# APPENDIX C. ERIM TESTBED VEHICLE AND DATA ANALYSIS SYSTEM

To support the evaluation of the TRW FLAR sensor in a true roadway environment, ERIM has developed an ITS Testbed System (TBS). ERIM's ITS Testbed System consists of two major components: (1) the Data Collection System (DCS), and (2) the Data Analysis System (DAS). The primary functions of the Testbed System are:

- Sensor data capture (both raw and processed data)
- Roadway environment monitoring to provide ground truth data
- Data reduction and analysis

The ERIM Testbed System was designed to be extremely flexible to support the future development and evaluation of sensors and algorithms for Advanced Vehicle Safety Systems. The remainder of this appendix will not go into detail on how the testbed vehicle was developed, but rather concentrate on its data collection and analysis capabilities, including the type of data collected, the DCS's limitations, the variety of processing techniques, indexing, and data reduction options.

This appendix is divided into three sections:

- C.1 Data Collection System,
- C.2 Data Analysis System, and
- C.3 ERIM Processing Software.

## C.1 DATA COLLECTION SYSTEM

The first component of the ERIM Testbed System is the Data Collection System which acquires the test data and stores it for later use in the Data Analysis System.

### C.1.1 Instrumentation Block Diagram

The Data Collection System (DCS) instrumentation is physically housed in a full-size van referred to as the Testbed Vehicle (TBV). Pictures of the TBV and instrumentation rack are shown in Figure C-1. The TRW FLAR sensor is mounted to the platform extending out from the front grill and bumper. A block diagram of the DCS instrumentation is provided in Figure C-2.

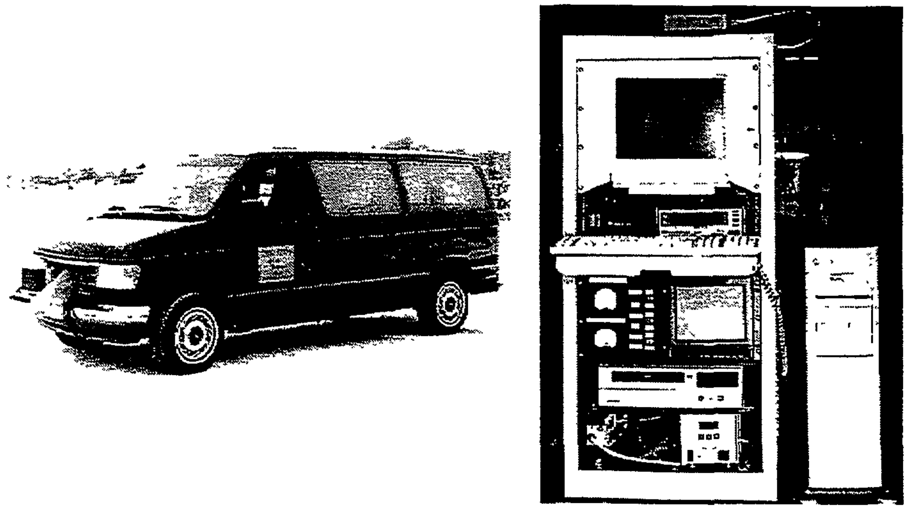

Figure C-1. Testbed Vehicle and Instrumentation Rack

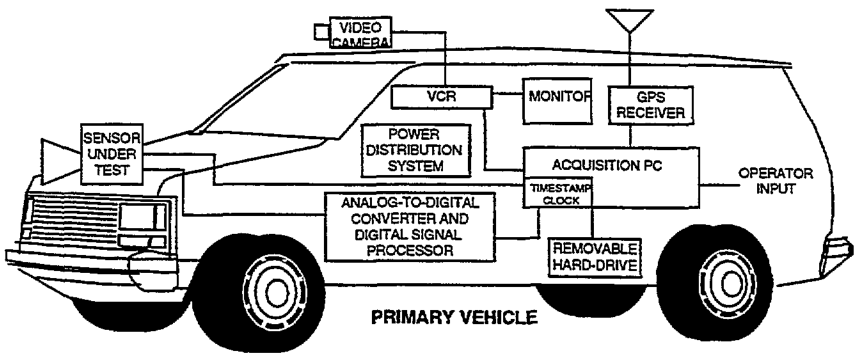


Figure C-2. Data Collection System Instrumentation Block Diagram

A 1300 Watt Power Inverter is used on board the TBV to convert the 12 volt DC vehicle power to 120v 60 Hz power. The 120v 60 Hz power is isolated from the vehicle and provides power to all the DCS instrumentation.

