Digital Radar Signal Simulator Design for Combat Management System Integration Into Warships

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Abstract—This paper presents an approach to development of digital radar signal simulator based on low cost 16-bit RISC based microcontroller. Typical, mostly used, radar output signals are given and then signal-video relationships are explained in addition to requirements of tactical display calibration with respect to stages of combat management system deployment. Later, generation of radar output signal methodology is explained in detail in terms of utilization of hardware accelerators and peripherals within the microcontroller. Furthermore; the usage of signals and generated discrete radar signals are given as well as digital radar video which emulates radar video returns from target or terrain. Finally; practical results of testing and calibrating of tactical display with such a solution are discussed.

Keywords—radar video simulation; combat management system; radar azimuth; radar range; microcontroller; XGATE accelerator.

I. INTRODUCTION

Combat Management Systems (CMS) are combination of distributed subsystems and allows warship commander to control and command whole sensors and weapons as well as communication systems on the platform from combat information center (CIC). Tactical Displays are key items that becomes an interface between sensors/weapons systems and operators located in Combat Information Center (CIC). Radars are the main sensors of warships and radar videos are displayed to operators through Tactical Displays. The operator can see terrain state in addition to plot and track data which are also displayed on tactical displays and provided by corresponding sub system’s radar signal processor.

Combat Management Systems are integrated into warship platforms after a few different test stages. Majority of these stages do not involve some sensors like Radars because of being provided by different suppliers. Moreover; it is too late to perform these tests when the system or sensor is readily available on the platform because the problems that may be detected during this stage cannot be cleared on the platform that is inconvenient environment for detailed analysis. Furthermore; replacing the system in this stage is not practical especially when the platform entry patches are completely closed. Therefore; majority of the systems need to be tested before all subsystems are available onboard. Some of these tests may be performed on land based test systems (LBTS) whereas some of them are platform based. As a result; tactical displays or combat management systems are need to be tested without having real radar system mainly with third party radar simulators.

In this study a low cost - highly portable, microcontroller (MCU) based radar video simulator design is discussed. Requirement analysis of such a simulator is given first in terms of radar video output signals, tactical display calibration and CMS test stages. Second, microcontroller resources that are used to generate these signals and some scenario are explained in detail as well as basic software algorithm. Then usage of simulator in various test scenarios is examined. Finally; basic results of such a design approach are given.

II. REQUIREMENT ANALYSIS

CMS has various distributed system interfaces like communication systems to be able to send and receive information belong to the other platforms of ground based stations. Countermeasures systems to give wrong direction to intercepting threats. Navigation system for travelling from one place to another, sensors for surveillance, tracking and target detection/kill. Operator consoles and system interface cabinets are the key operation items to keep system survival since they become an interface between sub systems and operators. Fig.1 shows general CMS interfaces.
A. Radar Signals

Although most modern radars nowadays provide digital radar data mainly in the form of plot and track information, there are already many types of radar located in the platforms that are still in the inventory and provide radar data as analog and discrete outputs. Analog signal is the echo returned from the target or clutters while discrete signals are used for azimuth and range determination for this echo [1]. The raw radar data consists of multiple data values collected at a range gate and called as Level-I data. The Level I data is used for signal processing at the radar site, but are not distributed operationally outside the radar site. Instead, the processed signals are distributed as “moment” data, called Level II [2].

The subject of this study is to give an approach to design a stand-alone Level-I raw radar data output simulator. Radars detect two major component of video to provide data on its output. One is angle or azimuth and another is range or returns. Azimuth information is provided by radars by means of some discrete signals as ACP/ARP, CSYNCH, AN/UYK-21, SYNCHRO and PARALEL. ACP/ARP type of azimuth signal is the most generally used one as indicated in [1]. Range information is provided by a reference signal that indicates transmission time of radar signal. Thus collecting of echoes returned from target and correlating the echo with azimuth and range discrete signals gives actual data, angle and distance. Moreover; CSYNCH type of azimuth is also used in majority of systems especially on the platforms rather than radar itself since it combines both azimuth and range discrete signals into one single discrete signal to be able to carry it easily across the ship. Following sentences gives a little detail about the signals [3-5]:

1) Azimuth Change Pulse (ACP): This signal indicates angle of rotating radar. The shape of the signal is generally active high single ended. Moreover sometimes it can be provided as RS-422 differential standard. The angle of antenna that is rotating is incremented in particular angle on per rising edge of the signal after a reference point. General edge (pulse) count of the signal is 1024, 2048, 4096 and 8192 for per rotation. 4096 and 8192 are the most common. Fig.2 is the example of ACP signal.

