Educational hardware and simulator development of Multifunction Array Radar

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Abstract: In this paper we show the hardware testbed and software simulator of multi function array radar (MFAR). The hardware MFAR is simple and flexible hardware to implement various radar beamforming and detecting algorithms. To overcome the limitation of hardware MFAR, the software simulator is proposed. User can simulate radar under the various environment conditions adjusting the parameter of simulator. User can set environment of radar, such as the location and velocity of target, jammer and the terrain clutter. The radar use various probing pulses and supports two operation mode, surveillance and tracking mode.

Keywords: Multifunction Array Radar, Simulator, MATLAB

1. Introduction

Multifunction Array Radar (MFAR) is the equivalent of a multitude of radars in a single package, and widely used in civil and military application [1,2,3]. Shipboard version of MFAR can perform all the functions previously performed by individual, dedicated radars for surface search, long range air search, weapon control, and aircraft control. Land-based versions similarly can replace a multiplicity of radars performing similar functions. Airborne versions also can take over the functions previously performing by several radars, such as search, weapon control, terrain avoidance, and navigation. The MFAR can also be used effectively for secure communication.

In this paper, we show a hardware and software development of MFAR. The goal of our work is to give radar designer useful information and intuition of designing MFAR. We make two frameworks to reach the goal. MFAR hardware framework with 4 antenna elements and software MFAR simulator. The philosophy of designing MFAR hardware is to make a small and flexible MFAR system (Flexibility means that we can change various radar detecting methods and radar operation without modifying hardware structure).

Although the hardware MFAR framework is useful, there are many limitations comparing with commercial and military radar systems. Most big limitations are that the number of antenna elements is small and the transmit power is limited. Additionally it is hard to use the MFAR hardware under the realistic radar operating condition.

The MFAR simulator framework is one of the solutions of the preceding problems. Unlike the MFAR hardware simulator, using the MFAR simulator we can simulate various MFAR operating scenarios and overcome the limitations of the MFAR hardware. We designed MFAR simulator as similar as a real MFAR system.

In section 2 we show the requirements of MFAR to design the simulators. We show the hardware MFAR simulator and software simulator in section 3. In section 4 we show the conclusion and future works.

This paper is supported by the Ministry of Science and Technology managed by MICROS and KOSEF (R01-2003-000-10829-0) in part.

2. Multifunction Array Radar and its requirement

MFAR has two main fields of application, civil application and military application. For civil application we examine the air traffic control system and for military application we examine the defense missile system. The air traffic control system represents one of the most diffuse radar applications. Specific operational concepts have taken on a new and relevant important: (1) accuracy of the control of traffic flow in the terminal area (2) reduce separation of the traffic, and (3) methods of survey and transmission of important information relevant to the flight, such as risks originated by the weather conditions in the terminal area. The requirements for safety are as follows

1. Prediction and/or detection of meteorological hazards that involves detection and prediction of dangerous wind shears, detection of turbulence, recognition of ice condition and detection of forms of precipitations.
2. Detection of intrusions into the controlled airspace deriving from the increase in traffic congestion in most terminal areas.
3. Traffic advisories to control a number of satellite airports, outside the terminal control area, which are often used by aircrafts not carrying beacons.

One of the application of the military radar, the missile defense system require various requirements. In particular

1. The intercept range, the dynamic characteristic of the missile, and the system reaction time determine the track formation ranges and their probability as a function of the various target radar cross section (RCS).
2. The track formation range and the kinematic characteristic of the target dictate the search requirement in terms of detection ranges, their relevant probabilities, and the update rate of each search direction.
3. The number of targets, their spatial density, and the tim-

