ARMY RESEARCH LABORATORY

Non-Intrusive Missile Control Surface Monitor System

by David J. DeTroye and
Vincent J. Ellis

ARL-TR-505 October 1994

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1994	Progress, October 1991–September 1992

4. TITLE AND SUBTITLE
Non-Intrusive Missile Control Surface Monitor System

5. FUNDING NUMBERS
PE: 62120

6. AUTHOR(S)
David J. DeTroye and Vincent J. Ellis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Attn: AMSRL-WT-NF
2800 Powder Mill Road
Adelphi, MD 20783

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-505

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
AMS code: 612120.1400011
ARL PR: 2FE4E5

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The non-intrusive missile control surface monitor system uses optical technologies for non-intrusive monitoring of various aspects of the movements of a missile control surface (or any control surface) that is undergoing electromagnetic testing. The system comprises a laser source, an optical detector positioned opposite the laser source, an attenuator assembly, which is a framed translucent grey-scale shaded window positioned between the laser source and the detector, and means for recording output signals derived from the detector. The attenuator assembly is an electromagnetically transparent member, mounted on the missile control surface. The attenuator assembly moves in concert with the missile control surface and yet does not affect the electromagnetic signature of the missile. Generated laser beams project on the grey-scale shaded window. The grey-scale shading affects the intensity of the directed laser beams (the darker areas attenuate more light and the lighter areas allow more light to pass through). Accordingly, data are obtained by optical detecting of the different light intensities passing through the translucent grey-scale shaded window, which are directly related in synchronization with the movements of the attenuator assembly and, therefore, the

(continued on reverse)

14. SUBJECT TERMS
Laser, movement, electromagnetic, detection, missile

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

13. Abstract (cont'd)

missile control surface. The resulting intensity data are detected and output via the optical detector means, then processed by the recorder means, which can be either an oscilloscope, chart recorder, or a magnetic tape recorder, etc. Thus, as the control surface moves, by whatever means, the recorded data provide a basis for determining recognition characteristics for the missile control surface, such as the direction, distance, and speed of the movement. When this method is applied to electromagnetic testing, where a known input is applied to control the movement of a control surface, one can detect any changes as a result of the electromagnetic influence. This paper discusses in detail the actual method and results of using this approach to detect effects during electromagnetic testing of a missile control surface.

Contents

Figures

Table

1. Introduction

The evaluation of a missile's susceptibility or vulnerability to electromagnetic (EM) environments must include an examination of the guidance system. The guidance system is the primary mission-critical subsystem of a missile, subordinate only to the fuzing system. Although guidance system technologies vary considerably from the myriad missile systems, all missile guidance systems have the same end result, namely, "steering" the missile.

The steering of a missile can be done in various ways, but, in principle, it relies on either the deflection of aerodynamic surfaces or the forced direction of motor exhaust. The efforts and outcomes described herein concern the development of an inexpensive and effective method of monitoring a missile's guidance control. The method may be used for any missile that relies on a physically moveable structure to affect steering. This method was specifically developed to monitor the guidance system of a missile while the missile is being subjected to various EM environments, but the method may be used for many other circumstances under which missile guidance must be monitored. In fact, the present monitor system may be used to monitor any moveable structure large enough for the attachment of a grey-scale window.

The present monitor system is particularly suited for EM response testing. Since the lasers and the detectors are remotely located, the missile and the EM environment are not corrupted. Furthermore, the grey-scale window may be made entirely of materials that will not appreciably affect the missile or the EM environment. Therefore it may be stated that the present monitor is non-intrusive to a missile undergoing EM testing.

2. Background

Several methods have been used in the past to monitor the movements of missile guidance actuators. These methods have been shown to be wholly or partially inadequate. The present monitor system serves to overcome the problems in other measurement systems.

