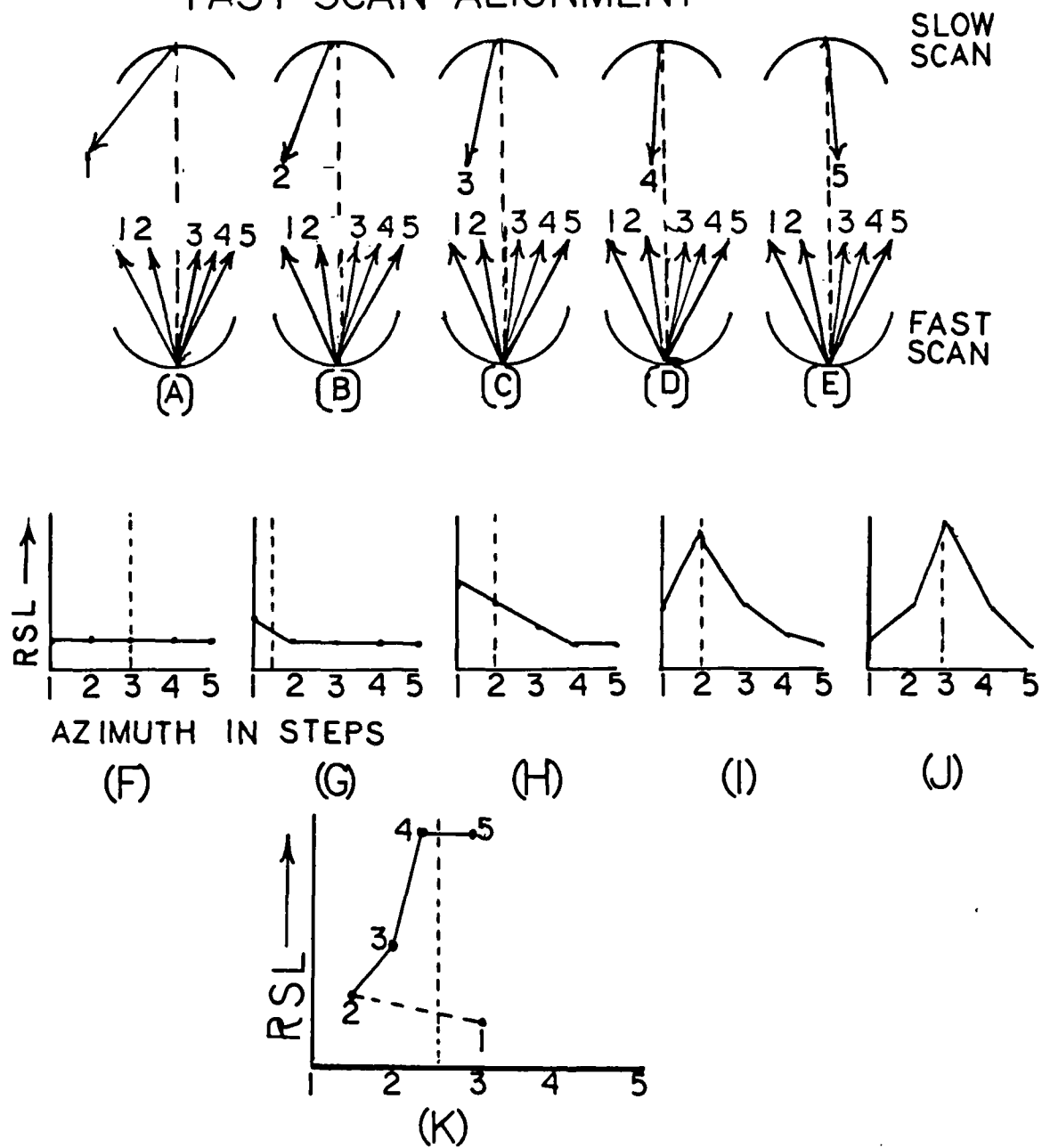


Figure 2-1

moves from its initial position of 3 degrees north of GC (in position 3) to 7 degrees north, then to 5 degrees north, then to its initial position and so on until it has been in 5 positions in 2 degree steps about the initial position. The slow scan antenna stops at each position long enough for the fast scan antenna to test it with a 5 step scan (about its initial position of 1 degree south). An RSL measurement is taken at each position. At the end of the process, a plot of the RSL versus fast scan antenna position can be obtained for each slow scan position as illustrated in Figures 2-1f to 2-1j.

An estimate of the angle of arrival for each slow scan position is indicated in Figures 2-1f to 2-1j by a vertical dotted line. The results of each estimate are plotted in 2-1k and the estimate of GC given. Since the fast scan antenna started out 1 degree south of GC, the estimate of 1 degree to the north of initial position is the correct position of GC.

The RSLs of Figure 2-1 are put in matrix form in Figure 2-2a. Each row represents the test scan (by the fast scan site) of each slow scan beam position. Note that each column can be considered a test scan by the slow scan antenna on the angle of arrival of each fast scan beam position. RSL for this configuration of the data is plotted in 2-2b to 2-2f and the decisions of each test plotted in 2-2g. The final decision is to move the slow scan antenna 3 degrees to the south which is the correct GC position.

This technique, therefore, allows simultaneous azimuth alignment of antennas at both terminals of a tropo link. If all things are equal at each site, (transmit power, transmission line losses etc.) the average RSL data at each terminal will be the same. Thus each site can predict not only its own GC position but the direction and relative amount of step movement necessary at the far terminal to reach GC.

The azimuth alignment technique, as implemented, was combined in a 10 minute period with a simple elevation step scan for the antenna at each terminal and a waiting period during which the operators could communicate before the start of the next cycle.

The complete azimuth test takes 6 minutes and 40 seconds.

SLOW SCAN ALIGNMENT

FAST SCAN POSITION

SLOW SCAN POSITION	FAST SCAN POSITION				
	1	2	3	4	5
	1	1	1	1	1
	2	2	1	1	1
	3	4	3	2	1
	4	3	9	4	2
	5	2	4	9	3

(A)

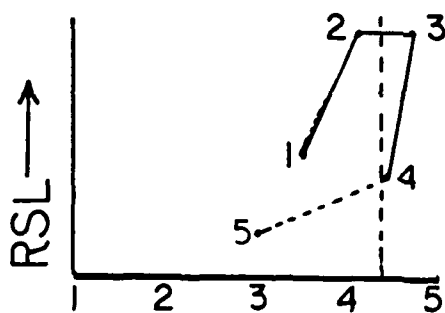
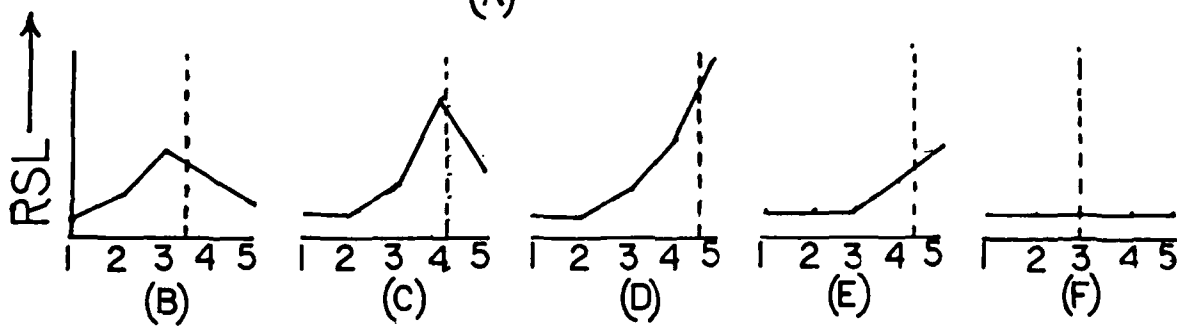


Figure 2-2

The elevation alignment at each site takes 48 seconds, leaving 1 minute and 44 seconds for communication. At this time, the crews may decide to terminate the alignment process or allow another cycle to begin by doing nothing.

2.2 Antenna Modifications

Since an 8 foot parabolic reflector antenna had been modified successfully for use with the aligner built by Raytheon, it was decided to attempt modification of the 15 foot MRT-2 antenna in conjunction with the new alignment technique. Some TRC-97A radios in the field are provided with the MRT-2 antenna. The narrower beamwidth (1 degree) of the MRT-2 compared to 8' antenna (2 degrees) would also provide a more severe test of the alignment system.

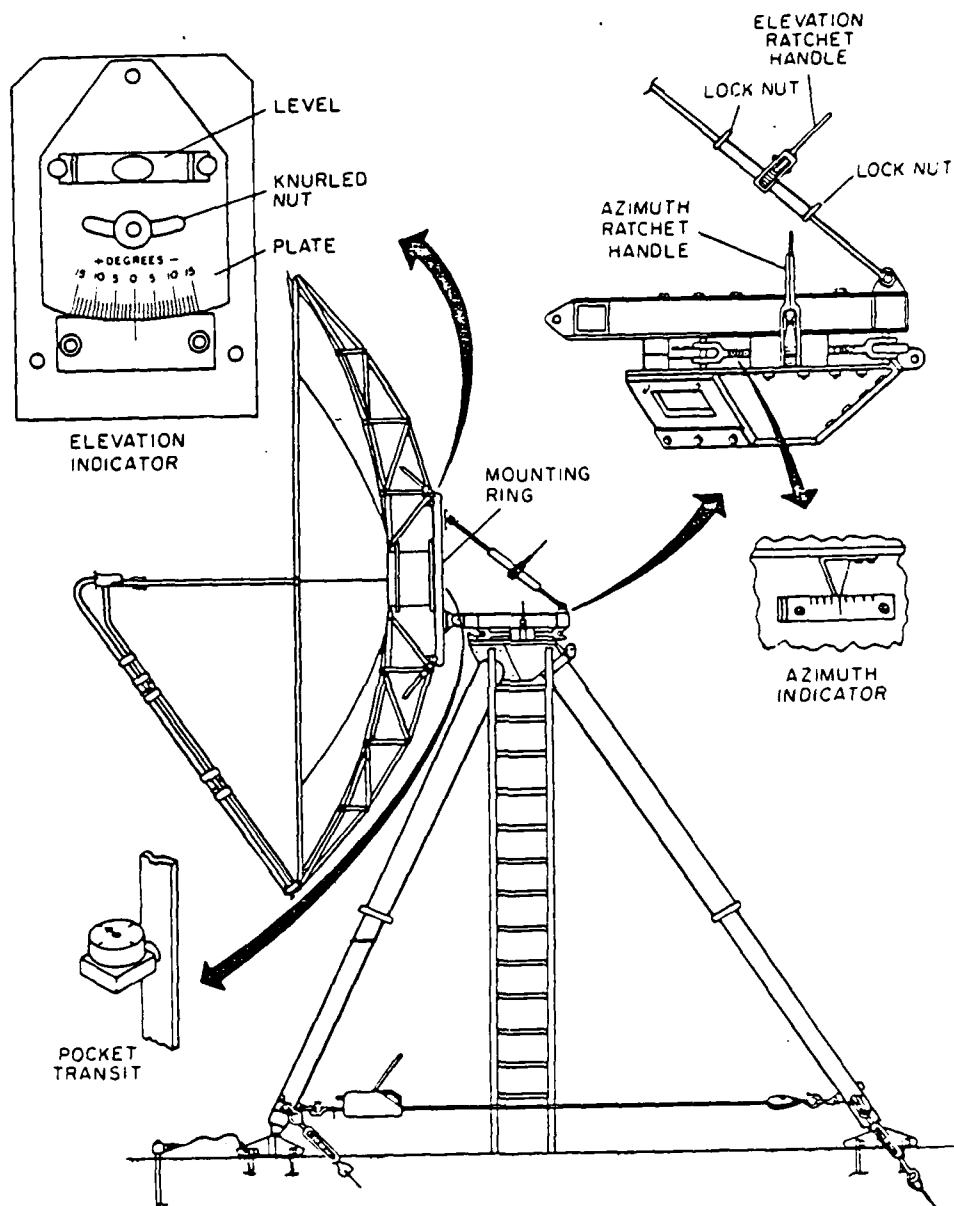
Figures 2-3 and 2-4 show unmodified and modified antennas respectively. The required modifications included a new rear mounting bracket and standoffs for the azimuth actuator and an extension rod for the elevation actuator. The elevation sensor was a pendulum potentiometer mounted on a horizontal reflector strut. The azimuth sensor was fashioned by attaching a rubber wheel to a 10 turn potentiometer. This was then mounted to the antenna tripod assembly with the wheel in contact with the moving pedestal. Cables for actuator power and sensors completed the arrangement.

2.3 Experimental Configuration

Figure 2-5 is a block diagram of the equipment used for the alignment system at each terminal. Antenna movement was accomplished by applying power to the appropriate actuator for a calculated period of time. Relays in the relay box served this purpose and were controlled by low power switches addressable by the 9825A computer via an IEEE 488 Interface bus. RSL and azimuth or elevation sensor voltages were routed through the same type addressable switches to a 3437A digital voltmeter. A clock interface provided interrupt signals to schedule alignment functions. The IEEE 488 interface bus formed the communications from the 9825A computer to the switches and the digital voltmeter.

