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Reliability Enhancement of the Analog Computer of Gyroscopic Naval Navigation System Using Integration by Field Programmable Analog Arrays

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Abstract: In this study, we present the results of research carried out in order to increase the reliability of the analog computer of a gyroscopic naval navigation system by integration of a collection of the circuits of the analog computer using field programmable analog arrays. The failure rates of the existing analog computer system and its integrated version using an FPAA are computed. The results show a substantial reduction in the failure rate, a considerable increase in the mean time to failure and therefore an improvement in the reliability of the system. It is proposed that the whole gyroscopic navigation system of the naval vessel be integrated as a mixed system using FPAAs and FPGAs. If this work is extended by integrating other parts of the system, there will be a substantial increase in the MTTF of the system and improvement in the reliability of the whole navigation system. The calculations for the mean time to failures were carried out using MIL-HDBK-217F for the Naval Sheltered and the Naval Unsheltered working conditions per the real operating conditions of the system.

Key words: Analog computer, integration by using FPAA, reliability enhancement, gyrocompass

INTRODUCTION

The reliability of a system is affected by the reliability of its components and the way they are interconnected to serve its intended mission under certain operating conditions. It is well known that the reliability of discrete components, analog circuits and their associated interconnects is very low. The reliability of a system can be improved if the reliability of its constituents could be increased. This can either be done by using more reliable components, for example, MIL SPEC parts or by redesign of parts of the system using newer technologies with a higher reliability. We have chosen the second approach in this research project and used integration of several analog circuit boards by using an FPAA.

Filed Programmable Analog Arrays (FPAA) which are the analog counterparts of Filed Programmable Gate Arrays (FPGA) for digital circuits can be used to integrate various analog boards in existing electronic systems in order to enhance their reliability. This can also result in a smaller, lighter, cheaper and more robust system. The performance of the system could also be improved. Modern FPAA's enable one to translate complex analog circuits to a set of low level functions and describe analog functions such as filters and gain stages without worrying about components such as op amps, capacitors, current mirrors, etc.

Analog signal conditioning and processing is used in a variety of applications including sensor interfaces, industrial controls, medical monitoring, seismic systems and laser control. In most applications the analog signal conditioning is done with discrete components, analog ASSP/ASIC, or a DSP following digitization of the signal. However, all signal conditioning functions such as linearization, summation, rectification, phase detection, threshold detection and integration can be integrated within a single FPAA device (Fig. 1).

The new FPAA technology provides an elegant way of implementing these designs with the added benefit of reconfiguration and improved reliability. Looby and Lyden (2000) proposed a new continuous-time FPAA architecture which simultaneously achieves bandwidth and repeatability comparable to the accuracy tolerance of switched-capacitor FPAAs and the bandwidth of continuous-time FPAAs. Even neural network applications could be realized with FPAAs. Lee and Gulak (1991) presented the design details and test results of a Field-programmable Analog Array (FPAA) prototype chip in 1.2 μm CMOS based on sub-threshold circuit techniques which consists of a collection of homogeneous Configurable Analog Blocks (CABs) and an interconnection network. Interconnections between CABs and the analog functions to be implemented in each block are defined by a set of configuration bits loaded serially into an onboard shift register by the user. They have even developed macromodels for the analog functions in order to simulate various neural network applications on the field-programmable analog array.