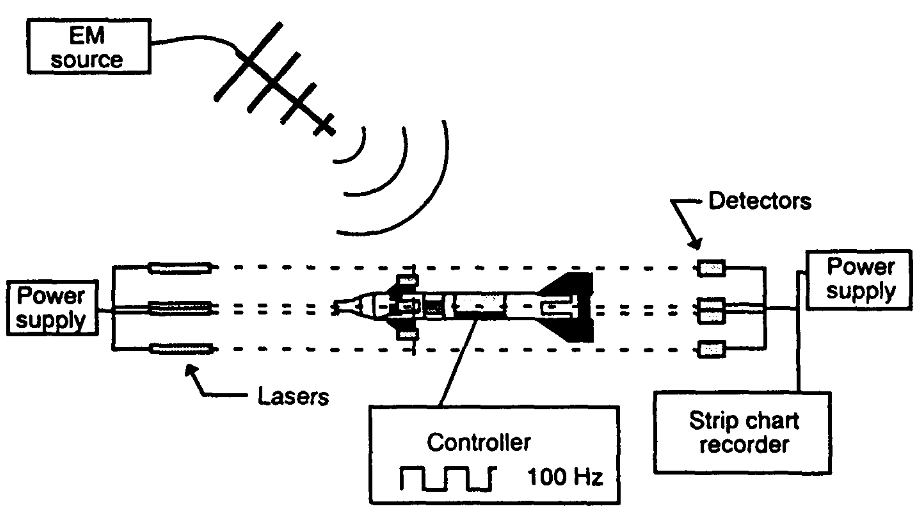
One method that has been used is simply visual observation, by a human or by video camera. This method is inadequate, partly because only motion slow enough and large enough to be distinguishable by the human eye can be observed. Slow-motion replay (video-tape) can reveal faster or minute changes, but this replay method cannot provide real-time observation and can be an extremely slow and tedious process. Furthermore, in order to obtain actual spatial measurements of guidance actuator position, one would have to develop a rather complex calibration scheme.

Another method that has been used is the probing of the output circuits that provide the guidance actuator commands. This method can provide very detailed and accurate data because the data indicate the exact commands that are received by the guidance actuators. This method is inadequate however, partly because probing of the missile's circuitry can inadvertently cause loading of the circuit and hence affect the operation of the circuitry. Also, if metallic cables are used as a conduit for probe data, the possibility exists that the EM environment and/or the missile's topology could be corrupted. Fiber optics is another probing method that could be used, but the circuit loading problem remains and, likewise, fiber-optic transmitters can affect the missile's topology.

3. Test Configuration

The non-intrusive missile control surface monitor system was used to monitor the control surfaces of a missile while undergoing EM testing. The exact test configuration can be seen in figure 1. Four independent channels monitored the movements of the four control surfaces of the missile under test. The monitor system used lasers, photoelectric transducers, and a semi-transparent shaded grey scale to detect the movement of a missile's control surfaces. The grey scale varied from light to dark across its 1-in. width. The semi-transparent grey scale was framed to form a rigid window and attached to the control surfaces. A remotely located laser source was positioned to cause the generated light beams to impinge on the center of the windows. Remotely located light detectors were positioned to receive

Figure 1. Test configuration.



the light beams passing through the windows and the detected light intensities were input to a strip chart recorder. As the control surfaces were caused to move, by whatever means, the light beams received by the detectors varied in intensity as a function of attenuation afforded by the grey-scale windows. The attenuation of light was a direct function of the movement of the windows and hence the control surfaces. By pre-measuring the light intensity for various spatial positions of the control surfaces, we could have calibrated the monitor system and the resultant data would have indicated the actual spatial position of the moveable actuator.

Shielding was incorporated into the entire monitor system to prevent unwanted EM energy from disturbing the laser source and the detectors. The lasers were housed inside of a wave-guide-beyond-cutoff and the power supply and cables enclosed in a metal shield or covered with braid. Likewise, the detectors were enclosed in a metal shield and double shielded cable used to output the signal to the measurement system.

A simulator was interfaced with the missile under test to move the missile control surfaces at a set pattern and rate. The output of the monitor system was then compared to the simulator output.

3.1 Laser System

The primary component of the monitor system was the visible diode lasers. The lasers that were used for the test had the following manufacturer's specifications.

Laser type	Visible laser diode
Output power	3 or 5 mW
Wavelength	670 nm deep red
Size	80% of beam intensity in 1 in^2 @ 50 ft
Beam divergence	Typically 1.5 mrad
Beam diameter	Typically 4 x 0.6 mm
Laser diode life	100,000 hr
Warranty	One-year limited warranty
Dimensions	0.560 in. D x 1.125 in. L (14.7 x 28.5 mm)

The lasers used for this test had a power output of 3 mW. The lasers were positioned approximately [illegible] the detectors, which related to a spot size on the shaded [illegible]e of about 1/2 in.