Figure 2-6 shows the 9825A computer and the high power motor controller built by RADC. The system is in operation

MRT-2 FIFTEEN FOOT ANTENNA



Antenna Adjustments

Figure 2-3

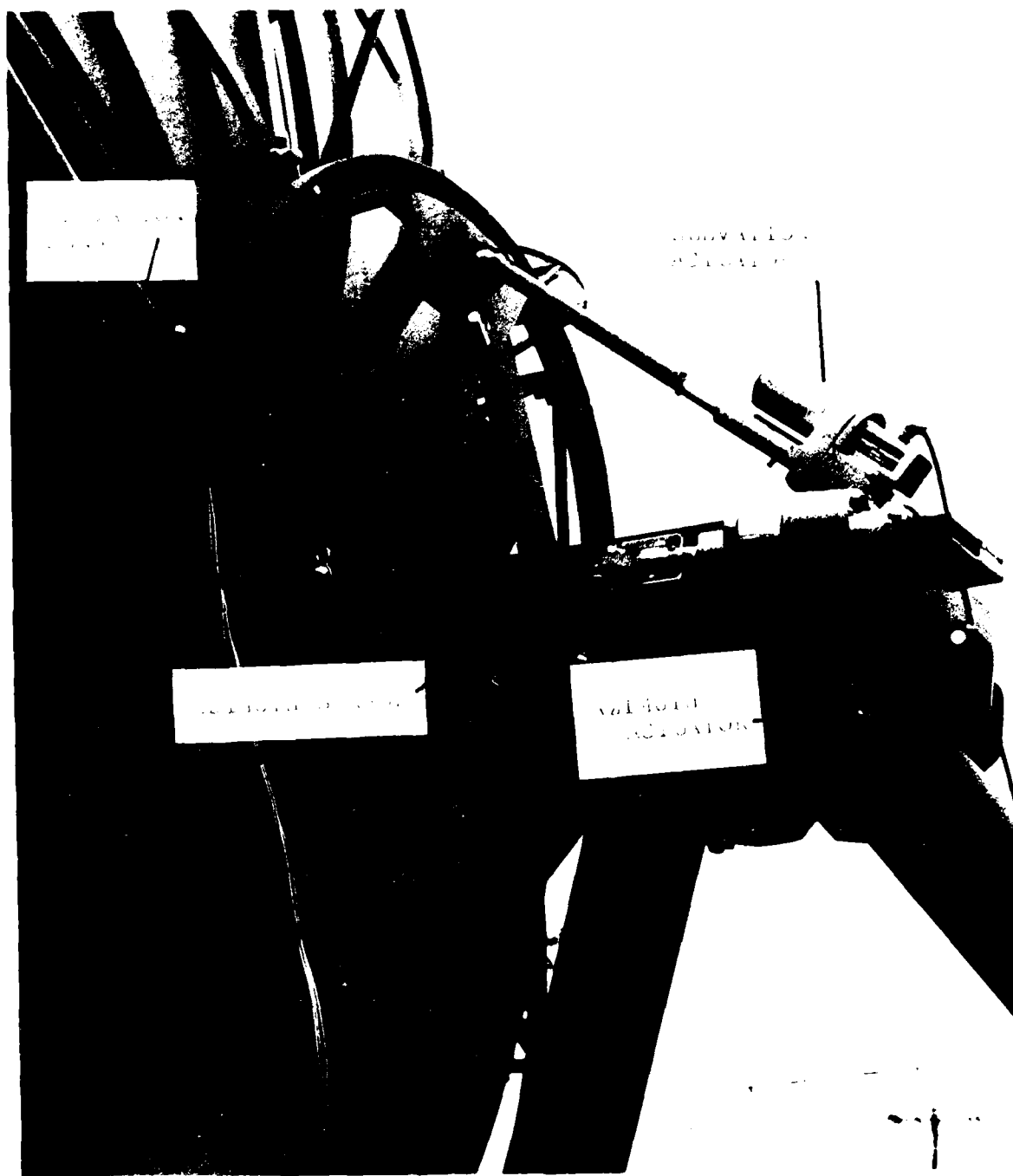


Figure 2-4

EXPERIMENTAL CONFIGURATION RADAR ALIGNER

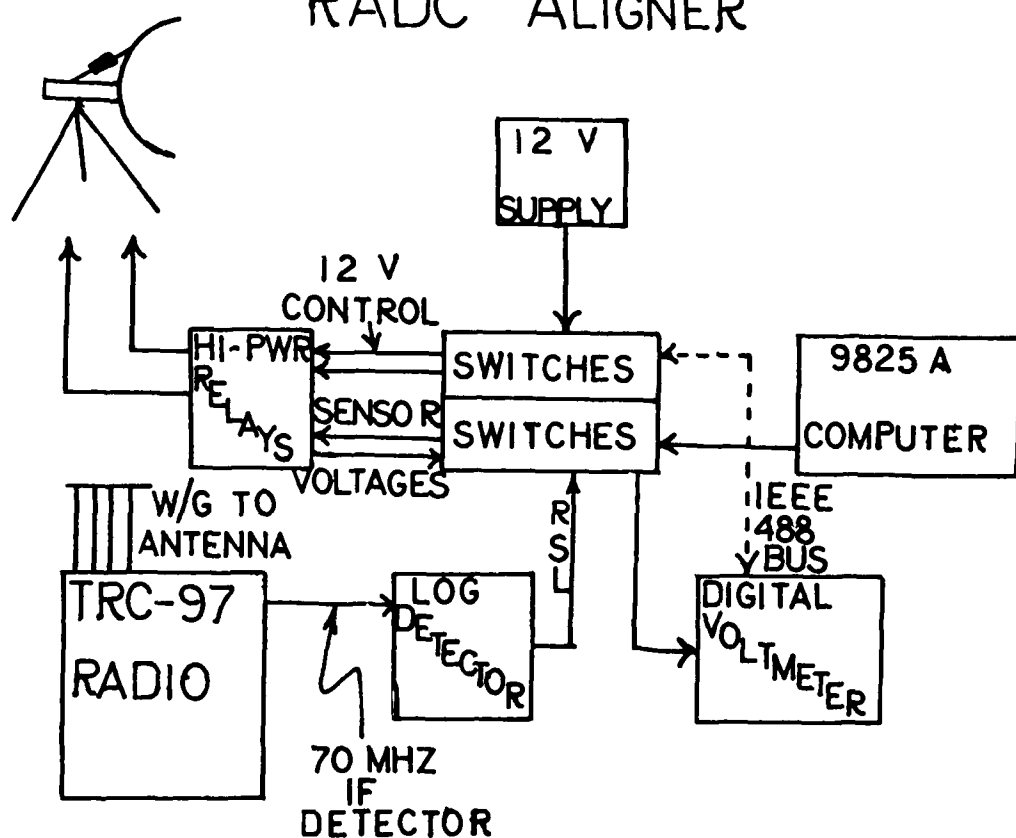


Figure 2-5





Figure 2-7

with a 15 foot MRT-2 antenna in Figure 2-7.

Since a simple on/off scheme was used for motor control of antenna movement, the antenna tended to oscillate about its final position for some time after the actuator shutdown. The computer was programmed to wait a period of time to allow this oscillation to decay before taking a new reading of elevation or azimuth. If the position was within .25 degrees of the required position, then the computer merely waited for the data period. If not, then a new on time for the actuator was calculated and the process repeated. Time allotted for antenna movement was 8 seconds. If the required position was not reached within the 8 seconds, then the start of the data period automatically stopped the antenna and RSL data was taken at that position. At the end of the data period the position of the antenna was determined and that value used subsequently in calculating the centroid.

2.4 LIMITING FACTORS

2.4.1 Antenna Settle Time

Because of antenna oscillation after actuator shutdown, as much time had to be assigned to antenna positioning as to actual RSL data gathering. To keep the entire cycle time to a reasonable value (10 minutes) this limited measurement time of RSL to 8 seconds per position. During slow fading conditions this is insufficient time to acquire an accurate estimate of the RSL.

2.4.2 Clock Accuracy

Relative clock accuracy between the terminals is important. With 8 second data periods, a 2 second misalignment in clocks means that 12.5% of the data is taken when the far beam is moving off the required position. In practice, a 0.5 second relative accuracy between the clocks was obtained by independent setting to WWV.

2.4.3 Aircraft

Both the computer and bus system are relatively slow with the result that only 40 readings of RSL per second were obtained. This is sufficient speed for normal fade rates but not

for fade rates associated with aircraft in the common volume. No provision was made, therefore, for detecting and removing data corrupted by aircraft reflection. It is not necessarily the data with the highest flutter that causes the most corruption of the alignment process, but the greatly enhanced RSLs (with low fade rate) that occur when the aircraft is in the center of the common volume. Since aircraft enhancement can be as much as 40 db, beam intersections off the GC with aircraft in the common volume can cause severe errors in the alignment process.

2.4.4 Sidelobe Reception

The choice of 2 degree steps between positions was made because a 4 degree excursion on either side of initial position agrees well with expected compass and mechanical to electrical axis errors. If one or both terminals are misaligned outside this range such that no beam intersections are possible near GC, then extremely low energy levels will be received. In this case, the best expectation is that one beam near GC will receive sidelobe energy from the far end along the GC. Since the sidelobes increase in gain near the main beam, the tendency is for alignment in the proper direction. Sufficient receiver sensitivity is necessary for reception at these low signal levels. The filters used with the RADC design were 2 Mhz. A 10 db increase in sensitivity could be gained by supplying 200 khz filters. Filters more narrow than 200Khz are not practical with the TRC-97A radios with present frequency accuracy and stability.

SECTION 3

RESULTS TO DATE

Tests have been conducted over the RADC 87 statute mile link between Ontario NY. and Verona NY.

3.1 Accuracy and Time

Worst case alignment should be with beams misaligned on opposite sides of GC. This results in the least number of beam intersections and therefore the least amount of usable data available to the computer upon which to make a centroid decision. The results of tests with the Verona terminal beam offset various amounts to the north while the Ontario terminal beam was offset equal amounts to the south can be seen in Table 3-1.

For 2 and 3 degrees from GC, one 10 minute cycle is usually sufficient for alignment within 0.5 degrees (1/2 beam-width). A second cycle is sometimes necessary when beams are misaligned by 4 degrees. In the case of 5 degrees misalignment, the technique will never achieve GC alignment within the first cycle because the maximum correction possible is 4 degrees. Two cycles are sufficient to get within 0.5 degree accuracy.

3.2 Alignment Confidence

A feature of the system is that once GC has been reached by both terminals, an additional test cycle will produce symmetrical data on both sides of GC for both sites. Figure 3-1 is a printout from the internal computer printer. A simple graph of the 5 beam angle of arrival decisions can be seen near the bottom. The numbers at the left represent azimuth position in terms of steps from the initial position (00). The numbers 1 through 5 are the angle of arrival results of the 5 beam positions. Relative signal strength is indicated by the position in the graph with stronger signal strength to the right.



TABLE 1

AZIMUTH RESULTS

RADC ALIGNER----15 FOOT ANTENNA
(AVERAGED DATA)

INITIAL ERROR	AFTER 10 MINUTES	AFTER 20 MINUTES	AFTER 30 MINUTES
(VER) 2 DEG. N.	0.2 DEG.	0.2 DEG.	0.1 DEG.
(ONT) 2 DEG. S.	0.2 DEG.	0.1 DEG.	0.1 DEG.
(VER) 3 DEG. N.	0.9 DEG.	0.5 DEG.	0.2 DEG.
(ONT) 3 DEG. S.	0.2 DEG.	0.2 DEG.	0.2 DEG.
(VER) 4 DEG. N.	1.1 DEG.	0.5 DEG.	0.1 DEG.
(ONT) 4 DEG. S.	0.1 DEG.	0.1 DEG.	0.2 DEG.
(VER) 5 DEG. N.	1.7 DEG.	0.4 DEG.	0.2 DEG.
(ONT) 5 DEG. S.	2.5 DEG.	0.4 DEG.	0.3 DEG.

In this case, both antennas had started at GC and the plot is symmetrical. Beam positions 1 and 5 produced weak intersections at best with the result that the centroids are much closer to the initial position than would be expected. If all RSL's for these positions had been below noise, then the centroids of each would have been at the initial position.

The final decision on the position of GC (Best Azimuth) was that the initial position (13, 23, 33, 43 and 53 in the position matrix) was correct. Comparing the azimuth sensor voltages for these matrix positions and Best Azimuth (519 millivolts) shows that there is no change.

The predicted movement for the far end antenna at Ontario is given in terms of step size and is here (ONT. EST.) shown close to zero. The computer could be programmed to recognize these features and output a number to the crew chief representing a confidence factor that correct GC alignment had been reached by both terminals.

3.3 LARGE INITIAL MISALIGNMENT

Figure 3-2 shows results of tests in which one beam was started at GC and the other with misalignments of up to 7 degrees from GC. In general, larger initial misalignments take longer for accuracy within one-half beamwidth. Data symmetry is a factor here. If the initial misalignment was 1 degree, then the alignment process obtains RSL data on each side of GC and is able to make an accurate decision based on the symmetry. A 4 degree offset, however, means that all the RSL data is on one side of GC and, lacking symmetry, the decision will not be as accurate.

With 6 and 7 degree offsets and a 2 mhz filter, much of the RSL data was buried in noise. A 200 khz filter in each aligner would enable sidelobes to be detected which would hasten the alignment process. It can be seen in the 7 degree offset curve that the first 10 minute test period produced only a 1 degree movement toward GC. Since the offset beam center approaches no closer than 3 degrees to GC, main beam intersections here may have RSL's less than that of sidelobe reception when the far beam is near GC. Only the gradual increase in sidelobe gain as the main beam approaches GC is available to bias the decision towards GC.