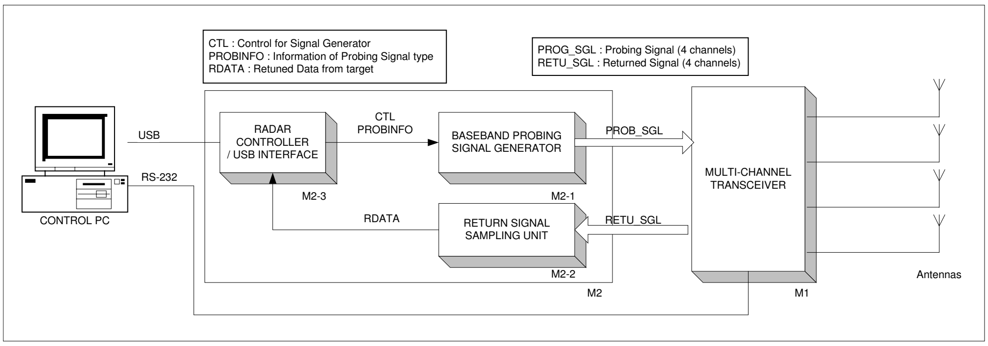

Fig. 1. The block diagram of the educational MFAR hardware.

ing sequence of arrival dictate the requirement of the minimum number of simultaneous tracks needed to avoid system saturation.

4. The data necessary for the missile are characterized by specific accuracies and updating rates; then they determine the accuracy of the track measurements of ranges and angles as well as track measurement update rate.

5. The clutter conditions and the interference, together with the target characteristics, influence the anti-clutter and anti-interference required capabilities.

3. Proposed two MFAR Platforms

We explain a hardware MFAR testbed and software MFAR simulator. The details of them are described below.

3.1. Educational MFAR hardware testbed

The block diagram of educational MFAR hardware is shown in fig. 1. The details of the signal processing block is shown in fig. 2. Multi-channel transceiver (M1 block in fig. 1) up-converts IF signal to RF signal, and amplify its power using power amplifiers. The RF signal rebounded from the targets are amplified using LNA and downconverted to IF signal. The transceiver has two modes for protecting circuit (transmit power is so big that leakage signal may damage LNA and receiving circuit), transmit mode and receive mode. The receiving path is electrically open using the pin diode switch while transmit signal is being sending. The RF frequency is 2 GHz, and IF frequency is 10MHz. The signal processing block (M2) detects the targets from the received signal, generates next probing signals and communicates with the control PC. It has 4 D/A and A/D converters to connect analog and digital domains, and their sampling frequency is 25MHz. We directly get IF signal samples from A/D converters and synthesize probing pulses using D/A converters. The core of signal processing blocks are implemented with DSP, FPGA (Field Programmable Gate Array) and SDRAM because that it is flexible structure to implement many types of detecting algorithms and MFAR operation modes such as surveillance and tracking. The block diagram of signal processing board is shown in fig 2.

3.2. Educational MFAR simulator

In this subsection we show the eduction MAR software simulator. The fundamental operation of radar is to detect targets and to estimate the location and velocity of them.

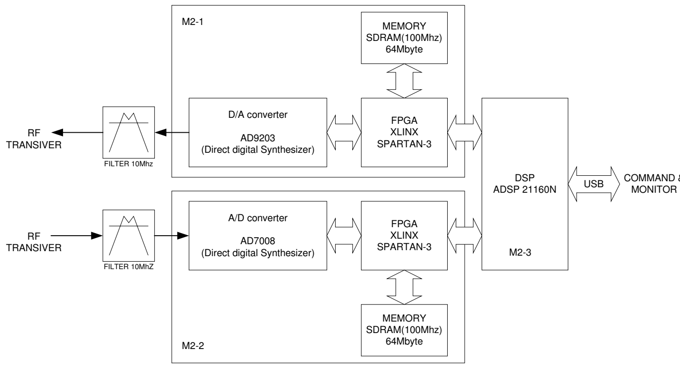

Fig. 2. The details of signal processing block of MFAR hardware.

Radar sends a probing pulse, waits for the returning signal bounded from targets, and estimate the location and velocity of target by analyzing the received signals. For testing the hardware MFAR we don't need to synthesize the received signal, but we must synthesize it for MFAR software simulator. Therefore the major difference between MFAR hardware and MFAR software simulator is synthesizing the received signal. In fig. 3 we show the block diagram of MFAR software simulator. The block B is functionally identical to the hardware MFAR and the block A is the radar received signal synthesizer.

