GLOBAL MARKETS, GLOBAL TECHNOLOGY, AND GLOBAL STUDENTS?

Ulrich L. Rohde, Prof. Dr. Ing. habil.

der Bundeswehr Universität München

Historic venue where Leibnitz, Einstein, and Heisenberg presented groundbreaking ideas.

Academy President Prof. Schwaiger pictured right

University of Florida

THE

DEPARTMENT OF ELECTRICAL ENGINEERING

With the approval of the Faculty

hereby recognizes the permanent appointment of

ULRICH L. ROHDE

as

Professor of Electrical Engineering

March 15, 1977

Wayne H. Chen

Dean, College of Engineering

Donald G. Childers

Chairman, Department of

The George Washington University

THE

DEPARTMENT OF ELECTRICAL ENGINEERING

With the approval of the Faculty
hereby recognizes the permanent appointment of

Ulrich L. Rohde

as

Adjunct Professor of Electrical Engineering

Arthur D. Friedman

May 4, 1982

Arthur D. Friedman
Chairman, Department of Electrical

ROMANIA
MINISTERUL INVATAMANTULUI
UNIVERSITATEA DIN ORADEA

DIPLOMA

The University of Oradea, with the recommendation of the Senate and the Faculty hereby appoints permanently

Ulrich L. Rohde

as Professor of Electrical Engineering and Microwave Technology.

ROMÂNIA MINISTERUL EDUCAȚIEI NAȚIONALE UNIVERSITATEA DIN ORADEA RECTORAT

Rector
prof. dr. ing. TEODOR MAGHIAR
May 30, 1997

Brandenburgische Technische Universität Cottbus

Urkunde

Herr
Ulrich L. Rohde PhD
Prof. Dr. h. c. mult.

wird auf Antrag der Fakultät für Maschinenbau, Elektrotechnik und Wirtschaftsingenieurwesen
gemäß § 52 Absatz 2 des Brandenburgischen Hochschulgesetzes

zum

Honorarprofessor

für das Fachgebiet

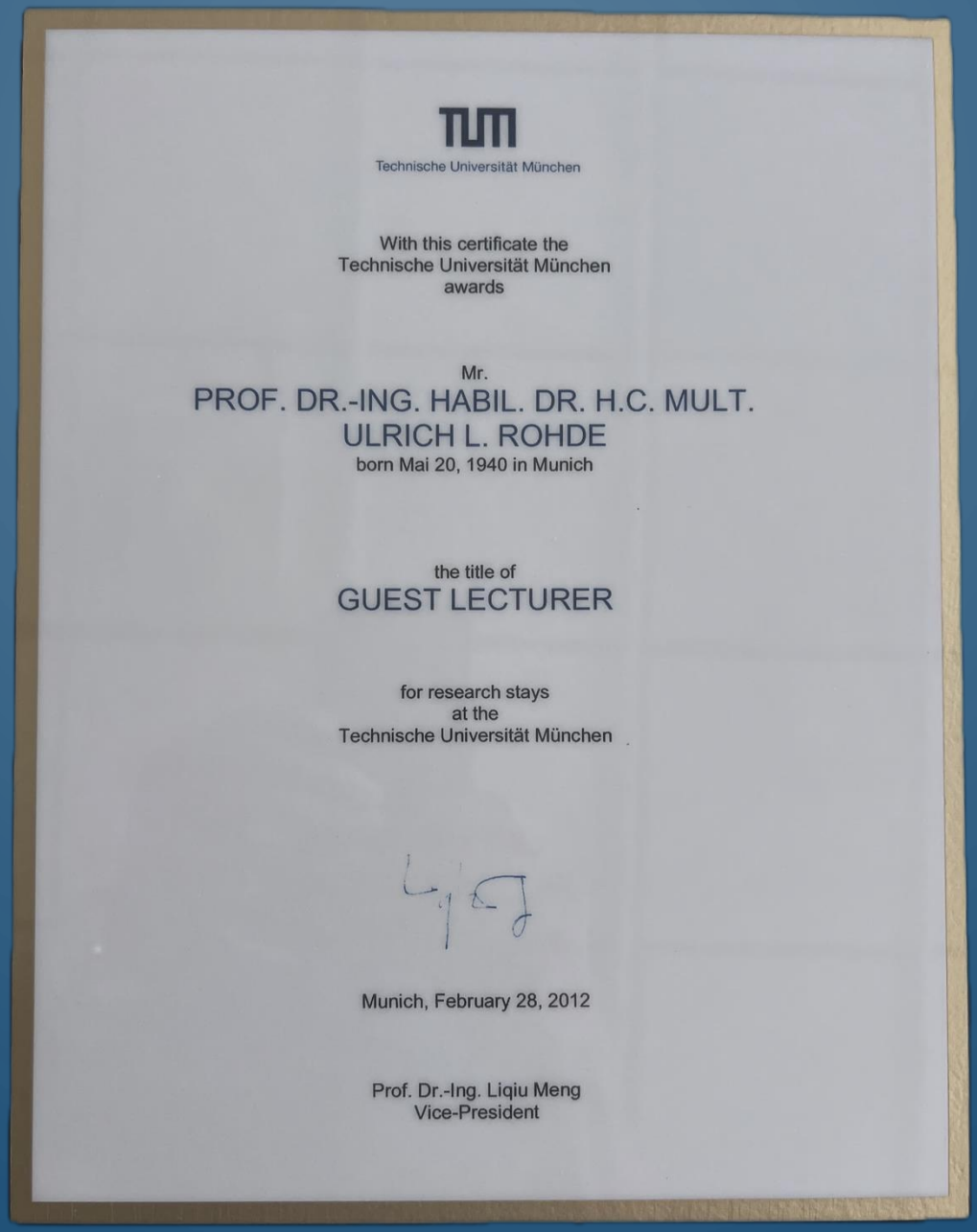
Hochfrequenz- und Mikrowellenschaltungstechnik

bestellt.

Cottbus, den 18. April 2002

Der Präsident

Prof. Dr. rer. nat. habil. Dr. h. c. Ernst Sigmund



Technische Universität München

With this certificate the
Technische Universität München
awards

Mr.
PROF. DR.-ING. HABIL. DR. H.C. MULT.
ULRICH L. ROHDE
born Mai 20, 1940 in Munich

the title of
GUEST LECTURER

for research stays
at the
Technische Universität München

Munich, February 28, 2012

Prof. Dr.-Ing. Liqiu Meng
Vice-President

Im Namen der

Bundesrepublik Deutschland

bestelle ich

Herrn

Prof. Dr.-Ing. habil. Dr. h.c. mult. ULRICH L. ROHDE

zum

Honorarprofessor

an der Universität der Bundeswehr München

Bonn, den 12. Juli 2017

Die Bundesministerin der Verteidigung

Translation

In the name of the Federal Republic of Germany
I appoint

Prof. Dr.-Ing. habil. Dr. h.c mult. ULRICH L. ROHDE
as
Honorary Professor
At the Universität der Bundeswehr München
(University of the federal armed forces in Munich Germany)

Bonn, 12 July 2017

Secretary of Defense

Ursula von der Leyen

Ulrich L. Rohde

Visiting Scientist, Research Laboratory of Electronics

ulrohde@mit.edu

Massachusetts Institute of Technology

MTL MICROSYSTEMS TECHNOLOGY LABORATORIES

ULRICH L. ROHDE

Visiting Scientist
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MTL MICROSYSTEMS TECHNOLOGY LABORATORIES

mtl.mit.edu

GLOBAL MARKETS, GLOBAL TECHNOLOGY, GLOBAL STUDENTS

Using the example of the cell phone industry

International communications market

The technologies involved are a combination of analog and digital applications as well as passive and active components.

The globally/universally useful RF engineering additionally understands

- A/D converters
- DSP, digital signal processing (DSP),
- Micro processor coding in C++
- Data science in Python
- Business education (MBA)
- Innovative design with an eye for quality and reliability of the product.