3.2 Detectors

The detectors used to measure the light intensity of laser sources were based on an NTE3031, NPN-silicon phototransistor. Table 1 shows the manufacturer's specifications.

Table 1. NTE3031, NPN-silicon phototransistor specifications (visible and IR).

Characteristics	Light current	Dark current	Collector breakdown	Emitter breakdown	Saturation voltage	Light current rico time(1)
Test condition	*V_{CE} = 5 V	V_{CE} as shown	I_C = 100 μA	I_E = 100 μA	I_C = 0.4 mA	R_L = 1000 V_{CC} = 5 V I_L = 1 mA
Symbol	I_L	I_D	BV_{CEO}	BV_{ECO}	$V_{CE(sat)}$	t_r
Units	mA	nA	V	V	V	μs
	min	max @ V_{CE}	min	min	typ	typ
	1.0	100 @ 10	30	5	0.2	6

Absolute maximum ratings (25°C free-air temperature unless otherwise noted)

Collector-emitter voltage	30 V
Emitter-collector voltage	5 V
Continuous device dissipation at (or below)	
25°C free-air temperature	150 mW(2,3)
Operating free-air temperature range	–55°C to 125°C
Storage temperature range	–65°C to 150°C
Load soldering temperature (3 min)	260°C

[1] *Angular response is defined as the total included angle between the half sensitivity points, and assuming a point source.*
[2] *Derate linearly from 25 °C free-air temperature at the rate of 1.43 mW/°C.*
[3] *The base is connected on the NTE3031 standard product.*
**Measured with a tungsten filament lamp operated at a color temperature of 2875 K with a radiation flux density of 5 mW/cm².*

The NTE3031 phototransistor was built into the circuit shown in figure 2. The circuit works in this way: The light intensity coming from the laser source enters the phototransistor base and biases the transistor into the active region. Current flow is initiated through R1, which generates a voltage potential at the measurement point proportional to the incoming light intensity from the laser. Linearity is achieved through the proper biasing of the NT3031 phototransistor, by either attenuating the incoming light intensities or through applying voltage across an additional base lead. The additional base lead can be used for biasing the phototransistor when the light intensities are not large enough to push the phototransistor into the active region. The measurement point is connected to a series of inductors and capacitors, which forms a low-pass filter. The filter was added to the detector circuit to help eliminate noise above 2 kHz, which was found to be characteristic of the 3-mW lasers being used. The filter was designed to have a break frequency of approximately 1 kHz and to be –35 to –40 dB down at about 3 to 4 kHz. Figure 3 is a sweep of the filter using a network analyzer.

Figure 2. Detector schematic.

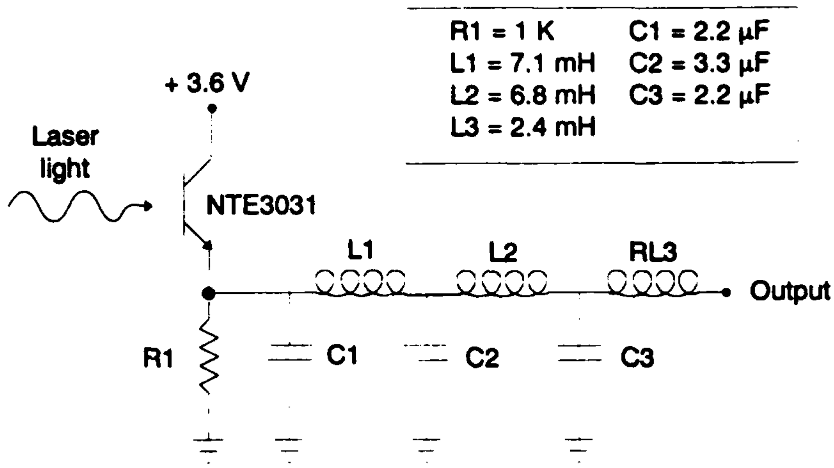
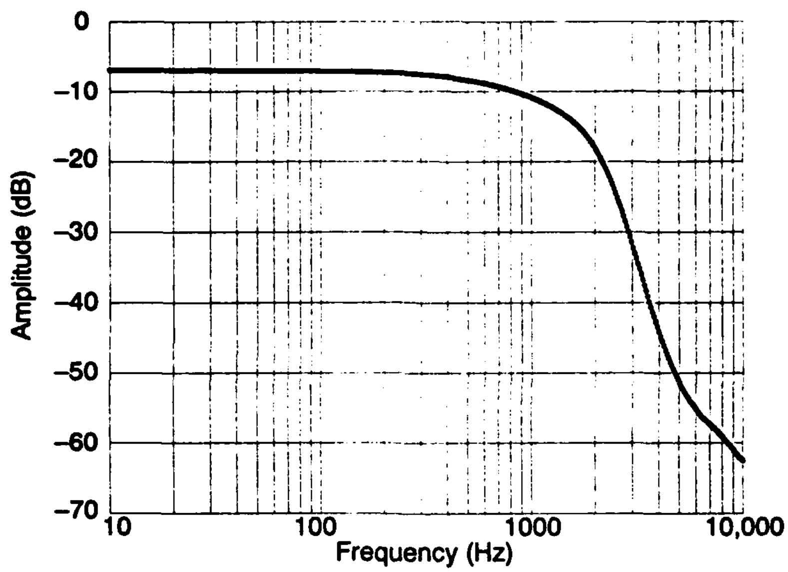


