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TRACKING ACCURACY OF AN INCOHERENT OPTICAL CORRELATION TECHNIQUE

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Redstone Arsenal, Alabama

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of an investigation of the effect of nutation radius on the tracking accuracy of an incoherent optical correlation technique such as the one used in the Terminal Radar Aera Correlation Experiment (TRACE).

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CONTENTS

1. Introduction

The function of a radar or optical correlation guidance system is to determine the relative position of a vehicle to a predesignated target area (reference image) and provide this position data to a steering or guidance computer on the vehicle. The basic elements of a correlation guidance system are a sensor, correlator, and a reference. The function of the correlator is to match the sensor "live" image with the reference "stored" image and determine the difference in position.

This report discusses the relationship of the size or width of the nutating tracking radius to the width of the correlation function (independent of scene content and radar parameters that affect the correlation function), which in turn relate to the correlator accuracy.

While this exploration was performed using radar type data, the results and conclusions are applicable to correlators in general independent of the sensor employed.

The conclusion reached in this analysis is that the accuracy of tracking the correlation peak position increases as the size of the tracking radius decreases up to the point where the radius is equal to one-half the correlation width. This finding suggests that the tracking radius be adaptively constructed to allow for variation in correlation widths that can be caused by scene content and sensor parameters.

2. Area Correlation Guidance

An area correlator on board the vehicle compares the video or scene generated by the "live" sensor in the vehicle to a reference (sometimes referred to as stored) image or scene and determines the required $\Delta x, \Delta y$ needed to align the two scenes. This alignment error ($\Delta x, \Delta y$) is then translated into downrange, crossrange error and used to update the guidance system. The technique used to determine the alignment of the two scenes is to generate the correlation function (correlation being a goodness of match) and determine the position of the correlation peak by tracking the correlation peak position. Tracking of the correlation peak is accomplished by nutating around the peak and estimating the exact location of the maximum. This is similar to a conventional con-scan tracker in a radar system.

3. Experimental Procedure and Simulation Results

It has been shown [1,2] that the cross-correlation operation gives the best linear estimate of the similarity between two functions. As stated mathematically, the cross-correlation between f(x,y) and h(x,y) is

$$r(u,v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y)\, h(u+x,\, v+y)\, dy\, dx.$$

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Although the integrals are over infinite limits, it is understood that f(x,y) and h(x,y) are of finite extent.

Incoherent optical processing is basically a mask matching technique and a wide variety of specific implementations are possible. Figure 1 shows an incoherent optical correlator which includes a distributed source S placed in front of a transparency with transmittance $t_1(x_1,y_1)$. At a distance d from t_1 and immediately in front of a lens is a transparency $t_2(x_2,y_2)$.

The resulting intensity distribution in the back focal plane of the lens has been shown to be proportional to the desired cross-correlation.

$$I(x_0,y_0) = k \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t_1(x_1,y_1)\ t_2 \left[x_1 + \frac{d}{f} x_0, y_1 + \frac{d}{f} y_0\right] dx\ dy.$$

More detail on the method of cross-correlation can be obtained from References 1, 2, 3, and 4.

The Adaptive Correlation Evaluator (ACE), as described in Reference 1, was utilized to generate the sensor images and perform the tracking of the correlation functions.

ACE provides a light-sensitive, electronic scanning technique for determining the correlation function of two scenes. The scanning pattern used searched the two-dimensional correlation function in a decreasing spiral, detecting any point that is above the average noise level by a preset amount. If this point on the two-dimensional correlation function meets all the requirements of a correlation peak then it is tracked by the nutation radius to determine the position mismatch of the two transparencies. Figure 2 shows a typical spiraling search and nutation tracking circle along with the cross-correlation function in the two orthogonal planes about the match point.

The results obtained from ACE are depicted in Figures 3 through 11 in the form of tracking error (CEP) versus tracking nutation radius. The vertical line on these figures depicts the correlation width (defined as 1/e) of the correlation function (such as shown in Figure 1) being tracked. The reference transparency for all tracks are the side looking radar (SLR) of the Tangleo Park area of Orlando, Florida. The transparencies used to correlate against this reference were synthetic forward looking radar images with the beamwidths and pulse widths shown. These images were generated from the reference transparency with ACE in the image generation mode (IGM). This IGM mode is discussed in detail in Reference 1. Figures 12 and 13 show the reference image and an example of the synthetic radar image generated by ACE, respectively.

The time required to search the correlation function while not shown directly in the results is implied from the fact that the correlation function must be searched in sufficient increments to assure the peak is traversed. However, if this increment is larger than the correlation width, the peak could be missed and if smaller than the correlation width, more time than necessary is required to find the peak. Therefore, the optimal search increment is equal to the correlation width.

4. Conclusions and Recommendations

Based on this investigation of nine different scenes producing nine different correlation functions which were tracked with various nutation radius, the following conclusions have been reached:

a) Tracking accuracy is a function of the tracking nutation radius.

b) There is no significant improvement in tracking accuracy once the tracking nutation radius is equal to one-half the correlation width. This point is where the tracking nutation is rotating about the 1/e points of the correlation function.

c) When the tracking nutation radius is larger than the correlation width, the tracking error goes up at a high rate for small changes in nutation radius.

d) Optimal search increment is equal to the correlation width.

It is recommended that tracking circuits of incoherent optical correlators be designed to allow the tracking nutation radius and the search increment be adaptively set equal to the correlation width. This width can be approximated by a correlator before flight with equipment similar to ACE. This would allow maximum accuracy with minimum search time.