Analog Technology, Examples

RF front ends consists of

- Analog low noise preamplifiers
- “Linear mixers”
- PLL based synthesizers with low power consumption

Design parameters may be:

- Noise figure, i.e.: < 1dB
- Intermodulation distortion IP3>1dBm
- Input selectivity
- Phase noise (-145dBc/Hz @ 200KHz)
- Settling speed, less than 1mS

Digital Technology Example

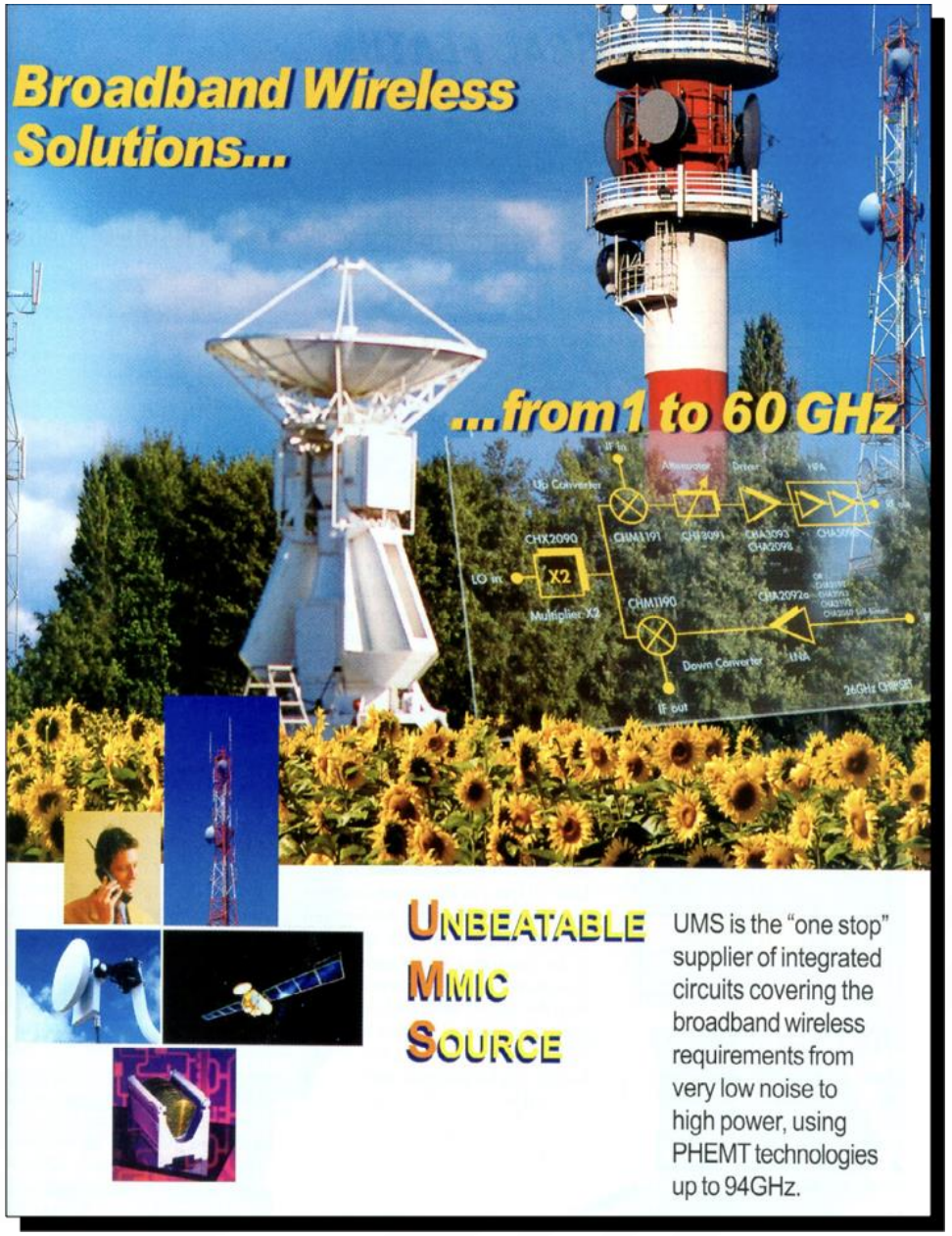
Analog to digital converters (A/D)

- Optimized IF frequencies
- Impedance matching
- Overload and saturation vs. noise figure

Design decisions may be:

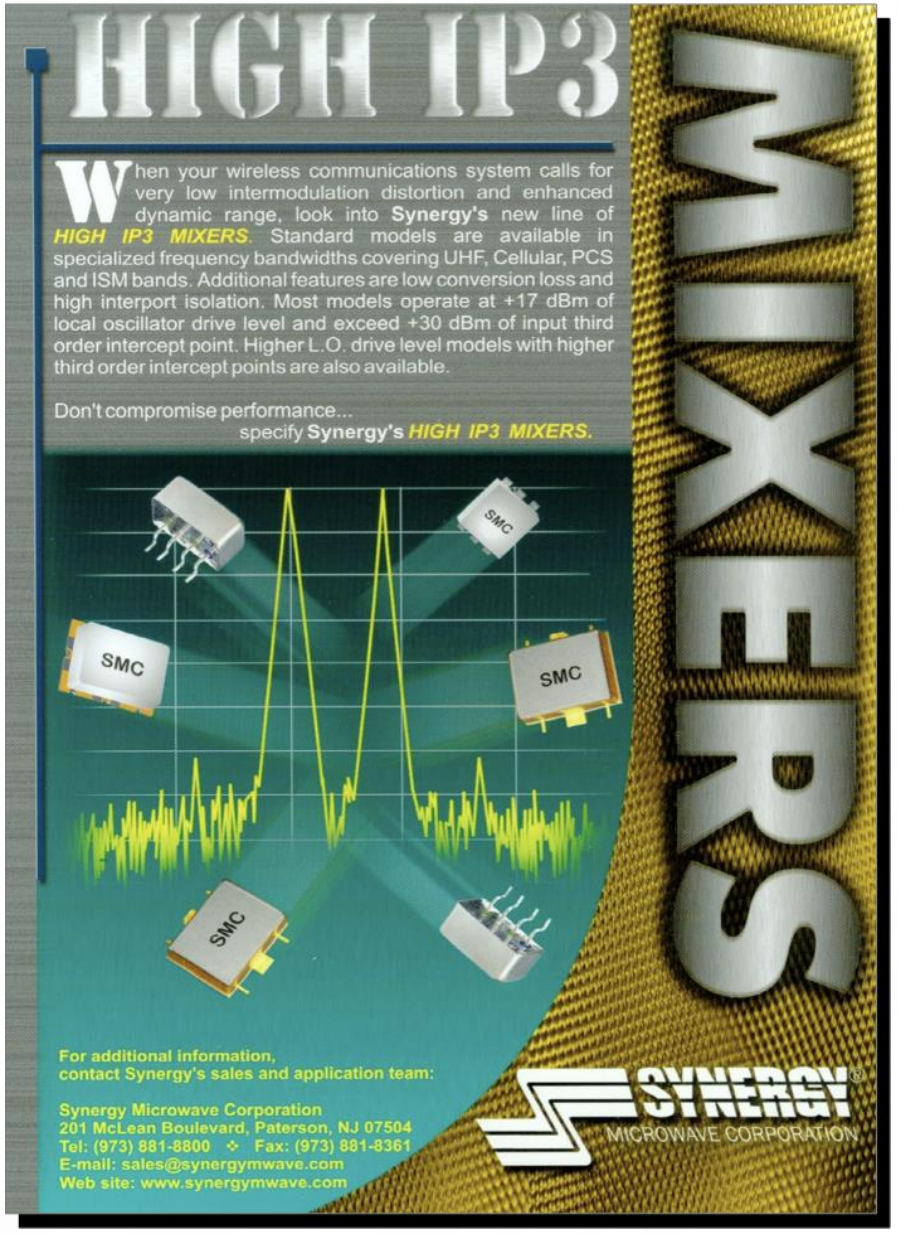
- IF selectivity
- Coding scheme
- Composite filters implementation in DSP
- Automatic gain routines
- Computational delay time

ANALOG AND DIGITAL TECHNIQUES



HIGH PERFORMANCE ANALOG TECHNIQUES

AN EXAMPLE



GLOBAL MARKETS, GLOBAL TECHNOLOGY, GLOBAL STUDENTS

Using the example of the cell phone industry

Evolution of the cellular technologies

EVOLUTION OF DIGITAL CELLULAR TECHNOLOGIES

2G

Mainly GSM

Narrowband 270 kHz

Few frequencies 900/1800/1900 MHz
No global frequencies

Low data rates, initially 9.6 kbps evolving up to 384 kbps

Very high latency

1991

3G

Mainly WCMDA

Bandwidth 5 MHz

Initially 2.1 GHz almost global availability
Evolved to a global standard

Data rates 384 kbit/s evolving to 42 mbit/s

Medium latency
Suffered from IPR fights

2002

4G

LTE

Flexible bandwidth up to 20MHz

Deployed from 400 MHz to 3.7 GHz

Data rates from 40 Mbit/s to todays 1.2 Gbit/s

Low latency

2010

5G / 6G?

