Memorandum of Understanding

Between

Sapience Consulting, a Texas Instruments University Program Partner, India

And

Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur

This memorandum of understanding (MOU) is signed on the 26th FEB 2016 and expires on 25th FEB 2018.

IS BETWEEN

Sapience Consulting, having its registered office No: 4, 4th Floor, 6th Block, 6th Cross, Koramangala Club Road, Koramangala, Bangalore-560095, India (hereinafter referred to as "COMPANY", which expression shall, unless it is repugnant to the context or meaning thereof be deemed to include its successors and assigns) of the FIRST PARTY.

AND

Madan Mohan Malaviya University of Technology, Gorakhpur (MMMUT) Established by U.P. Act no. 22 of 2013 of U. P. Government as a Non Affiliating Residential Technical University having its registered office at Deoria Road, Gorakhpur, U.P- 273010 hereinafter referred to as "UNIVERSITY", which expression shall, unless it is repugnant to the context thereof be deemed to include its successors and assignees represented by its Registrar of the SECOND PARTY.

(COMPANY and UNIVERSITY shall hereinafter be individually referred to as "Party" and collectively referred to as the "Parties")

WHEREAS

A. COMPANY, which is University Program partner of Texas Instruments (India) Private Limited (TI-India) which works with leading universities and engineering colleges in India, helping them to improve curriculum.

B. UNIVERSITY is one of India's most renowned engineering technological university and often collaborates with leading companies in the area of curriculum enhancement in order to provide advanced technical knowledge to students.

C. The Parties are now desirous of collaborating on curriculum amendment and setting up center of excellence activities subject to the terms contained herein.

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1. A **steering committee** will be set up to monitor the activities of the MoU. The committee will consist of Ms. Apurva Varma from Sapience Consulting and Prof. K. G. Upadhyay, Dean, Faculty Affairs & Dean Student Affairs; Prof. V. K. Giri, Dean Planning, Resource Generation & Alumni Relations; Maj. G. S. Tripathi, Head, Electronics and Communication Department representing Madan Mohan Malaviya University of Technology with mutual consent. The steering committee / Team can be expanded to include more members from the two organizations. The steering committee will be the supreme body as far the implementation of the activities of the MoU, the continuation of the MoU, and termination of the MoU are concerned.

    a. Steering committee to meet on Quarterly basis to discuss, analyze the progress of activities and milestones achieved as per ANNEXURES B & C.
    b. Steering committee to send monthly update to TI -India, giving the status report of labs, syllabus amendments, workshop in line with ANNEXURES B & C.

2. **Roles and Responsibilities**:

    a. <u>COMPANY's Responsibilities:</u>

        1. COMPANY, along with steering committee, will work with UNIVERSITY for curriculum amendment.
        2. After curriculum amendment as per ANNEXURE B , COMPANY will set up TI Center of Excellence (CoE) at Department of Electronics and Communication Engineering, M.M.M. University of Technology, Campus, Gorakhpur, U.P- 273 010 at the UNIVERISTY as per ANNEXURE A.
        3. COMPANY will conduct faculty development program (FDP) to increase awareness on the usage of TI Analog and Embedded technologies
        4. COMPANY, along with steering committee, will support and ensure the proper usage of CoE at the UNIVERSITY.
        5. COMPANY to collaborate with UNIVERSITY in showcasing activities carried out at the COE.

    b. <u>UNIVERSITY Responsibilities:</u>

        1. UNIVERSITY to work with COMPANY for curriculum amendment as per Annexure B.
        2. After curriculum amendment as per Annexure B, UNIVERSITY to provide infrastructure to set up "Texas Instruments Centre of Excellence" on Analog and Embedded technologies at the UNIVERSITY.
        3. The UNIVERSITY will use the CoE to build technical capabilities through experiential learning on TI Analog and Embedded technologies and also to develop teaching and learning content around Texas Instruments products.
        4. UNIVERSITY will be responsible for purchasing any other equipment required for setting up the CoE.

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5. UNIVERSITY will designate technical staff to operate and maintain the CoE and ensure its proper usage
6. UNIVERSITY will support COMPANY in obtaining quarterly reports.
7. UNIVERSITY will collaborate with COMPANY in showcasing the activities carried out at the CoE.
8. UNIVERSITY will collaborate with COMPANY in creating awareness on TI online resources (e.g. myTI, Webench etc) to strengthen activities at CoE.
9. UNIVERSITY to encourage faculty and students to actively participate in TI e2e forum by publishing articles, blogs and collaborating with peers on TI technology.

3. **Curriculum:** The UNIVERSITY, as per ANNEXURE B, along with COMPANY and steering committee, will introduce teaching and lab core courses on TI analog and embedded technologies in their Undergraduate engineering curriculum. UNIVERSITY will publish the course curriculum on the UNIVERSITY website.

4. **Faculty Development Program (FDP):** UNIVERSITY will organize at least 2 faculty development programs in its premise for its faculty mentors within 12 months of signing the MoU. UNIVERSITY will provide the infrastructure facility for conducting the faculty development program. COMPANY will assist the UNIVERSITY in conducting this program (see 2.a.1). FDP will happen as per ANNEXURE C.

5. This MOU constitutes the entire agreement between the parties in relation to the matters referred to in it and supersedes any previous agreement, documentation and correspondence between the parties in relation to those matters.