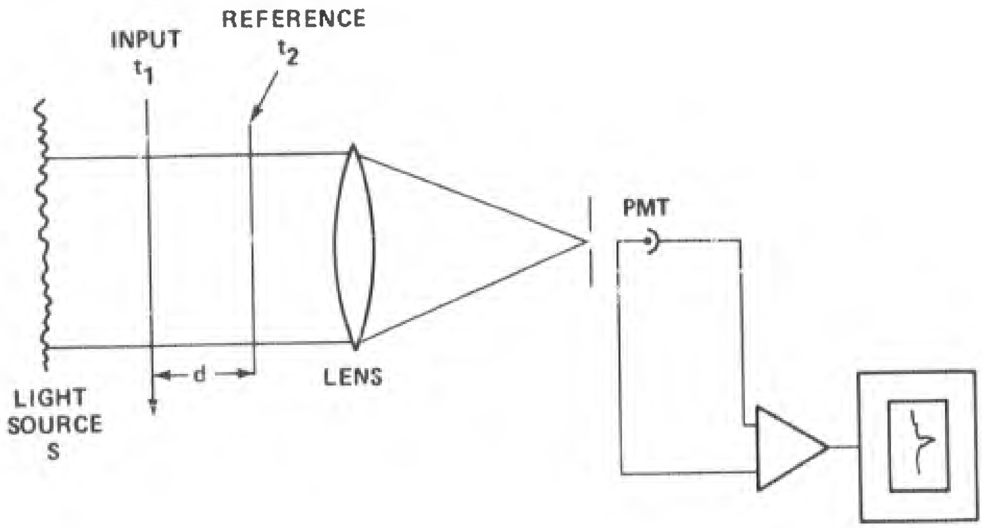

Figure 1. Optical correlator incoherent processor.

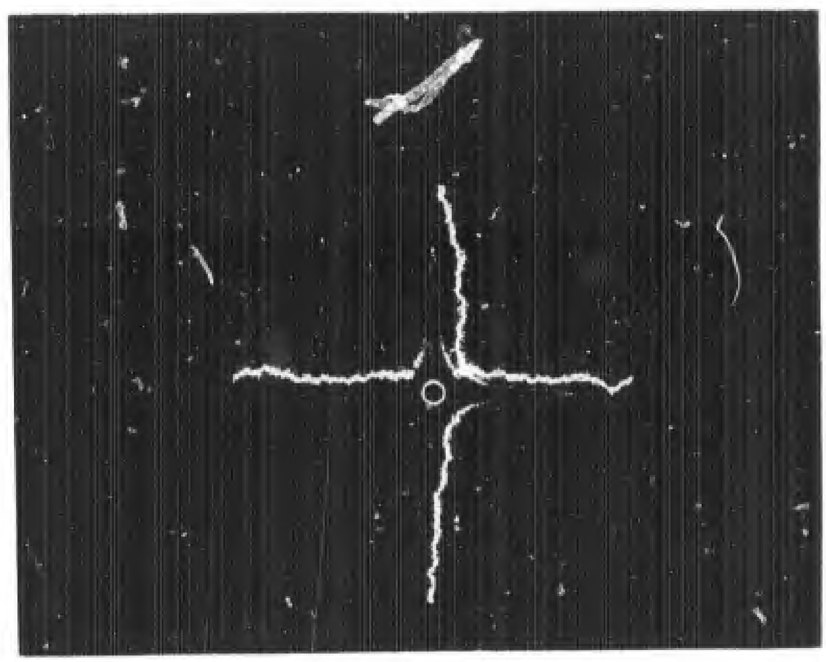

Figure 2. Search and track of a correlation function with the correlation function in the two major planes.