5G NR (New Radio)

Scalable bandwidth up to 2000 MHz

Frequencies up to 71 GHz

Very high data rates

Ultra low latency possible

2019

HAS 5G DELIVERED ON ITS PROMISES? YES AND NO

- ✓ Download speeds are up, latency is down
- ✓ Is the "playground" where new features are being developed
  - ✓ Non terrestrial networks
  - ✓ Reduced capabilities devices
- Current 5G networks are more 4.9G networks maintaining legacy 4G functionality
  - Increased user equipment complexity, cost and power consumption
- Slow take up on low latency and Internet of Things (IoT) applications

GLOBAL MARKETS, GLOBAL TECHNOLOGY, GLOBAL EDUCATORS & STUDENTS

Winners and others: Some examples

Winners

Apple

- Entered the mobile world 2007
- Most profitable manufacturer since 2009

Samsung

- Highly vertically integrated, from components to phones
- In house touch screen expertise
- World’s largest manufacturer

Google

- Android has 85% market share as mobile OS
- 38% of all devices connected to the internet are using Android
- 2021 – 3 billion active devices

Losers

Nokia

- 2009 the largest cellphone maker in the world
- Too proud to adopt Android
- Strong innovation culture – failed to bring innovations to the market – sold to Microsoft – Name sold to HMD

Motorola

- Sold to Google – sold to Lenovo

Ericsson

- Cellphones were a mean to sell infrastructure - when 3G matured – not able to compete.
- Sold to Sony

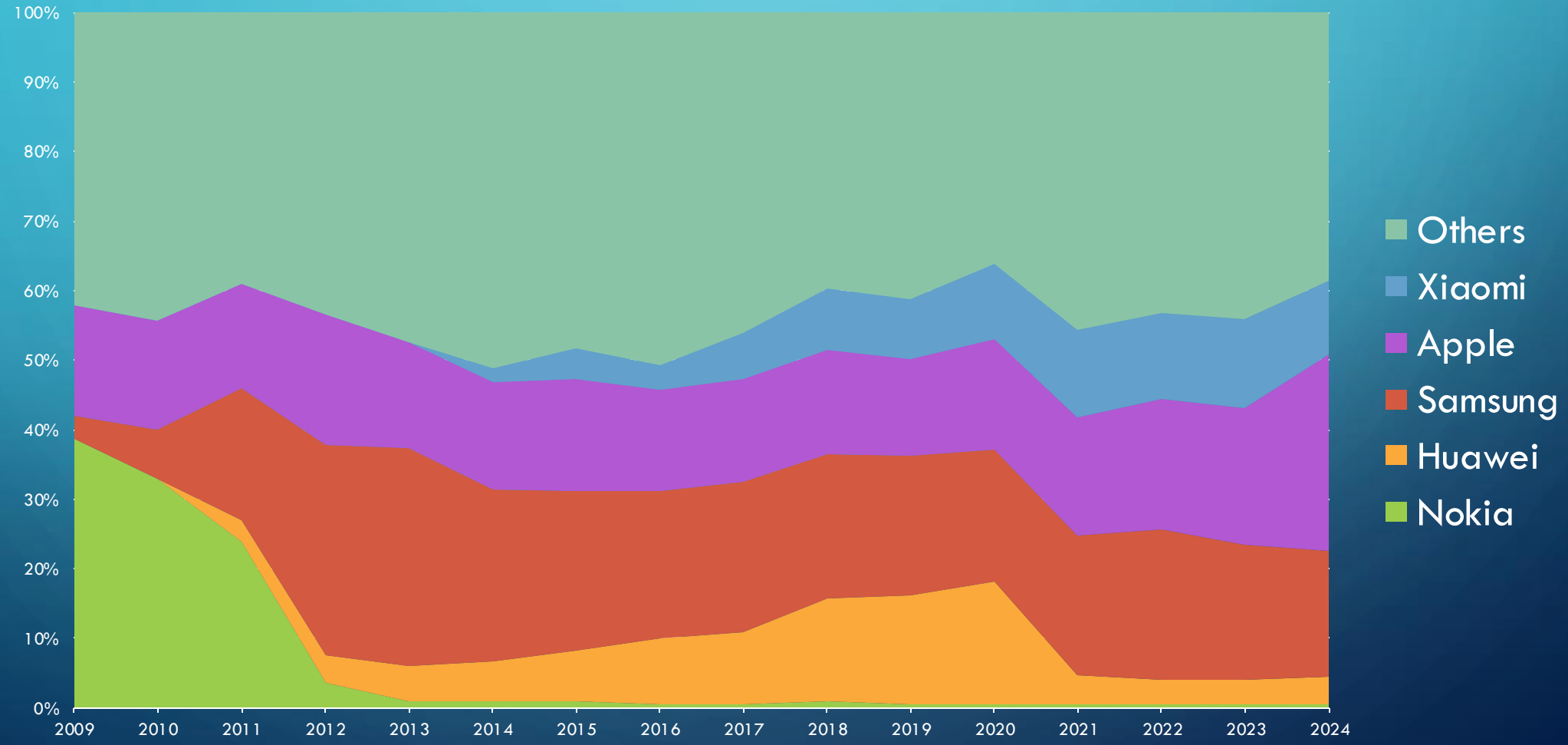
Blackberry

- Focused on messaging
- Missed the touch screen revolution

Huawei

- First cellphones 2003
- 2019 worlds second largest supplier of smartphones
- "Killed" by US trade sanctions –Renamed to Honor -sold

