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CONSIDERATION OF RADAR TARGET GLINT FROM ST DURING OMV RENDEZVOUS

By Malcolm W. McDonald, Lee B. Malone, and Edmund H. Gleason

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16. ABSTRACT

This report discusses the nature of radar target glint and the factors upon which it depends when using the Hubble Space Telescope as a radar target. An analysis of the glint problem using a 35 MHz or 94 MHz radar on the orbital maneuvering vehicle is explored. A strategy for overcoming glint is suggested.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ACRONYMS

Acronym	Interpretation
FMCW	Frequency-Modulated Continuous Wave
GHz	Gigahertz
OMV	Orbital Maneuvering Vehicle
RCS	Radar Cross Section
R/A	Rendezvous and Docking
ST	Edwin P. Hubble Space Telescope

TECHNICAL MEMORANDUM

CONSIDERATION OF RADAR TARGET GLINT FROM ST DURING OMV RENDEZVOUS

INTRODUCTION

This report results from study and calculations directed toward understanding and anticipating answers to questions which can properly be asked regarding the effects of radar target glint (also known as angle noise, angle scintillations, or angle fluctuations) which might be manifested during a radar-assisted rendezvous/docking (R/D) encounter of the Orbital Maneuvering Vehicle (OMV) with the Edwin P. Hubble Space Telescope (ST). The analysis pertains likewise to R/D of any radar-assisted spacecraft with any other complex radar target.

The report includes (1) a discussion of the nature of radar target glint and the factors upon which it depends, (2) a discussion of the ST as a complex radar target, (3) an analysis of the glint problem for a 35-GHz ranging radar fitted with a 4-degree-beamwidth transmit-receive antenna, positioned on the OMV, (4) an analysis of the glint problem if a 94-GHz OMV radar transmits from a 30-degree-beamwidth antenna and receives on a 0.6-degree-beamwidth antenna, and (5) a summary of the results and recommendations.

It is assumed throughout this report that the R/D of the OMV with the ST is to be accomplished with the aid of a tracking and ranging radar. It is further assumed, and this is important to the analysis, that the radar is supported by a video camera mounted on the OMV and a man-in-the-loop guiding the operation from a remote point (either Earth or the orbiter, for instance).

TARGET GLINT

The term "target glint" (or any of the synonyms previously mentioned) suggests an uncertainty in the angular location of a complex target being tracked by a radar system. It stems from the fact that radar echoes are returned from a large number of scattering points on a complex target. The returning radar echoes differ in phase by amounts determined primarily by the differing distances of their reflection points on the target from the radar antenna. The total amount of power returned in the echoes is a function of the total radar cross section (RCS) of the complex target. It is known that RCS for complex targets is generally very dependent upon the aspect of the target as viewed by the incident radar beam. In fact, complex targets such as large aircraft can exhibit RCS fluctuations of 10 to 15 dB for target aspect changes of a fraction of a degree [1]. As this effect is occurring due to changes in target aspect, the apparent center of radar reflections from the target (which is what a tracking radar tracks) wanders from one point to another on (or even outside the angular limits of) the complex target. The angular uncertainty in the angular coordinate position of the returning signal produced by the wandering apparent center of radar reflections is what is known as target glint [2].

A theoretical model for treatment of target glint has been presented by DeLano and applied by others [3-5]. The theoretical treatment is too limited to be of great use in the present problem, however. It restricts the treatment to complex targets, for example, which do not exhibit large fluctuations in RCS as a function of small changes in target aspect. That is far from the case expected from the ST.

Clearly there are instances wherein target glint is a negligible concern. If the dimensions of the target are small in comparison to the range of the target any glint problems are correspondingly diminished. In other words, the extent of target glint becomes negligible at long range but increasingly large at close range. The special problem of the angular size of the target exceeding the radar antenna beamwidth will be considered later in this report.

A second circumstance that would cause negligible glint would arise in a special case where the target dimensions are small in comparison to the wavelength of the radar waves. In such a case, the small dimensions (small fractions of a wavelength) of the target would permit only small phase differences in the returning echoes. Hence the interference effects produced by vector summation of the individual radar echoes which cause the wandering of the apparent center of radar reflections, and thus glint, would be diminished. Unfortunately, the problem at hand has to consider a large complex target illuminated by relatively short wavelength microwaves. Thus, glint is a very real problem to be considered.