The signal flow of the MFAR simulator is that the MFAR block sends a probing signal to the radar received signal synthesizer and then the synthesizer synthesizes the received signal and sends it to the MFAR block. To synthesize the received signals the information of array antenna of radar, targets, jammers and clutters must be required. The signal synthesizer acquires these information from the antenna element designer and the environmental scene designer. The rotatable array antenna used in this simulator is shown in fig 4 and it can be controlled by the MFAR controller, so azimuth and elevation angle are the input of the radar signal synthesizer also and are generated from the MFAR. Because that Air or ground targets is moving, their location and velocity is varying with time and the received signals are varying also. Therefore we must consider the time information. The synthesized received signals which transfer to the MFAR is vector signal because that the antenna has many antenna

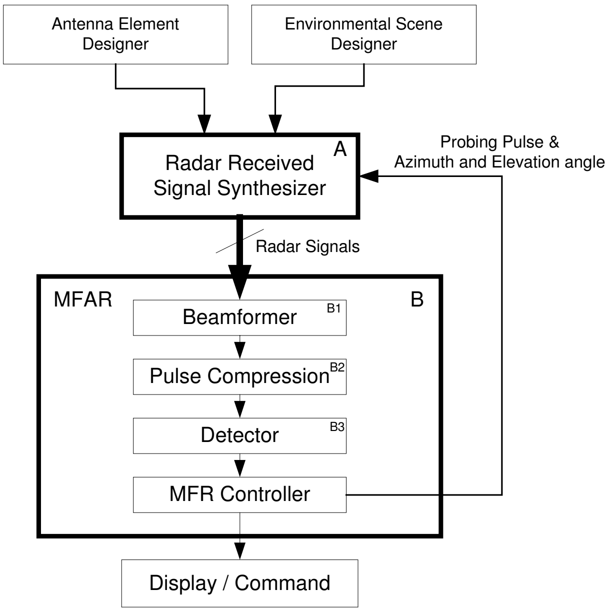

Fig. 3. The block diagram of the MFR software simulator

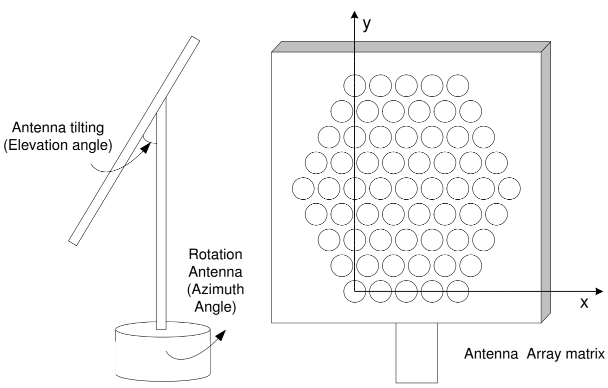

Fig. 4. The antenna used in the MFAR simulator.

elements and auxiliary antenna. In the MFAR block(B in fig. 3) beamformer block, pulse compression block, detector block and MFR controller block are exist. The beamformer convert the multiple received signals to a single signal for beamforming. The pulse compression block concentrates the receiveing probing pulse which was spread with time to increase the performance of detecting using matched filter. The detector block detects targets using various detecting algorithm. The MFR control block identifies the targets and decides to track the targets or not. It also determines the next probing pulse type, the azimuth and elevation angle of the antenna array, the looking direction of beamformer and send them to the received signal synthesizer.

We show the main dialogbox of MFAR software simulator in fig. 5. There are three panels, general parameter setup, single pulse simulation and continuous time simulation. We can design and adjust various parameters to initialize the MFAR simulator in the left panel. It presents two kinds of simulations. The single pulse simulation synthesize one returning pulse with arbitrary probing pulse and algorithm and examine the signal step by step. The continuous simulation