CELLPHONE SHIPMENTS UNTIL 2024



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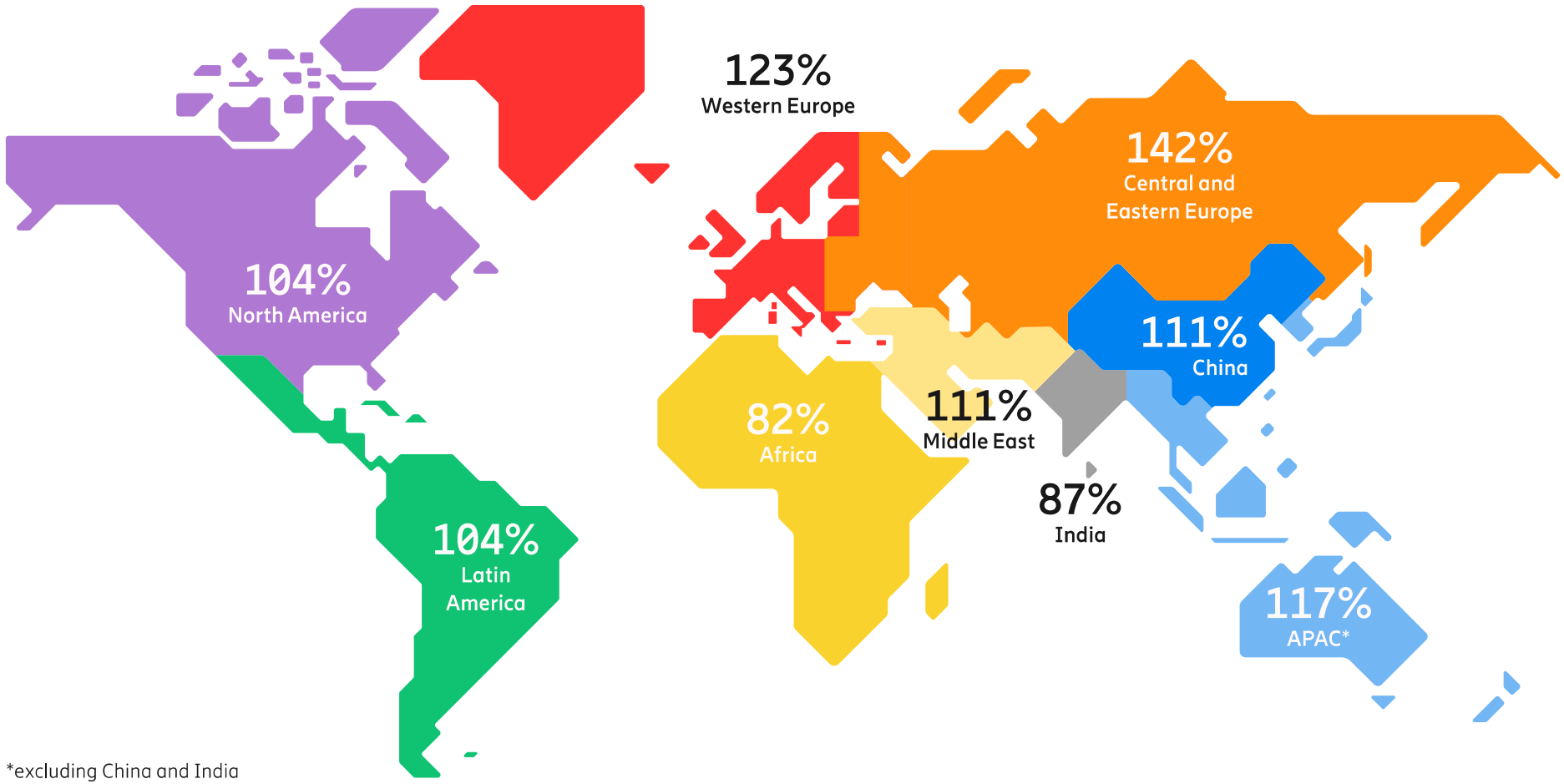
Looking Forward: What will drive the technological development?

Subscriptions per capita

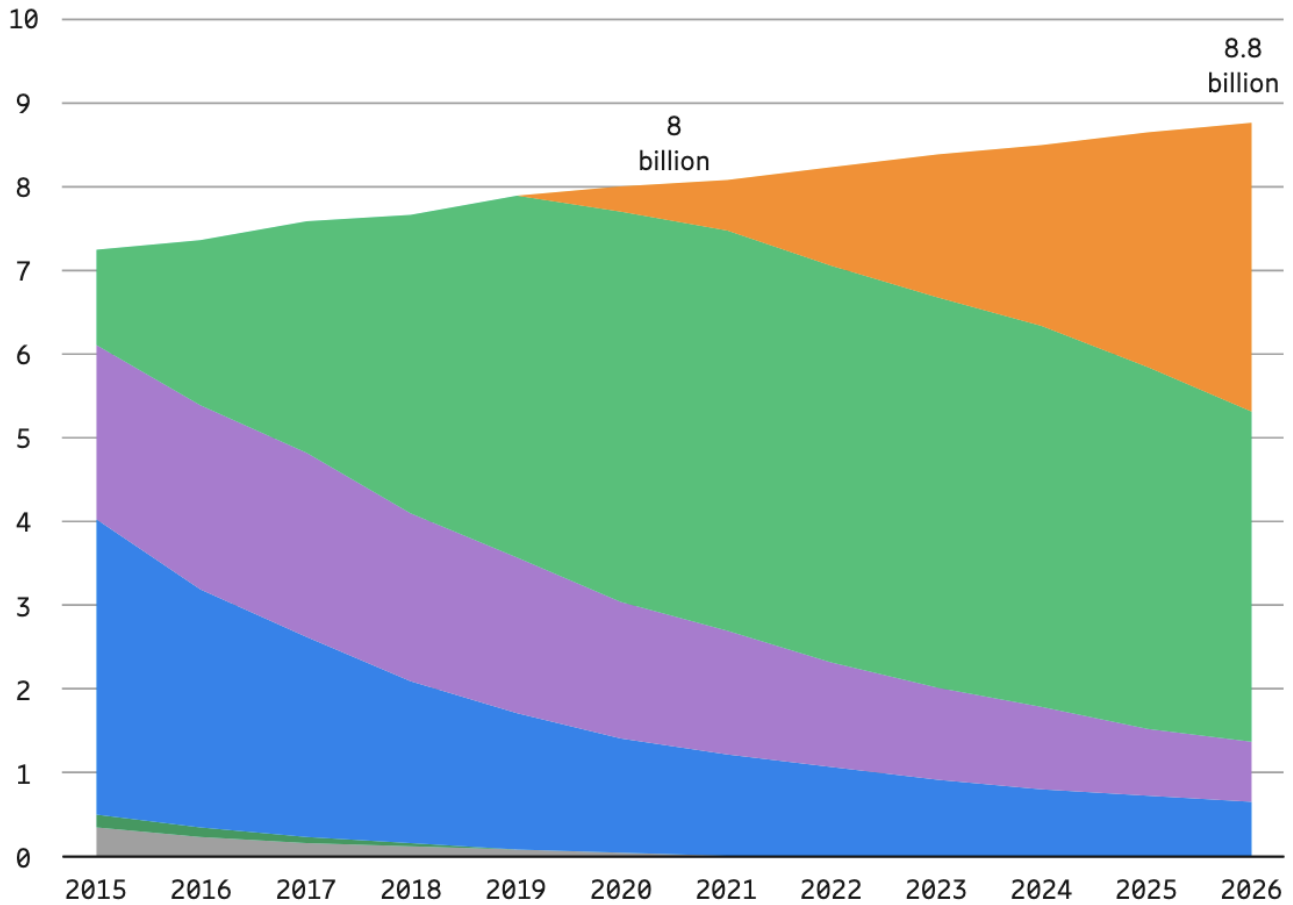


*excluding China and India

THE FUTURE OF WIRELESS TECHNOLOGIES

SOURCE: ERICSSON MOBILITY REPORT

Figure 1: Mobile subscriptions by technology (billion)