ALIGNMENT TIME RADC ALIGNER 15' ANTENNA

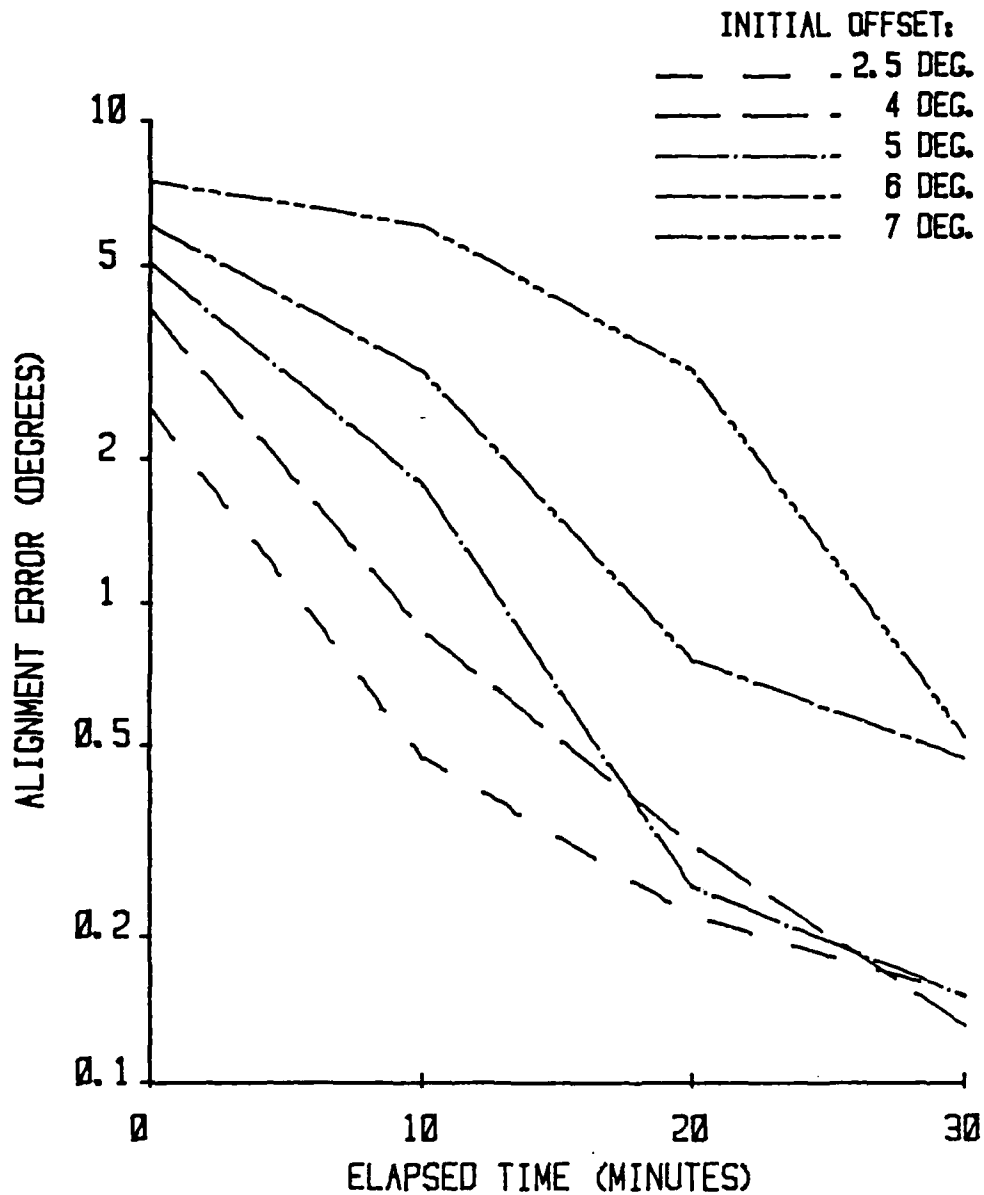


Figure 3-2

It should be noted that the beam that was originally on GC may be drawn in the direction of the misaligned beam during interim runs (if main beam intersections produce significant RSL's). This makes sense when one considers that since the transmitted beam does not cross GC, the aligner may see energy only in the skewed direction. Subsequent runs with both antennas crossing GC correct the situation.

3.4 ASYMMETRICAL PATHS

Appendix B contains an analysis of the effects of path geometry on antenna alignment. Differences in elevation of the antennas at the terminals produces different azimuth alignment patterns for the terminals. In general, the GC position will be more sharply defined for the terminal with the lower beam elevation.

This effect was observed experimentally during the alignment tests. Data for figure 3-3 was extracted from a typical aligner test where both terminals have started on GC. As outlined previously, within the 25 RSL data points available in a test are 5 point scans by each terminal on each of the 5 positions of the other terminal. If antenna elevations are equal then the path is symmetrical and a scan by either terminal for a given beam skew should produce the same curve.

The Verona-Ontario link is unsymmetrical with the Verona antenna takeoff angle at .75 degrees as opposed to Ontario antenna takeoff angles of .25 degrees. For the 87 mile path distance the asymmetry factor S for the link is 1.7.

Figure 3-3 shows the plot of a 5 point scan by each terminal when the other terminal's beam was fixed at 2 degrees skew to the north. The Ontario scan determines the beam center (as shown by the vertical line for the centroid) to be less than 1 degree from GC. When Verona scans under the same circumstances, it determines that the centroid of the Ontario beam is near 2 degrees north. Plotting scans when the skew is to the south produces similar results.

3.5 IMPACT OF RESULTS ON ALIGNMENT SCENARIO

3.5.1 Time to Alignment

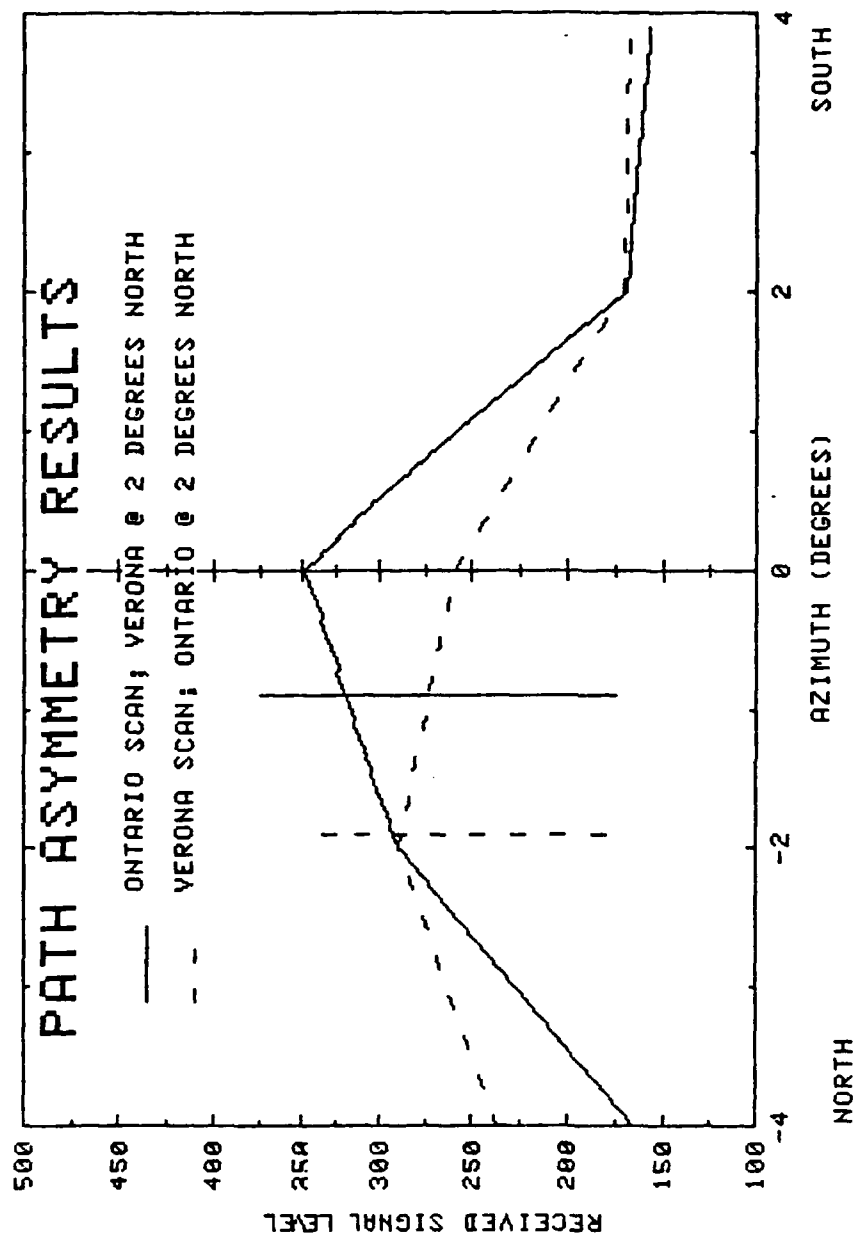


Figure 3-3

The results show that this technique can align antennas at both terminals to within 1/2 degree accuracy in 10 minutes when initial misalignments are within 3 degrees. A misalignment of larger than 4 degrees will always take at least 20 minutes. In a majority of cases, random time entry into a test cycle will lose enough data to make the first incomplete cycle worthless. An average of 5 minutes should therefore be added to all time figures. Therefore, 3 degree error alignments would average 15 minutes, 4 to 5 degree errors would average 25 minutes and 6 to 7 degree errors would produce an alignment time of 35 minutes. Large misalignments of 10 degrees on one antenna could take up to an hour with the present program and receiver sensitivity.

3.5.2 Present 3-Man Schedule

Table 3-2 shows the present work schedule for a 3-man crew. Two of the crew concentrate their time (after step 4) on the assembly and erection of both antennas while the 3rd man prepares the radio. Antenna alignment commences after communications contact is attempted as described in section 1. If each item in the assignment sheet represents 15 minutes, the total time for installation and alignment would be 4.5 hours with 1.25 hour passing from the first attempt at contact through optimum alignment. This assumes that compass alignments are within 4 degrees, that the crews are rested enough to complete alignment with no errors, and that the asymmetry of the path enables correct alignment.

3.5.3 Proposed Schedule

Table 3-3 illustrates a proposed alignment schedule for use with the RADC alignment system. In general, it is desirable to energize the equipment as soon as possible for warm-up. The next priority is the erection and compass alignment of one antenna. The transmitter is connected to this antenna and the automatic alignment process is initiated. 30 minutes are available for alignment before the second antenna is assembled, erected, and initially pointed by compass. If, at this time, the antennas at the far terminal and the transmit antenna at the local terminal are aligned, then a simple multistep alignment should align the last antenna within 3 minutes. A reasonable estimate of time to operation is 4.5 hours for the manually aligned case and 3.5 hours for the case of automatic alignment for a savings of 1 hour.

TABLE 3-II

PRESENT WORK ASSIGNMENTS 3 MAN CREW
MANUAL ANTENNA ALIGNMENT

	MAN A JOB #	MAN B JOB #	MAN C JOB #
	1	1	1
	2	2	2
HOUR 1	3	3	3
	4	4	4
	12	12	5
	12	12	6
HOUR 2	12	12	7
	12	12	8
	12	12	9
	12	12	10
HOUR 3	12	12	11
	12	12	12
	13	13	14
	15	15	15
HOUR 4	16	16	16
	16	16	16
	16	16	16
	16	16	16
	17	17	17

JOB #	DESCRIPTION
1.	SITE LAYOUT
2.	UNLOAD ANTENNA TRANSIT FRAME
3.	DRIVE ALIGNMENT STAKES
4.	MOVE RADIO INTO POSITION
5.	PRIMARY POWER CONNECTIONS
6.	SHELTER VENTILATION
7.	PREPARE FOR POWER
8.	START GENERATOR
9.	ENERGIZE EQUIPMENT
10.	ALARM MONITOR AND ALIGNMENT METER HOOKUP
11.	COMMUNICATIONS MODE AND CIRCUITS
12.	ASSEMBLE AND ERECT ANTENNA GROUP
13.	COMPASS ALIGNMENT
14.	PUT EQUIPMENT IN OPERATION
15.	INITIAL COMMUNICATIONS CONTACT
16.	OPTIMIZE ALIGNMENT
17.	PASS TRAFFIC

TABLE 3-III
PROPOSED WORK ASSIGNMENTS 3 MAN CREW
AUTOMATIC ANTENNA ALIGNMENT

	MAN A JOB #	MAN B JOB #	MAN C JOB #	ANTENNA ALIGNER
	1	1	1	
	2	2	2	
HOUR 1	3	3	3	
	4	4	4	
	5	6	7	
	12	12	8	
HOUR 2	12	12	9	
	12	12	12	
	12	12	12	
	12	12	13	
HOUR 3	12	12	14	
	12	12	12	16A
	10	11	13	16A
	15	15	15	16B
HOUR 4	17	17	17	

16A. ALIGN TRANSMIT ANTENNA AT NEAR END AND BOTH ANTENNAS AT FAR END.

16B. ALIGN NEAR END RECEIVE WITH SIMPLE SCAN.

SECTION 4

FUTURE WORK

4.1 Improvements to RADC System

4.1.1 Actuators

Alternate actuators should be investigated or speed control of the actuators should be attempted. If the speed of positioning the antennas or antenna oscillation is improved, then overall speed to alignment and accuracy of alignment can be improved.

4.1.2 Sensors

Linear potentiometers can be directly attached to actuator extension tubes for use as sensors. Less movement because of antenna oscillation would occur than with the present rotary potentiometers. This would increase the speed of positioning.

4.1.3 Filters

Filters used with the RADC technique were 2 Mhz bandwidth. 200 Khz filters should be installed as this would increase sensitivity by 10 db. While 200 Khz is about the limit for present TRC-97 frequency accuracy, the synthesizer/local oscillator chains are scheduled for replacement with more stable units. TRC-170 radios are supplied with synthesizers driven by a rubidium standard. Narrower filters would enable alignment under larger initial misalignment conditions.

4.2 Demonstrate Tracking

Fine resolution alignment and angle of arrival tracking have yet to be demonstrated. Microclimates in the terrain near the GC path (bodies of water, hills and cities) may produce isolated turbulence and are agents for variations in optimum alignment. Periodic elevation adjustments may be particularly worthwhile because of diurnal variations which tend to strati-

fy the troposphere. Improvements in antenna control are necessary, however, to obtain a fine resolution capability for the MRT-2 antenna.

4.3 Alternate Strategies

A major problem remaining is that of large initial misalignment. Significant portions of the installation time are now spent on careful initial compass alignment. These attempts are not always successful, resulting in confusion, need for secondary communications and long alignment times.

4.3.1 Global Positioning System (GPS)

The NAVSTAR GPS promises, when fully operational, the capability to determine the location of a GPS receiver on the earth's surface with errors within a few meters. This could be exploited to reduce errors in the initial alignment of tactical tropo antennas.

Use of the GPS could aid the present system by preventing the error of wrong location. Additionally, flexibility could be increased by allowing a crew to calculate a new bearing when use of an alternate site was necessary (although, without communications, the far terminal would be unaware of the change).

Replacement of the compass as a means of determining a reference bearing is desirable. One approach would use the GPS to determine the locations of both a tropo antenna and a distant (easily viewed) benchmark. The bearing between the antenna and the benchmark would become a reference bearing from which the antenna could be rotated to the desired GC bearing. For maximum positional errors of 10 meters at each location, required base line distance to the benchmark would be 1000 meters or more to keep reference bearing error below 1 degree.

A second possibility is to add an interferometer capability to the GPS receiver. Since location of both the tropo site and the satellite are determinable with the GPS technique, the addition of two GPS antennas in an interferometer configuration would allow the bearing to the satellite to be computed and transferred to the tropo antenna as a reference bearing.

4.3.2 Automated T.O. Method

A solution to these problems could be a complete automation of a modified T.O. technique with a supervisory communications channel (narrowband) between the computers. Iterative asynchronous scanning could be combined with synchronous scanning, ending with an operational fine resolution alignment when antennas at both terminals were near the GC.

By supplying intersite communications, the computers can optimally control the alignment process. A wide range azimuth scan by one or both sites can reduce large initial offsets. Once narrowband communications is established, the computers can pass control back and forth for the asynchronous scans with no delay between scans. Adjustment of elevations at each site can take advantage of path asymmetry (low terminal scans reduce high terminal azimuth errors). Once sufficient RSL for traffic was achieved, small increment asynchronous and synchronous alignment schemes could be automatically implemented while the link was operational.