6. Confidentiality

a. Each Party (the "Receiving Party") recognizes that in the course of the transactions envisaged between itself and the other Party (the "Disclosing Party"), it shall be privy to certain Confidential Information relating or belonging to such Disclosing Party/its affiliates. The Receiving Party therefore agrees that:

1. It shall not, without the prior written permission of the Disclosing Party, directly or indirectly disclose or cause to be disclosed any Confidential Information to any third party;
2. It shall take all steps as may be reasonably necessary to protect the integrity of the Confidential Information and to ensure against any unauthorized disclosure thereof;
3. It shall promptly inform the Disclosing Party of any potential or accidental disclosure of Confidential Information and shall take all steps, together

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Registrar
M.M.M. University of Technology
Gorakhpur (U.P.)-273010

with the Disclosing Party, to retrieve and protect the said Confidential Information;

4. It shall ensure that all of the Receiving Party's faculty, employees, students, scholars, researchers and/or representatives or other persons who are given access to the Confidential Information shall at all times be bound by legally valid, written non-disclosure obligations at least as stringent as those contained herein;
5. And it shall use the Confidential Information only for the purpose for which it was provided and shall not profit from the same in an unauthorized manner to the exclusion of or to the detriment of the Disclosing Party/its affiliates.

b. Upon the termination of this Agreement or upon demand by the Disclosing Party, whichever is earlier, the Receiving Party shall forthwith ensure the return to the Disclosing Party of all Confidential Information and copies thereof in the possession or under the control of the Receiving Party, its faculty, employees, students, scholars, researchers and their affiliates and shall thereafter provide written confirmation to the Disclosing Party affirming the Receiving Party's compliance with the foregoing.

c. The term "Confidential Information" as used hereinabove means, with respect to the Disclosing Party/its affiliates, any and all information in written, representational, electronic, verbal or other form relating directly or indirectly to present or potential business, functionalities and specifications of the Disclosing Party's/its affiliates' products, devices or silicon (whether existing or planned), research/development, intellectual property, technology, designs, computer software, training methodologies, production techniques, testing plans and results, associates, customers, suppliers, competitors, regulatory matters, pricing, business development, marketing plans or strategy, sales matters/data, employees, financial matters or data, litigation/disputes and any information which might reasonably be presumed or identified to be proprietary or confidential in nature. However, "Confidential Information" would not include any such information which (i) is known to the public (through no act or omission of the Receiving Party in violation of this Agreement); (ii) can be demonstrated to have been lawfully acquired by the Receiving Party from an independent source having no obligation to

d. maintain the confidentiality of such information; (iii) can be evidenced to have been known to the Receiving Party prior to its disclosure under this Agreement (iv) is required to be disclosed by governmental or judicial order, in which case the Receiving Party shall give the Disclosing Party prompt written notice, where possible, and use reasonable efforts to ensure that such disclosure is accorded confidential treatment and also to enable the Disclosing Party to seek a protective order or other appropriate remedy.

e. Neither Party shall issue any press releases or website announcements or otherwise publicize the existence or any of the terms of this Agreement or other writing executed between the Parties without the prior written consent of the other Party.

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

f. The Parties acknowledge and agree that the above provisions relate to special, unique and extraordinary matters, and that violation of any of the terms of the same by the Party shall cause irreparable injury to the other Party/its affiliates and such other Party/its affiliates shall therefore be entitled to an interim injunction, restraining order or such other equitable relief as may be available to it under applicable law. These remedies are cumulative and are in addition to any other rights and remedies that the said other Party/its affiliates may have at law or in equity.

7. Intellectual property

a. The term "Intellectual Property" as used herein means all intellectual property, whether or not capable of being registered, including but not limited to patents, copyrights, computer software, code, designs, chip topography rights, mask works, trade secrets, know how, techniques, methodologies, trademarks, service marks, logos, trade names and corporate names.

b. It is hereby expressly clarified that any Intellectual Property independently created by UNIVERSITY / its faculty / students at the Texas Instruments Centre for Excellence which is not derived from and does not embody TI Intellectual Property or TI Confidential Information shall vest solely with UNIVERSITY, and TI/TI-India shall not be entitled to the same.

8. Representations and warranties

a. The Parties hereby represent and warrant that:

1. Each of them has full power and authority to enter into this Agreement.
2. The execution and delivery of this Agreement will not result in breach of any terms and conditions of any agreements, or constitute default under or violate any law, rule or regulation or any order, judgment or decree of any court, tribunal or governmental body.

b. It is clarified that COMPANY or its affiliates does not provide any warranty or undertaking to UNIVERSITY or assume any obligations as regards the quantum or nature of TI hardware and software development tools and educational materials that would be funded/provided by COMPANY.

9. Indemnity

a. Each Party (the "Breaching Party") shall indemnify and hold the other Party/its affiliates (the "Non-Breaching Party') harmless against any and all losses, claims, damages,

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Registrar
M.M.M. University of Technology
Gorakhpur (U.P.)-273010

liabilities, actions, proceedings, costs, charges, expenses and interests incurred by the Non-Breaching Party and arising out of any breach of the terms of this Agreement by the Breaching Party or out of any representation made by the Breaching Party being incorrect, misleading or materially incomplete in any manner whatsoever.

