Executive Summary

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1. Title of the Project: **Design of SHAKTI based secure Microprocessor**

2. Date of Start of the Project: **February 1, 2020**

3. Aims and Objectives:

   The aim was to develop a secure computing environment for our country that is open source and available to all interested parties wishing to develop System-on-Chips for various applications, including, strategic and civilian. The security features in a compute system may be classified into three: Hardware, Software and Firmware. The objective of this fellowship is to develop these security features for a family of microprocessors.

4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc)

   The proposal is to develop the complete security stack – hardware, software and firmware environments on RISCV ISA based SHAKTI microarchitectures. While the software and firmware are made agnostic to the microarchitecture, many of the hardware features including Hypervisor support, Physical Memory Protection and Compartmentalization are architecture specific. These supports are already implemented in the C-class SHAKTI processor. All software and firmware stacks

are fully developed and tested. The high assurance boot feature has been developed and integrated with C-class SHAKTI processor. An indigenous Separation Kernel has been compiled, ported on the Hypervisor mode and demonstrated on FPGA. Multiple cryptographic accelerators were developed and integrated to serve the different requirements of the security stack.

In addition, research has been carried out on developing system layer protocols/hardware accelerators to ensure secure network communication, edge Artificial Intelligence implementations, and secure data handling using block chain.

Six startup companies, incubated due to the SHAKTI effort, are today using the SHAKTI code line and are involved in development of various products that not only cover the different application domains but also ensures an end-to-end System-on-chip (SoC) development ecosystem within our Country. The ecosystem involves design of compute core, design of SoC by integrating peripheral IPs to the compute Core, Verification of the SoC, Physical Design converting soft model of SoC to a mask-like representation, Fabrication and packaging of SoC, development of software tool chain and related software development kit, and, development of mother board and board support packages.

The entire platform is made available as an encumbrance and royalty free open source for the benefit of the Indian Startups. We expect many more companies to use the same. A RISCV Knowledge Centre is being setup to facilitate the same.

Funding to the tune of 3 million dollars has been received from MeIty, Government of India, ISRO, IGCAR and Industry. Among many other things, the research outputs of this proposal have resulted in the Government of India developing more confidence on RISCV and accepting the same as India's instruction set architecture and launching the Digital India RISC-V initiative (DIRV). The main objective of this program is to make RISC-V processor as the processor of choice in this country over a period of time by having aggressive collaborations between academic research organizations, Indian public sector organizations, high-end technology startups coupled with both non-strategic and strategic end-users in India. Based on my contribution to the RISCV ecosystem in the country, I am appointed as the Chief

Architect of the DIRV program by Government of India. In order to meet the entire set of objectives for which DIR-V has been initiated, a RISC-V Knowledge Center (RKC) is proposed by me that shall serve as a nodal house for quick acceleration of RISC-V adoption across the country by start-ups and end-users.

5. Concluding remarks

The SHAKTI program was inspired by the statement made by Dr. A.P.J. Abdul Kalam in 2012 as a part of his Vision 2020 speech, "Create something for the country by 2020 that is not abstract but is a lifeline." Motivated by this, the SHAKTI project was initiated in 2013 in collaboration with Berkeley and MIT. This fellowship, that too in the name of Dr. Kalam, is the best gift I had every received. Needless to state, this has certainly motivated me to work harder and deliver the best. The entire project administration and follow-up from INAE has been extremely smooth. I conclude by thanking INAE for all these wonderful efforts.