A Gateway I486 66MHz EISA-bus PC functions as the primary controller for the DCS instrumentation. A PC-based architecture was used so that the system can be easily expanded in the future. The collection PC has a precision time-stamp board which is synchronized to GPS time. Data from the time-stamp board is used to tag each set of data which gets recorded to disk by the PC. The collection PC also has a removable hard drive which is used to transfer data files between the Data Collection System and the Data Analysis System.

The interface between the collection PC and the raw TRW FLAR output is a high speed A/D converter and a programmable digital signal processing (DSP) board. The A/D converter runs at 10 MHz to provide ample oversampling of the FLAR 2 MHz IF signal. The DSP option provides a way to experiment with new processing techniques in real time. Under normal conditions, no DSP is performed and the raw data is recorded by the collection PC for later analysis. The A/D board, which is dual channel, also records the analog AGC signal. Knowledge of the AGC signal value is critical for properly interpreting the return signal levels intercepted by the FLAR. In addition to capturing the raw FLAR data, it is necessary to record the processed TRW data for analysis purposes. The collection PC uses an RS232 data link as a means of transferring the TRW processed data from the FLAR to the collection PC memory.

To capture a visual representation of the roadway environment, a video camera is mounted in the front windshield of the TBV. The video data is recorded on a video cassette recorder and displayed to the DCS operator on a 9" monitor. The video cassette recorder has an on-board clock which timetags each frame. This enables later reconstruction of the roadway testing on the Data Analysis PC.

The final piece of instrumentation on the TBV is a Global Positioning System (GPS) receiver and associated antenna. The GPS receiver serves two functions. First, the highly accurate GPS clock and 1 pulse-per-second output provides the time reference for synchronized time-tagging of data collected by the PC and the video cassette recorder. Second, the GPS position data is used as a rough truthing mechanism for the FLAR sensor evaluation. By placing another GPS receiver in a lead vehicle, the position data from each vehicle can be used to help identify errors in the reported FLAR range data.

### C.1.2 Basic Collection Capabilities

A summary of the DCS capabilities is provided below:

- Record a 12-bit digital version of the unprocessed FLAR IF signal on a pulse-by-pulse basis
- Perform some digital signal processing (e.g., FFTs) on the FLAR IF signal in real time, to quickly test new processing algorithms in the field
- Record video images of the roadway environment during data collection experiments
- Record GPS location information in both the TBV and a secondary lead vehicle for range truthing purposes
- Time tag all radar, GPS position, and video data so it can be synchronized during playback on the Data Analysis System
- Store all radar data on a removable hard drive and video data on a VHS cassette, for transportability and archiving

The real value of the DCS is realized by its ability to capture raw FLAR IF data corresponding to a specific roadway scenario, as represented by the video images. Since the IF data is stored in a computer file, a host of different processing algorithms can be applied to the raw data and the resulting sensor performance compared. Without the DCS, the developer would have to re-create the roadway scenario in order to compare algorithm techniques—an extremely difficult task. However, since the DCS stores the pertinent data for each scenario, a particular scenario can be replayed again and again on the Data Analysis System (described below) with any combination of processing algorithms.

As previously mentioned, the DCS architecture was designed to be as flexible as possible. This flexibility will allow for the future incorporation of new sensors and equipment. The primary issues for interfacing to new sensors are the data rates and frequencies of the signals to be collected. If the combination of these parameters exceeds the current limitations of the 10 MHz A/D board in the collection PC, the system can be upgraded with a new off-the-shelf data acquisition or custom hardware can be designed as necessary.

Other expansion possibilities include is monitoring brake, throttle, and steering angle to begin investigating human factors issues associated with automotive radar. There is also potential for tying the FLAR system to the testbed vehicle's cruise control, anti-lock braking, and supplemental restraint systems.

## C.1.3 Enhanced Collection System Capabilities

### C.1.3.1 New Sensor Head

A new three beam FLAR sensor head (Model # AICC-3B-02) was received from TRW. The new sensor represented the next generation of packaging technology, combining more functions (e.g., ability to select one of three beams in azimuth) in a smaller package. This new sensor was mounted on the ERIM Testbed System with a swivel mount that allowed the sensor to be aligned with the vehicle centerline without having to drill new mounting holes or use shims.