A third case in which there would be absolutely no glint problem does not involve a complex target, rather an isotropic reflector of radar waves (a perfect sphere target). Regardless of the aspect at which it is viewed it unfailingly presents the same RCS and the same apparent center for radar deflections. We will now look at some of the physical dimensions of the ST which must be weighed when considering the possibilities of radar glint from it as a target.

THE SPACE TELESCOPE — A COMPLEX RADAR TARGET

A depiction of the gross features of the ST structure is given in Figure 1. The ST main body consists roughly of two large coaxial cylindrical structures joined. One cylinder measures approximately 3 m in diameter by 8 m in length. The second cylinder section measures about 4.3 m in diameter by 5 m in length. In its operational state (as it will be during OMV R/D maneuvers) it will have two large flat solar array panels, each measuring about 2.5 m by 12 m, mounted on either side of the ST main body at center-to-center distances of about 9 m. Two other prominent appendages project from the main body. They are high-gain communication antennas, each a parabolic dish over a meter in diameter and centered by a positioning arm about 5 m from the cylindrical axis of the main body.

In actuality, virtually none of the exposed surfaces of the ST is smooth; rather the reflective surfaces are highly contoured and faceted with innumerable projections, corners, and reflective depressions. Those structural details smaller than the wavelength of the radar waves will be responsible for Rayleigh scattering primarily and will not contribute greatly to enhancement of the RCS or target glint of the ST. Unfortunately, most of the detailed surface structures are many radar wavelengths in size and will, in many instances, provide large local contributions to the target RCS. They will also tend to shift the apparent center of radar reflections over several meters of distance around the actual ST target center in response to changes in ST aspect.

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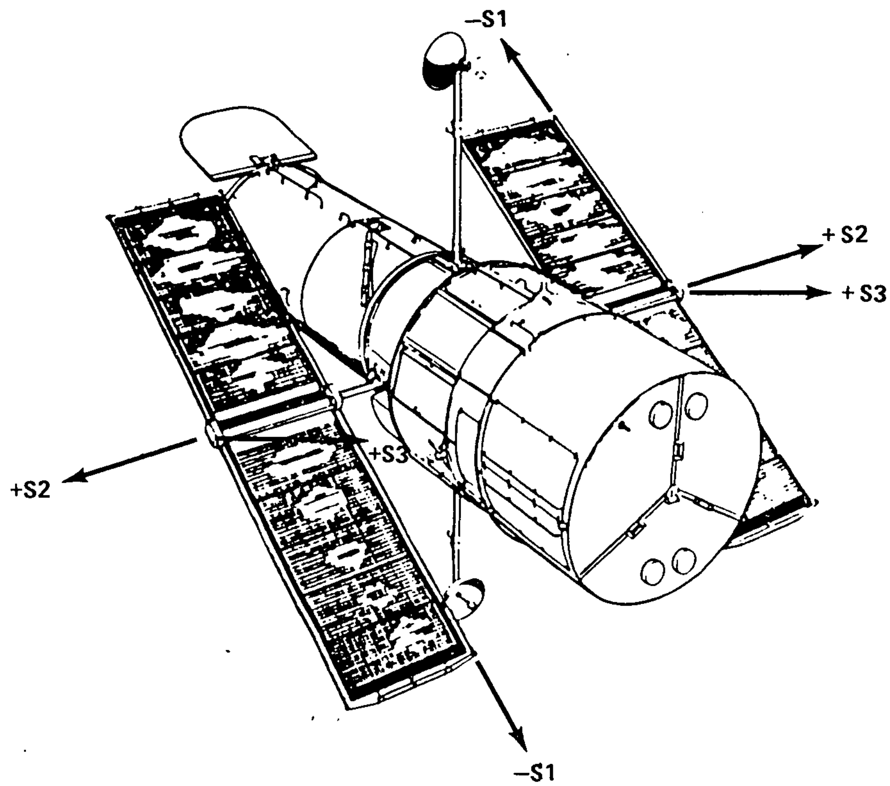

Figure 1. The Edwin P. Hubble Space Telescope.