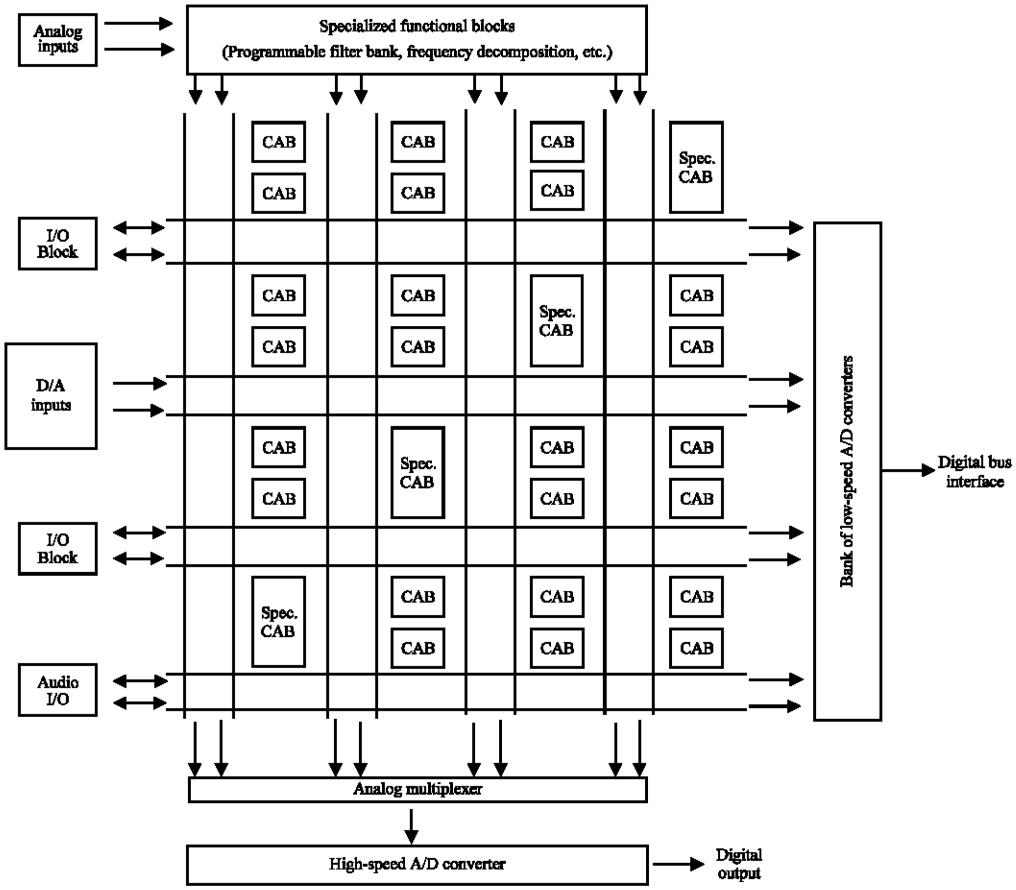

Fig. 1: The block diagram of an FPAA

The key benefits of an FPAA over a fixed-function solution are:

- The design process is simplified
- There is a one-component solution for multiple designs, greatly simplifying inventory management and repairability which also improves reliability
- The integrated design provides design specifications that are immune to temperature, process and component aging
- There is precision operation and increased system reliability

Becker *et al*. (2008) presented a FPAA to implement a unique hexagonal topology of 55 tunable OTAs as a prototyping environment for rapid reconfigurable analog signal processing.

There are even possibilities for developing mixed signal solutions using FPAAs where there is a mixture of both digital and analog signals. In such cases the usual solution is the use of analog circuits for interfacing, digital circuits for control and computation and DSPs for signal processing. However, the disadvantage of this type of solution is that DSPs use a lot of power. In such situations FPAAs can be used to implement the analog part of the system while FPGAs could be used for the digital parts shown in Fig. 2.

The analog computer of the gyrocompass in the navigational system of a naval vessel is usually used to find the proper direction of the north and corrections for the horizontal direction. It uses the information it receives from the accelerometers and gyroscopes to calculate the necessary settings for the motor drives for the stable platform. Reliability is an important issue especially in sensitive applications like the system under study.

The gyroscopic navigational system of the naval vessel under study is exactly a mixed signal system. We proposed to integrate its analog computer with FPAAs and its digital parts with FPGAs. The integration of the analog computer using FPAAs was carried out and its effect on the reliability improvement of the system was shown. Further work should be funded in order to carry out the integration of the total gyroscopic navigation system.