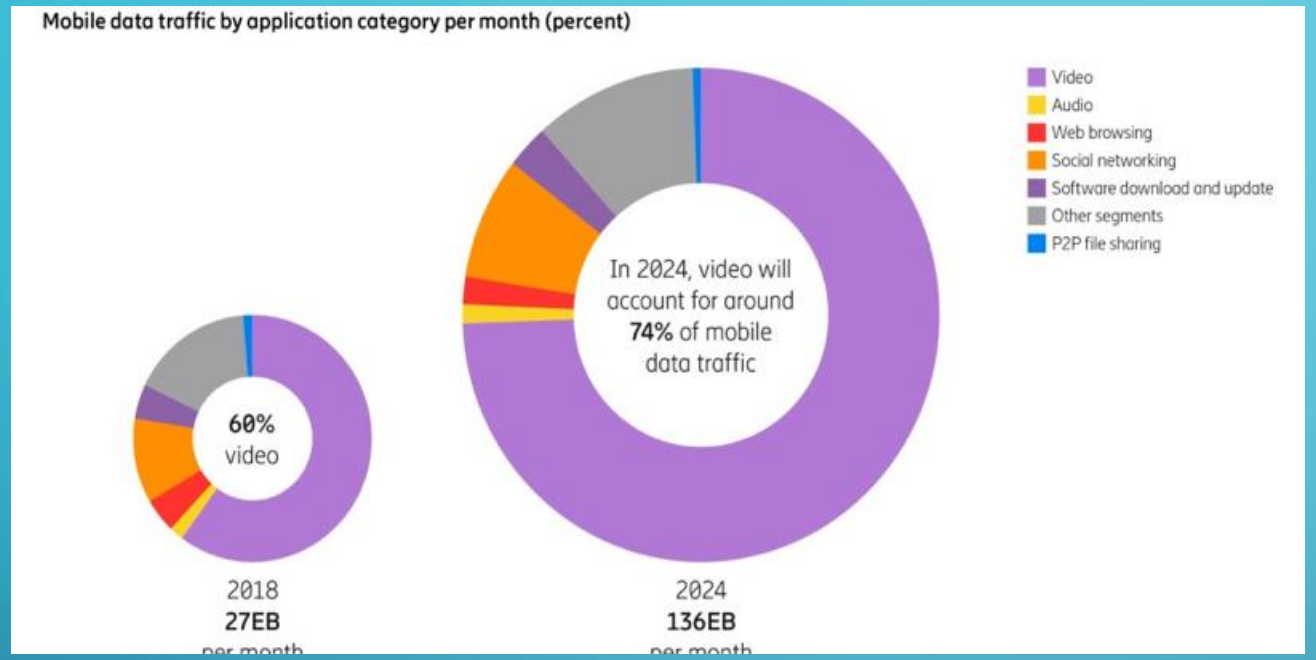


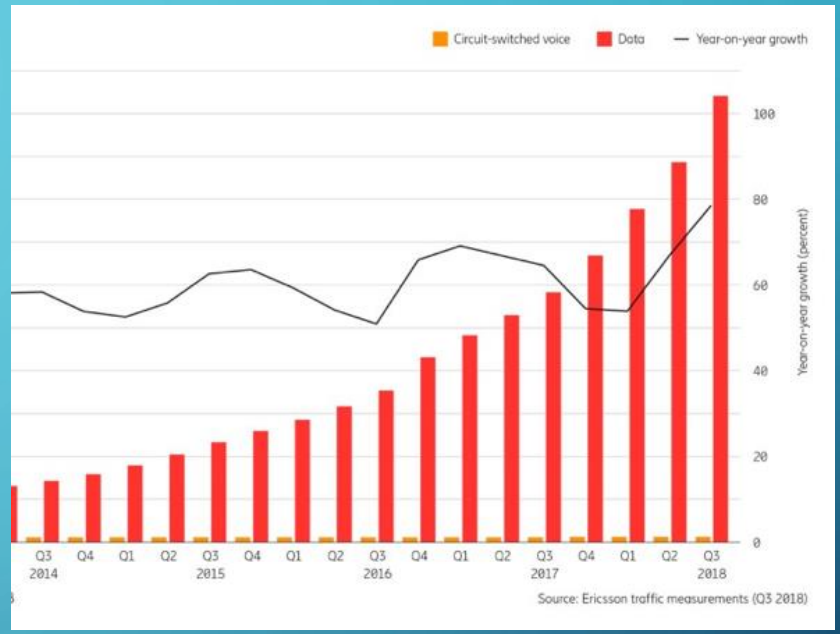
3.5bn

In 2026, 3.5 billion 5G subscriptions are forecast.

- 5G
- LTE (4G)
- WCDMA/HSPA (3G)
- GSM/EDGE-only (2G)
- TD-SCDMA (3G)
- CDMA-only (2G/3G)

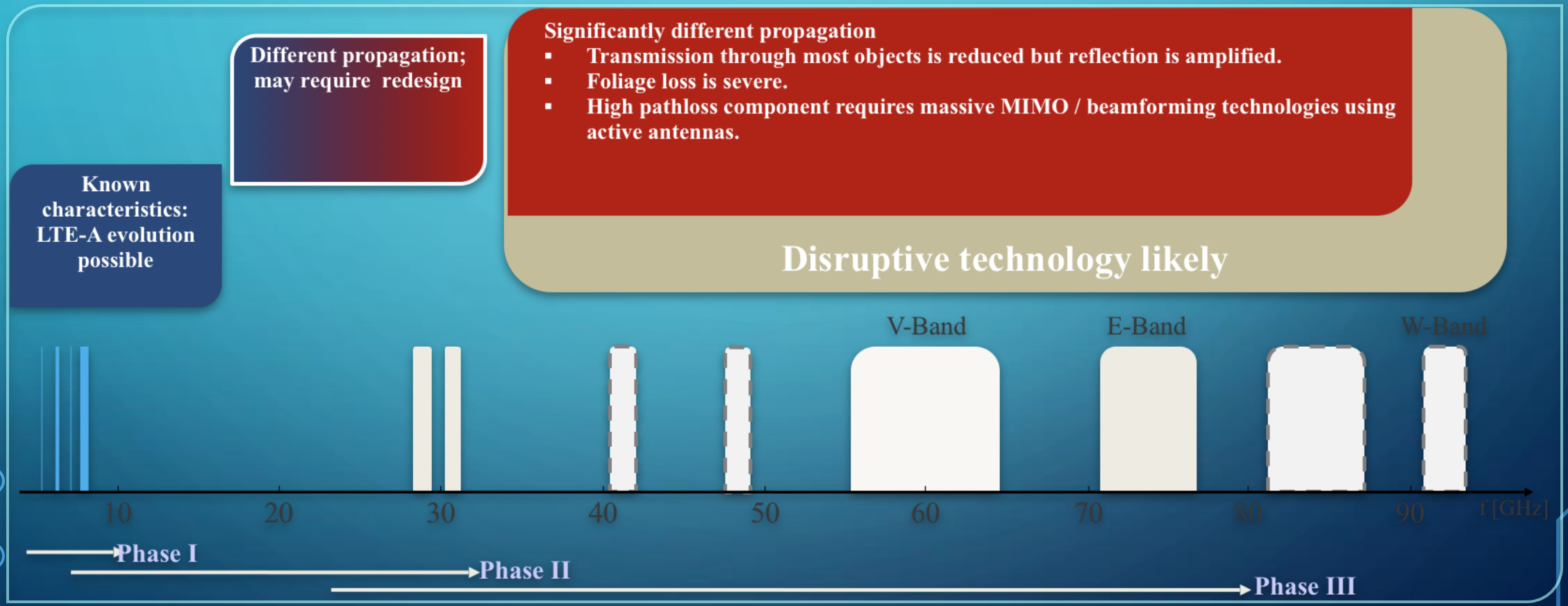
Note: IoT connections are not included in this graph. Fixed wireless access (FWA) connections are included.





DATA WILL BE DRIVING THE FUTURE OF THE CELLULAR INDUSTRY

HIGHER DATA RATES REQUIRES BANDWIDTH ONLY AVAILABLE AT HIGHER FREQUENCIES



AI-DRIVEN WIRELESS TECHNOLOGIES

ARTIFICIAL INTELLIGENCE IS TRANSFORMING WIRELESS COMMUNICATIONS

AI Applications in Wireless

- **Intelligent Beamforming**: AI algorithms optimize antenna patterns in real-time
- **Spectrum Management**: Machine learning predicts and allocates spectrum dynamically
- **Network Optimization**: Self-organizing networks (SON) using AI for coverage and capacity
- **Predictive Maintenance**: AI analyses RF component health before failures occur
- **Signal processing:** AI dynamically performs channel estimation to increase throughput

AI in Modern Smartphones

- **Computational Photography**: AI enhances camera performance beyond hardware limits
- **Battery Optimization**: Machine learning manages power consumption intelligently
- **Voice Processing**: Real-time speech enhancement and noise cancellation
- **Network Selection**: AI chooses optimal network connections automatically

AI-DRIVEN WIRELESS TECHNOLOGIES

ARTIFICIAL INTELLIGENCE IS TRANSFORMING WIRELESS COMMUNICATIONS

Technical Requirements

- **Edge Computing**: Processing AI at the device level
- **Reduced Latency**: <1ms response times for real-time AI decisions
- **Energy Efficiency**: AI algorithms optimized for mobile power constraints

QUANTUM TECHNOLOGIES IN COMMUNICATIONS

PROMISE REVOLUTIONARY ADVANCES IN SECURITY AND PROCESSING

Potential Quantum Applications in Wireless

- **Quantum Computing**: Complex optimization problems in network design
- **Post-Quantum Cryptography**: Preparing for quantum-resistant security
- **Quantum Key Distribution (QKD)**: Unbreakable encryption for sensitive communications

WHERE ARE WE WITH 6G STANDARDIZATION?