Consideration is now given to the degree of wandering of the apparent target center of the ST which might reasonably be expected. In a very idealized case involving a "complex" target consisting of two separate reflectors spaced a distance L apart, Meade [6] has shown that angle noise (glint) can cause the apparent target center to be displaced ten, or more, target diameters from the actual target center in the limit as the phase difference between the two reflected returns approaches 180 deg. In this ideal case, such conditions would doubtless cause the radar to lose track of the target. In the real case of the ST, however, due to the multiplicity of the local return centers on the target and the concommitant statistical averaging which would of necessity accompany that fact, it is considered likely that the apparent target center never wanders outside the actual target aperture.

For further analysis of the ST target glint problem, it will be assumed that the maximum wandering distance for the apparent center of radar reflections is 9 m or about 4.5 m away from the actual target center in any direction. The 9 m value is chosen as a suitable upper limit because it approximates the center-to-center separation between the solar array panels. It is also roughly the distance between the centers of the two major cylindrical components of the ST main body. Thirdly, it is roughly the distance between the two high-gain antenna appendages. Thus, the maximum amount of target glint shall be construed as the total angle defined by the transverse target dimension (L = 9 m) and the target range, R.

Wisdom would dictate a couple of paths of rendezvous approach that should be avoided by the OMV, especially at those range values close enough for glint to be experienced and yet far enough away for the full target dimension, L. to be found in the beam of the OMV receiving radar antenna. One path to avoid during OMV approach is any that includes the direction normal to the plane defined by the solar array panels, as the two large flat reflecting surfaces would be expected to provide two quite large RCS return centers which, in turn, could cause the apparent center of radar reflections to wander significantly as perhaps first one then the other provided the dominant RCS as their aspects changed during the approach. A second path equally to be avoided would be any that would place the OMV near the boresights of the high-gain antennas. By avoiding those two OMV-ST relative positions it is believed that the major glint contributions would be limited to the radar returns from the main cylindrical body of the ST.

Next, this report will attempt to examine, in more detail, the ST glint considerations for two separate OMV radar ranging and tracking systems. The two systems are (1) a 35-GHz FMCW radar utilizing a 4-deg beamwidth transmit/receive parabolic antenna and (2) a 94-GHz unit operating, within the OMV-ST ranges considered in this report, in a mode whereby pseudo-random noise modulated continuous radar waves are transmitted by a broad beam antenna (30-deg beamwidth) and received by a high-gain (0.6-deg beamwidth) dish.

ST GLINT ANALYSIS FOR 35-GHz OMV RADAR

Some pertinent parameters for the 35-GHz radar and its illumination of the ST are given in Table 1. Most of the parameters either have already been described or are commonly understood. The range at which ST (the transverse dimension, L) fills the 3-dB beamwidth of the antenna, R(B), has been calculated and is included in the pertinent parameters in order to illustrate that there is a crossover range point outside which the entire target can be seen in the main lobe of the receiving antenna (assuming the antenna boresight is directed at the ST target center) and within which the antenna will, of necessity, be limited to viewing (for a given boresight direction) a diminishing portion of the ST surface as the range decreases during the OMV-ST R/D proceedings. To put this crossover range in some kind of perspective, it would correspond to the latter stages of the rendezvous operation but prior to the initiation of docking procedures. This is the case if one considers the rendezvous phase giving way to the docking phase at a rule-of-thumb distance of approximately 100 to 200 ft (or 30 to 60 m). In other words, as the docking operation progresses the radar will be processing echoes returning from a diminishing area of the ST surface. Thus, it will largely ignore those echoes from elsewhere on the ST surface unless, during the process of ST aspect variation, a temporary high RCS local surface contribution from outside the beamwidth becomes apparent. (Data by Stecca, et al. [7] indicates that tracking radar tends to resolve two targets as separate if their separation is more than about 0.85 times the antenna beamwidth.) Such fluctuating local surface RCS contributions could produce quite sizeable glint effects at close range if the OMV radar were operating in an autotrack mode at those close ranges.

In reality, at close range it is certain that visual contact with the ST will have been established with the video camera on the OMV. Thus, it would have ceased being a blind (autotracking) operation. Instead the wise move would be to fix the pointing of the radar beam to coincide with the pointing of the video camera, steered by the actions of the man-in-the-loop. From that point inward to OMV-ST contact there would be no target glint problem to be considered. In other words, at the close range values where glint would present large effects for a radar that was operating in an autotracking mode, the requirement for autotracking vanishes and with it, most of the glint effects.