4.3.3 Random Scanning

A second technique (which would not require supervisory communications) is a random scanning scheme. Both terminals would scan at the same time continuously throughout the entire mechanical range of the antennas. Random beam intersections over a period of time would give best RSL near the GC region. As data accumulated, the scan could be narrowed to speed the process. The alignment would finish with a fine resolution technique.

4.3.3 Feedhorn Transmission/Reception

Another approach that should be investigated is based on the fact that if one transmit antenna is known to be aligned on GC, then distant antennas can be aligned quickly to this beam with a simple scan. The object then is to align one antenna quickly to GC. If energy is transmitted on a horn antenna, the initial misalignment problem disappears because of the large beamwidth. If sufficient receiver sensitivity is available for RSL indication, then scanning by the distant narrow-beam antennas essentially measures the tropo scattering efficiency about the GC. Once these antennas are aligned, then the

terminal with the original horn aligns both narrow beam antennas to the far transmit beam. A fine resolution technique finishes the alignment.

The horn could also be used in a receive only mode which would save time but would require a narrow band supervisory channel to pass horn RSL results between sites.

4.4 ECCM

4.4.1 Jammer DF

If a jammer is within the mechanical range of scan of a narrowbeam antenna (usually ± 15 degrees), the aligner could be made to perform direction finding duties.

4.4.2 Jammer Avoidance

If the antenna aligner is modified to accept signal to noise ratio, bit error rate or some other detected signal quality parameter instead of RSL as the quantity to be optimized, then fine resolution scans can be used to optimize signal to jammer ratio. The sidelobe structure of antenna patterns show peaks and nulls at periodic intervals, decreasing in amplitude as angle from the main beam increases. The object of the scan would be to remove a jammer from a sidelobe peak to a null of the pattern without appreciably affecting the RSL of the desired signal.

If a jammer is situated on G.C., moving the beams of the antennas off G.C. will produce a loss to both the jammer and the tropo signal. If the far end terminal antennas scan for optimum RSL, then part of the tropo loss may be restored. If the differential loss of the jammer versus the tropo exceeds 10 db, then a sidelobe canceller can be used to further suppress the jammer. In this way the jammer would have been converted from a main beam jammer to a sidelobe jammer. The cost for this benefit, of course, is a drop in RSL, and sufficient carrier to noise margin must have been originally available (or must be added to the system) for this technique to be useful. Since the antenna must be adjusted to a fixed skew angle for Line of Sight (LOS) loss to the jammer, the percentage increase in scatter angle is less for longer links than for shorter links. Longer links suffer less loss than the shorter

links which can more readily afford the loss.

Jammer terrain scatter is a problem with sidelobe cancellers when the jamming source is to the rear of the antennas. Terrain will be widely illuminated by an elevated jamming source. Some of the tropo antenna sidelobes intersect this terrain and receive the scattered jammer energy. Since a wide area of terrain is usually involved, large phase dispersion is experienced in the reception of a wideband jammer signal. Sidelobe cancellers cannot suppress these large dispersion components of the jammer.

The lower portion of the main beam (which is often blocked by the terrain) and the first sidelobe region are of most importance in terrain scatter because of their high gain. An optimum elevation of the antenna should be obtainable where terrain scattered jammer is reduced with minimal RSL loss to the desired tropo signal.

4.4.3 Antenna Alignment During Jamming

Moderate to strong jamming is likely to affect an alignment technique which uses RSL as the factor to be optimized. Substituting SNR or BER may enable the antennas to be aligned during moderate jamming. Addition of a sidelobe canceller may enable alignment in the presence of a strong jammer.

4.4.4 Detection Vulnerability During Alignment.

The use of a narrowband signal for antenna alignment purposes increases the chances that the presence of the link will be detected early by the enemy. An economical means of spreading the signal at the transmitters and restoring the signal to its narrow band condition at the receiver prior to filtering is required.

4.5 Field testing.

To date, the aligner has only been tested on an 87 mile tropo link. The aligner packages, as configured, were not suitable for testing under field conditions. It is of great importance that a field qualified aligner be built for testing on a wide variety of links, including LOS, tropo and diffraction links. Enough flexibility must be designed into the unit

to enable field software modifications to tune the unit for best operation in the various communications modes. In this way, the full range of usefulness of the unit can be discerned and the necessary techniques for alignment delineated. The impact of the alignment equipment on the entire radio installation process as well as accuracy and time for alignment should be evaluated.

APPENDIX A

COMPUTING SCATTER ANGLE FOR SKEWED BEAMS

Figure A-1a illustrates the ray geometry between two tropo terminals T and R, where TR is the chord joining the terminals through the earth. TA and RA are rays along the Great Circle (GC) route between the terminals which make angles β_T and β_R with chord TR. Theta is the well known scatter angle for GC transmission.

In figure A-1b, rays PT and PR are skewed in azimuth from GC by angles α_T and α_R , and have angles γ_T and γ_R with respect to the chord TR. It is desired to obtain total skewed scatter angle in terms of GC scatter angle, the azimuthal skew of one terminal (α_T), and the path symmetry ratio S.

$$S = \frac{\tan \beta_T}{\tan \beta_R} = \frac{\tan \alpha_T}{\tan \alpha_R} = \frac{\tan \gamma_T}{\tan \gamma_R}$$

if the angles are small:

$$S \approx \beta_T / \beta_R \approx \alpha_T / \alpha_R \approx \gamma_T / \gamma_R \quad A.1$$

$$\overline{TD}^2 = \overline{AD}^2 + \overline{DC}^2$$

$$[\overline{DT} \tan \gamma_T]^2 = [\overline{DT} \tan \beta_T]^2 + [\overline{DT} \tan \alpha_T]^2$$

for small angles this reduces to: $\gamma_T^2 = \beta_T^2 + \alpha_T^2 \quad A.2$

the GC scatter angle: $\Theta_0 = \beta_T + \beta_R = \beta_T(S+1)/S \quad A.3$

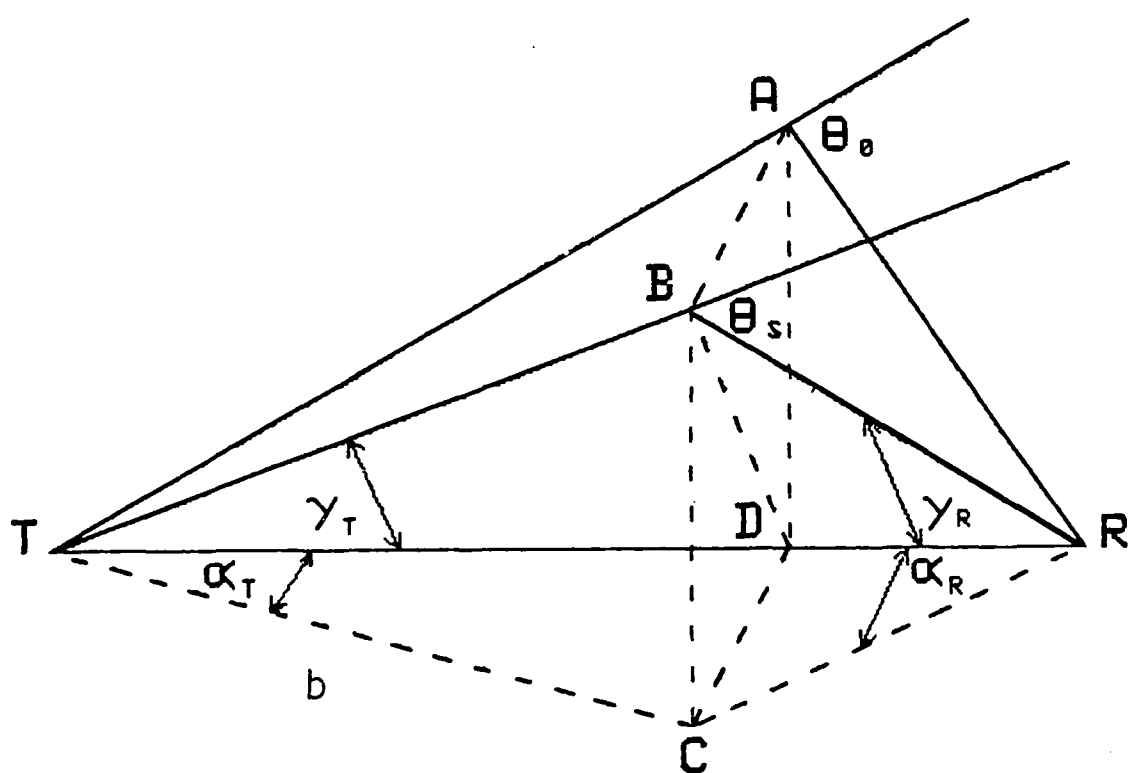
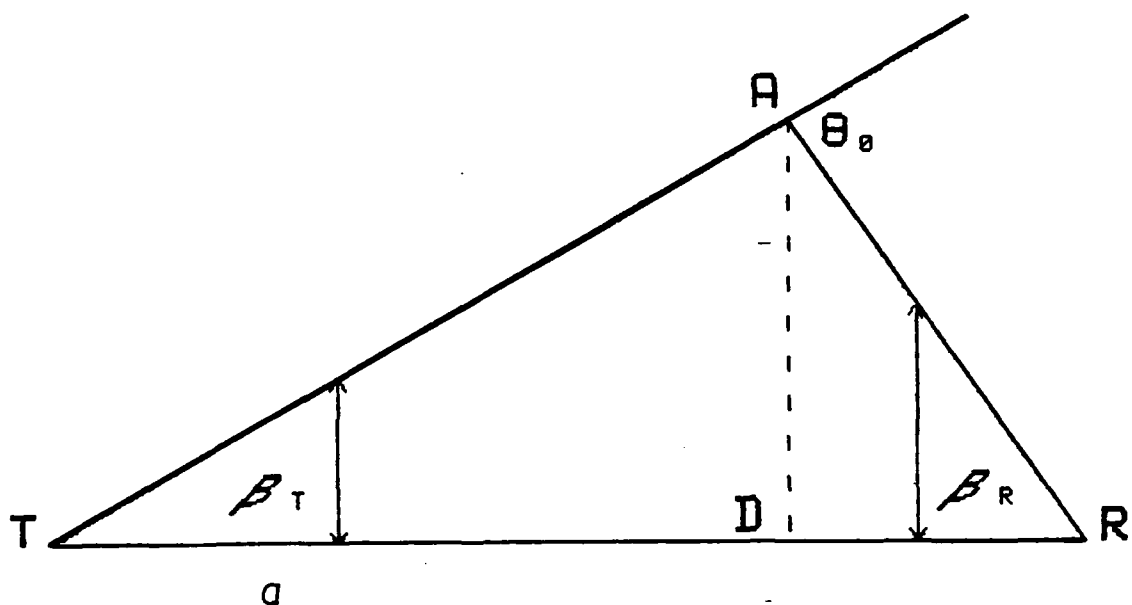


Figure A-1

A-2

if $(S+1)/S$ is set equal to K_T : $\beta_T = \Theta_0 / K_T$

the skewed scatter angle: $\Theta_S = \gamma_T + \gamma_R$ A.4

$$\Theta_S^2 = [\gamma_T + \gamma_R]^2 = [K_T \gamma_T]^2 = K_T^2 [\beta_T^2 + \alpha_T^2]$$

$$\Theta_S^2 = K_T^2 [\Theta_0^2 / K_T^2 + \alpha_T^2]$$

$$\Theta_S = [\Theta_0^2 + K_T^2 \alpha_T^2]^{1/2} \quad \text{A.5}$$

$$\text{similarly: } \Theta_S = [\Theta_0^2 + K_R^2 \alpha_R^2]^{1/2} \quad \text{A.6}$$

where $K_R = 1+S$

Equations A.5 or A.6 are used to calculate scatter loss in equations A.7 or A.8. (from NBS technical note 101).

for $N = 301$:

for $0.01 < \theta d < 10$:

$$F(\theta d) = 135.82 + 0.33 \theta d + 30 \log \theta d \quad \text{A.7}$$

for $10 < \theta d < 70$:

$$F(\theta d) = 129.5 + 0.212 \theta d + 37.5 \log \theta d \quad \text{A.8}$$

APPENDIX B

ANTENNA MISALIGNMENT SIMULATIONS

A computer simulation of the alignment of a 15 foot antenna over a 50 mile path is shown in figures B1 and B2. RSL (relative to both antennas on GC) is plotted for a scanning antenna at one terminal when the far terminal beam is skewed. In figure B1, a beam at 2.5 degrees elevation scans a far beam which is elevated 0.5 degrees and is skewed 2 degrees in azimuth. In figure B2, the low elevation terminal scans the high elevation terminal which has a 4 degree skew. Note that the apparent maximum energy point for the low elevation scan is much closer to GC than in the case of the high elevation scan. This is true even though the skew in the transmitted beam in B1 is greater than that in figure B2.

The reason for this can be seen clearly in figure B3. Figure B3a shows the side view of a GC path AB with unequal antenna elevation angles. Intersection of rays AC and BC occurs at C, closer to the high angle terminal. Figure B3b illustrates a top view of rays AE and BE which are skewed in azimuth from the GC path AB. Intersection for the skewed beams occurs at E at the same horizontal distance along GC as in figure B3a. The skew angle EBD for ray intersection is larger at the high angle terminal B than the skew angle EAD at the low angle terminal at A. The implication is clear that for alignment with fixed far ray offset, the high terminal would align further from GC and the low angle terminal would align closer to GC.

In actual alignment, the antennas have finite beamwidth in both azimuth and elevation so that multiple intersections of rays with various gains are possible. Tropo loss increases with scatter angle so that those rays which are closer to GC and at lower elevation angles have less loss. Alignment of real antennas in the troposphere is therefore biased closer to GC and at lower elevation angles than a simple ray analysis indicates.