- 3GPP has not started yet – First 5G advanced work will be started in release 18, with completion in 2024
- ITU-R is working on “IMT for 2030 and beyond” (aka “6G”)
  - Targeting commercialization around 2030
- Currently inputs are collected around use cases to find suitable technologies

HTTPS://WWW.ITU.INT/DMS_PUB/ITU-S/OPB/ITUJNL/S-ITUJNL-JFETF.V1I1-2020-P09-PDF-E.PDF

6G TECHNOLOGIES WITH AI AND QUANTUM

AI-Native 6G Features

- **AI-Native Network Architecture**: Devices and Networks designed from ground up for AI processing
- **Autonomous Network Management**: Self-healing, self-optimizing networks
- **Predictive Quality of Service**: AI predicts and prevents network issues
- **Quantum-Secured Communications**: Unbreakable encryption as standard feature

WHAT ARE THE USE CASES FOR 6G ?
A FEW EXAMPLES FROM THE NGMN ALLIANCE

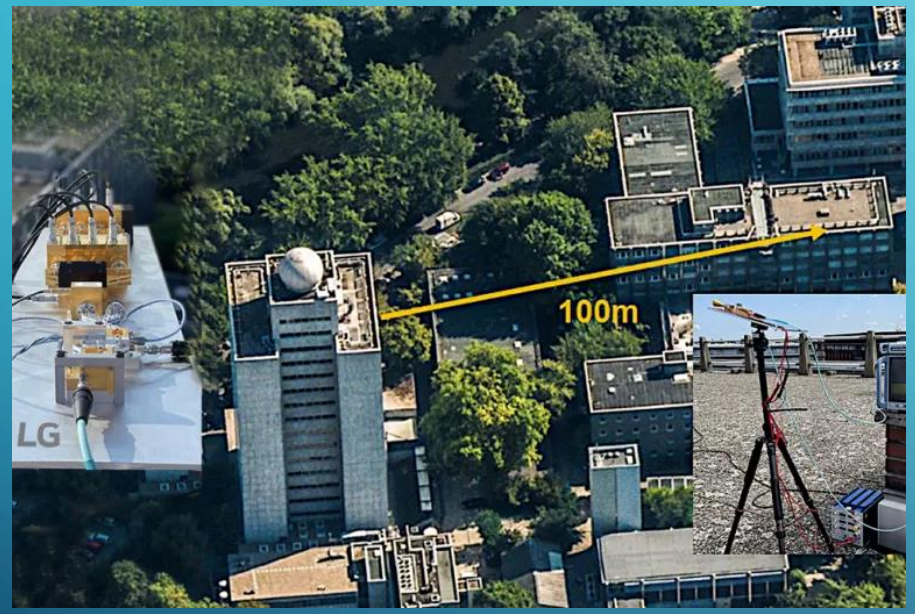
- Enhanced Human Communication – Metaverse, digital twin and holographic telepresence
- Enhanced Machine Communication -Robots, interactive collaborative robots and autonomous machines
- Enabling Services - high accuracy location, mapping, environmental, or body sensing data
- Network Evolution – AI and energy efficiency
- Social needs – environmental sustainability, security and privacy

HTTPS://WWW.NGMN.ORG/WP-CONTENT/UPLOADS/220222-NGMN-6G-USE-CASES-AND-ANALYSIS-1.PDF

WHAT TECHNOLOGIES CAN WE EXPECT TO BE USED 6G IN 2030? SOME CURRENT RESEARCH AREAS ARE

- Faster data transmission using higher frequencies & wider bandwidth
- ISAC – Integrated Sensing and Communication and “radar” like functions
- AI and ML for better performance on the physical layer
- RIS – Reflective intelligent surfaces for better and more dynamic coverage
- New network structure with LEO and GEO satellites, drones and others to provide true worldwide coverage
- Increased security – Quantum secure encryption
- Energy harvesting
- Edge computing

FIRST 6G DEMOSTRATORS USING D-BAND AIMING FOR COMMERCIALIZATION 2029



https://www.lgnewsroom.com/2021/08/lg-records-6g-thz-band-milestone/

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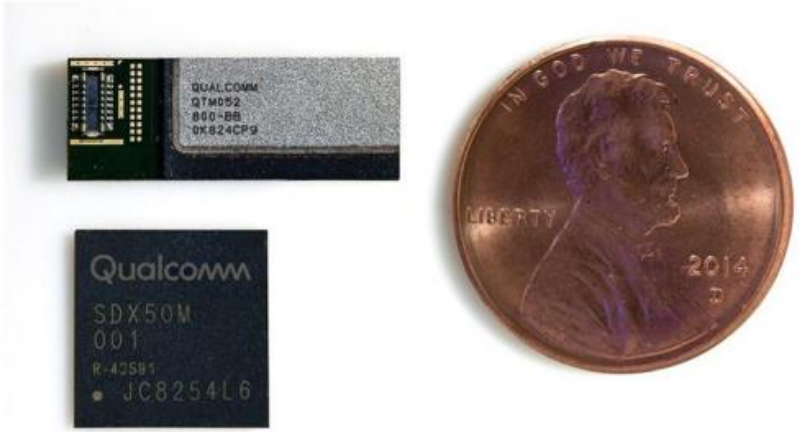
How has the cellphone antenna developed over the years ?

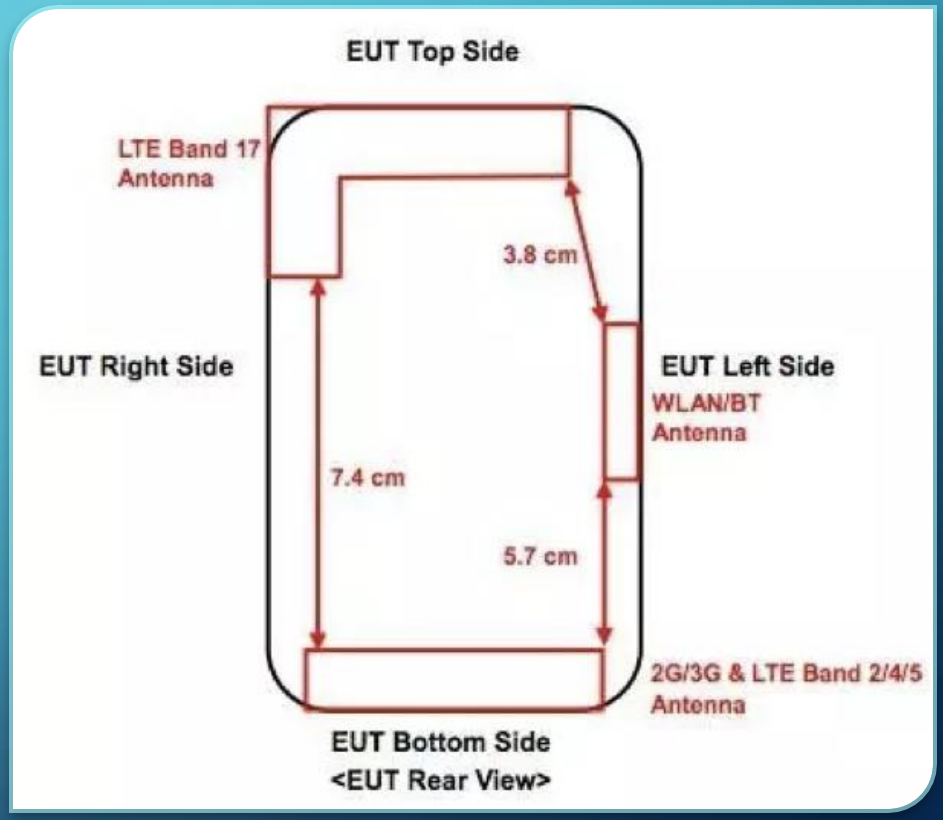
Qualcomm QTM052 mmWave Antenna Module & Snapdragon X50 5G modem



Antennas in a modern cellphone

Not just one antenna

- Up to 10 different frequency bands
- Multiple cellular technologies:
  GSM, UMTS,LTE, TD-SCDMA, 5G
- Non cellular technologies: WIFI, Bluetooth, GPS, Glonass, Galileo, Baidu, NFC
- Receive diversity antennas