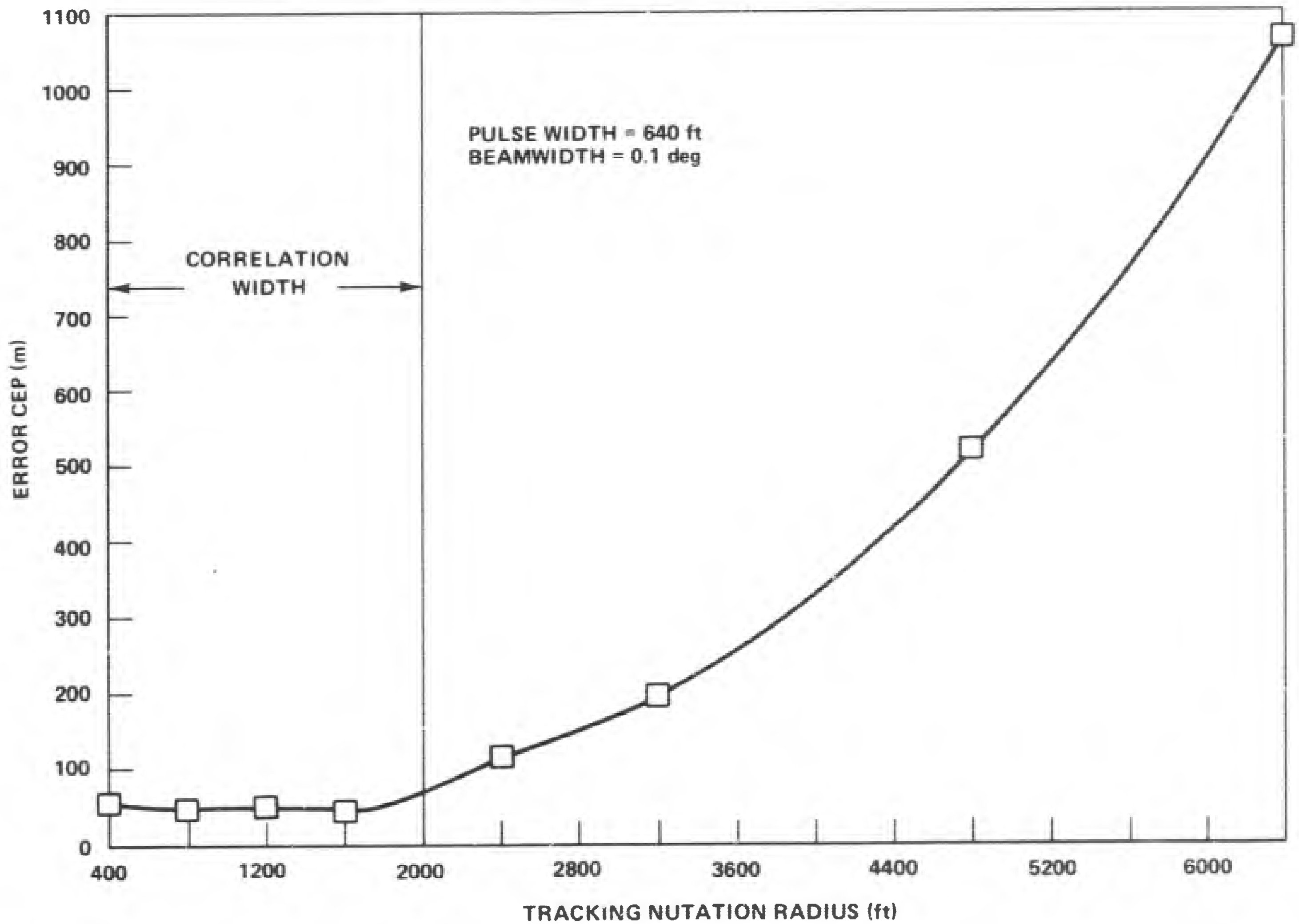

Figure 3. Tracking error versus nutation radius.

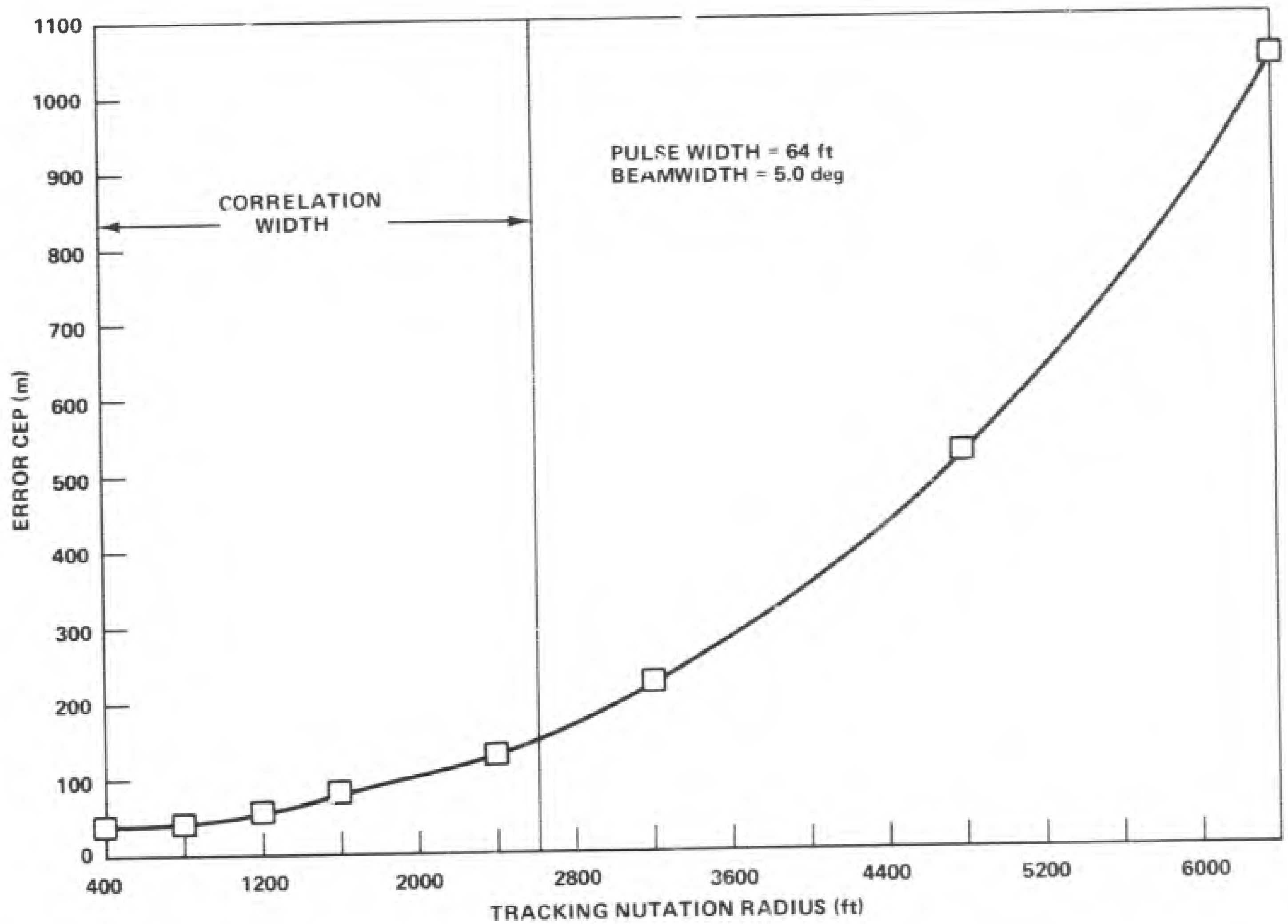

Figure 4. Tracking error versus nutation radius.