This suggests a simple change in technique when antennas are to be manually aligned. The fixed beam should be elevated as high as practical while the scanning beam should be lowered in elevation. The scanning antenna will align closer to GC

TROPO LOSS--AZIMUTH MISALIGNMENT

HIGH ANGLE TERMINAL 15' ANTENNA

50 MILE PATH; TAKE OFF ANGLES 0.50 AND 2.50 DEG.

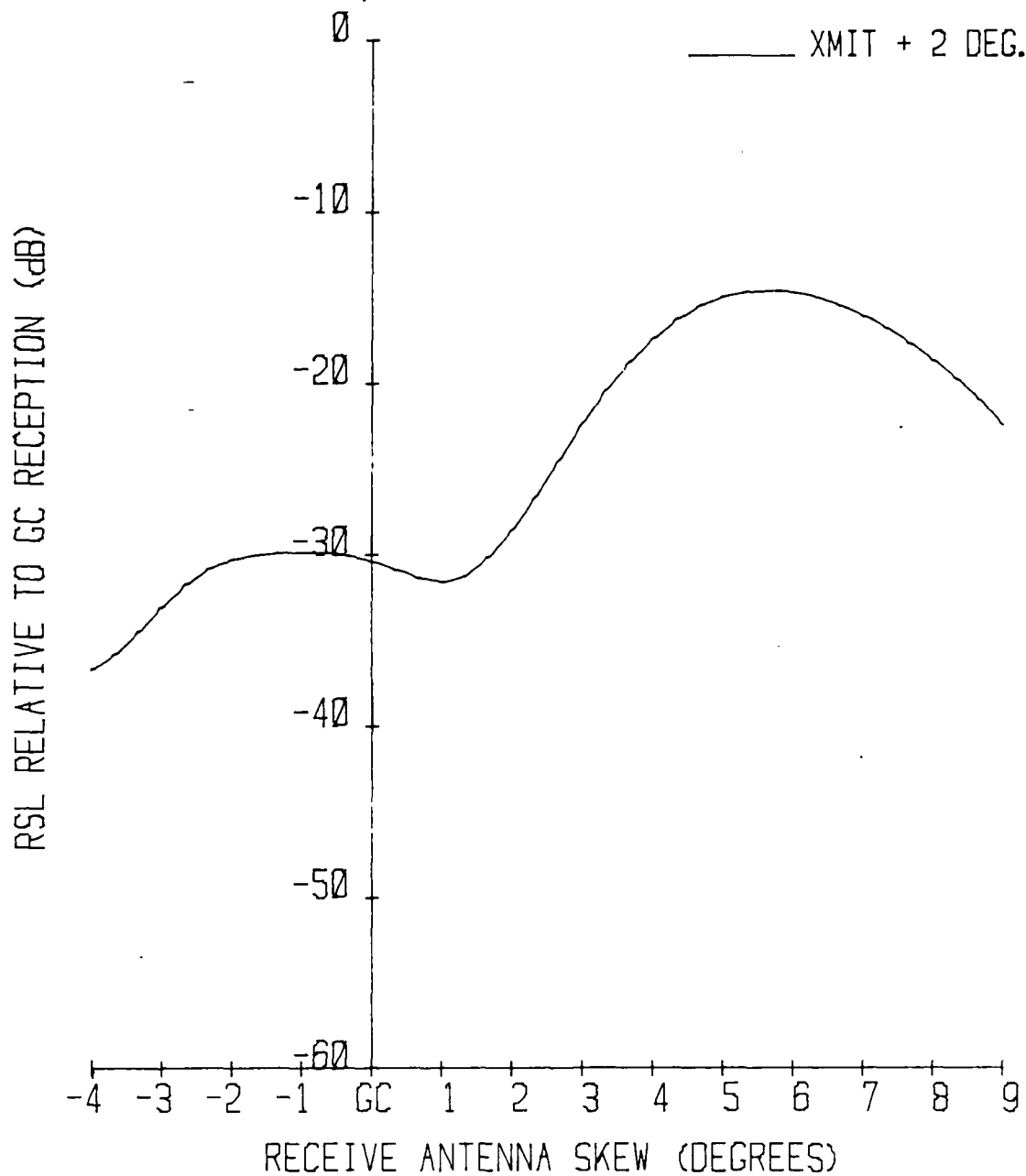


Figure B-1

B-2

TROPO LOSS--AZIMUTH MISALIGNMENT

LOW ANGLE TERMINAL

15' ANTENNA

50 MILE PATH; TAKE OFF ANGLES 0.50 AND 2.50 DEG.

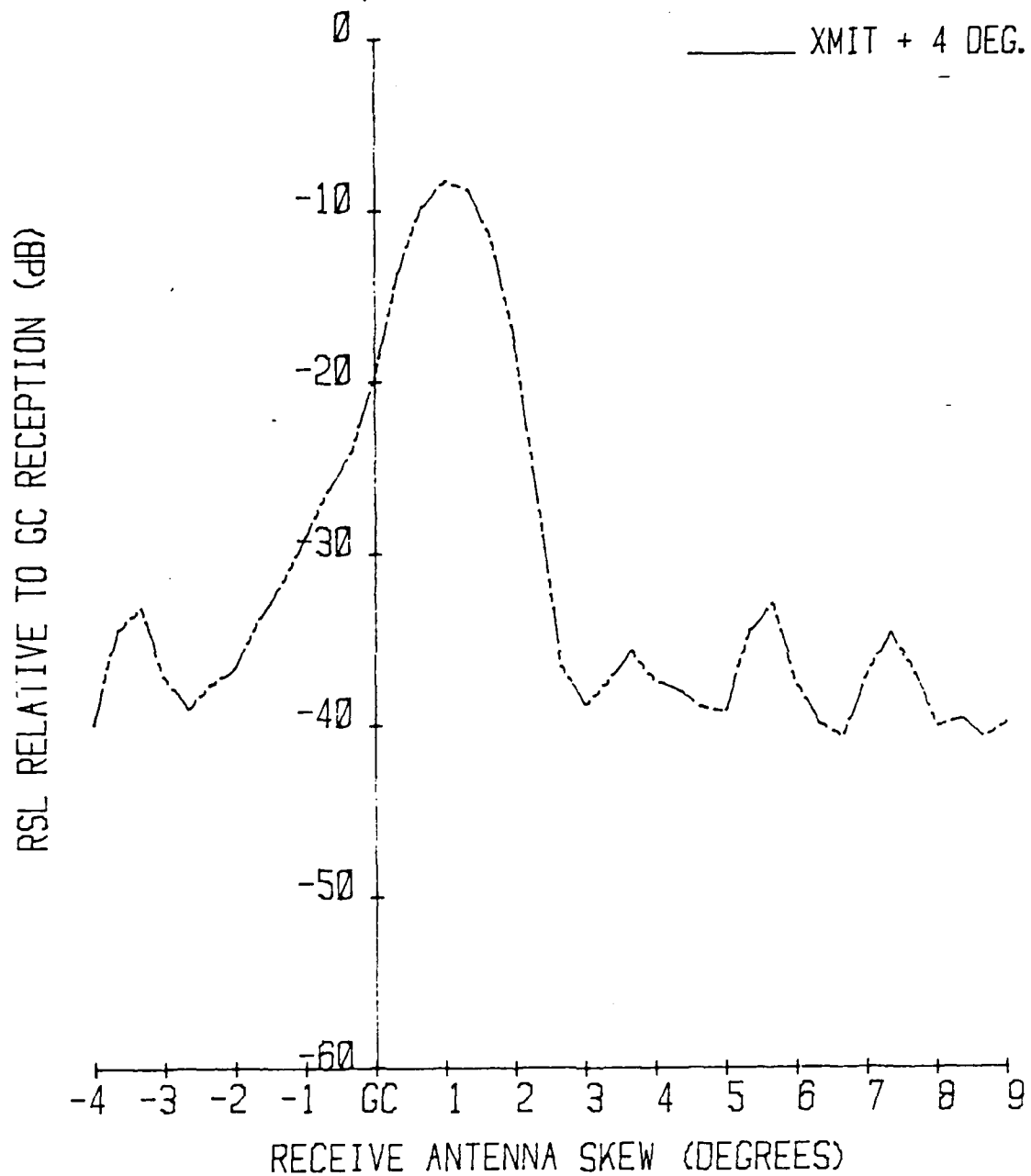


Figure B-2

B-3

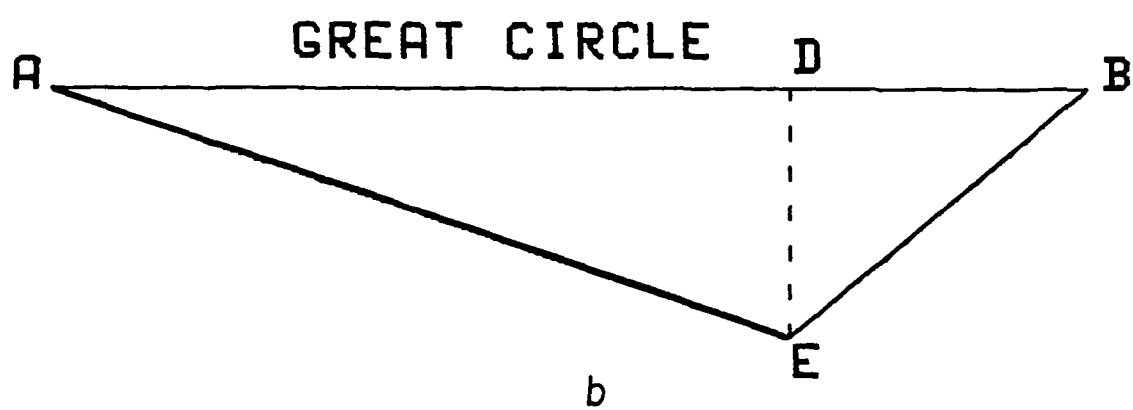
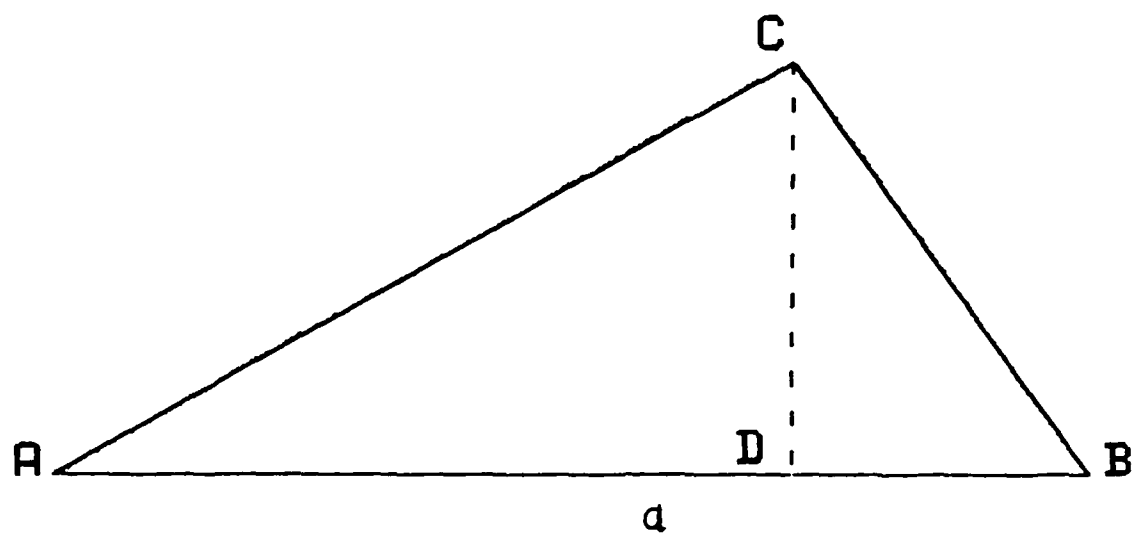


Figure B-3

B-4

than the position of the fixed, skewed beam. When the first terminal has completed its alignment, the elevations should be reversed for alignment of the second terminal.

It should also be evident that if a skewed alignment has occurred, then an elevation alignment may produce little significant change in elevation even if the scanning beam was originally elevated well above the horizon. This is because the beams are already intersecting after the azimuth alignment and a change in elevation of one antenna degrades the intersection. Lowering one beam reduces scatter loss due to reduction of the scatter angle but the antenna azimuths are now incorrect for full beam intersection. Only when both beams are close to GC will elevation alignments produce optimum takeoff angles.

Figure B4 illustrates this with computed elevation alignments for a link which has undergone a skewed azimuth alignment (the results of the skewed alignment of figure B1 are used). An elevation alignment by either the low angle terminal or the high angle terminal produces little change.

Performing elevation alignments before both beams are close to GC is often a waste of time. If sufficient RSL is present, azimuth alignment should be completed before elevation scans are commenced at either terminal. A means of reducing the initial (mechanical) elevation misalignment would be useful in the overall alignment process. Greater elevation asymmetries could be obtained with moderate RSL loss to speed azimuth alignment.

Tables B1 through B4 depict four alignment scenarios for one communications link. Initial compass alignment for each case is the same. In the last two alignments, additional time has been taken to reduce an elevation error present in the initial setting. In the first scenario, the lower elevated terminal A commences alignment. Terminal B starts the alignment in the second case. In the third and fourth scenarios, the fixed (non scanning) beams are purposely elevated at the start of azimuth alignment periods and elevation alignments are left for last.

In table B1, alignment proceeds without great difficulty. Terminal A completes azimuth and elevation scans in steps 1

ELEVATION SCAN---AZIMUTH SKEW

15' ANTENNA 50 MILE PATH;

TAKE OFF ANGLES 0.50 AND 2.50 DEG.