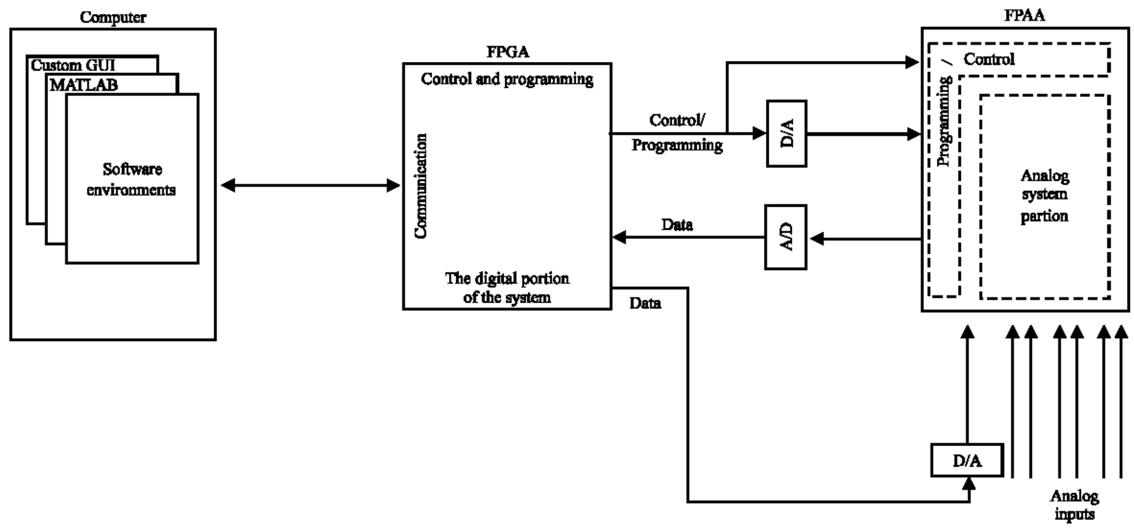

Fig. 2: An FPGA/FPAA solution for reliability improvement of mixed systems

Navigational information and control signals used in the navigation of naval vessels include the vessels direction, range, roll, pitch, etc. Each naval vessel should be equipped with navigational equipment. The gyroscopic compass system on a naval vessel is used to provide such signals. This system under study works based on the input information and a mathematical model already programmed in its analog computer and provides analog and digital outputs for position, roll, pitch, etc. in real time. The input to this system is the ship's speed, the speed of the currents, longitude and latitude as well as the outputs of the accelerometers.

This provides a reference plane on board the ship which always follows a certain direction relative to the Earth despite any movements by the ship. These directions are usually the geographical north/south, east/west and local horizontal direction. Therefore, we always have a coordinate system on board the ship using which the measurement of roll, yaw or pitch are easily measured. The analog computer calculates the position and establishes the proper latitude and altitude using the initial latitude and altitude as well as the inputs from the speedometers and the accelerometers.

THE VARIOUS TYPES OF FPAA

There are various techniques used in the manufacture of FPAAs including OTA, current conveyor, bipolar and operational amplifiers. FPAAs usually operate in one of two possible modes: continuous time and discrete time. There are several manufacturers such as Anadigm and Zetex which produce FPAAs. We used Zetex TRAC020 series totally reconfigurable analog circuit in this research which is a BiCMOS and Bipolar chip that works in continuous mode. It can be programmed using a hardware programmer which can program an EPROM and 4 TRAC 020 chips (Zetex Semiconductors, 1994).

INTEGRATING ANALOG PARTS WITH FPAAS

An analysis of analog circuits shows that they are usually composed of parts such as amplifiers, attenuators, log and antilog, inverters, summers, buffers, differentiators and integrators. Zetex's Totally Reconfiguarable Analog Circuit (TRAC) offers facilities to implement the analog circuit using a set of configurable analog blocks plus a programmable interconnection network. Zetex's TRAC chip has a 20 cell, continuous-time-based architecture based on logarithmic amplifiers. There is a design tool with which a designer can work at a high level and does not need to know anything about the underlying analog circuits. It offers functions non-inverting pass, negate, add, log, auxiliary, alog, rectify, Log/alog and Log/rec with which one can implement analog circuits. One can also use the "OFF" function to not use a given cell. One can use TRAC and develop a solution for a signal management problem at hand rapidly.

RELIABILITY OF THE CIRCUITS UNDER STUDY

Reliability of electronic circuits has been a major concern especially in important subsystems of naval vessels and military apparatus. The reliability is the probability of successful operation during the mission and under pre-specified conditions. Since naval vessels must operate at sea, the general conditions for which electronic subsystems of naval vessels are evaluated are the Naval Sheltered and the Naval Unsheltered as per MIL-HDBk-217F (1995). The failure rates for the parts which make up the electronic circuits can also be either estimated based on the generic rates of MIL-HDBK-217F or other data sources. The reliability can be calculated using various techniques including RBD, Markov state space, analytical, or Monte Carlo Simulations. We used the RBD technique along with failure rate data from MIL-HDBK-217F. For example, the general failure rate for a resistor is $\lambda_p = \lambda_b \pi_T \pi_p \pi_S \pi_Q \pi_E$ where, λ_b is the base failure rate, π_T is the temperature factor, π_p is the power factor, π_S is the power stress factor, π_Q is the quality factor and π_E is the environment factor. There is a similar relationship for other devices with appropriate factors to include stresses and operating environment.

EXPERIMENTAL RESULTS

The circuits in the analog computer mostly consisted of metal film resistors, cermet trimmer potentiometers, polyester capacitors, glass diodes, transistors, op-amps, regulators plus the printed circuit and interconnections. The circuits were integrated into a new one using several discrete components and TRAC020 FPAA. The system was first integrated using software to redesign the I/O interface. Then it was implemented and tested. The new system was much smaller in volume and weight and much more reliable than the original system. The data from MIL-HDBK-217F was used for the failure rates of the electronic parts of the system under study. We obtained the following results:

λ_{NU} = 180.203242 FPMH
λ_{NNS} = 54.04694 FPMH
$MTTF_{NU}$ = 5548.391349 HRS
$MTTF_{NS}$ = 18502.43511 HRS

These results are shown in Fig. 3-6 to compare the reliability measures for the analog computer before and after integration by using FPAAs.