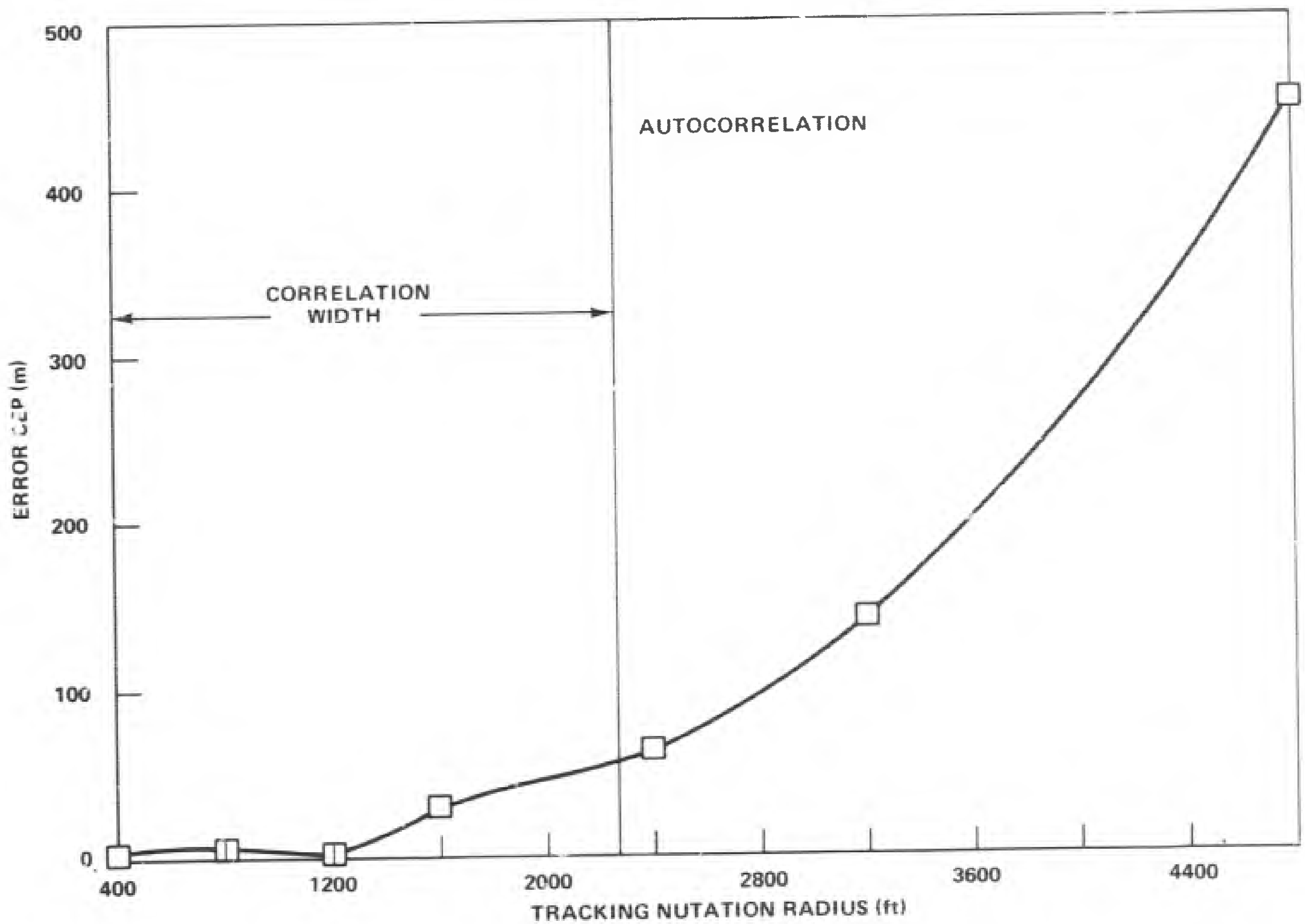

Figure 5. Tracking error versus nutation radius.