AZIMUTH ANGLES 2.00 AND 5.65 DEG

--- LOW TERMINAL SCAN

--- HIGH TERMINAL SCAN

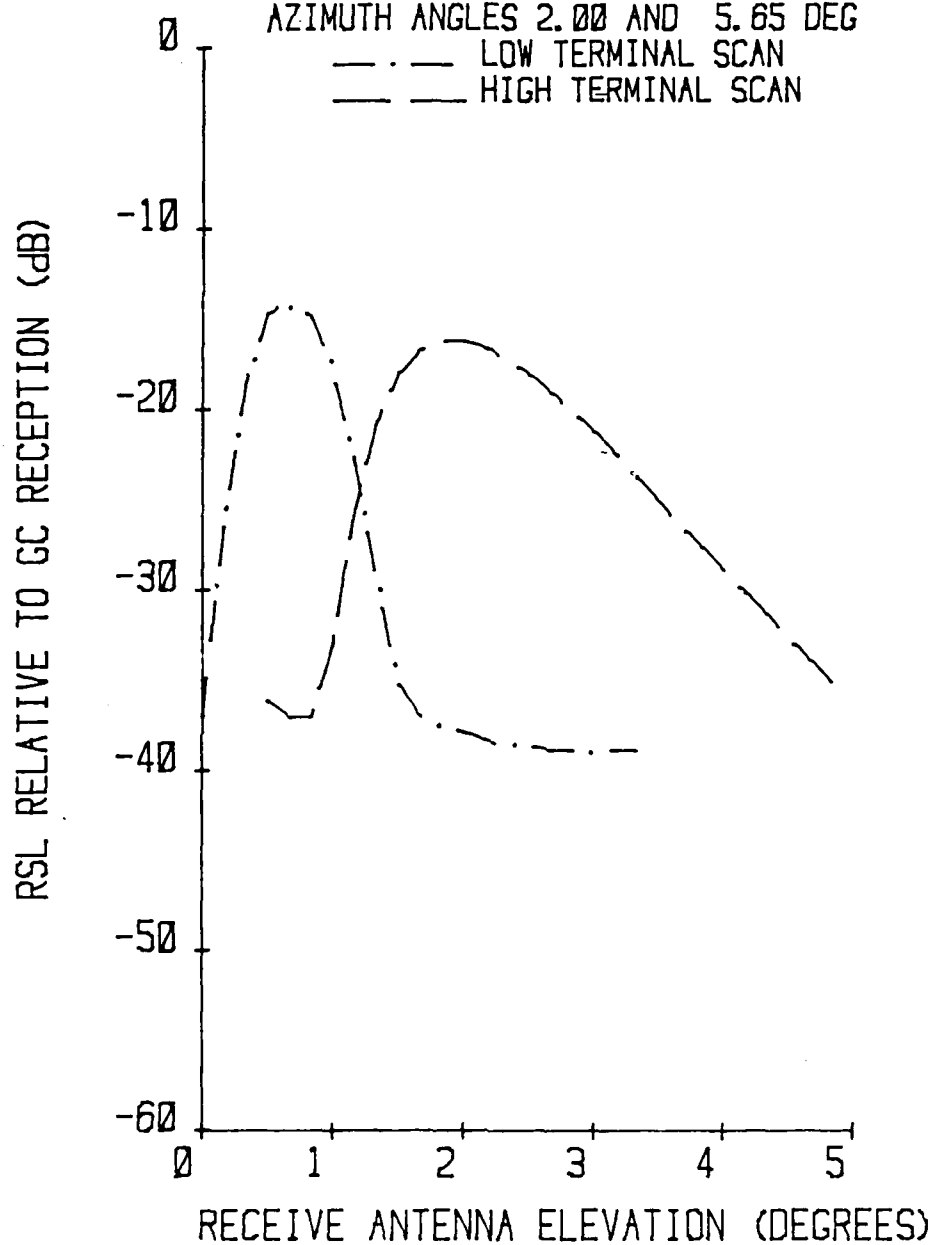


Figure B-4

TABLE B1

STEP	TERMINAL A		TERMINAL B	
	ELEVATION	AZIMUTH	ELEVATION	AZIMUTH
0	0.5	2	2.5	4
1	** 0.25	** 1	2.5	4
2	0.25	1	** 0.83	** 2.1
3	** 0.0	** 0.8	0.83	2.1
4	0.0	0.8	** 0.0	** 0.5
5	0.0	**+0.1	0.0	** -0.2

TABLE B2

STEP	TERMINAL A		TERMINAL B	
	ELEVATION	AZIMUTH	ELEVATION	AZIMUTH
0	0.5	2	2.5	4
1	0.5	2	** 2.0	** 5.65
2	** 0.45	** 1.9	2.0	5.65
3	0.45	1.9	** 1.55	** 4.65
4	** 0.40	** 1.8	1.55	4.65
5	0.40	** 1.1	1.55	** 3.95

MISALIGNMENT LOSS = 30.6 dB

** Parameter changed after scanning

and 3 while terminal B does the same in steps 2 and 4. Each alignment scan brings the scanned parameter closer to optimum (GC and zero elevation). Initial elevation alignments by both terminals, however, do not result in zero elevation angles. Step 5 is a synchronous alignment with both terminals scanning their antennas in step in the same direction.

In Table B2, alignment starts with the high angle terminal B. The azimuth scan results in an angle of 5.65 degrees which is further from GC than that of terminal A. In fact, because of the large asymmetry, the angle is larger than the 4 degrees initial misalignment of terminal B.

The elevation scan reduces terminal B's elevation to 2 degrees. If this terminal were now to repeat the azimuth scan, the azimuth misalignment would decrease because of the reduced elevation asymmetry. The table assumes, however, that B's time period is exhausted.

Terminal A (low elevation) azimuth scan opposite B's 5.65 degree azimuth misalignment and reduced elevation produces an azimuth angle of 1.9 degrees. (if the high terminal had not reduced its elevation, the low terminal scan would have produced an azimuth of 1.5 degrees). Terminal A's elevation scan produces no significant change.

The process repeats until after four separate azimuth alignments, terminal A has an azimuth misalignment of 1.8 degrees and terminal B azimuth misalignment is greater at 4.65 degrees than when it started. After four elevation scans, the low terminal has barely improved and the high terminal is still elevated by 1.55 degrees.

Step 5 is a synchronous alignment with both antennas moving in step. A small correction is made in both antennas toward GC. Further movement towards GC produces less beam intersection and greater loss. Synchronous scanning is of little use in this case. Over 30 dB of loss is suffered by this alignment scenario with the crews unaware of what has happened.

In tables B3 and B4, a better method is illustrated. More time is allocated for initial mechanical elevation alignment. This can be done by dropping a plumb bob over the face of the

TABLE B3

TERMINAL A			TERMINAL B	
STEP	ELEVATION	AZIMUTH	ELEVATION	AZIMUTH
0	0.5	2	2.5	4
1	** 0.5	2	** 1.0	4
2	2.0	2	1.0	** 1.1
3	0.5	** 0.25	2.5	1.1
4	2.0	0.25	1.0	** 0.1
5	** 0.0	** 0.1	2.5	0.1
6	0.0	0.1	** 0.0	0.1

TERMINAL A			TERMINAL B	
STEP	ELEVATION	AZIMUTH	ELEVATION	AZIMUTH
0	0.5	2	2.5	4
1	** 0.5	2	** 1.0	4
2	0.5	** 1.1	2.5	4
3	2.0	1.1	1.0	** 0.6
4	0.5	** 0.15	2.5	0.6
5	2.0	0.15	** 1.0	** 0.05
6	** 0.0	0.15	0.0	0.05

** Parameter changed after scanning

antenna to calibrate the elevation scale. This reduces the initial elevation angle for terminal B to 1 degree.

Whichever terminal commences scanning will reduce its elevation to minimum while the other terminal raises its elevation 1.5 degrees. An iterative process of scanning a low beam against a high beam continually reduces the azimuth errors. When terminal A starts the alignment process in table B3, azimuth angles of 1.1 and 0.25 degrees result (steps 2 and 3) after one scan each and 0.1 degrees each after two scans (steps 4 and 5). When terminal B commences alignment, (table B4) the results are similar. The elevation scans in Tables B3 and B4 are left for last. Since both beams are close to GC, beam intersection occurs at all elevations and one elevation scan per terminal produces the optimum zero degree elevation angles.

Tables B1-B4 were produced for 15 foot antennas. Figure B5 compares 15 foot with 8 foot antennas for low angle terminals and 2 degree azimuth misalignment. The low angle scans are similar for both antennas. The high angle scans in Figure B6 indicate that the 8 foot antenna scan results in a peak closer to GC than in the case of the 15 foot antenna. The curve is extremely broad, however, and may confuse a crew chief into returning to his original position under low RSL conditions.

Figure B7 illustrates the scans of 4 degree misalignments by high angle 8 and 15 foot antennas. In both cases, the curve shows low RSL's and is very broad with peaks near GC. Beam intersection is so far from GC that overall loss for intersecting beams is greater than that of reception of sidelobes as the scanning beam passes GC. Less relative power (absolute gains of the antennas are not referenced in the graph) is received by the 15 foot antenna because of lower relative sidelobe gains.

If improper alignment procedures are used, it is apparent that the 15 foot antenna is easier to misalign. The smaller beamwidth and higher absolute gain produce above noise RSL peaks that look normal when a skewed alignment has actually occurred. In contrast, the 8 foot antenna will align closer to GC because of the larger beamwidth and may appear to the crew to be much broader than normal. The lower absolute antenna gain may cause marginal radio performance which may prompt the

TROPO LOSS--AZIMUTH MISALIGNMENT

LOW ANGLE TERMINAL 50 MILE PATH

TAKE OFF ANGLES 0.50 AND 2.50 DEG. XMIT + 2 DEG.

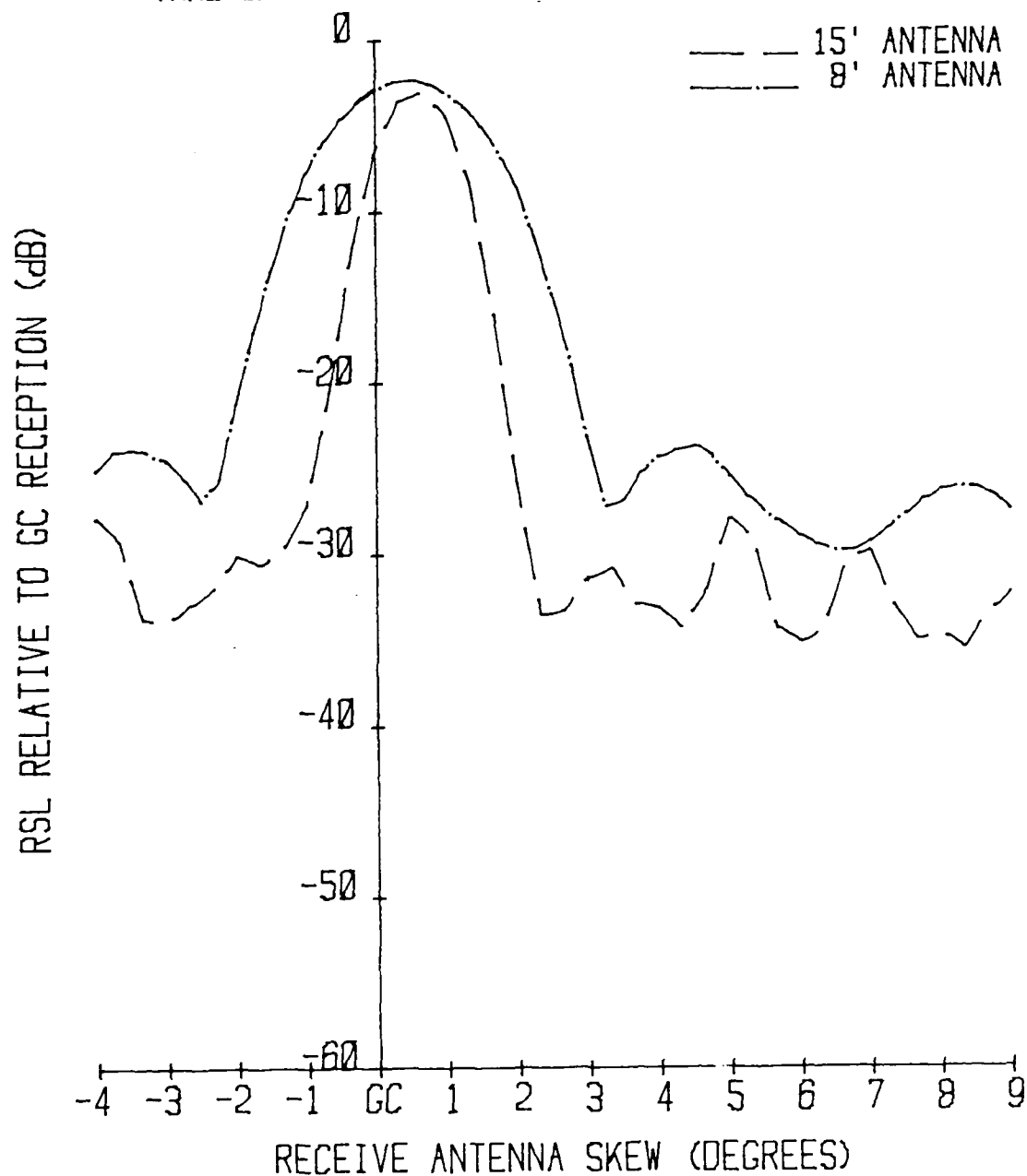


Figure B-5

B-11

TROPO LOSS--AZIMUTH MISALIGNMENT

HIGH ANGLE TERMINAL 50 MILE PATH

TAKE OFF ANGLES 0.50 AND 2.50 DEG. XMIT + 2 DEG.