The new sensor head was tested against a known target to verify correct installation and performance.

### C.1.3.2 Beam Select Switch

A beam select switch was provided by TRW. This switch was installed inside the testbed vehicle and allows the user to override the beam select signals sent from the DSP. That is, it allows the user to control which beam the FLAR is using independent of the radar operating mode.

### C.1.3.3 Real Time DGPS Link

The Global Position System (GPS) is a satellite-based navigation system operated and maintained by the U.S. Department of Defense. GPS consists of a constellation of 24 satellites providing world-wide, 24 hour coverage. GPS provides the most accurate positioning of any currently active system. Being a satellite-based system it also does not suffer from degradation due to weather or limited coverage. Position accuracy is 100 Meters Circular Error Probability (CEP) for non-differential operation. That is, the reported position is within 100 meters of the actual position 95 percent of the time. Position accuracy improves to 5 meters CEP when operating in Differential GPS (DGPS) mode.

GPS is used in the ERIM TBS to provide truthing of vehicle positions during dynamic testing. One GPS unit is installed in the Testbed System and another in the target vehicle. The relative position of the two vehicles can be determined by post-processing the data from the two DGPS units. Each GPS unit receives the same correction data for the given set of satellites via the differential link. This being the case, the relative accuracy of the two units should be much better than the 5 meters absolute accuracy specified for each unit.

The differential unit installed in the Testbed System is a Trimble Navigation SVeeSix PLUS XT DGPS. The unit consists of a receiver module and a magnetic mount antenna. The system is integrated with the Data Collection System as shown in Figure C-3.

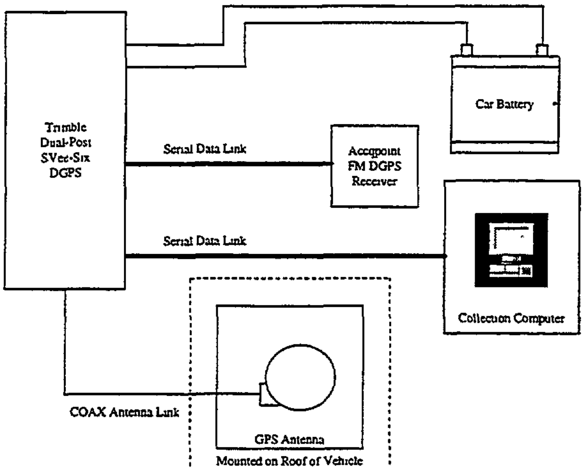


Figure C-3. The DGPS System

Upon power-up the GPS unit starts to search for satellites. The unit is designed to ensure that at least three satellites are found within the first two minutes of power-up. As soon as three satellites are found the unit starts to calculate an initial position fix. Typically the first position fix will occur in less than 5 minutes.

Differential operation is provided via an ACC-Q-POINT FM subcarrier receiver. The ACC-Q-POINT data is provided by a subscription service which ERIM has acquired. Upon power-up, the differential receiver module starts a search for correction data from an FM radio station that, as a subscription service, carries the differential correction parameters in a sub-band. The receiver then decodes the correction data and then transmits the data via a serial data link to the Trimble S-Vee-Six GPS receiver. If no differential correction sub-bands are found the unit defaults to a non-differential operating mode.

Position data (latitude and longitude in WGS-84 datum) is output to the collection computer twice per second (2 Hz). Velocity data is also output to the collection computer at a 2 Hz rate. Both the velocity and position data are time stamped with GPS time and store on the collection computer hard disk. GPS time stamps differ from Universal Coordinated Time (UTC) by a slowly varying constant. The equation describing this difference is:

$$UTC = GPS(time) — GPS/UTC(offset)$$

The GPS/UTC(offset) was 10 seconds as of August 1994. This offset increases by 1 second approximately every 18 months.

A duplicate GPS/DGPS system is located in a secondary vehicle and the location is recorded on a laptop PC. This secondary vehicle is used in conjunction with the testbed vehicle to run orchestrated tests. The GPS information from each vehicle is then used to provide truthing data against which the FLAR performance can be compared. See Appendix D for more on DGPS truthing.