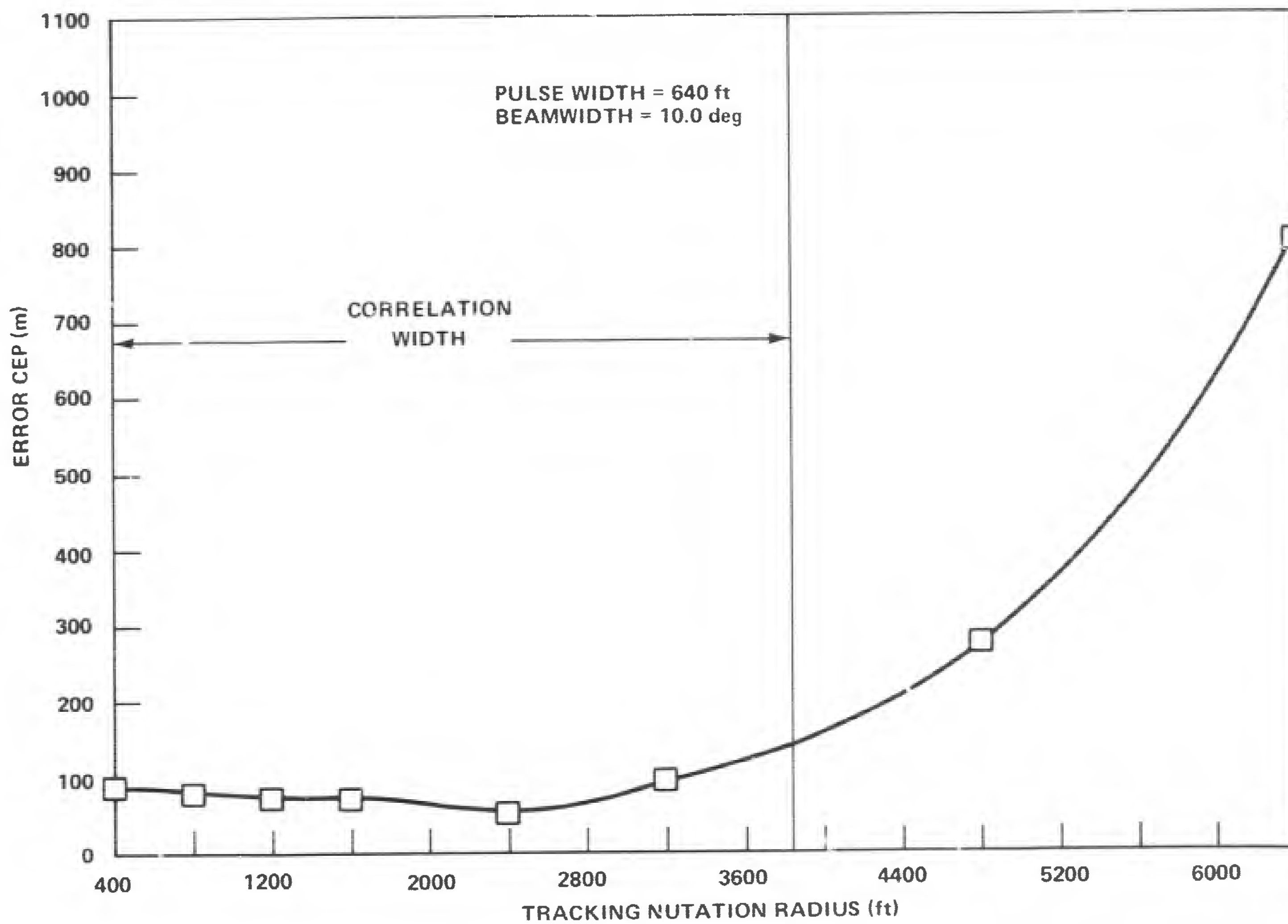

Figure 6. Tracking error versus nutation radius.

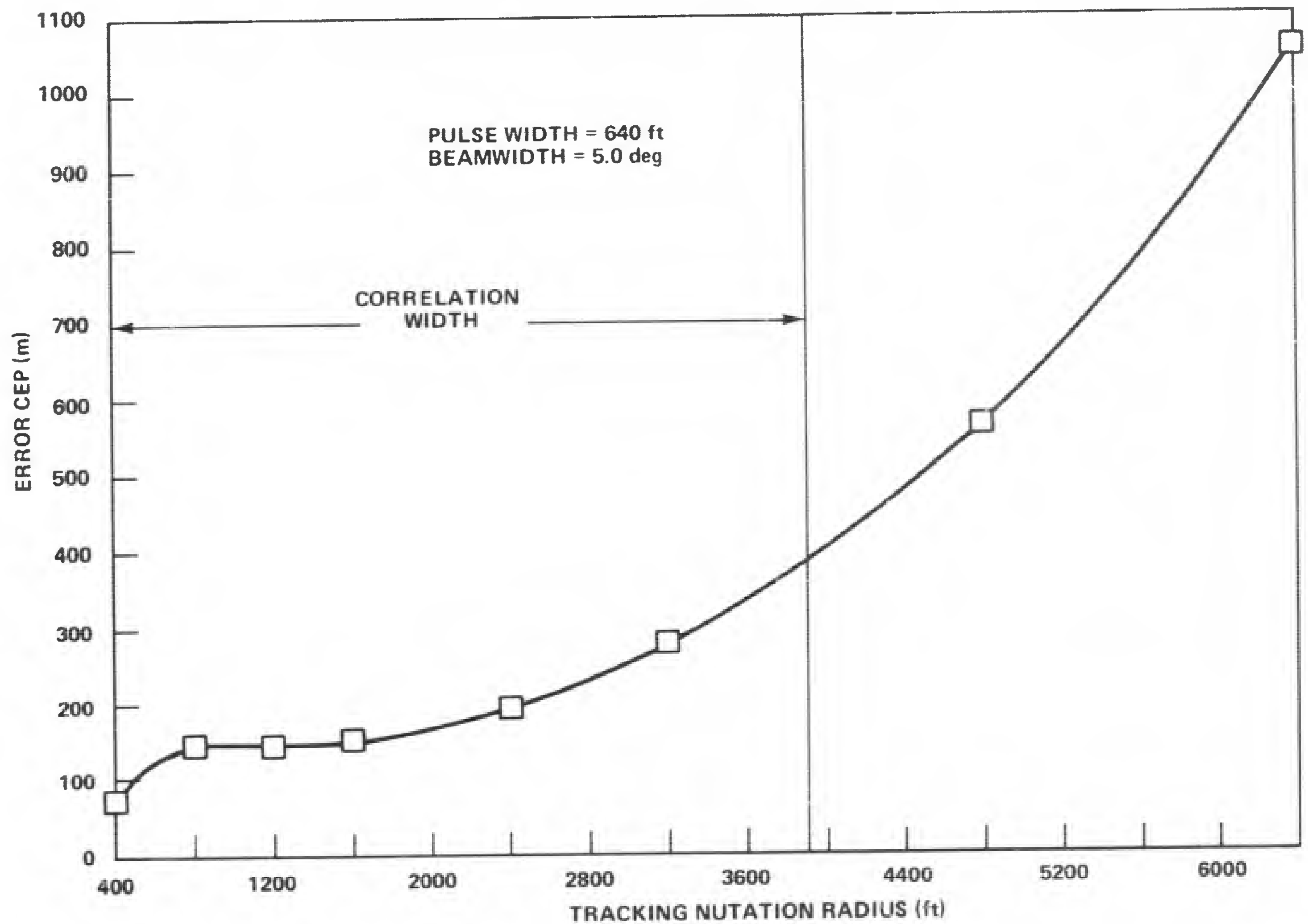

Figure 7. Tracking error versus nutation radius.