2) Azimuth Reset Pulse (ARP): This signal provides a reference point for ACP pulse declared above. When this signal is seen then incremental value of azimuth counter is cleared. This signal is generally provided as active high single ended output, sometimes RS-422 differential format as well. The meaning of this signal in fact completion of one rotation around antenna reference point which means generally geographical north but sometimes ships own heading which is called as relative north. Fig.3 provides an example of single ARP pulse that hits per antenna rotation.

3) Master Trigger (SYNCH): This signal is the reference point of the radar returns which consists of clutters from terrain and targets if available. Type of the signal is generally active high single ended. Fig.4 shows typical trigger signal which is generally active high signal.

4) Video: This signal corresponds to radar video return that is reflected by target platforms or terrain which is called as clutter. Fig.5 gives an example analog signal of such a return.

5) Composite-SYNCH (C-SYNCH): This signal is used to combine ACP, ARP and Trigger signals into one single line. Fig.6 shows typical 12-bit C-SYNCH signal generally provided as RS-422 signal format.

![Radar ACP Signal Output](image1)

![Radar ARP Signal Output](image2)

![Radar Master Trigger Signal Output](image3)

![Radar Video Signal](image4)

![C-SYNCH Signal](image5)
B. Tactical Display

Tactical Display is the main interface between operator and system’s sensors and weapons. Operators can see whole terrain data over the primary/secondary radars and electro optic sensors as well as enemy targets. Therefore, whole sensors’ reports as well as scan converted radar video are displayed on tactical information display of the consoles. Fig. 7 gives an example of scan-converted radar video on tactical display. The example shows only surface raw radar video that lets operator observing medium and does not involve any processed data like plots and tracks. Despite of most modern systems, traditional operator consoles which involve tactical displays can have interface with radar by using radar input cards. Calibration or testing of Tactical Displays is an important point prior or during deployment into platform since the tactical display window gives main interface for system sensors especially seeing raw radar video.

C. CMS Test Stages

Combat Management System mainly consists of some system interface unit cabinets and operator consoles located at different locations of the ship platform. System Interface Unit Cabinet (SIUC) encloses high performance computers, L2/L3 managed switches, embedded systems and Subsystem Adaption Units (SAU) that are typically single board computers or embedded systems. Operator Consoles (OPCON) has also computers in addition to displays. Prior or during to the deployment into ship platform, these SIUCs and OPCONs are tested as a part like OPCONs themselves or as a whole system like CMS that include hardware and software components. General test stages of Combat Management System can be given as:

1) Factory Acceptance Test (FAT): This test is generally performed on vendor basis. When the product is ready, it is tested based on vendor capabilities by giving required inputs from simulators and seeing expected results on the outputs.

2) Harbour Acceptance Test (HAT): This test is implemented when the platform is in the port and majority of the systems which are provided by different suppliers are deployed onboard.

3) Sea Acceptance Test (SAT): This is the final and most critical test stage that confirms whole system functionalities and performance requirements of the platform when the ship is operational in the sea.

D. Simulator Need

Warship platforms may typically have navigation radar medium/long range search radar, low probability of intercept radar, Identification Friend and Foe (IFF) system (as secondary surveillance radar) and tracking radar. As stated in previous sections, these systems commonly give their raw data as discrete signal outputs to provide azimuth and range information in addition to analog signal for returns from target or terrain.

From initial land based test stages to final sea based acceptance tests, availability of the above systems or their stimulation is an important parameter to be able to prove functionalities of the equipment (or subsystem/system) under test. In land based test systems, availability of the above systems almost impossible, therefore; radar signal simulators are actively used in this stage. Moreover; simulators are also referred on initial platform based tests due to lock of radar systems when required. Furthermore; this radar signal simulators may be frequently consulted along the life time of the platform in terms of problem recovery, that is, when a problem happen, generally node by node investigation is needed in which providing related signals for every node become a must a part from using actual system signals, it is not easy to open and close the actual system continuously or manipulating signals as required. In conjunction with this, portability of the simulator is highly appreciable due to be used in various locations within platforms.

Typical characteristics of radar signals are given in Table I. Although the pulse width of the trigger signal which indicates minimum range, range resolution and bandwidth seems as changing, it is generally 1μsec on baseband radar signal outputs. The variation of trigger frequency which is called as PRF (Pulse Repetition Frequency) is important parameter because slowly rotating long range radars (i.e. IFF system) has lower rates (i.e.150 Hz) while fast rotating short range radars (i.e. tracking), has higher rates (i.e. 4 KHz). Azimuthal signal periods are related with antenna rotation time while pulse width is generally 1μsec. Note that azimuth change pulse period is also depends on azimuth count selected that defines radar output angular resolution. Fig 8, has an example of radar signals that are captured from medium range surveillance radar. Although analog radar video can be a preferable method for such system simulators it is not necessarily to be. Instead, digital signals can be used to simulate target returns from particular ranges thus keeping design simple by avoiding analog signal stage.