### C.1.4 Collection Software

The collection PC runs a DOS-based application that collects data from all the devices shown in Figure C-2. The DOS-based application runs in real-time and provides a menu-driven user interface. The operator has complete control over the data collection parameters. The operator also has options which allow for system as well as FLAR performance testing. This allows verification of system operation and FLAR baselining characterization before and after each collection run.

The flow diagram in Figure C-4 describes the data collection software processes. Once all the devices have been properly configured and the data acquisition board has been synchronized to the FLAR operation, the software enters the main loop of the data collection process. The main loop consists of capturing and time-tagging each radar pulse IF signal in a seven pulse frame. At the end of each frame, the TRW processed data is time-tagged, data integrity checks are made, and the entire set of data for that frame is written to disk. The main loop continues to execute until halted by the operator.

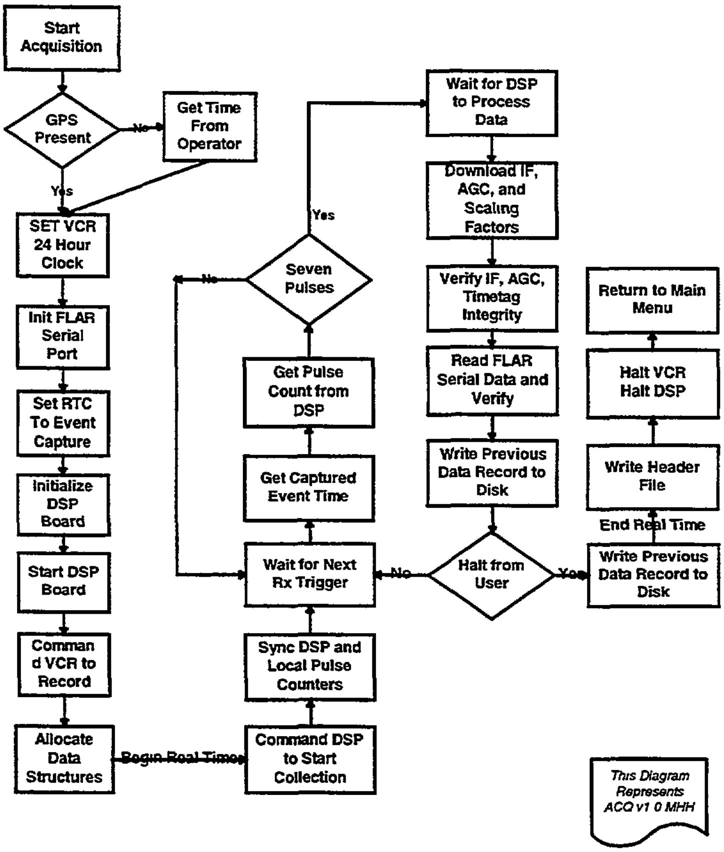


Figure C-4. Collection Software Flow Diagram

## C.2 DATA ANALYSIS SYSTEM

The second component of the ERIM Testbed System is the Data Analysis System (DAS). The DAS is designed to accept data from the Data Collection System and give the operator the means of analyzing and reducing the data. The concept for the Data Analysis System is illustrated in Figure C-5. The DAS is hosted by a 90 MHz Pentium PC. Other equipment includes the removable hard drive which, allows data to be transferred from the collection PC to the analysis PC, and a VCR with time-stamp indexing capability.