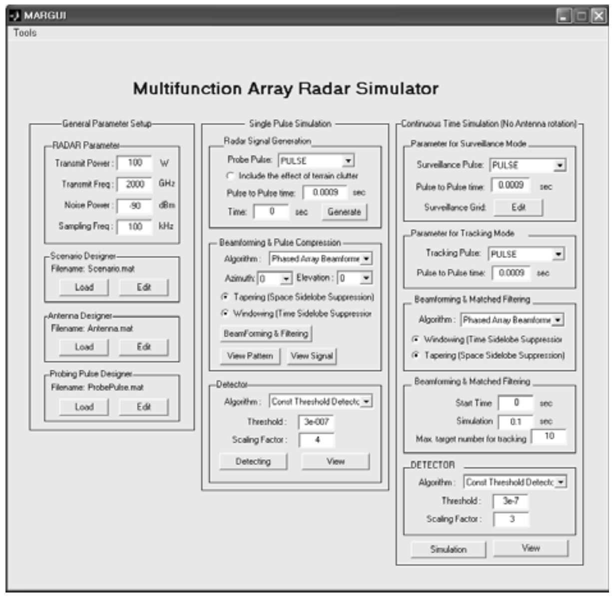

Fig. 5. The main dialogbox of the MFAR software simulator

is generating receiving signals repeatedly with multifunction array radar operation. The probing pulses are determined by the mode, tracking and surveillance mode. The mode is automatically chosen by the MFAR control algorithm.

We explain the main dialogbox panels from left to right. The left panel is the general parameter setup panel. The first input box is radar parameter, such as the transmit power, background noise power, RF transmitted frequency and sampling frequency. Antenna designer, scenario designer and probing pulse designer are shown below the radar parameter box.

We show the environmental scene designer in fig. 6. The terrain clutter (mountains and valleys), the targets (airplane or missile) and jammer are located in a 3 dimensional view. Because of the size of figure the detail of model is not clearly shown, but we can magnify and explorer in the scene. We can easily add/delete the targets and jammers and edit their information (radar cross section, velocity, direction, jammer's power) conveniently. For editing terrain map we suppose the terrain designer (because of paper limitation, it was not shown in this paper).

In fig. 7 we show the antenna designer. We provide main antenna, auxiliary antenna(some beamforming algorithms such as multiple sidelobe canceller require auxiliary antenna), sub-array configuration(sub-array configuration is used for decreasing numerical computation). The antenna formation we provide is linear, rectangular and hexagonal shape and we can select the beampattern of antenna elements(element's pattern are changed with the type of elements, such as patch, yagi, parabolic, dipole and so on). The antenna location and number are shown also. We can see the antenna pattern to click the button.

In fig. 8. we show the probing pulse designer. Generally linear frequency modulation (LFM), coded pulse, pulse train are used radar system and we can design them. MFAR uses more than one kinds of probing pulses according to tracking,

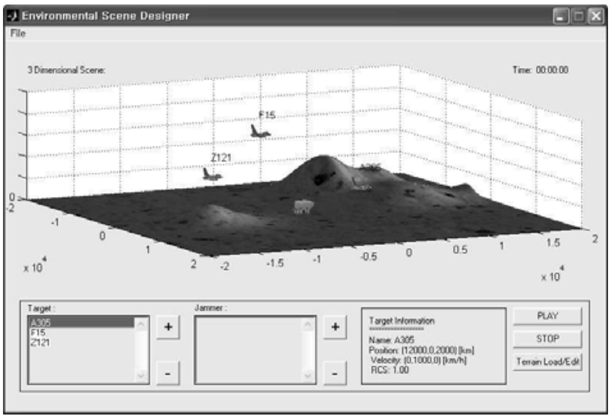

Fig. 6. The environmental scene designer dialogbox of the MFAR software simulator

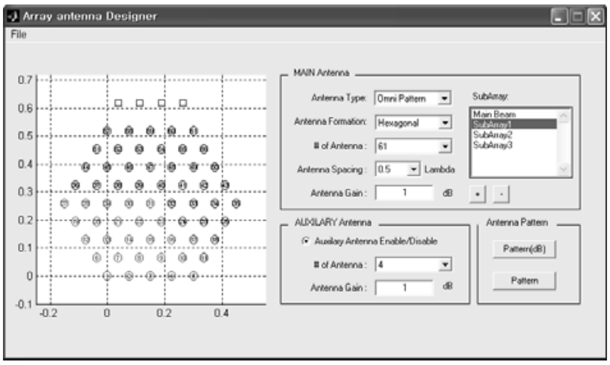

Fig. 7. The antenna designer dialogbox of the MFAR software simulator

surveillance mode and the existence of clutter. We support the ambiguity plot of pulse to click the button. Left axes in the pulse designer show the waveform of probing pulse.