TABLE 1. 35-GHz OMV RADAR - ST GLINT PARAMETERS

Parameter	Value
L, Effective ST Target Dimension	9 m
f, Frequency	35 GHz
λ, Wavelength	8.57 mm
D, Antenna	15.2 cm
B, Beamwidth (3-dB to 3-dB)	4 deg
R(FF), Far-Field Range Threshold ($2D^2/\lambda$)	5.4 m
R(B), Range at Which ST Fills Beamwidth	130 m

A reasonable choice of range at which the radar tracking mode is stopped and the video vector pointing mode is begun would be the range at which the ST dimension, L. fills the beamwidth, R(B), or around 130 m. For ranges, R > R(B), the glint would necessarily be less than the beamwidth, B. For close range, R < R(B), there would be no glint to consider. In other words, the worst possible case of glint in this scenario is $\Delta\theta$ = 4 deg.

ST GLINT ANALYSIS FOR 94-GHz OMV RADAR

Pertinent parameters of the 94-GHz radar and its capacity for illuminating and "seeing" the ST are given in Table 2. Probably the most revealing bit of information in the table is R(B). This indicates that from about 1300 m range on in to OMV-ST contact the ST will subtend an angle larger than the beamwidth. The radar will therefore be looking at a decreasing fraction of the ST aperture area, at a given moment, as the range closes to zero. Within this range (R < 1300 m) there would

TABLE 2. 94-GHz OMV RADAR - ST GLINT PARAMETERS

Parameter	Value
L, Effective ST Target Dimension (Assumed)	9 m
f, Frequency	94 GHz
λ, Wavelength	3.2 mm
D(t), Diameter of Transmitting Antenna	0.76 cm
D(r), Diameter of Receiving Antenna	23 cm
B(t), 3-dB Beamwidth of Transmitting Antenna	30 deg
B(r), 3-dB Beamwidth of Receiving Antenna	0.6 deg
R(FF), Transmitting Far-Field Threshold ($2D^2/\lambda$)	3.5 cm
R(B), Range for ST to Fill Receiver Antenna Beamwidth	1300 m

be target glint as the apparent center of radar echo danced around in the ST aperture region as a result of fluctuating ST aspect, but never more than approximately the angle subtended by the ST at the OMV radar receiving antenna.

The glint results therefore turn out to be about the same for the 94-GHz radar as they were for the 35-GHz radar. If the autotracking mode of the radar is terminated at the point where the man-in-the-loop establishes good visual contact with the ST and the direction of the radar is guided by the visual vector pointing of the video camera there would be no glint problem from that point on in to docking contact.

SUMMARY AND RECOMMENDATIONS

This study has considered radar target glint as it pertains to the R/D of the OMV with the ST. Implicit in all these considerations has been the assumption that the radar ranging and tracking system will be supported by both a video camera and a man-in-the-loop operator. The definition of the term, target glint, for complex targets has been reviewed. The detailed nature of the reflective surfaces of the ST entitle it to qualify as a very complex target (increasingly so at higher radar frequencies). An analysis of ST target glint for both a 35-GHz radar and a 94-GHz radar has shown that each will be subject to roughly the same effects of glint, and that to a limited degree. In fact, given the stated assumptions in the analyses, glint would never exceed the approximate angle subtended by the ST target. At a range of about 130 m that would amount to about 4 deg. This value seems acceptably small. From that range inward the radar should be programmed to track the visual vector of the steered video camera. Such is recommended as both feasible and sound. It is certain that good video contact will be available at those OMV-ST ranges.

An important recommendation is tendered to the effect that if a radar ranging system is to be used during the docking operation it is absolutely essential that a strong RCS reflector (corner cube or Luneberg lens reflector) be affixed to the aft section of the ST. This is necessary to provide a strong and relaible range reference point on the target. This need exists for the ST, not for all other vehicles with which the OMV will be called upon to dock. The OMV-ST dynamic docking requirements produced by Lockheed are so stringent (and perhaps could even be more stringent) that jitter in the range (and especially the range-rate measurements) can not be tolerated. That is the reason why an OMV-ST docking guided by a radar range sensing system must be supported by a high RCS reference target, in the opinion of this author.

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APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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