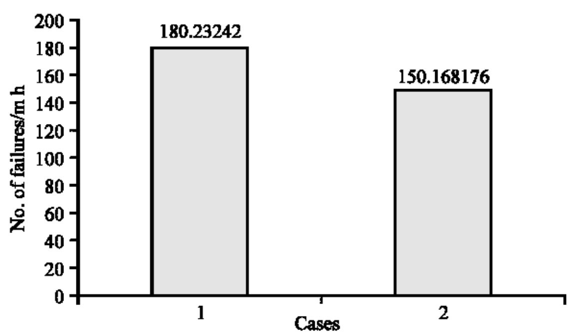

Fig. 3: The failure rate of the analog computer in the naval unsheltered case before and after integration using FPAA (1 is the case before and 2 is the case after integration)

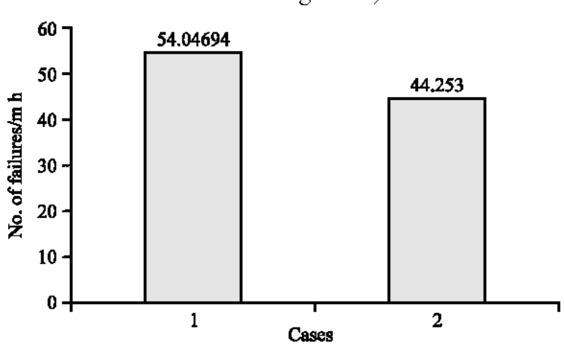

Fig. 4: The failure rate of the analog computer in the naval sheltered case before and after integration using FPAA (1 is the case before and 2 is the case after integration)

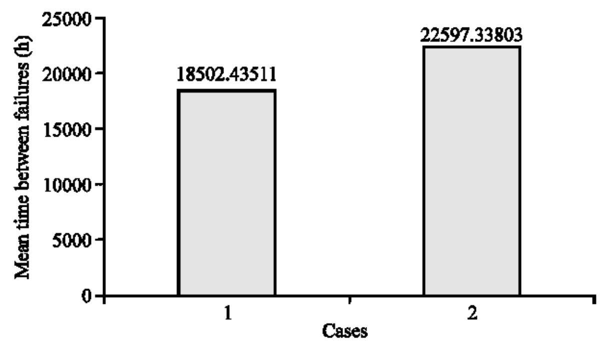

Fig. 5: The MTTF of the analog computer in the naval sheltered case before and after integration using FPAA (1 is the case before and 2 is the case after integration)

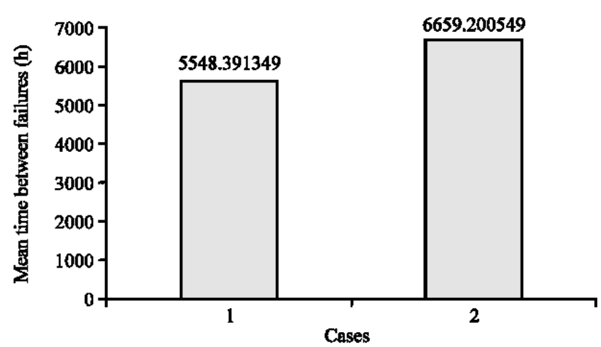

Fig. 6: The MTTF of the analog computer in the naval unsheltered case before and after integration using FPAA (1 is the case before and 2 is the case after integration)

CONCLUSIONS

In this study we have presented the results of integration of the various circuits of the analog computer of the gyrocompass of a naval vessel and showed the improvement in reliability. We showed a 16.67% improvement in the Naval Unsheltered case and a 18.2 % improvement in the Naval Sheltered case. The comparison of the MTTF from Fig. 3-6 also show an improvement in reliability. Since the gyrocompass of the naval vessel is composed of several analog modules similar to the one presented, plus several other digital modules, we can integrate the whole mixed system using several FPAAs and FPGAs. We will gain a great improvement in its reliability measures such as MTTF, MTTR and MTBF and achieve a much more reliable system with a smaller weight, volume and cost plus better performance. This has been proposed as the next step in our research.

REFERENCES

Becker, J., F. Henrici, S. Trendelenburg and Y. Manoli, 2008. Rapid prototyping environment for high-speed reconfigurable analog signal processing, in IPDPS 2008. Proceedings of 22nd IEEE International Symposium on Parallel and Distributed Processing. April 14-18, IEEE, pp: 1-4.

Lee, E.K.F. and P.G. Gulak, 1991. A CMOS field-programmable analog array. IEEE J. Solid State Circuits, 26: 1860-1867.

Looby, C.A. and C. Lyden, 2000. Op-Amp based CMOS field-programmable analogue array. Proc. IEEE Circuits Devices Syst., 147: 93-99.

MIL-HDBK-217F, Notice 2, 1995. Military Handbook. Reliability Prediction of Electronic Equipment, Feb 28, 1995.

Zetex Semiconductors, 1994. Totally Re-Configurable Analog Circuit-TRAC http://www.zetex.com/3.0/pdf/TRAC020LH.pdf.