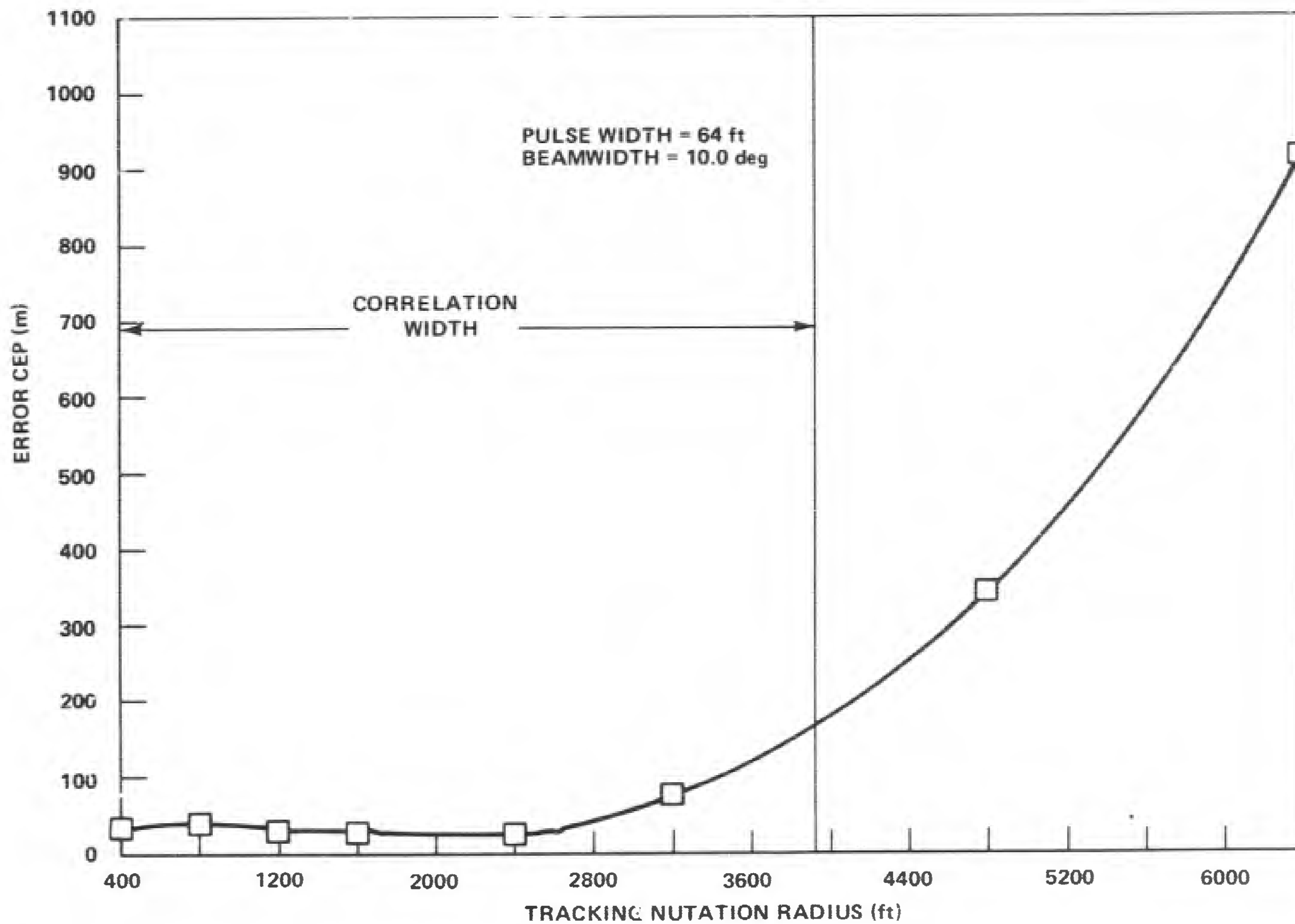

Figure 8. Tracking error versus nutation radius.