Figure 3. Filter response.



3.3 Shaded Grey Scale

A computer-generated transparency made up the shaded grey scale. Several grey scales were tried, but the one used for the test was a 2400 dots-per-inch (dpi) grey scale that varied from clear to dark in 1 in. We found the resolution was critical to making the monitor system work. Grey scales of various resolutions under 1200 dpi were tried and eliminated. We found that the resolution of the grey scale was directly related to noise in the voltage measurement, because of the makeup of the grey scale. The grey scale was simply an array of dots that were spaced according to the resolution used. As the grey scale was moved in concert with the control surfaces, the detector measured the light attenuated by the grey scale, as well as the light between each of the dots that was not attenuated. This resulted in voltage spikes riding on the measured waveform. When less than 1200-dpi-resolution grey scales were used, the chart recorder measurements resulted in a waveform that appeared to be noisy.

4. Test Results

Numerous measurements were taken with the laser monitor system, as described in section 2. Two samples of the measurements taken are shown in figures 4 and 5. Figure 4 shows one channel of the baseline measurement with no EM stimulus. The missile control surfaces were being driven at a 100-Hz rate, hard over. Figure 5 shows one channel with the EM stimulus at the time indicated. The data show a noticeable difference in both the frequency and the amplitude during the EM event. The monitor system effectively monitored the EM effects induced in the missile.

5. Conclusions and Recommendations

A novel method for monitoring the movement of guidance actuators has been demonstrated. The present method has been shown to be a non-intrusive, highly effective monitor system. By using the present method in association with EM susceptibility/vulnerability testing, one can be assured that the test object and the EM environment are not corrupted by the present monitor system.

The monitor system provides data in the form of movement (light intensity) as a *function of time*. Therefore, the resultant data can indicate the spatial position of a guidance actuator over time. From these data, one can determine all required guidance actuator characteristics, including position, speed, frequency, angular displacement, etc.

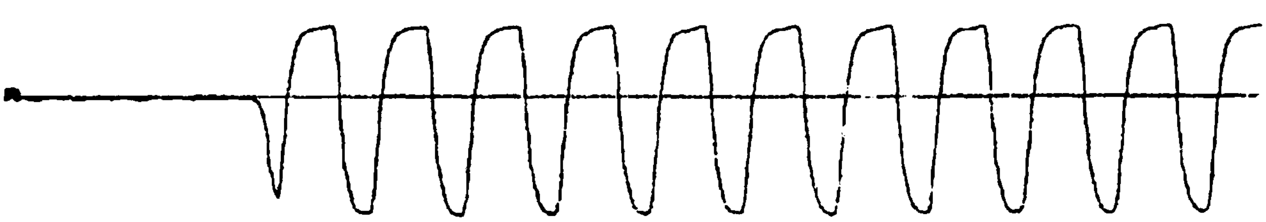


Figure 4. Baseline data.