As indicated before Composite-SYNCH signal is derived from ACP, ARP and Trigger pulses and is not given in Table I because of being generally used within the platform rather than actual radar outputs. Every pulse has a meaning on this pulse stream. Leading one resembles trigger pulse and a reference point for range determination while subsequent bits defines binary azimuth value as ones and zeros. The pulse width of the related bit defines whether corresponding bit is zero (1,1 μsec) or one (2,3 μsec). The period of pulses is defined as 3,5 μsec and 3 μsec for start pulse and azimuth bit streams respectively.
<table>
<thead>
<tr>
<th>Radar Signal</th>
<th>Signal Features</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Trigger Pulse Width</td>
<td></td>
<td>0.1 – 10</td>
<td>µsec</td>
</tr>
<tr>
<td>Master Trigger Frequency</td>
<td></td>
<td>0.150 – 33</td>
<td>KHz</td>
</tr>
<tr>
<td>Radar Video Bandwidth</td>
<td></td>
<td>0.1 – 10</td>
<td>MHz</td>
</tr>
<tr>
<td>Azimuth Reset Pulse</td>
<td></td>
<td>0.5–10</td>
<td>sec</td>
</tr>
<tr>
<td>Azimuth Change Pulse</td>
<td></td>
<td>1024,2048,4096,8192</td>
<td>Unit</td>
</tr>
</tbody>
</table>

This value is not applicable for this study due to be generated digitally.

A. Theory and Algorithms

There are two primary data available on radar outputs; first one is the angle and second one is the range. These data provided by means of discrete radar signals previously explained in section II. Analyzing of signal generation theoretically can be categorized in following two basic topics:

1) Angle Information: This data is provided by ACP and ARP pulses as detailed above. ARP pulse indicates north (true/relative) cross of rotating antenna or radar. Its pulse width is stable at 1 µsec. Period is derived from antenna rotation time. ARP pulse is a reference cross for ACP pulse as well. ACP pulse indicates actual antenna position by continuous pulse stream which starting point is ARP pulse. ACP period depends on azimuth count, or angular resolution, chosen for per rotation and calculated as in (1). Typical interval of this signal is from a few hundreds micro seconds to a few milli seconds. It should be noted that angular signals are completely independent from range signals.

\[
ACP_{\text{time}} = \text{Antenna Rotation Time} / \text{Azimuth Count} \quad (1)
\]

2) Range Information: This data is provided by video signals referenced by trigger signal as explained previously. Trigger pulse indicates radar transmission time. Target range determined as in (2) with respect to round trip delay of returned signal. \( c \) is the light speed and \( \tau \) is the time duration that elapsed between transmission of the signal and detection of returned echo in this equation. For example: to generate a target at 1 km range \( \tau \) should be 6,666 micro seconds. Time of the actual video signal can also be determined automatically for selected test picture such as ten units of range rings within given distance [6].

\[
r = \frac{c \times \tau}{2} \quad (2)
\]

B. Architecture and Resources

A RISC based S12X micro controller unit (MCU) architecture is used to perform required radar signal generation functionalities as well as user interface. One of the key feature of this architecture is having hardware accelerator called as XGATE which can execute code from internal random access memory directly after booting. Wide range of peripherals such as enhanced timers, pulse width modulation (PWM) module, port events and interrupt controller module are other key factors to select this highly integrated controller among other options [7].

Table II shows MCU resources that is assigned for ACP/ARP type of radar signal generation whereas Table III shows Composite-SYNCH type of radar signal generation assignments. Some of the functions, which are more important are handled by hardware accelerator while rests are assigned to S12X central processing unit (CPU) core like menu control, LED control, trigger control.
TABLE II. SIGNAL AND RESOURCE ASSIGNMENTS IN ACP/ARP TYPE

<table>
<thead>
<tr>
<th>Radar Signal</th>
<th>MCU Resource</th>
<th>Handler</th>
<th>Event</th>
<th>Peripheral</th>
<th>Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACP</td>
<td>XGATE</td>
<td>PIT0</td>
<td>PIT</td>
<td>PTT0</td>
<td></td>
</tr>
<tr>
<td>ARP</td>
<td>XGATE</td>
<td>PIT0</td>
<td>PIT</td>
<td>PTT1</td>
<td></td>
</tr>
<tr>
<td>Master Trigger</td>
<td>S12X</td>
<td>CH2</td>
<td>ECT</td>
<td>IOC2</td>
<td></td>
</tr>
<tr>
<td>VIDEO</td>
<td>XGATE</td>
<td>SWT4</td>
<td>PWM</td>
<td>PWM0</td>
<td></td>
</tr>
</tbody>
</table>