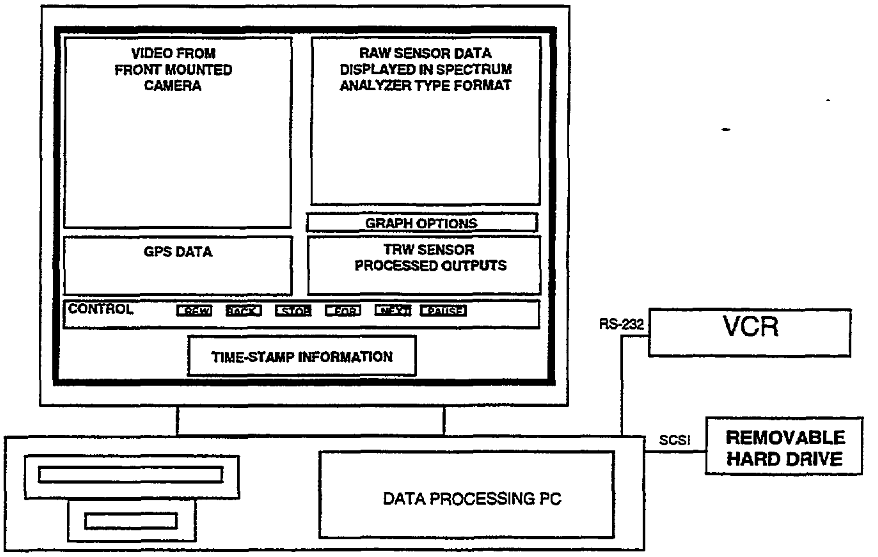


Figure C-5. Data Analysis Concept

## C.2.1 Operator Interface

The data analysis software is a windows-based application developed with Microsoft Visual C++. This provides a user-friendly graphical interface to the DAS controls. Once a data file has been specified, the analysis program's VCR-like controls allow the operator to run the collected data backward and forward as desired. The current position within the data set is indicated by the time-stamp information displayed at the bottom of the screen. Video data and raw radar data corresponding to the current time stamp are displayed in the two large windows at the top of the screen. This allows the operator to visually analyze how the radar is responding to the given roadway environment.

The TRW-processed range, range rate and other information are displayed just below the plot of the raw radar data. The operator can now visually analyze how the TRW processor is interpreting the raw radar data and how it corresponds to objects in the scene. The GPS truthing information is also displayed when available.

## C.2.2 Analysis Capabilities

The first step in the data analysis process is to pre-process the data using the ERIM generated FlarPP program. This program merges the radar data with the auxiliary data both provided by the FLAR sensor via the removable disk of the collection PC. The output is then sent to the data analysis software.

A summary of the DAS capabilities is provided below:

- Operator can replay collected data forward and backward via VCR-like controls
- Operator can quickly index through a data set by designating a specific time-stamp OR performing a video search to find a specific roadway event
- Data files can be segmented into smaller "specific scenario" subfiles by designating time-stamp information
- The beam pattern of the FLAR can be displayed on the video screen as a visual queue to the operator
- Various radar data processing algorithms can be applied to the same set of data and results compared

Combining the capabilities listed above into a single analysis package provides a powerful tool in performing data reduction, event searches, and data analysis. As previously mentioned, the real value of the Testbed System lies in its ability to perform various processing operations on a single set of data which corresponds to a particular roadway scenario. This offers developers an efficient way to refine algorithm implementation and meet functional requirements.

### C.2.3 Matlab Analysis Software

Matlab routines allow independent analysis of the raw sensor data. These programs were developed for two reasons. First they allow the ERIM developed software to be checked independently of the TRW sensor. Second, they allow characterization of the FLAR sensor solely as a radar sensor, not as a radar sensor tailored to automatic cruise control applications. In other words, the Matlab software allows analysis of the raw data without any FLAR DSP calculations added in.

Individual radar pulses may be observed and processed, or multiple radar pulses may be averaged, in order to reduce the effect of random noise. Figure C-6 shows the results of averaging the FFTs of six radar returns. The dotted line shows the FFT of one radar return. The solid line shows the average of six returns. The averaging has the effect of smoothing out and lowering the average noise power.

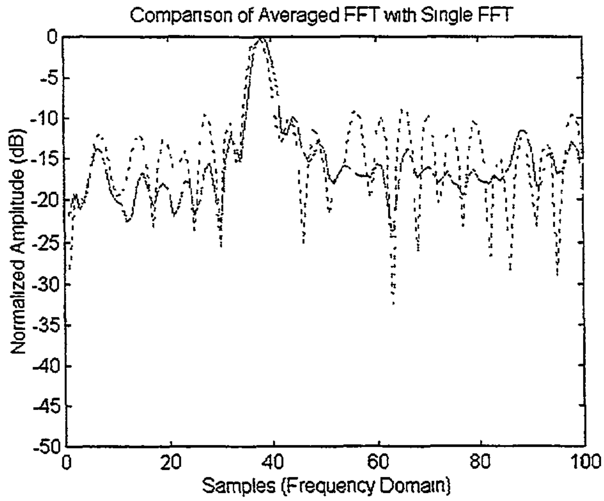


Figure C-6. Averaging Six Radar Returns

## C.3 ERIM PROCESSING SOFTWARE TECHNICAL DESCRIPTION AND VERIFICATION TESTS

### C.3.1 ABSTRACT

This section will present a description of the ERIM processing software used to verify the operation of the TRW Forward Looking Automotive Radar (FLAR). The ERIM hardware and software was verified using a synthesizer generated sine wave of known frequency and amplitude. The sine wave was recorded and processed through the data processing chain and also verified via independent analysis.

