COURSE NOTES

# LOW-TEMPERATURE ELECTRONICS

DISCLAIMER

These are *notes* only, not a formal or rigorous document. I have worked to ensure that the information in these Course Notes correct, but I make no claims regarding the accuracy, completeness, or suitability of the contents of these Course Notes. I have intended the information to be taken in the context of the Course. – R.K.K.

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# CONTENTS

## COURSE DESCRIPTION

Operation of electronics at low temperatures is a valuable option for substantially improving performance. Temperature may be thought of as an additional design choice when justified by system performance requirements.

**Low-Temperature Electronics** (LTE) may be based on semiconductors or on superconductors, or a combination of the two. The focus of this course is *semiconductor* electronics at low temperatures: device behavior, applications, advantages and drawbacks, technical issues and present situation. Basic materials characteristics related to electronics at low temperatures and passive electronic components are included. The temperature range covered in this course extends from room temperature down to absolute zero (0 K), with emphasis on the cryogenic range, approximately –150°C (~120 K) and below.

Applications include many areas of science and technology, including astrophysics, particle physics, computing, microwaves, communications, electric power, and biotech. Supercomputers have been built in which critical subsystems are cooled by liquid nitrogen at 77 K (–196°C). LTE microwave receivers for radio astronomy and deep-space communication, as well as signal-conditioning circuits for low-temperature infrared sensors and other cryogenic devices have been in use for decades, operating at temperatures throughout the LTE range. Superconducting and "hybrid" semiconducting/superconducting systems have been applied to cell-phone receivers, and LTE tracking is being developed for cryopreservation of biological specimens.

Benefits from cooling include faster switching, higher efficiency, and lower noise and higher sensitivity. At the same time there are technical challenges, related to component behavior circuit design, integrating the electronic system with the cooling system and overcoming difficulties related to thermal effects.

LTE has been primarily based on the field-effect transistor, of one type or another (JFET, MOSFET, MFSFET, MODFET). Conventional bipolar devices have not been satisfactory, but advanced types such as SiGe HBTs are proving valuable for low-temperature applications.

Although future developments in electronics are difficult to predict, it is likely that low-temperature operation will continued to be used when ultimate performance and operation in extreme environments is needed from devices, circuits, and systems.

## COURSE OBJECTIVES

Provide an overview of situations where the technologies of electronics and low temperatures are brought together.

Provide an overview of the applications for low temperature electronics.

Survey the relationships between fundamental phenomena, materials behavior, and device and system characteristics and performance at low temperatures.

Overview the behavior of materials and components used in electronics at low temperatures: metals, ceramics, plastics, passive components, semiconductor materials and devices, and electronic circuits and assemblies.

Provide practical information on materials, devices, circuits and techniques for those involved in low-temperature electronics.

## BIOGRAPHY OF PRESENTER

**Randall Kirschman** is an internationally recognized authority on low temperature electronics. He has been consulting to industry, government and academe since 1980 in the areas of microelectronic materials and fabrication technology, and electronics for extreme temperatures.

Before going into business for himself, he managed the processing laboratory at the R&D Center at a division of Eaton Corporation, where he was responsible for the fabrication of thin-film hybrids for microwave components. Prior to that he was on the staff of the Jet Propulsion Laboratory, performing research on a variety of superconductor and semiconductor materials and devices. During 1990-91 he was a Visiting Senior Research Fellow at the Institute of Cryogenics, University of Southampton, England. and between 1998-2005 was a member of the Physics Department at Oxford University.

He completed his undergraduate studies at the University of California, and earned his Ph.D. in Physics and Electrical Engineering at the California Institute of Technology in 1972.

He edited the 1986 IEEE Press book *Low-Temperature Electronics* and was on the International Advisory Board of *Cryogenics* journal (1988-2010). He has been on the organizing committees of more than half of the meetings on Low Temperature Electronics from 1983 to the present.