Now we explain the center and right panel of fig. 5. The single pulse simulation synthesize one received pulse and do signal processing. The signal processing are beamformer(B1), pulse compression(B2) and detector(B3). B1,B2 and B3 means the block in fig. 3. We select the pulse in the probe pulse listbox and push the generate button to synthesize a received signal. 'Pulse to pulse time' means the difference time between probing pulse and next probing pulse. Next we select the beamforming algorithm in the algorithm listbox and set the beamforming direction with azimuth and elevation angle. 'Tapering' is a beampattern's spatial sidelobe suppression method to window the beamforming weight. 'Windowing' is a time sidelobe suppression method to increase the pulse compression performance. We can see the beampattern by clicking the 'view pattern' button. We show an example of beampattern in fig. 9 and received signal in fig 10. The upper plot is the signal before pulse compression and below plot is the signal after pulse compression. The sharp peak is the target and small signal are clutter and noise. To detect targets we select the detecting algorithm and click the target.

The continuous time simulation is shown in right panel in fig. 5. The major difference from the single time simu-

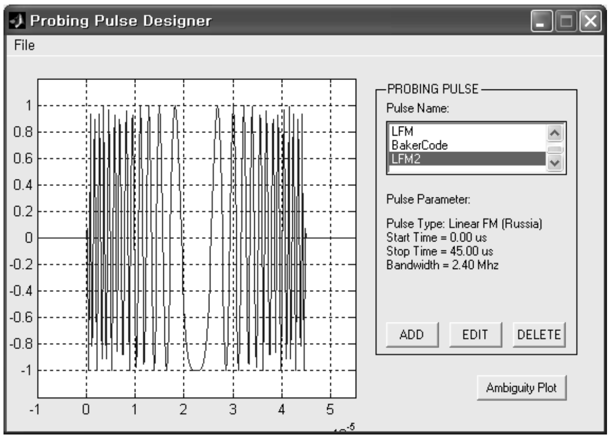

Fig. 8. The probing pulse designer dialogbox of the MFAR software

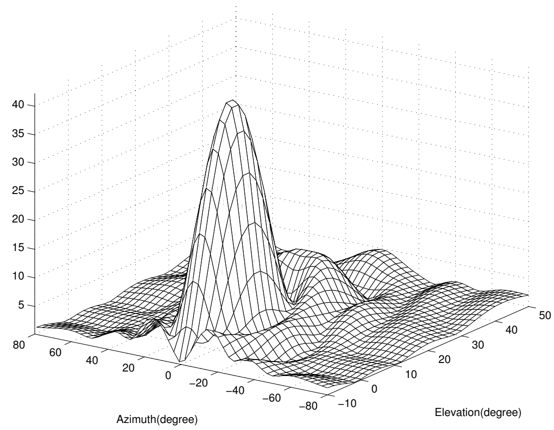

Fig. 9. The beampattern of beamformer after signal processing.

lation is beam scheduling. Multi function radar operation mode are surveillance and tracking mode and radar must decide the operation mode and the beam direction at every time. The beam schedule of the surveillance mode is defined as the beam grid(searching region) in the simulator. In surveillance mode radar search space and detect new targets. When a new target is appeared, radar decide to track the new target or not. After deciding targets, radar estimate the target's location, velocity and direction of heading. Not to miss the target radar look the target more frequently than the surveillance mode. Therefore the radar controller must determine the time for surveillance and tracking mode, and it is a trade-off problem. The probing pulse used MFAR is different according to the operation mode. When radar mode is surveillance, LFM pulses are used and pulse train signal is used in tracking mode to increase the resolution of estimating distance and velocity (doppler frequency). We can set the probing pulse of each operating modes and pulse-to-pulse time. We can select the algorithm of beamforming and detector. It is same to the single simulation. For target tracking mode we must set the number of maximum targets and the frequency of looking targets. Finally after setting