10. Relationship

a. UNIVERSITY understands and acknowledges that its relationship with COMPANY or its affiliates will be that of an independent principal and nothing in this Agreement is intended to or should be construed to create a partnership, joint venture, agency or employer-employee relationship and neither Party shall have any authority to bind the other or shall be deemed to have any authority of the other otherwise than as strictly provided herein.

11. Export control

a. Each Party hereby agrees that unless prior authorization is obtained from the U.S. Department of Commerce, neither it nor its subsidiaries or affiliates shall knowingly export, re-export, or release, directly or indirectly, any technology, software, or software source code (as defined in Part 772 of the Export Administration Regulations of the U.S. Department of Commerce ("EAR")), received from the other Party or any of its affiliated companies/entities, or export, directly or indirectly, any direct product of such technology, software, or software source code (as defined in Part 734 of the EAR), to any destination or country to which the export, re-export or release of the technology, software, software source code, or direct product is prohibited by the EAR.

b. Each Party understands and acknowledges that products, technology (regardless of the form in which it is provided), software or software source code, received from the other Party or any of its affiliates under this Agreement may be under export control of the United States or other countries. Each Party shall comply with the United States and other applicable non-U.S. laws and regulations governing the export, re-export and release of any products, technology, software, or software source code received under this agreement from the other Party or its affiliates. A Party shall not undertake on the other Party's/its affiliates' behalf any action that is prohibited by the EAR or other applicable US/non-US export control laws. Without limiting the generality of the foregoing, each Party specifically agrees that it shall not transfer or release products, technology, software, or software source code of the other Party or its affiliates to, or for use by, military end users or for use in military, missile, nuclear, biological, or chemical weapons end uses.

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12. FCPA and other compliances

UNIVERSITY shall comply with the US Foreign Corrupt Practices Act, the Indian Prevention of Corruption Act, 1988 and all similar or related US and Indian laws, rules and regulations as may be enacted, amended or applicable from time to time and shall refrain from either directly or indirectly doing or refusing to do anything that may result in any liabilities or claims accruing against the COMPANY.

13. Information Rights

a. UNIVERSITY shall, if requested by COMPANY or its affiliates, forthwith provide COMPANY nominees access to all information, records, books and documents as may be required by COMPANY to verify UNIVERSITY's and each Visiting Faculty Member's compliance with the provisions of this Agreement and other documentation that may be executed between COMPANY and UNIVERSITY/or the associated Faculty Member. COMPANY's nominees participating in such exercise shall be entitled to make copies of such information, records, books and documents and to interview the relevant UNIVERSITY personnel and associated Faculty Members. COMPANY undertakes that in the event that it incidentally becomes privy to any proprietary or secret/non-public information belonging to UNIVERSITY or its affiliates in the course of the above exercise which has no bearing on COMPANY's assessment of UNIVERSITY's compliance with the specified provisions hereof, COMPANY shall keep such information confidential and not disclose the same to any third parties or otherwise use the same to the exclusion or detriment of UNIVERSITY.

14. Term and Termination

a. This Agreement shall become effective from the date hereof and shall remain in force unless terminated in accordance with the provisions of this Section.

b. This Agreement may be terminated by a Party hereto if another Party commits material breach or default in performance of its obligations hereunder and the same (if capable of being remedied), has not been cured within 30 (thirty) days of receipt of written notice of such breach or default.

c. Any Party may terminate this agreement without specifying any reason by providing 90 days' prior written notice in that behalf to the other Parties.

d. The termination hereof shall not serve to release a Party from the performance of such of its obligations as may have arisen prior to termination. Further, the provisions of Sections [6, 7, 11, 15] shall continue to remain binding notwithstanding the termination or expiry hereof.

UNIVERSITY_____ Registrar
M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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15. Governing law and dispute resolution

a. This Agreement shall be governed and construed in accordance with the laws of India.

b. If any dispute arises between the Parties during the subsistence of this Agreement or thereafter, in connection with the validity, interpretation, implementation or alleged breach of any provision of this Agreement, the dispute shall be referred to a sole arbitrator, who shall be nominated by mutual consent. If the Parties are unable to agree upon the nomination of a sole arbitrator within 30 days of the dispute having arisen, each Party to the dispute (in case it is bipartite) shall nominate one arbitrator and the two arbitrators so nominated will appoint the third, presiding arbitrator. If the dispute is a tripartite one, each of the Parties will nominate one out of the total of three arbitrators. The place of arbitration shall be Bangalore. The arbitration proceeding shall be governed by the Arbitration & Conciliation Act, 1996. The arbitration proceedings shall be in the English language.

c. Subject to the provisions of Section 15b above, the courts at Bangalore shall enjoy sole jurisdiction over matters related hereto. It is hereby clarified that nothing herein or in Section 15b above shall be construed to prevent COMPANY /its affiliates from approaching courts in any jurisdiction deemed appropriate by them for the purpose of obtaining injunctive and equitable relief.