5G AND ENERGY CONSUMPTION

- Current 5G devices consume more energy when using 4G+5G (NSA)
- 5G devices with low (FR1) and high frequency (FR2) consume more than devices with FR1 only
- Most of the power in a cell phone is used during monitoring of control information
- Improvements to increase efficiency is being standardized

- 5G Networks consume less power than 4G Networks
- Energy consumption is a major expense for network operators

https://www.ericsson.com/en/blog/2020/2/mobile-devices-and-energy-efficiency

ARTIFICIAL INTELLIGENCE (AI) OPPORTUNITIES AND CHALLENGES IN TECHNOLOGY

PROS

- **Enhanced Productivity:** AI can automate repetitive tasks while preserving jobs requiring creativity and judgment
- **24/7 Availability**
- **Pattern Recognition:** Superior at detecting anomalies and predicting failures
- **Software Bug Detection:** AI excels at analysing code logic, finding vulnerabilities, and suggesting fixes through pattern matching
- **Language Translation:** Breaking communication barriers with, context-aware translation

CONS

- **Lacks True Innovation:** AI cannot create genuinely novel solutions - only recombines existing knowledge
- **Prone to Errors:** AI makes mistakes
- **Black Box Problem:** Complex AI decisions are often unexplainable, creating trust and regulatory challenges
- **High Energy Consumption:** Training and running large AI models requires significant computational resources
- **Dependency Risk:** Over-reliance on AI can erode human expertise and critical thinking skills

QUANTUM COMPUTING
PROMISE AND PERILS OF QUANTUM TECHNOLOGY

PROS

- **Scientific Research:** simulation of systems for advances in physics and chemistry
- **Drug Discovery & Materials:** Quantum simulation enables modelling of molecular interactions impossible with classical computers
- **Quantum-Safe Cryptography:** Drives development of new encryption methods already being implemented (e.g., Signal protocol)
- **Machine Learning Enhancement:** Quantum ML algorithms promise exponential speedups for certain problems

CONS

- **Extreme Operating Costs:** Requires near-absolute zero temperatures and sophisticated systems
- **Limited Applications:** Provides advantages for specific problem types - not a general-purpose solution
- **Cryptographic Threat:** Will break current encryption, endangering legacy devices and stored data
- **Technical Immaturity:** Current quantum computers are noisy, error-prone, and have limited qubit counts
- **Accessibility Barriers:** Extremely expensive and complex, limiting access

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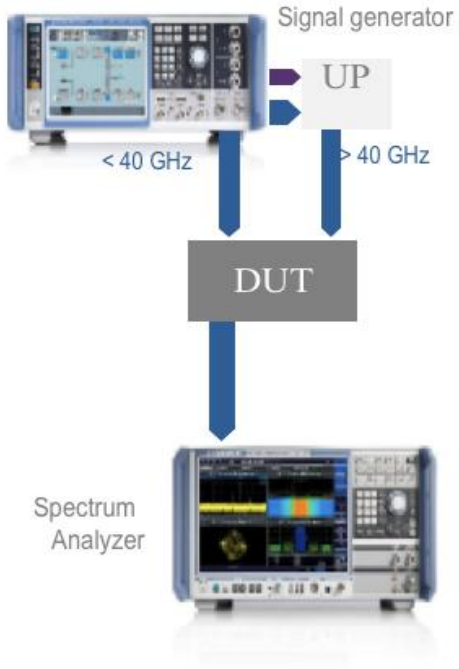
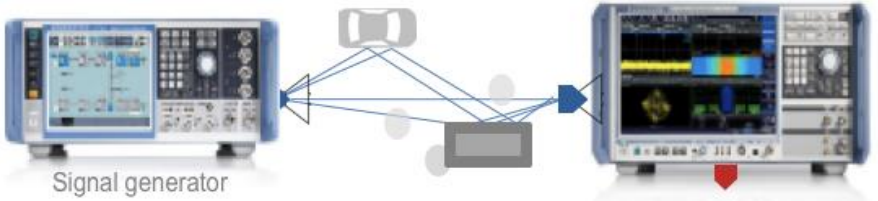
What tools are available for the RF engineers ?

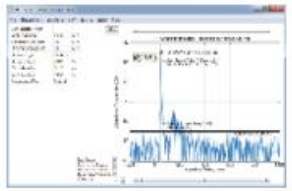
Wideband Signal Testing



Channel Sounding Solution



- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range

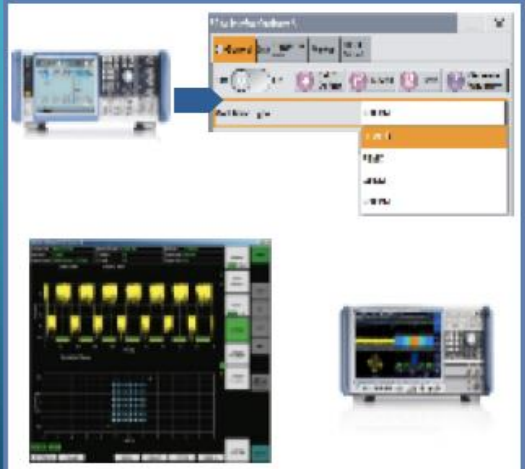


Data Analysis Software

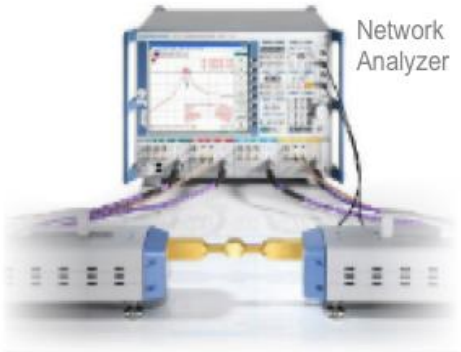
Massive MIMO - Beamforming

- Phase-coherent RF generation
- Multi-port VNA

New 5G PHY Candidates

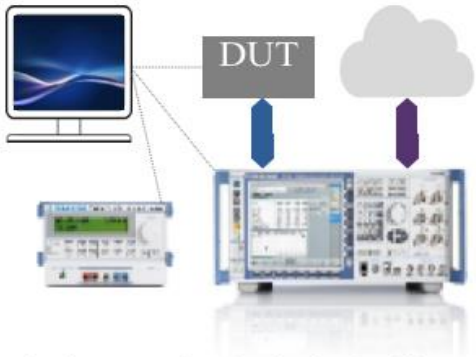


Component Characterization



Direct measurements up to 110 GHz

E2e Application Testing



Analyze application behavior like signaling load, delay, power etc.

GLOBAL MARKETS, GLOBAL TECHNOLOGY, GLOBAL STUDENTS

Requirements For Modern Adaptive Students

Requirement For Modern Educators (Professors)

“Professional programs must prepare workers to become professional practitioners in their chosen field of practice. As educators, we want our students to appreciate the importance of both classroom and field educational experiences and learn that there is nothing more practical than a good theory. While experience is a great teacher, it cannot replace what can be best taught in a classroom and vice versa”
Enhancing Learning by Integrating Theory and Practice Jan Wrenn and Bruce Wrenn, Andrews University

Not all curriculums are equal and have different focuses but need a blend of theory and practice.
In RF measurement setups, instrument capabilities and associated uncertainties as well as tools for data analytics need to be taught.

This applies to me too

Requirements For Modern Adaptive Students

Fewer young people nowadays choose engineering education, and what is even more worrisome is the fact that the most gifted students decide to study at the faculties of computer science and engineering, choosing zeros and ones over microwaves or curl and divergence. The said zeros and ones are significantly easier to comprehend than the area of curl and divergence.

Requirements For Modern Adaptive Students

Therefore, as a consequence, the computer students score higher than those who study the microwaves area, while putting, in fact, less effort into their learning. Difficult curriculum and fewer opportunities to obtain high grades cause the students to lose interest in microwaves.

Requirements For Modern Adaptive Students

“The only person who is educated is the one who has learned how to learn and change”

The general demand to master new skills results from constantly modernizing technologies.