## C.3.2 ERIM HARDWARE/SOFTWARE VALIDATION

This battery of tests was designed to check out the ERIM-specific hardware and software. Specifically it checks out the A/D converter board in the data acquisition computer and the FLAR Preprocessor (FlarPP) software.

## C.3.3 TEST SETUP

An HP 3325A Synthesizer/Function Generator was connected directly to the Acquisition Computer A/D board. The input sine wave was measured using a Tektronics 475 oscilloscope to establish a baseline. The collected data was then processed using a custom Matlab program and the FlarPP program. The data from all three sources was compared to verify the correct operation of the collection and preprocessor systems. The following list shows the primary frequencies and voltages injected into the collection system.

1. 10 mVolts P-P, 100 KHz.
2. 1 Volt P-P, 100 KHz
3. 10 mVolts P-P, 1 MHz
4. 1 Volt P-P, 1 MHz

Other frequencies were injected in order to find the A/D converter foldover frequency. The frequency exactly matched the theoretical frequency. Therefore none of the plots will be presented.

The FLAR PreProcessor (FLARpp) program calculates the Fourier Transform of the raw radar returns and acts as the bridge between the FLAR sensor/collection system and the Data Analysis System (DAS). The FLARpp program accepts as input the radar data file (*filename*.rdf) and the radar header file (*filename*.hdr) and outputs a processed data file (*filename*.ppr) formatted to be used by the DAS. Each individual return of 512 real time domain samples is zero padded (i.e., zeros are added to the end of the sequence) to a length of 1024 and Fourier Transform by a radix 2 FFT routine. The output of the FFT routine is 1024 complex data samples of which only the first 512 are unique. The first 512 samples are converted from complex to magnitude samples and scaled by Eq. (C-1).

$$X(n) = \frac{4}{N}\sqrt{I(n)^2 + Q(n)^2} \qquad \text{(C-1)}$$

where $X(n)$ is the $n^{th}$ output sample

$N$ is the size of the FFT

$I$ is the real component of the $n^{th}$ complex sample

$Q$ is the imaginary component of the $n^{th}$ complex sample

The factor of four in the numerator is different than the factor of two that is usually in the numerator because of the scaling effect of zero padding on the FFT routine. Had the data been transformed without the zero padding, then the number in the numerator would have been two.

The custom Matlab program calculates the FFT of the radar returns much like the FLARpp program, with two exceptions. First, the Matlab program zero pads by a factor of four to a total length of 2048 points. This does not affect the spectrum, but it does give finer gradations in the frequency domain. Second, it averages six consecutive pulses in the frequency domain. This reduces the noise power in the spectrum; in fact, a signal-to-noise ratio (SNR) improvement of about 8 dB is realized. This is closer to the algorithm implemented by the FLAR processing software than the FLARpp output is. The result is then output in a graphical format.

## C.3.4 TEST RESULTS

Tests verified that the A/D converter is a 12 bit converter that has an input voltage range of ± 1 Volt (i.e., 2 Volts P-P). The A/D converter samples at a 10 MHz rate. The collection software saves every other sample (i.e., it down-samples the data by a factor of two) without any anti-alias filtering. This process is considered valid as the input data is band limited to approximately 2 MHz. However some fold-over is inevitable, due mainly to the noise power which is spread equally over all frequencies.

Figures C-7 through C-11 show the results of the Matlab runs on both the raw radar data and the FlarPP processed data. The plots show very consistent results between the FlarPP data and the raw data processed independently through Matlab. The peak frequencies in the FlarPP generated plots are slightly different from the raw data Matlab plots because the FFT size is such that there is no bin at exactly the input frequency. The Matlab plots were generated using an FFT size twice as large as that used by the FlarPP, and thus the frequency resolution is greater.