16. General Provisions

a. Any notice under this Agreement will be in writing and will be: (i) given in person; or (ii) sent by facsimile or electronic mail and confirmed by sending through registered post or nationally recognized courier within three (3) calendar days thereafter, or (iii) sent by registered post or nationally recognized courier, with postage prepaid, to the address specified below or to any other address that may be designated by a party by prior written notice. Any notice delivered by facsimile or electronic mail will be deemed received the day it is sent. Any notice or other communication sent by registered post or nationally recognized courier will be effective as of the date of the receipt.

b. Entire Agreement: This Agreement, including the Schedules hereto, constitutes the entire agreement between the Parties relating to its subject matter and, this Agreement

c. supersedes any and other prior agreements, communications or understandings, whether oral or written, pertaining to the subject matter hereof.

d. Amendment to Agreement: This Agreement may not be amended, varied, waived, explained, added to, extended or changed in any way except in writing, signed by a person duly authorized to execute such modification or amendment on behalf of either Party.

e. Waiver: Any failure by either party to exercise its rights or any delay, forbearance or indulgence by either party in exercising any rights under this agreement shall not operate

UNIVERSITY_____ SAPIENCE CONSULTING_____

Registrar
M.M.M. University of Technology
Gorakhpur (U.P.)-273010

as a waiver of that right or preclude its exercise at any subsequent time or on any subsequent occasion.

f. Severability: In the event that any one or more of the provisions contained herein are, for any reason, discovered to be unenforceable in any respect under the laws of India, the remainder of this Agreement shall be in full force and effect.

g. No Exclusivity: Nothing herein shall be deemed to restrict any Party from entering into similar arrangements with any third parties.

h. Force Majeure: Neither Party shall have any right to terminate this Agreement for any breach caused by reason of, nor shall either Party be liable for any loss or damage caused to the other by reason of any failure or delay of such Party in meeting its obligations under this Agreement which is due to any riot, strike, fire, accident, explosion, flooding, terrorism or malicious damage not attributable to the default or negligence of such Party or to any other cause (whether similar to the foregoing or not) not so attributable. Each Party shall forthwith notify the other of any event likely to cause such failure or delay immediately upon the same having come to such Party's knowledge. Provided that in the event that any event of *force majeure* which prevents either Party from fulfilling its obligations under this Agreement persists for a continuous period of 45 days, either Party may forthwith terminate this Agreement and the consequences of such termination shall be the same as termination under Section 14 (d).

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

IN WITNESS WHEREOF, the Parties have caused this MOU to be signed by their duly authorized representatives as of the MOU effective date above.

Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur	**Sapience Consulting**
By:	By:
Name: Shri K. P. Singh	Name: Apurva Varma
Title: Registrar	Title: Director-Operations
Date: 26 · 02 · 2016	Date:
Witness	**Witness**
By:	By:
Name: Prof. V. K. Giri	Name:
Title: Dean, Planning	Title:
Date: 26 · 02 · 2016	Date:

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Gorakhpur (U.P.)-273010

ANNEXURE A: Definition of Centre of Excellence(CoE)

CoE will comprise of 5 labs as per the choice of the University. The lab definition is as given in the below list.

Sl. No	Lab Definition	Lab composition
1	One MSP 430 Lab	20 MSP430 G2 Launchpads OR
		10 MSP430 Launchpad + 2 MSP-EXP430F5529 experimenter kit
2	One C2000 Lab	10 LAUNCHXL F28027 Launchpads+Two 28335 Peripherial explorer kits
3	One TIVA Lab	20 EK-TM4C123GXL TIVA Launchpad
		10 TIVA Launchpads + 2 DK-TM4C123G kit OR
4	One Analog Attach Lab	15 Launchpads (MSP430 G2/ LAUNCHXL F28027 / EK-TM4C123GXL TIVA) and 5 Booster Packs (430BOOST-SENSE1/430BOOST-TMP006/BOOSTXL-SENSHUB/ BP-EDUC-01)
5	One Connectivity Attach Lab	6 EZ430-RF256x Bluetooth Evaluation Kit OR
		6 MSP Launch Pad (MSP-EXP430F5529) + 6 CC3100boost OR
		12 MSP-EXP430G2 + 6 CC110L Booster Packs OR
		CC2530EMK/CC2520EMK with MSP430 Experimenter Boards for 2.4GHz Zigbee applications.
6	One Analog Lab	6 ASLK PRO kits
Other material that may be needed in Lab		
1	IDE	Code Composer Studio — CCSv5.0 or above
Teaching & Branding Material		
1	Teaching ROMs on TI platforms	
2	Textbooks on TI technologies	
3	Lab Manuals available	
4	TI Lab posters, and collaterals	

- UNIVERSITY to receive tools as per above **definition of CoE** from COMPANY.
- UNIVERSITY to provide necessary instruments e.g. function generators, power supplies, oscilloscopes, computers etc at the CoE.
- COMPANY to provide TI branding material to UNIVERSITY to be placed at the CoE.
- UNIVERSITY to give acknowledgement letter to COMPANY, as per ANNEXURE D

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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ANNEXURE B – Curriculum Amendment to include TI Technology

1. COMPANY will provide curriculum framework and content to UNIVERSITY for incorporation into UG core courses.
2. Before curriculum amendment, COMPANY will identify theory and lab courses where TI technology will be incorporated.
3. UNIVERSITY as an apex technical body focused on bringing application oriented innovative curriculum for the benefit of all associated engineering colleges will ensure curriculum amendment as per ANNEXURE G to include teaching and lab courses on market relevant cutting edge TI analog and embedded technologies in its undergraduate engineering core curriculum (not as elective subject) to be adopted.
4. It is the responsibility of the UNIVERSITY to reflect the curriculum amendment on its website that could be accessed by the larger education community across India for the benefit of the ecosystem and be the guiding example of industry relevant curriculum. UNIVERSITY will share the website links, circular, course content with COMPANY.
5. It is a responsibility of the COMPANY to ensure that curriculum amendment and content are shared with TI in the form of circular and website announcement.
6. It will be the responsibility of the COMPANY to provide TI teaching material and online resources available on TI website to UNIVERSITY.
7. UNIVERSITY must encourage its faculty to use available teaching material and develop textbooks and other course material for the benefit of student community.