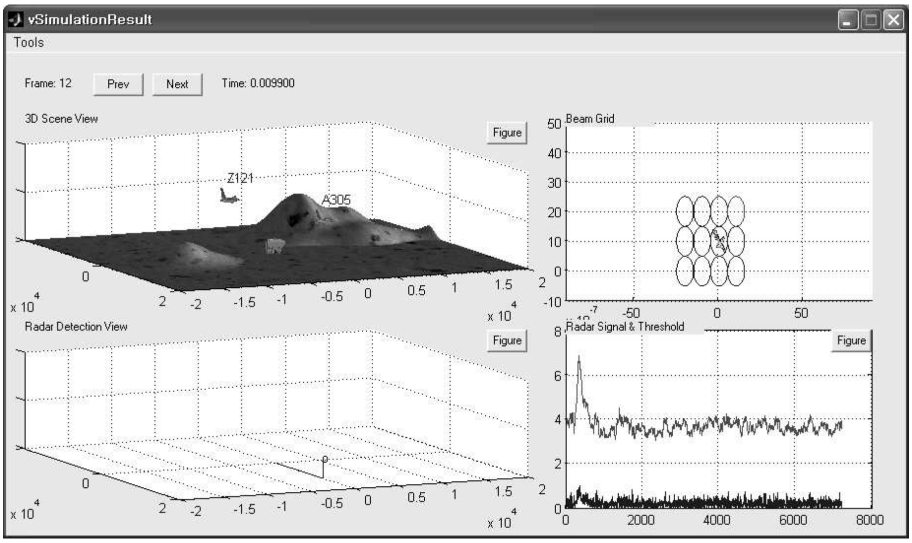

Fig. 11. The result viewer of the continuous simulation.

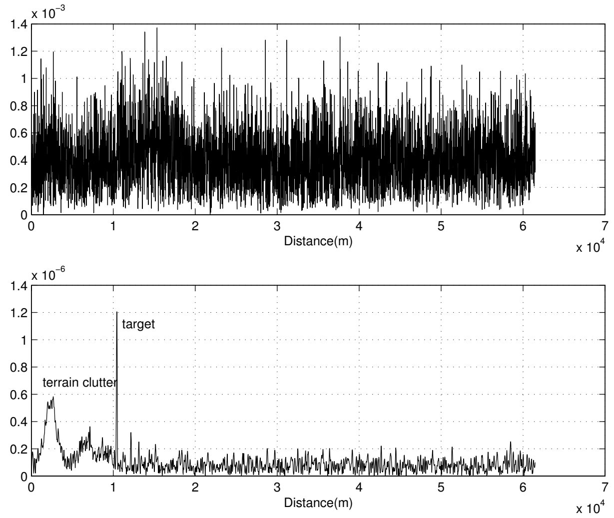

Fig. 10. The received signal before and after pulse compression.

the start and simulation time and click the simulation button to simulate MFAR.

bWe show the result viewer of the continuous simulation in fig. 11. 3 dimensional scene are shown in top left axes. When the MFAR are working on the surveillance mode, the beam are searching in the surveillance grid which was shown in the top right plot. When the target are found the airplane mark is displayed at the center of the circle. The right bottom graph is the radar signal and the threshold curve. The left bottom is the target tracking plot. The target which are being tracked is displayed and the traced of targets are displayed also.

4. Conclusion and Future works

We showed the educational MFAR hardware and the MFAR simulator. The hardware MFAR which is under development is designed as the flexible structure to test various radar algorithm. However the hardware MFAR is many limitation, so we designed the software MFAR simulator. The environmental scene designer give user a realistic radar simulation environment. All these simulator blocks are made of the MATLAB ver 6.5 and upgrading currently.

5. Availability

The software MFAR simulator is being developed. The public version of radar simulator is accessible at *http://sclab.kaist.ac.kr/MFAR/index.html*.

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