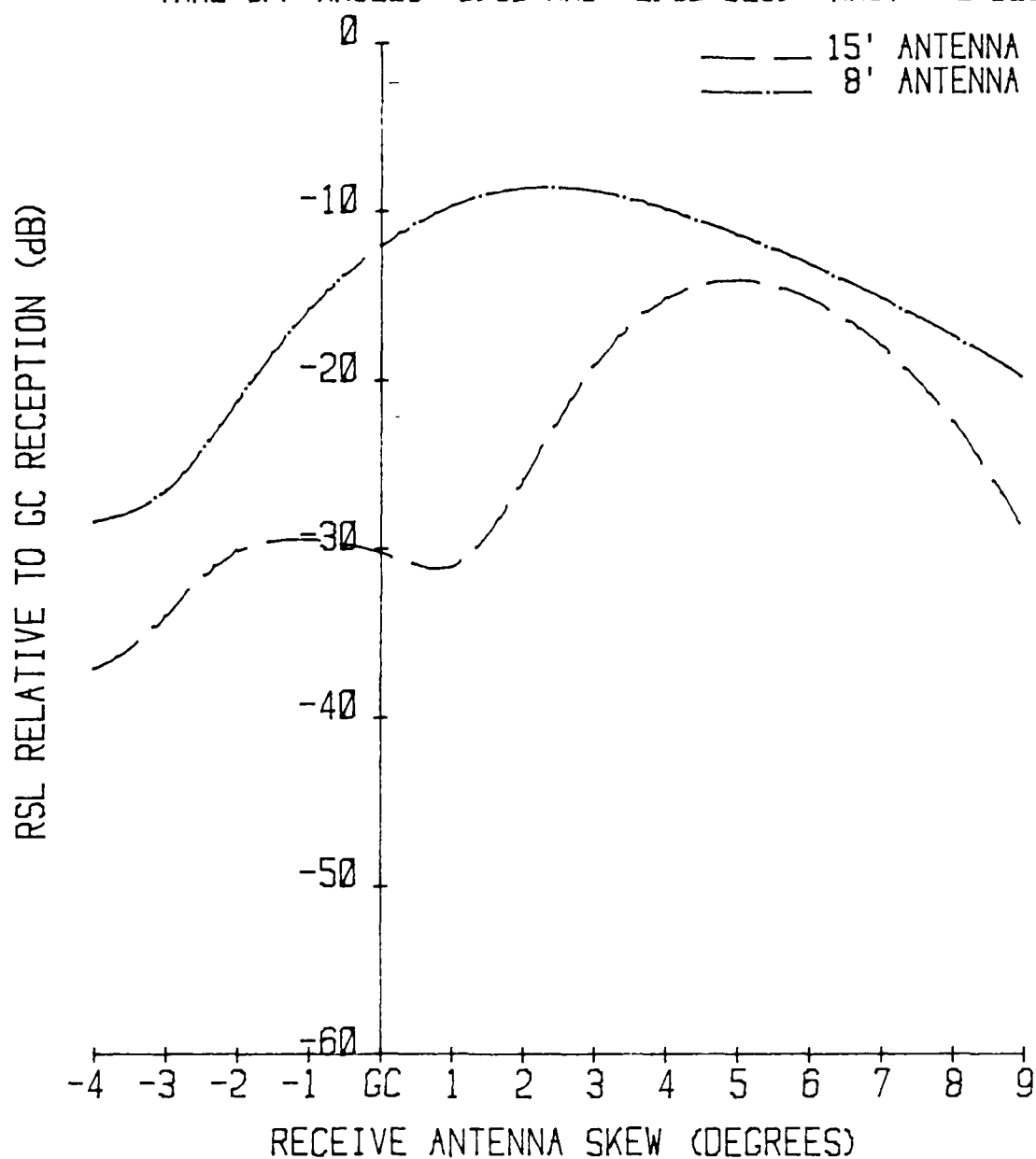


Figure B-6

B-12

TROPO LOSS--AZIMUTH MISALIGNMENT

HIGH ANGLE TERMINAL 50 MILE PATH

TAKE OFF ANGLES 0.50 AND 2.50 DEG. XMIT + 4 DEG.

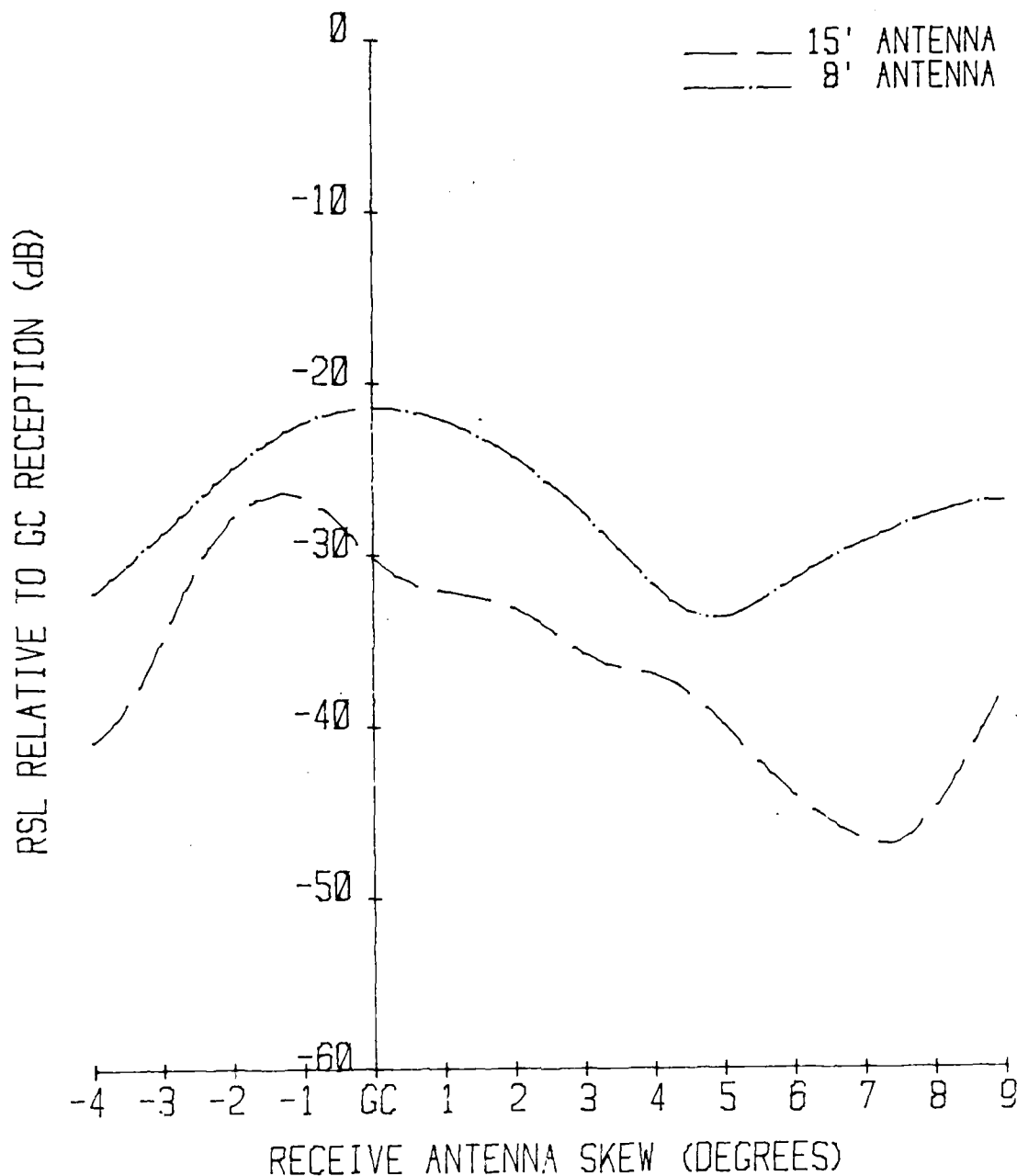


Figure B-7

crew to continue alignment. The worst case that may occur is large initial misalignments at both terminals with eight foot antennas. Scans by either terminal may not produce enough RSL to give indications on the alignment meter. The options to the crew are to complete a tedious incremental adjustment of antennas and realignment attempts or to look for equipment failure.

In any event, scanning low angle beams produces similar results for both antenna sizes. The 15 foot antennas have the advantage of higher gain which will therefore require less receiver sensitivity for the alignment process. If receiver sensitivity is the limiting factor, the 15 foot antennas (using the recommended procedures) should be the easier to align in the long run. Keeping the antennas in alignment without frequent fine resolution alignments is another problem and the eight foot antennas will be more forgiving because of the wider beamwidth.

APPENDIX C

AN/TRC-97A INSTALLATION PROCEDURES T.O. 31R5-2TRC97-2

EQUIPMENT TRANSPORTED BY TRUCK

2-39. GENERAL INSTALLATION PROCEDURES

2-40. Detailed installation procedures are referenced in the general outlines given below. A three-man radio relay team will normally be assigned to each AN/TRC-97A Radio Set. The installation procedures presented are based on having three men available to perform the various tasks and the work assignments in table 4. These three men are designated Man A,

Man B, and Man C and their work assignments are described in paragraphs 41 and 42.

2-41. EQUIPMENT TRANSPORTED BY TRUCK. The truck containing the shelter and towing the Transit Frame mounted in a trailer are driven to the approximate site area with all equipment necessary for installation. An alternate plan may be used whereby an available surveying team makes site selection and layout of the site in accordance with the Crew Assignment Form (table 1 shows a typical form), or assists the radio relay team by providing the required bearing marks and measurements. After arrival of the equipment at the site, the installation is performed in the following order:

1. Determine the approximate site layout.
2. Move the Transit Frame to the antenna location and unload the equipment.
3. Using the truck, move the Trailer to its final position. Allow the truck to remain with the trailer temporarily. The truck and trailer must be at least 45 feet away when the pocket transit is used. Determine the exact sighting direction. The detailed procedure is described in paragraph 48.
4. Disconnect the trailer with the Transit Frame and move the truck with the Shelter to its working position.
5. Establish the system primary power connections.

TABLE C-4

Team Member Work Assignments

WORK ASSIGNMENT PARAGRAPH REFERENCE		
MAN A	MAN B	MAN C
41.1	41.1	41.1
41.2	41.2	41.2
41.3	41.3	41.3
41.4	41.4	41.4
41.12	41.12	41.5
41.12	41.12	41.6
41.12	41.12	41.7
41.12	41.12	41.8
41.12	41.12	41.9
41.12	41.12	41.10
41.12	41.12	41.11
41.12	41.12	41.12
41.13	41.13	41.14
41.15	41.15	41.15
41.16	41.16	41.16
41.17	41.17	41.17

6. Set up the shelter ventilation system for the desired type of operation.
7. Prepare the equipment for primary power application.
8. Start the Generator.
9. Energize the electronic equipment.
10. Connect and energize the Alarm Monitor and connect the Antenna Alignment Meter to the Shelter for use during the establishing of communications contact.
11. Establish the communications circuit connections.
12. Assemble and erect the Antenna Group and interconnect the Antennas and Shelter.
13. Adjust the Antennas for initial alignment. The detailed

procedure is contained in paragraph 85.

14. Place the equipment in an operate condition.

15. Proceed to establish communications contact according to the operation (LOS, Tropospheric Scatter or Obstacle Gain) desired. The detailed procedure is described in chapter 3.

16. Optimize the Antenna alignment as described in chapter 3.

17. Proceed with the reception and transmission of communications traffic.

2-48. DETERMINING THE EXACT SITING DIRECTION The determination of the exact siting of the Radio Set AN/TRC-97A is described below when using the parabolic reflector antenna.

1. Remove the tripod and ball joint from the transit case.

2. Position the base plates in the locations determined in paragraph 2-45.3 above.

3. Place the ball joint on the tripod and set up the tripod over the base plate for antenna No. 1.

4. Using the pocket transit mounted on the tripod, determine the exact azimuth direction in accordance with the crew Assignment Form.

5. While looking through the pocket transit sight which is aimed on the exact azimuth heading, direct the placement of a sighting mark by a second man located approximately 25 yards from base plate No. 1 in the direction of the distant site.

6. Drive a ground rod into the earth at the sighting mark determined in step 5 above. This ground rod will be used later as a sighting stake during initial alignment of the antennas.

7. After the ground rod is driven, recheck with the pocket transit to ascertain that the sighting direction indicated by the ground rod is in agreement with that required by the Crew Assignment Form.

2-81C. AZIMUTH ALIGNMENT

NOTE

Guy cables must have very low tensions when azimuth adjustment is made.

1. Remove the transit mount from the transit case.
2. Screw the transit mount into the lower mast section.
3. Remove the pocket transit from the Antenna Alignment Kit and open it to the fully open position.
4. Place the pocket transit in the transit mount and tighten the holding screw.
5. Turn the pocket transit rear and front sights so that they are perpendicular to the rear sight holder and the mirrored cover respectively.
6. Adjust the pocket transit and transit mount to obtain a level indication on the circular level located within the compass position of the pocket transit.
7. Using the 3/4-inch socket, ratchet wrench and step/handle, turn the worm gear drive on the lower mast section until the pocket transit sights are in line with the sighting stake driven in paragraph 2-48.6. Sight through the pocket transit rear sight toward the front sight and the sighting stake.
8. Temporarily align Antenna No. 2 to the azimuth angle listed on the Crew Assignment Form.
9. Remove and stow the pocket transit and the transit mount. Do not remove the sighting stake at this time.
10. On both antennas, loosen the wing nut on the graduated azimuth scale ring and rotate the ring until the fixed pointer is over the desired azimuth reading as given on the Crew Assignment Form. Tighten the wing nut.

2-81D. ELEVATION ALIGNMENT.

1. Climb the mast and insert and secure the step/handle in the upper mast section.
2. Climb higher on the mast and stand on the step/handle.
3. Adjust the reflector elevation position by rotating the elevation adjustment rod to a level position as indicated by the tubular level on the reflector support.
4. Loosen the two wing nuts on the elevation scale pointer and move up or down until a zero degree indication is obtained. Tighten the wing nuts.
5. Adjust the reflector position, by means of the elevation adjustment rod, until the fixed indicator line is directly opposite the desired elevation angle as given on the Crew Assignment Form.

3.14. INITIAL ALIGNMENT FOR ANTENNA 1 (VOICE CONTACT). To perform the initial alignment for antenna No. 1, proceed as follows:

1. On the PA Control-Monitor Panel, place the MODE switch in the OPERATE position.
2. On the Line of Sight Panel, tune the CHANNEL NO. control to the assigned transmitting channel and then tune until the r-f output reflected power decreases to a minimum as indicated on the Monitor RF power meter.
3. Using the assigned transmitter power for search, contact is attempted for a specified period of time without antenna adjustments. Antenna alignment meter readings are checked at each receiver and voice calls made on the Alarm Monitor order wire handset.
4. During the second assigned time period (as given in the Crew Assignment Form) Site J stands by while Site I-1 antenna beam is swept slowly and systematically through the azimuth range until beam intersection is indicated in the test meter. If contact has been established proceed to step 9 for further adjustment.
5. If contact is not established, a third assigned time

period is used to increase the I-1 antenna horizon angle upward by one degree.

6. During the fourth assigned time period scan at Site I described in step 4 using the elevated horizon angle of step 5.

7. If contact is still unsuccessful, a fifth assigned time period is used to return antenna I-1 azimuth and elevation angle to their original settings followed by azimuth angle scanning at J-1 (as described in step 4 for I-1).

8. If efforts have been unsuccessful to this point, the crew at each site should follow emergency procedures assigned during preliminary briefing.

9. After contact is established, further adjustment of antenna angles is usually required to increase received signal power since, in azimuth, the antenna beams are not aligned along the direct path and vertically, the horizon angles are not optimum at this time. Azimuth angle positions should now be read off the antenna mast for reference in further adjustments.

10. Temporarily adjust number 2 antenna by listening for noise quieting as heard on the Alarm Monitor handset.

3-15. AZIMUTH ALIGNMENT FOR ANTENNA 1. The senior crewman directs mutual adjustment of the No. 1 antennas at both sites. They are rotated simultaneously from their azimuth settings as recorded in step 3-13.9 in 1/2 degree intervals clockwise at local site I and counterclockwise at remote site J while test meter readings at the remote site are reported to the senior crewman who checks the signal power trend for each site after each simultaneous movement of the I-1 and J-1 antennas.