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Gorakhpur (U.P.)-273010

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ANNEXURE C – Faculty Development Program (FDP))

1. COMPANY will conduct **2** FDP in CoE established at UNIVERSITY within **12** months' time frame after signing the MOU.
2. UNIVERSITY will ensure identification of ____ relevant faculty to be trained in each FDP. The trained faculty will be designated as mentors/technical experts on TI technology at the UNIVERSITY.
3. UNIVERSITY will provide hospitality for participating faculty, infrastructure, lab facility (as mentioned in ANNEXURE A) to conduct the FDP.
4. COMPANY will provide technical expertise.
5. UNIVERSITY will carry out publicity to draw participation for FDP.
6. COMPANY will share event announcement with TI at least two weeks prior to the event.
7. COMPANY will share photographs, registration documents and technical experts' remark with consolidated feedback.

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Gorakhpur (U.P.)-273010

ANNEXURE D: Acknowledgement letter

(To be printed on University letter-head)

To,
TI India University Program
Texas Instruments India
Bagmane Tech Park
CV Raman Nagar
Bangalore – 560093

Sub: - TI Sponsored _____ CoE.

Dear Sir,

On Behalf of _____<name of the UNIVERSITY>. We acknowledge that COMPANY has provided hardware platforms as listed in the table below towards setting up the CoE. The CoE has been set up at<Address>.

S.NO.	Name or Description of the Hardware platform	Quantity

As committed in the MoU, TI CoE will be set-up with the above mentioned Hardware platforms and will be used for curriculum activities and research at the UNIVERSITY.

We also assure that we will maintain the branding of TI CoE in the UNIVERSITY as per the MOU guidelines and will use the teaching material given to us by the COMPANY.

Thank You,

With Regards,

Signature of the Registrar and Coordinator of TI Program with Seal

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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Timeline for FDP:

University & Company will strive to achieve their quarterly goals in providing training to the relevant faculty as detailed below:

S.No.	Minimum no. of participants	Tentative timeline	COMPANY & UNIVERSITY shall ensure the following deliverables to TI for each lab setup
1		To be mutually discussed and decided	• Acknowledgement letter from the concerned as per format in Annexure D • Quarterly report from University which will highlight on programs run, list of experiments being • carried out, projects being carried out, workshops etc.
2		-do-	

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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(To be printed on University letter-head)
Letter date/Ref Number

To,
TI India University Program
Texas Instruments India
Bagmane Tech Park
CV Raman Nagar
Bangalore – 560093

Sub: Approval of curriculum in Analog Integrated Circuits and Microcontrollers and Embedded Systems

REF: MOU Between Sapience Consulting, a Texas Instruments University Program Partner, India and Madan Mohan Malaviya University of Technology Gorakhpur

Vide reference cited above; it is to confirm that, effective immediately, the University has made changes to the curriculum structure and content for following undergraduate core courses:

S. No.	Course Name	Course Code	Semester	Course Credits Total (L-T-P)
1.	Analog Integrated Circuits (Core course)	BEC-27	V	5 (3-1-2)
2.	Microcontrollers and Embedded Systems (Core course)	BEC-61	VIII	5 (3-1-2)

The modified course for both theory and lab of 5th and 8th semesters will be taught starting 2016-17 session for undergraduate students of Madan Mohan Malaviya University of Technology.

Enclosures:
Approved course content for (total 11pages)

1. Analog Integrated Circuits (BEC-27)
2. Microcontrollers and Embedded Systems (BEC-61)

Thank You,
With Regards,
(Seal and Signature)

26/2/16

Registrar
Madan Mohan Malaviya University of Technology, Gorakhpur

Chairman, Board of Studies

Head
Deptt. of Electronics & Comm. Engg.
M.M.M. University of Technology
Gorakhpur

UNIVERSITY Registrar
M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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Analog Integrated Circuits

Abstract:

Analog Electronics occupies a very special and significant place in modern day systems. In the past decade, India has seen the emergence of a number of system design companies. Manufacturing of electronic products has also received a significant boost. These companies look for system-level design skills in both analog and digital domains. Currently, Analog System design is not emphasized in the conventional way of teaching analog. We believe it is important to bridge this gap at an early stage in the undergraduate coursework.

In this course the focus is on system design. This will prepare the students for the real world, where a system designer uses the analog ICs as building blocks. Starting with understanding the characteristics of an op-amp, which is a basic building block in Analog Systems, it will cover the design and test of practical circuits based on Op-Amps. This will follow by study of comparators, data converters, multipliers, voltage regulators and their implementation. The final section will cover more advanced applications of analog systems.