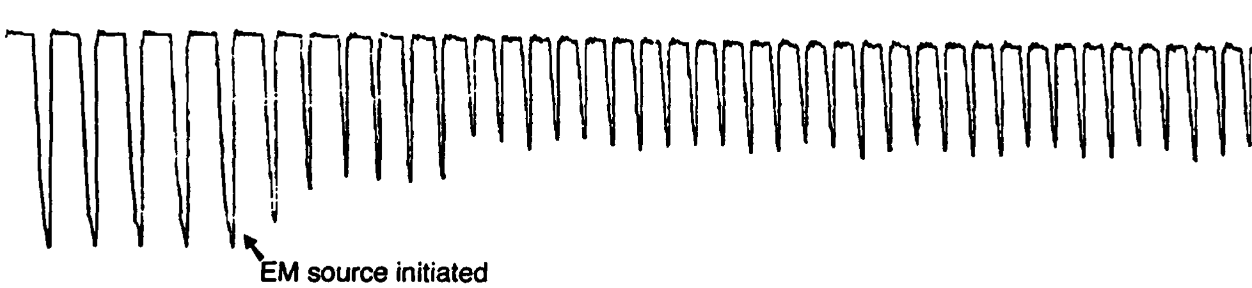


Figure 5. EM effects data.

The monitor may be used to observe all movements of a guidance actuator, whether intended or induced. The monitor is inexpensive, yet highly effective. The only limitations in performance are affected by laser spot size, response time of the photoelectric transducer, grey-scale window size, and the grain of the grey-scale shading. Although alignment of the laser-window-transducer is a critical and sometimes tedious procedure, once aligned, the monitor can perform extremely well. The present method is superior to previous methods where EM testing is employed.

The present monitor may be used to monitor the movement of any structure as long as the structure is large enough for the attachment of a grey-scale window. The only further limitations are affected by the state of technology in lasers and photoelectric transducers.

It is highly desirable to provide a grey scale that is a true analog print quality graduation from light to dark. In this way, light beam noise would be minimized and extremely accurate measurements of spatial position could be made. Currently, the light beam is diffracted by the dots composing the grey scale, causing noise and limiting spatial resolution.

Distribution

Admnstr
Defns Techl Info Ctr
Attn DTIC-DDA (2 copies)
Cameron Sta Bldg 5
Alexandria VA 22304-6145

Ofc of the Secy of Defs
Attn ODDRE (R&AT) S Gontarek
The Pentagon
Washington DC 20301-3080

Army Matl Comnd
Attn AMCRD-AR G Aveta
Attn AMCDE-PQI J Kreck
5001 Eisenhower Ave
Alexandria VA 22333-0001

Belvoir Rsrch Dev & Engrg Ctr
Attn STRBE-NA S Schaedel
FT Belvoir VA 22060-5606

Hdqtr US Army Cmmctn-Elect Cmnd RD&E Ctr Night Vsn & Elect Sensors Dirctrt
Attn AMSEL-RD-NV-ADS M Kovach
FT Monmouth NJ 07703-5206

Ofc of the Assist Scy of the Army for Rsrch Dev & Acqstn
Attn SARD-TT F Milton Rm 3E479
Attn SARD-TT C Nash Rm 3E479
Attn SARD-DOV LTC B Adams Rm 3E411
The Pentagon
Washington DC 20310-0103

US Army CECOM Intllgnc/Elect Warfare Drctrt
Attn AMSEL-RD-IEW-SPO D Helm
Vint Hill Farms Sta
Warrenton VA 22186-5100

US Army Mis Cmnd
Attn AMSMI-RD-WS-UB D Holder
Bldg 4500-West
Redstone Arsenal AL 35898-5248

US Army Sp & Strtgc Dfse Comnd
Attn CSSD-SL-S R Berg
PO Box 1500
Huntsville AL 35807-3801

US Army Rsrch Lab
Attn AMSRL-OP-SD-TA Mail & Records Mgmt
Attn AMSRL-OP-SD-TL Tech Library (3 copies)
Attn AMSRL-OP-SD-TP Tech Pub
Attn AMSRL-WT-NA R A Kehs
Attn AMSRL-WT-ND D DeTroye (5 copies)
Attn AMSRL-WT-NF L Jasper
Attn AMSRL-WT-NH J Corrigan
Attn AMSRL-WT-NF T Bock
Attn AMSRL-WT-NH V Ellis (10 copies)