TABLE III. SIGNAL AND RESOURCE ASSIGNMENTS IN C-SYNCH TYPE

<table>
<thead>
<tr>
<th>Radar Signal</th>
<th>MCU Resource</th>
<th>Handler</th>
<th>Event</th>
<th>Peripheral</th>
<th>Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-SYNCH</td>
<td>XGATE</td>
<td>KW0</td>
<td>PWM</td>
<td>PWM7</td>
<td></td>
</tr>
<tr>
<td>VIDEO</td>
<td>S12X</td>
<td>SWT0</td>
<td>PWM</td>
<td>PWM0</td>
<td></td>
</tr>
</tbody>
</table>

C. Implementation

In ACP/ARP type of radar signal generation; timer (PIT0) is set to generate periodic interrupt with respect to ACP pulse period and routed to the XGATE core. This handler generate required pulse width for both ACP and ARP pulses. At the same time, a timer output compare channel (CH2) is set to generate periodic signal that corresponds to trigger signal. This handler is processed by S12X core as well. A software called vector (SWT4) assigned to the XGATE core is triggered immediately to generate video signal with PWM channel. This continuous until user stops the simulation [8-10].

In C-SYNCH type of radar signal generation; generated PWM (PWM7) signal is connected a port interrupt (P0) to assign next PWM period to be able to generate fast changing width and period. It is noted that CPU runs at 80 MHz while bus clock is 40 MHz which provides 25ns maximum time reference for PWM module. When we refer Fig.11, it can be seen PWM widths and periods must be updated at most per 3 μsec and this must be done without CPU intervention. This is done by port interrupt handler assigned to XGATE core. PWM67 is used as cascaded mode to be able to get required time scale that corresponds to ACP period. When pulse stream is finished PWM period is filled with ACP period minus pulse stream generation time. Note that; although it seems theoretically applicable that updating width and period values within PWM period event assigned to S12X CPU for this scenario, in practice it generates corrupted signals since interrupt latency affects update process. Robust signal generation without crash is succeed by dedicated hardware loop in this design despite of CPU performance limitation for such a radar application [11-12].

Fundamental parameters of radar signal simulator is given in Table IV. Whole signal characteristics are calculated based on this settings and device starts generating signals. Generated radar signals are given in Fig.9, Fig 10 and Fig 11. Tactical display view of simulator generated static targets and range rings that are generally mostly used test pictures during test stages is given in Fig. 12. Ten different test target and ten different range rings are created based on selected scenario.

TABLE IV. SIMULATOR PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
</tr>
<tr>
<td>Antenna Rotation Time</td>
<td>1-10</td>
</tr>
<tr>
<td>Static Test Pictures b</td>
<td>1-10</td>
</tr>
<tr>
<td>Range Rings b</td>
<td>1-4</td>
</tr>
<tr>
<td>Azimuth Granularity c</td>
<td>1024,20148,4096,8192</td>
</tr>
<tr>
<td>Azimuth Types ACP/ARP, C-SYNCH</td>
<td>N/A</td>
</tr>
</tbody>
</table>

b Indicates selectable different picture counts

Only 2048, 4096 for C-SYNCH signal

Fig. 9. ACP/ARP Signals Generated by the Simulator

Fig. 10. Trigger-Video Signals Generated by the Simulator
IV. CONCLUSION

A portable, low cost, highly flexible Radar Signal Simulator design is intended in this study to be able to use it on different test stages of combat management system from initial factory acceptance test to problem recovery along the platform life time. It is succeed by utilizing XGATE hardware accelerator involved in low cost 16-bit S12X microcontroller. Radar like signals are generated as given and then their correspondence view on tactical display is seen. In example second target generated by radar signal simulator at 25 μsec displayed on tactical display at 2.03 nautical mile which corresponds to 3759 meter. This is expected results for the signals generated in terms of (2).

This type of simulators generally designed based on FPGA architectures enclosed in a computer. Although they may have more advanced capabilities designing of such a system based on FPGA may be time consuming, more complicated and even more expensive. Furthermore; higher performance processor or digital signal processor (DSP) architectures can also be used to implement these functionalities easily with additional cost and complexity. In this design, a low cost MCU with internally ready peripherals is used and basic test requirements has been succeed. Design has been used and validated through various platform integration test stages given in Section II-C on navy GENESIS and MILGEM warship platforms.

REFERENCES