Prerequisites

1. Network Analysis & Synthesis

Course Objectives:

1. Basic concepts of op-AMPs characteristics and specifications
2. Op-AMP applications to signal conditioning for amplifiers, filters and oscillators
3. Op-AMP applications for comparators and data conversions
4. Op-AMP for advanced applications such as PLL, VCOs, V-I converters, I-V converters, AGC,AVC, analog multipliers

Course Name	**Analog Integrated Circuits(5 Credits)**
Level	Intermediate
Credits	L – T – P **3– 1 – 2**
Total hours	(40) + 15 sessions of lab practical
Semesters	V
Branches	ECE

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M.M.M. University of Technology
Gorakhpur (U.P.)-273010

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Course outcomes:

1. Students will be able to learn about the operational amplifiers and its characteristics as well as various types of op-amps.
2. Students will acquire the ability to design and test practical circuits for amplifiers, filters and oscillators.
3. Students will be able to analyze the operation of comparators, data convertors and implementation of the same.
4. Students will be able to learn the functioning of PLL, VCO, V-I, I-V converters, AGC, AVC and analog multipliers and implement them for suitable applications

Theory Course:

UNIT I

Introduction to Integrated Circuit design: Power Supply configurations for Op-amp application,Various types of Op-amp, Current mirrors using BJT and MOSFETs, Base current compensated mirrors, Wilson current mirrors, Cascode current mirror, Widlar current source.

UNIT II

Linear and Nonlinear applications of IC Op-amp: An overview of Op-amp, V-I and I-V converters, Log-antilog amplifiers, Precision rectifier, Peak detector, Sample and Hold Circuits, Analog multiplier and their applications, Op-amp as a comparator, Zero-crossing detector, Schmitt trigger, Astable and Monostable multivibrator, Generation of triangular waveform

UNIT III

Filters: Characteristics of filters, Classification of filters, Butterworth filters, Chebyshev filters, Bessel filters, Low Pass and High Pass filters, Band Pass filters, Band reject filters, Notch filters, Self-tuned filters, KHN filters

UNIT IV

Advanced applications of an Op-amp : Frequency Divider, PLL, AGC, AVC using op-AMP and analog multipliers, Integrated circuit Timer: 555 IC timer, Astable and Monostable Multivibrators using 555 IC, Standard Regulator ICs and their characteristics.

Lab Course:

1. Study the characteristics of negative feedback amplifier.
2. Design of an instrumentation amplifier.
3. Design and test an astable multivibrator for a given frequency
4. Study the characteristics of integrator circuit.
5. Design of Analog filters-I.
6. Design of Analog filters-II.
7. Design of self-tuned Filter.
8. Design of function generator.
9. Design of a voltage controlled oscillator.
10. Design of a phase locked loop.
11. Design and testing of Automatic Gain Control (AGC) and Automatic Volume Control (AVC)
12. Design of a low drop out regulator

13.Design of a switched mode power supply that can provide a regulated output voltage for a given input range using the TPS40200 IC

Lab course:

Tools Required: –Function Generator, Power Supply, TL082, MPY634, ASLK Pro, Oscilloscopes, Connecting wires.

List of Experiments:

1. Study the characteristics of negative feedback amplifier

Aim:

Design the following amplifiers:

a) A unity gain amplifier
b) A non-inverting amplifier with a gain of 'A'
c) An inverting amplifier with a gain of 'A'

Apply a square wave of fixed amplitude and study the effect of slew rate on the three type of amplifiers.

Applications:

- Amplifying bioelectric potentials (ECG, EEG, EMG, EOG) and piezoelectric with high output impedance.
- Amplifying sensor output signals (temperature sensors, humidity sensors, pressure sensors etc.)

Sample questions

Explain the need for unity gain amplifier.
Advantages of op-amp based amplifiers as compare to BJT amplifiers.
Mention the applications for inverting and non-inverting amplifiers.
Give your inference on the frequency response of the amplifier.
Give the significance of gain-bandwidth product.

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2. Design of an instrumentation amplifier

Aim:

Design an instrumentation amplifier of a differential mode gain of 'A' using three amplifiers.

Applications:

- Used in measuring instruments designed for achieving high accuracy and high stability.
- Used for amplifying low voltage, low frequency and higher output impedance signals.

Sample questions

Explain the need for two stages in any instrumentation amplifier.
Why CMRR is high for instrumentation amplifiers?
Give some examples for low voltage, low frequency and higher output impedance signals.
How does the tolerances of resistors affect the gain of the instrumentation amplifier?

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3. Study the characteristics of regenerative feedback system with extension to design an astable multivibrator

Aim:

Design and test an astable multivibrator for a given frequency.

Applications

- It can be used in signal generators and generation of timing signals.
- It can be used in code generators and trigger circuits.

Sample question

Discuss the difference between astable and bi-stable multivibrator.
Discuss the frequency limitation of astable multivibrator.
Discuss the various applications of bi-stable multivibrator.

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4. Study the characteristics of integrator circuit

Aim:

Design and test the integrator for a given time constant.

Applications

- Used in function generators, PI/PID controllers.
- Used in analog computers, analog-to-digital converters and wave-shaping circuits.
- Used as a charge amplifier.

Sample questions

Compare the output with that of ideal integrator.
How will you design a differentiator and mention its drawback.
Discuss the limitation of the output voltage of the integrator.
How will you obtain drift compensation in an inverting integrator?

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5. Design of Analog filters – I

Aim:

Design a second order butterworth band-pass filter for the given higher and lower cut-off frequencies.

Applications:

- Used in signal conditioning circuits for processing audio signals.
- Used in measuring instruments.
- Used in radio receivers.

Sample questions

Discuss the effect of order of the filter on frequency response.
How will you vary Q factor of the frequency response.
Discuss the need for going to Sallen Key circuit.
Compare the performance of Butterworth filter with that of Chebyshev filter.