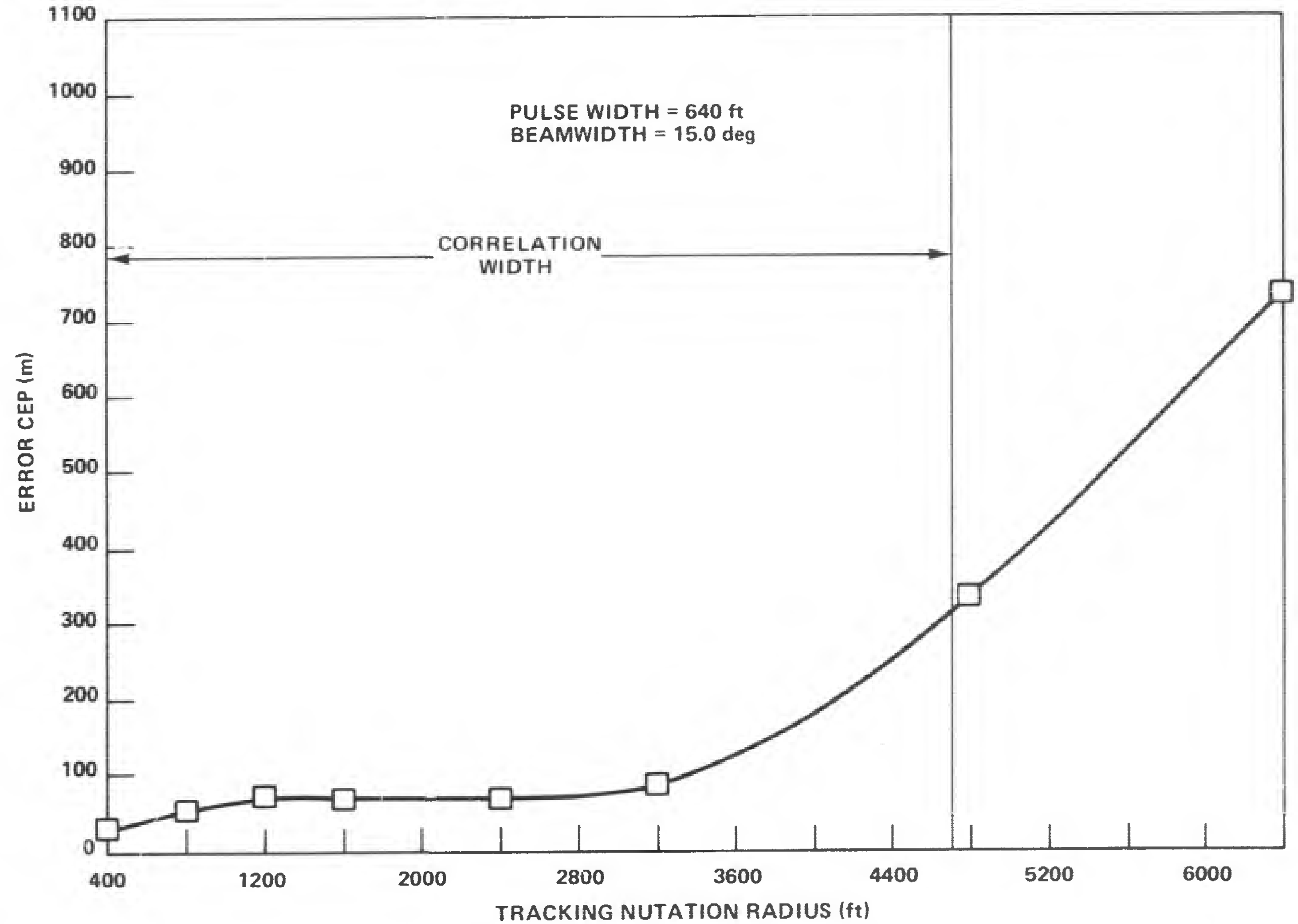

Figure 9. Tracking error versus nutation radius.

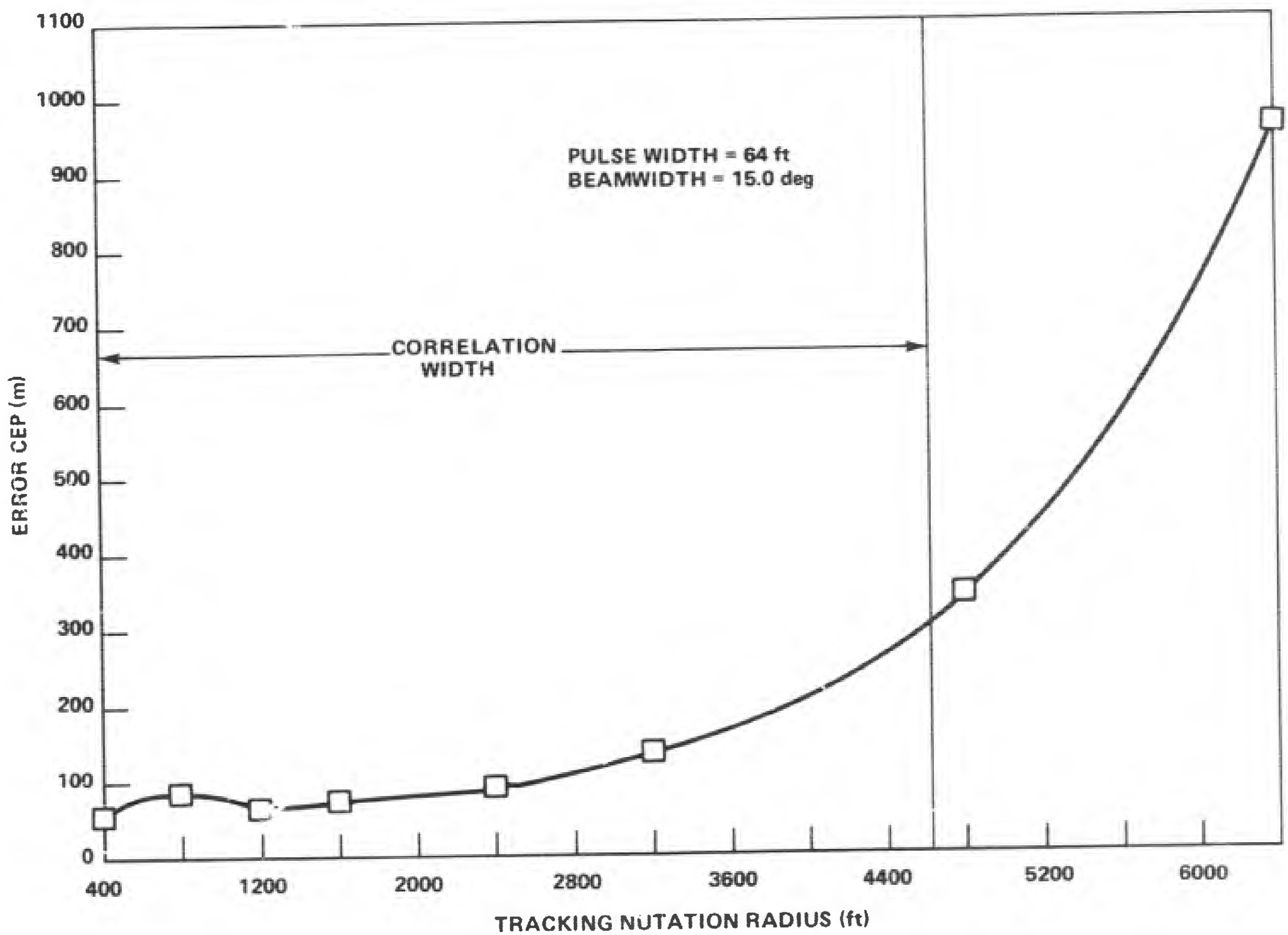

Figure 10. Tracking error versus nutation radius.