1. If signal power decreases, rotation of each antenna should be reversed.

2. The rotation procedure is continued until beam positions are found for maximum received power. The azimuth angle positions are now recorded at each site for further reference.

NOTE

If contact is lost, each antenna is returned to its reference position before rotation as given in step 3-13.9. If contact is still not restored, site J crew stands by while the site I crew re-establishes contact by azimuth scanning. Both crews should also check panel indicator lamps for indication of malfunction.

3-16. VERTICAL ANGLE ADJUSTMENTS FOR ANTENNA 1. The senior crewman directs 1/4 degree adjustments at both sites. They are made on a sequential basis, one site then the other. Antenna alignment meter readings at the remote site J are reported to the senior crewman who observes local readings at Site I while vertical scanning is applied to the local I-1 antenna. The I-1 antenna angle is set for highest meter readings at the local site. The same procedure is followed under senior crewman direction while vertical scanning is applied to the remote site J-1 antenna. Angle settings are recorded at each site for further reference.

3-17. ANTENNA 2 ADJUSTMENTS. Since this antenna is for receiving only, adjustments are made at each site independently. Proceed as follows:

1. Set antenna vertical angle equal to that for No. 1 antenna (see paragraph 3-16) at each site.
2. After setting the azimuth angle to the value of antenna 1, apply azimuth "rocking" to obtain best received power, as indicated by the antenna alignment meter which is connected to the No. 2 receiver. Final azimuth position is now recorded.
3. Adjust the vertical angle to improve received signal power and record the final setting.

	Assigned Site	Remote Site	Comments
1. Shelter Serial No.			
2. Site Designation			
3. Latitude	" ' "	" ' "	Deg. - Min. - Sec.
4. Longitude	" ' "	" ' "	Deg. - Min. - Sec.
5. Military Grid Position			
6. Path Length	Statute Miles	Statute Miles	
7. Magnetic Declination Angle from grid north			E or W, Deg. and minute
8. Magnetic Declination Angle from true north			E or W, Deg. and minute
9. Site Altitude	feet	feet	
10. Preliminary Elevation Setting for Reflector			± Deg to 1/2°
11. Preliminary Antenna Azimuth Angle	°	°	Degrees (to 1/2°) magnetic
12. Type of Propagation			Tropo. Obstacle Gain or LOS
13. Antennas Quantity			Non-Diversity (one) Dual Diversity (two)
14. Estimated Reliability	%	%	
15. Polarization Assignment Transmit Receive			Horizontal or Vertical Horizontal or Vertical
16. Frequency and Channel Number Channel ____ Freq ____ Channel ____ Freq ____	Xmit Channel ____ Rec. Channel ____	Xmit Channel ____ Rec. Channel ____	
17. Alternate Frequency and Channel No. Channel ____ Freq ____ Channel ____ Freq ____	Xmit Channel ____ Rec. Channel ____	Xmit Channel ____ Rec. Channel ____	
18. Transmitter Power For Contact Search For Operation	Watts Watts	Watts Watts	
19. Call Sign			
20. MUX Manual-Servo Assignment			
21. Type of Service, Terminal, Through REPEATER (Baseband), or Drop-Insert REPEATER			
22. Designation of Site for Initiating Contact Search Procedures			
23. Voice Channel Termination Channel 1 Channel 2			4W, 2W, or TTY MUX (4W) and subscriber

TABLE C-1 CREW ASSIGNMENT FORM

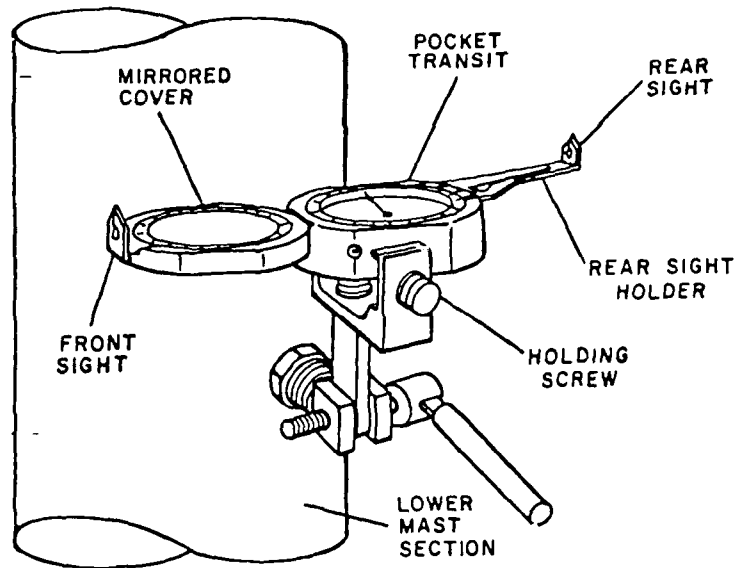
	Assigned Site	Remote Site	Comments
Ch. 3			
Ch. 4			
Ch. 5			
Ch. 6			
Ch. 7			
Ch. 8			
Ch. 9			
Ch. 10			
Ch. 11			
Ch. 12			
Ch. 13			
Ch. 14			
Ch. 15			
Ch. 16			
Ch. 17			
Ch. 18			
Ch. 19			
Ch. 20			
Ch. 21			
Ch. 22			
Ch. 23			
Ch. 24			
23. TTY Channel Termination			4W, 2W, and subscriber
Ch. 1			
Ch. 2			
Ch. 3			
Ch. 4			
Ch. 5			
Ch. 6			
Ch. 7			
Ch. 8			
Ch. 9			
Ch. 10			
Ch. 11			
Ch. 12			
Ch. 13			

- TABLE C-1 (Continued)

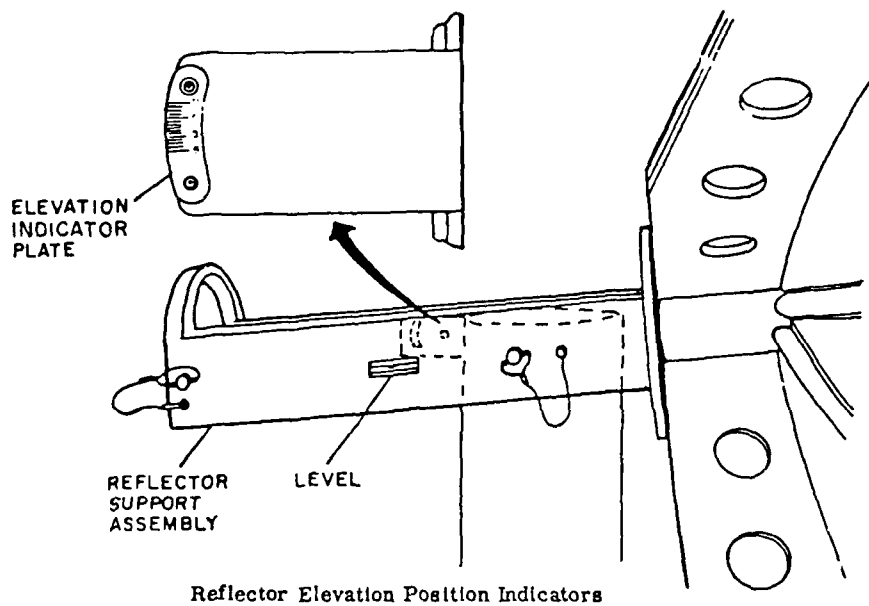
Ch. 14			
Ch. 15			
Ch. 16			
24. Time-Periods (Pre-Contact)			Date X Hrs to Y Hrs
Time Period #1			
Time Period #2			
Time Period #3			
Time Period #4			
Time Period #5			
Time Period #6			
Time Period #7			
Time Period #8			
Time Period #9			
25. Fuel Required	gals.	gals.	
26. Cable/Wire Length Between Repeater Shelters	feet	feet	
27. Additional Instructions:			
Prepared by _____ Accepted by _____ Date _____			

TABLE C-1 (Continued)

TRC-97A EIGHT FOOT ANTENNA



Pocket Transit Mounted on Mast



Reflector Elevation Position Indicators

FIGURE C-1

TRC-97A EIGHT FOOT ANTENNA

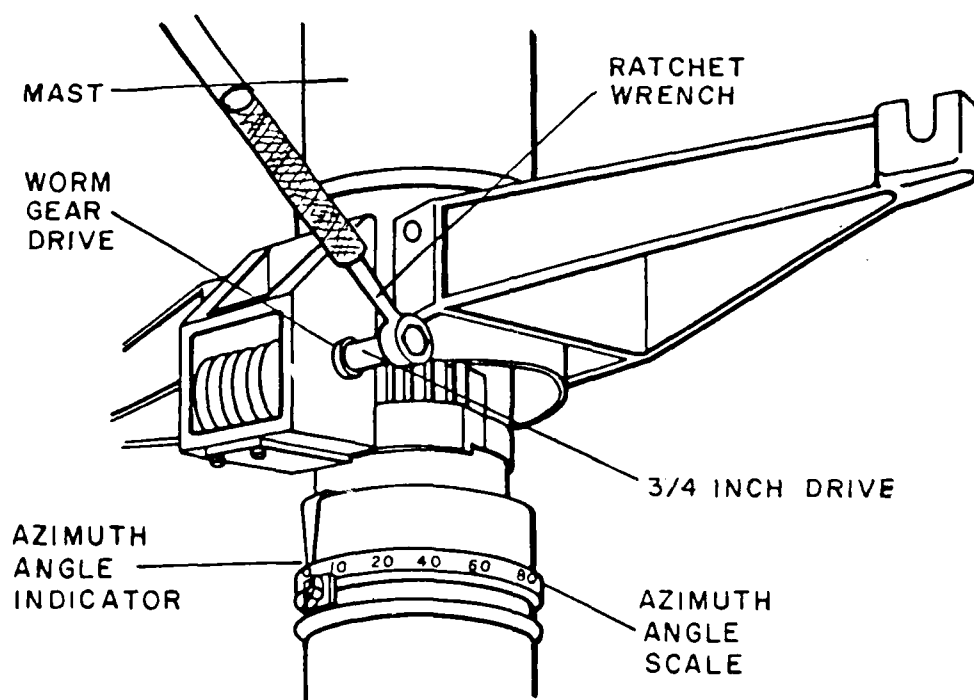


FIGURE C-2

AD-A173 282

ALIGNMENT OF TACTICAL TROPO ANTENNAS(U) ROME AIR
DEVELOPMENT CENTER GRIFFISS AFB NY P A BRADLEY JUL 86
RADC-TR-86-96

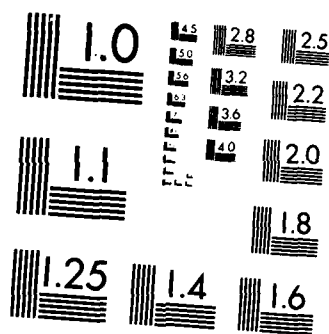
2/2

UNCLASSIFIED

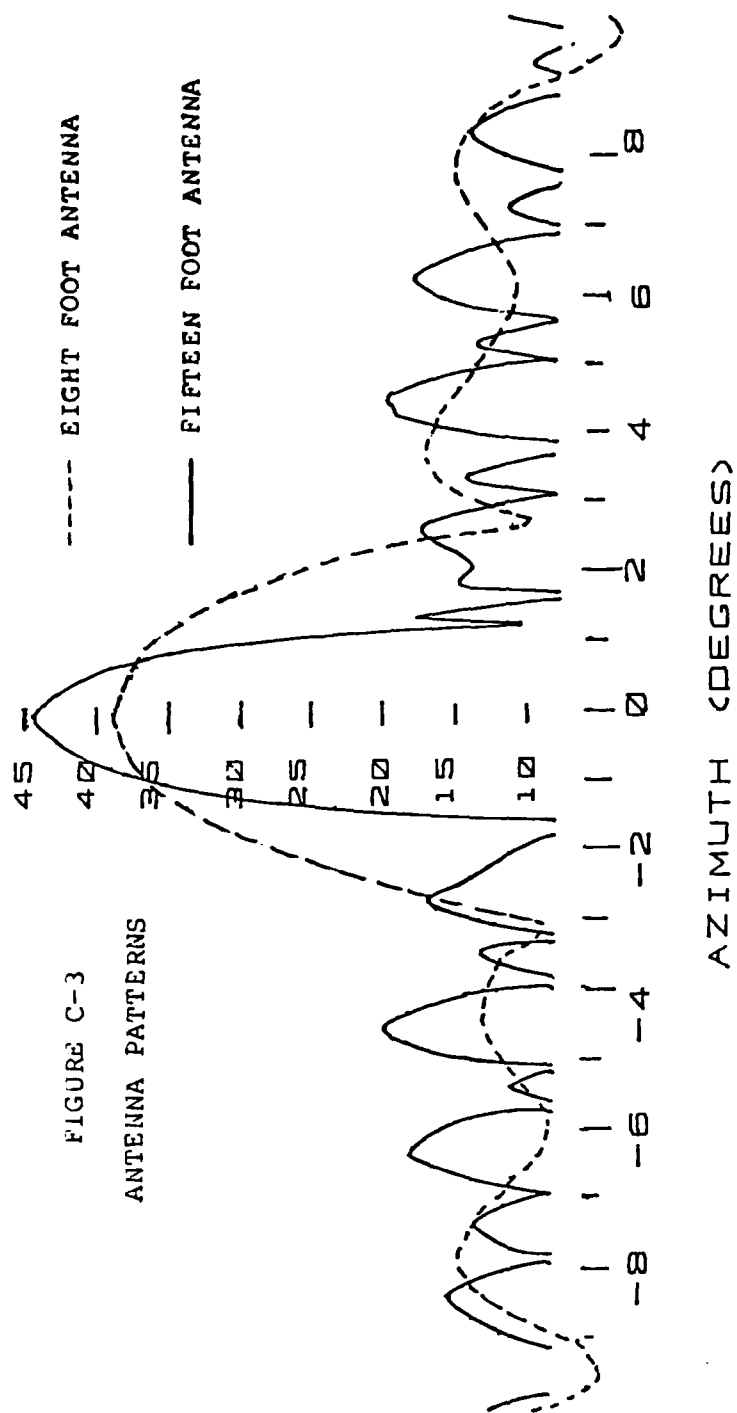
F/G 9/5

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



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END

12-86

DTIC