6. Design of Analog filters – II

Aim:
Design and test a notch filter to eliminate the 50Hz power line frequency.
Applications

- Used for removing power supply interference.
- Used for removing spur in RF signals.

Sample questions
Explain the effect of supply frequency interference while amplifying sensor signals.
Suggest a method for adjusting the Q factor of the frequency response of notch filter.
What is the purpose of going for Twin T notch filter circuit?

7. Design of a self-tuned Filter

Aim: Design and test a high-Q Band pass self-tuned filter for a given center frequency.
Applications:

- Used in spectrum analyzers

Sample Question:
Discuss the effect of the harmonics when a square wave is applied to the filter
Determine the lock range of the self-tuned filter

8. Design of a function generator

Aim:

Design and test a function generator that can generate square wave and triangular wave output for a given frequency.

Applications:

- Used in testing, measuring instruments and radio receivers.
- Used for obtaining frequency response of devices and circuits.
- Used for testing and servicing of Electronic equipment's.
- Used in Electronic musical instruments.
- Used for obtaining audiograms (Threshold of audibility Vs frequency)

Sample questions
Discuss typical specifications of a general purpose function generator.
How can you obtain reasonably accurate sine wave from triangular wave.
Discuss the reason for higher distortion in sine wave produced by function generators.
What do you mean by Duty cycle and how can you vary the same in a function generator?

9. Design of a Voltage Controlled Oscillator

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Aim:

Design and test voltage controlled oscillator for a given specification (voltage range and frequency range).

Applications:

- Used in Phase Lock Loop (PLL) circuits.
- Used in frequency modulation circuits.
- Used in Function generators
- Used in frequency Synthesizers of Communication equipments.

Sample Questions

Discuss the following characteristics of a voltage controlled Oscillator.

i) Tuning range
ii) Tuning gain and
iii) Phase noise

Compare the performances VCO based Harmonic Oscillators and Relaxation Oscillators
What are the various methods adopted in controlling the frequency of oscillation in VCOs
Discuss any one method of obtaining FM demodulation using a VCO.

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10. Design of a Phase Locked Loop(PLL)

Aim:

Design and test a PLL to get locked to a given frequency 'f'. Measure the locking range of the system and also measure the change in phase of the output signal as input frequency is varied with in the lock range.

Applications:

- Used in tracking Band pass filter for Angle Modulated signals.
- Used in frequency divider and frequency multiplier circuits.
- Used as Amplifiers for Angle Modulated signals.
- Used in AM and FM Demodulators
- Used in Suppressed Carrier Recovery Circuits

Sample Questions:

Draw the block diagram of a PLL based divider and multiplier and explain the functions performed by each block.
Distinguish between Lock range and Capture Range, Explain the method of estimating the same for a given PLL circuit.
Discuss the differences between Analog Phase Lock Loop and Digital Phase Lock Loop.

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11. Automatic Gain Control (AGC) Automatic Volume Control (AVC)

Aim:
Design and test an AGC system for a given peak amplitude of sine-wave output.
Applications

- Used in AM Receivers
- Used as Voice Operated Gain Adjusting Device (VOGAD) in Radio Transmitters
- Used in Telephone speech Recorders
- Used in Radar Systems

Sample Questions

Explain clearly the need for AGC in AM Receivers.
Draw the block diagram of feedback and feed forward AGC systems and explain the functions of each block.
Discuss any one gain control mechanism present in biological systems.
How can you use AGC in a Received Signal Strength Indicator (RSSI)

12. Design of a low drop out regulator

Aim:

Design and test a Low Dropout regulator using op-amps for a given voltage regulation characteristic and compare the characteristics with TPS7250 IC

Applications:

- Used in Power Supply of all Electronic Instruments and Equipment's
- Used as Reference Power Supply in Comparators
- Used in Emergency Power Supplies
- Used in Current Sources

Sample Questions

Distinguish between Load Regulation and Line Regulation.
Mention some of the other important parameters in selecting a LDO.
What is power supply rejection ratio (PSRR)?

13. DC-DC Converter

Aim:
Design of a switched mode power supply that can provide a regulated output voltage for a given input range using the TPS40200 IC
Applications:

- Used is DSL/Cable Modems
- Used in Distributed Power Systems

Sample Questions

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- Discuss the effect of varying the input voltage for a fixed regulated output voltage over the duty cycle of PWM.

Books and other References:

1. Data Sheet: http://www.ti.com/lit/ds/symlink/tl082.pdf
2. Application Note: http://www.ti.com/lit/an/sloa020a/sloa020a.pdf
3. MPY634 Data Sheet: http://www.ti.com/lit/ds/symlink/mpy634.pdf
4. Application Note: http://www.ti.com/lit/an/sbfa006/sbfa006.pdf
5. ASLK Pro Manual: ASLK Manual
6. Ramakant A. Gayakwad, "Op-amps and Linear Integrated Circuits", PHI
7. Millman and Grabel, "Microelectronics", 2nd Ed., Mcgraw Hill
8. D. Roy Chudhry, "Linear Integrated Circuits", New Age International

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Microcontrollers and Embedded Systems

Abstract

Modern day Embedded Systems curriculum requires an application and Systems Design approach balancing the performance, connectivity requirements and system cost with an eye on power. This course is designed to inculcate this perspective in the students using Cortex-M4 based Tiva, an industry standard hardware platform.