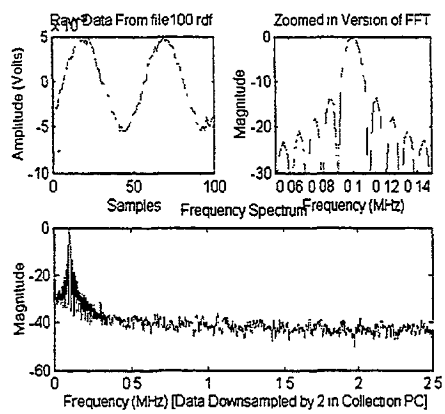


Figure C-7. Matlab Processed Data

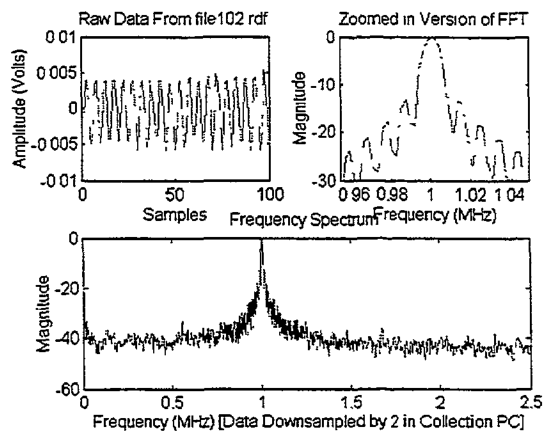


Figure C-8. Matlab Processed Data

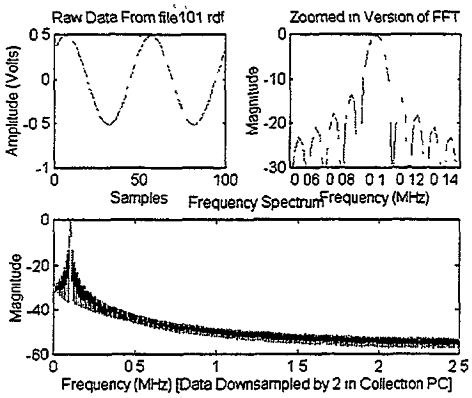


Figure C-9. Matlab Processed Data

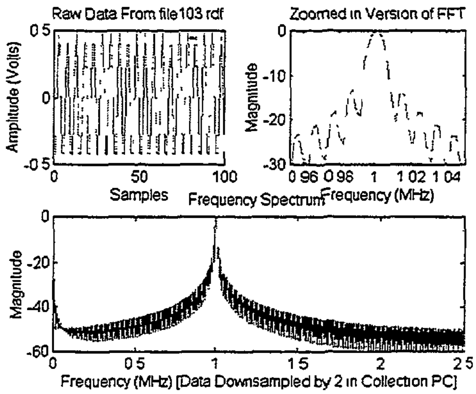


Figure C-10. Matlab Processed Data

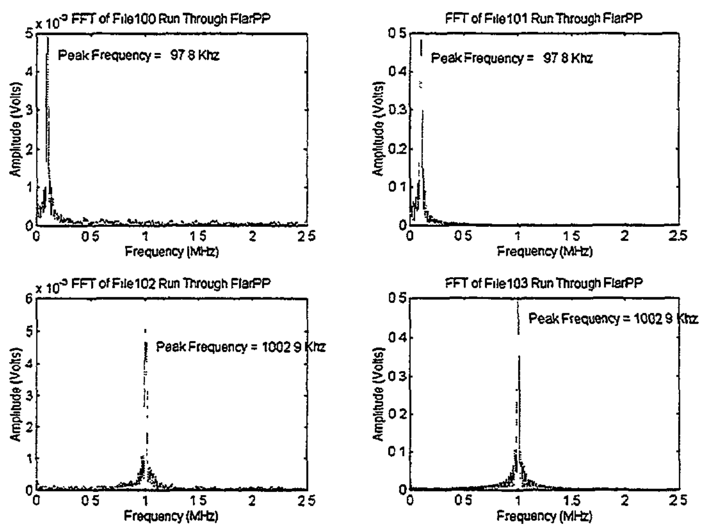


Figure C-11. Data Processed Using FLARPP Software

## C.3.5 CONCLUSIONS

This test verified the operation of the ERIM constructed portion of the FLAR testbed system. Known test signals were input and followed throughout the system in order to verify the correct operation of the FLAR testbed.