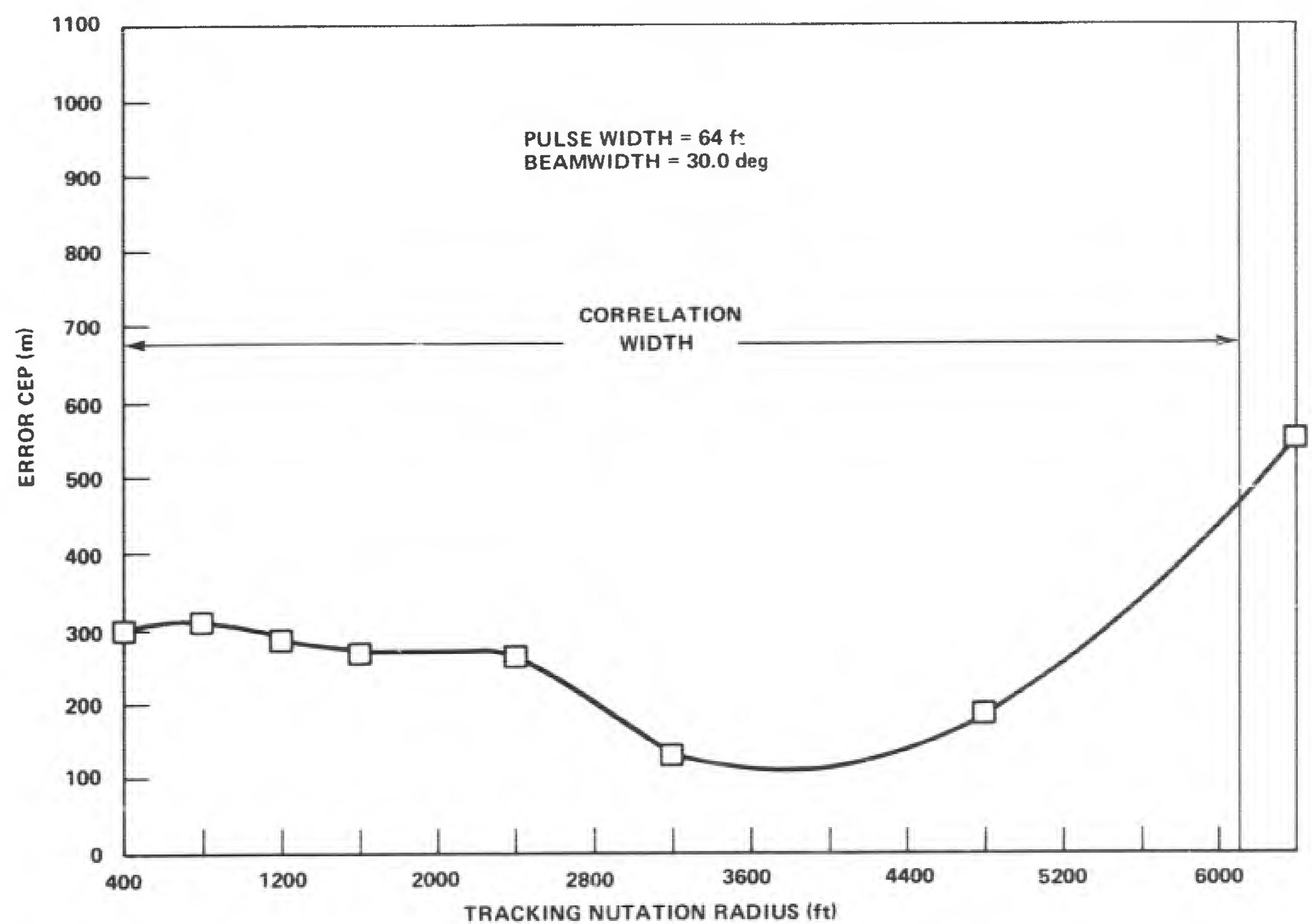

Figure 11. Tracking error versus nutation radius.

Figure 12. Reference image of Tangelo Park.

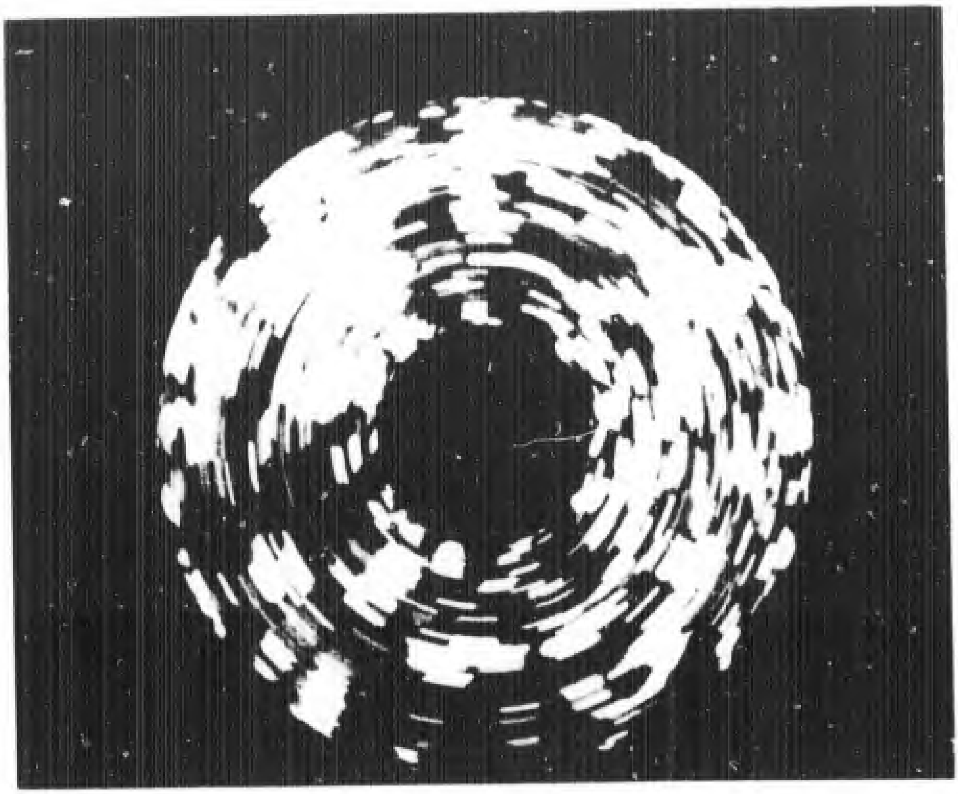

Figure 13. Example of synthetic forward looking radar image of Tangelo Park (beamwidth = 10 degrees, pulse width = 640 feet).

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