The course helps us to understand 32-bit architecture and its programming considerations using C language. Later part is focused on programming various inbuilt features of the platform with more focused approach on analog and digital interfacing concepts and related protocols. Embedded systems whether they are standalone or networked need various communication interfaces and standards so that they communicate and process data from external sensors and actuators. It will cover how to connect the device to external peripherals including those needed for internet connectivity.

Course objectives

- Teach basic architecture of 32-bit microcontrollers
- Understand hardware interfacing concepts to connect digital as well as analog sensors while ensuring low power considerations.
- Reviews and implement the protocols used by microcontroller to communicate with external sensors and actuators in real world.
- Understanding Embedded Networking concepts based upon connected MCUs

Prerequisite

1. Digital Electronics & Circuits

Course details

Course Name	Microcontrollers and Embedded Systems
Course Type	CORE
Credits	L – T – P **3 – 1 – 2**
Semester	VIII
Branches	ECE

Course outcomes:

At the end of the course the students will be able to understand the concept and scope of microcontrollers specially32-bit microcontroller, programming, interfacing of various external I/O devices, communication protocols used by microcontrollers and embedded networking.

Theory Course:

UNIT-I: Microprocessors for embedded systems

Embedded system overview and applications, features and architecture considerations-ROM, RAM, timers, data and address bus, Memory and I/O interfacing concepts, memory mapped I/O. CISC Vs RISC design philosophy, Von-Neumann Vs Harvard architecture, instruction set, instruction formats, and various addressing modes of 32-bit. Fixed point and floating point arithmetic operations.

Introduction ARM architecture and Cortex – M series, Introduction to the Tiva family viz. TM4C123x & TM4C129x and its targeted applications, Tiva block diagram, address space, on-chip peripherals (analog and digital) Register sets, Addressing modes and instruction set basics.

UNIT-II: Microcontroller Fundamentals for Basic Programming, Timers, PWM and Mixed Signals Processing

I/O pin multiplexing, pull up/down registers, GPIO control, Memory Mapped Peripherals, programming System registers, Watchdog Timer, need of low power for embedded systems,

System Clocks and control, Hibernation Module on Tiva, Active vs Standby current consumption. Introduction to Interrupts, Interrupt vector table, interrupt programming.

Case Study: Tiva based embedded system application bringing up the salient features of GPIO, Watchdog timer, etc.

Timer, Basic Timer, Real Time Clock (RTC), Timing generation and measurements, Analog interfacing and data acquisition: ADC, Analog Comparators, DMA, Motion Control Peripherals: PWM Module & Quadrature Encoder Interface (QEI).

Case Study: Tiva based embedded system application using ADC & PWM.

UNIT- III: Communication protocols and Interfacing with external devices

Synchronous/Asynchronous interfaces (like UART, SPI, I2C, USB), serial communication basics, baud rate concepts, Interfacing digital and analog external device, I2C protocol, SPI protocol & UART protocol. Implementing and programming I2C, SPI & UART interface using Tiva. CAN & USB interfaces on Tiva platform. Case Study: Tiva based embedded system application using the interface protocols for communication with external devices "Sensor Hub BoosterPack"

UNIT IV: Embedded networking and Internet of Things

Embedded Networking fundamentals, Ethernet, TCP/IP introduction IoT overview and architecture, Overview of wireless sensor networks and design examples. Various wireless protocols and its applications: NFC, ZigBee , Bluetooth, Bluetooth Low Energy, Wi-Fi. Adding Wi-Fi capability to the Microcontroller, Embedded Wi-Fi, User APIs for Wireless and Networking applications Building IoT applications using CC3100 user API: connecting sensor devices using Tivaware sensor library.

Case Study: Tiva based Embedded Networking Application: "Smart Plug with Remote Disconnect and Wi-Fi Connectivity"

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Lab course:

1. Interfacing and programming GPIO ports in C using Tiva (blinking LEDs , push buttons)
2. Interrupt programming examples through GPIOs
3. Use Hibernation mode and wake on RTC interrupt
4. PWM generation using PWM Module on Tiva
5. Interfacing potentiometer with Tiva GPIO
6. PWM based Speed Control of Motor controlled by potentiometer connected to Tiva GPIO
7. Connect the Tiva to terminal on PC and echo back the data using UART
8. Interfacing an accelerometer with Tiva using I2C
9. Experiment on USB (Sending data back and forth across a bulk transfer-mode USB connection.)
10. Using IQmath Library for implementing Low pass FIR filter
11. Review of User APIs for TI CC3100 & Initialization and Setting of IP addresses
12. A basic Wi-Fi application – Communication between two Tiva based sensor nodes using TIVA sensor library in TivaWare
13. Setting up the CC3100 as a HTTP server

References:

1. Embedded Systems: Real-Time Interfacing to ARM Cortex-M Microcontrollers, 2014, ISBN: 978-1463590154.
2. http://processors.wiki.ti.com/index.php/Hands-On_Training_for_TI_Embedded_Processors http://processors.wiki.ti.com/index.php/MCU_Day_Internet_of_Things_2013_Workshop ;
3. http://www.ti.com/ww/en/simplelink_embedded_wi-fi/home.html
4. R. Kamal, "Embedded Systems: Architecture, Programming & Design", 2007, McGraw Hill, USA 2007.

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