“The world does not pay for what a person knows. But it pays for what a person does with what he knows.”

Reference: Josef W. Modelski, MTT-S Microwave Magazine, August 2008

Requirements For Modern Adaptive Students

Skills for the AI-Quantum-RF Era

Traditional RF Engineering Skills (Still Essential)

- Electromagnetic theory and antenna design
- Circuit analysis and microwave engineering
- Signal processing and communication theory
- Measurement and instrumentation

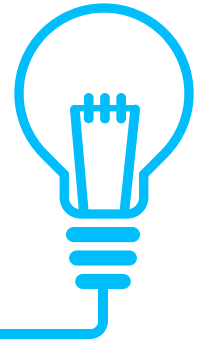
NEW: AI/Machine Learning Skills

- Programming: Python, TensorFlow, PyTorch for AI development
- Data Science: Statistical analysis and pattern recognition

NEW: Quantum Mechanics: Basic principles of quantum information

The Modern RF Engineer Must Be:

"An engineer who speaks the languages of waves, algorithms, and quantum states"



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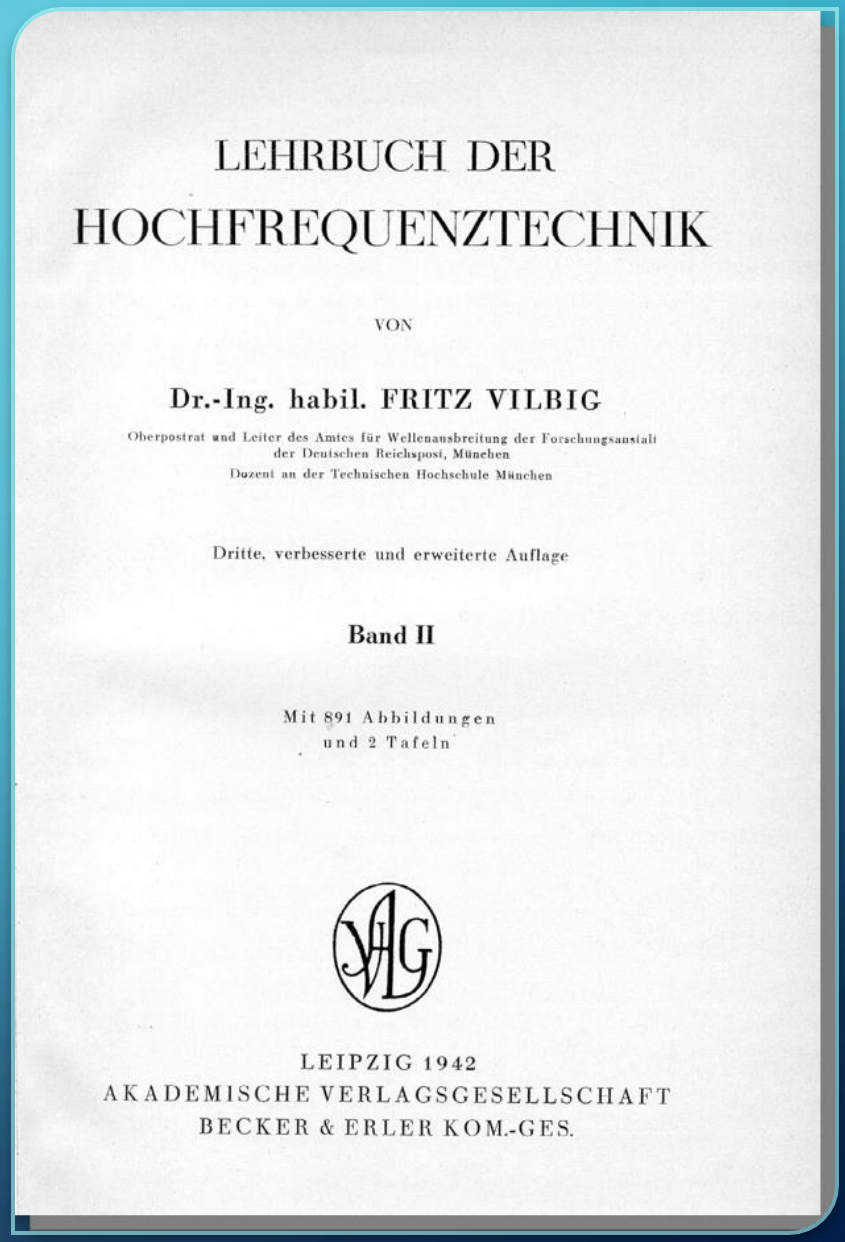
Literature- How did it all started

From 1942

- RF/Microwave Education (in German)
- Focus mostly on theory
- No international conferences
- No technology exchange or transfer due to language problems
- No digital technology (did not exist at that time)



LEHRBUCH DER
HOCHFREQUENZTECHNIK

VON

Dr.-Ing. habil. FRITZ VILBIG

Oberpostrat und Leiter des Amtes für Wellenausbreitung der Forschungsanstalt der Deutschen Reichspost, München
Dozent an der Technischen Hochschule München

Dritte, verbesserte und erweiterte Auflage

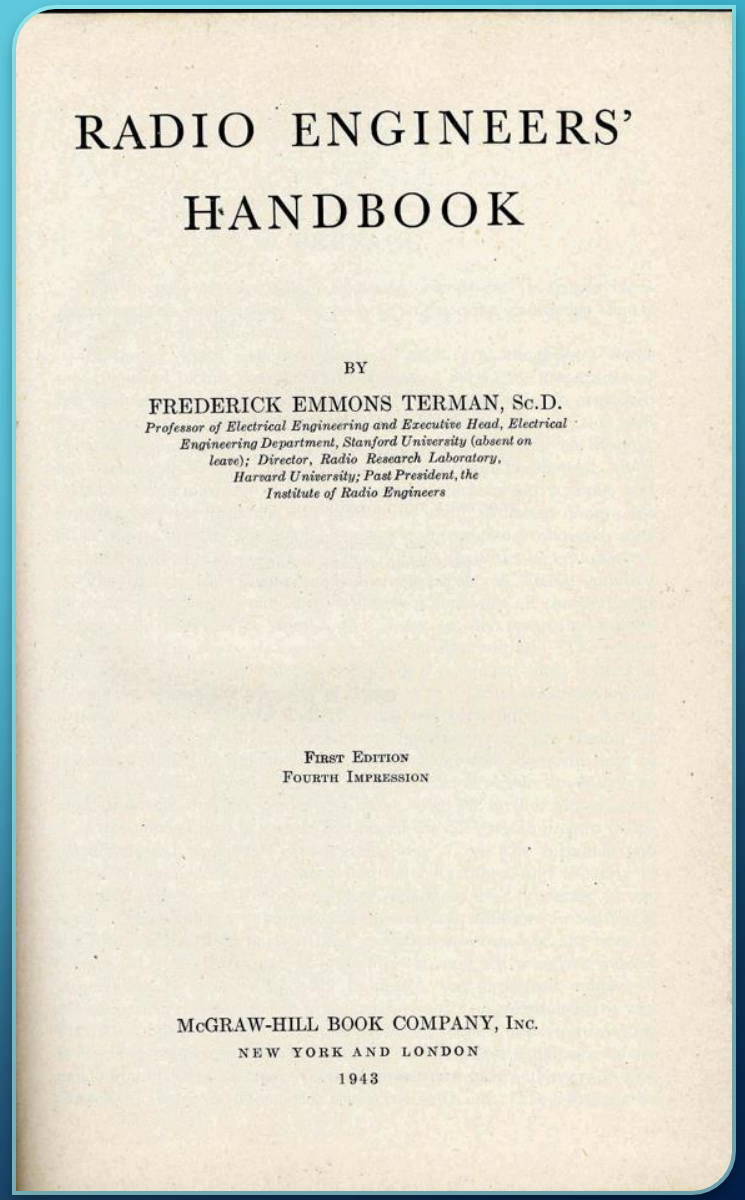
Band II

Mit 891 Abbildungen
und 2 Tafeln

LEIPZIG 1942
AKADEMISCHE VERLAGSGESELLSCHAFT
BECKER & ERLER KOM.-GES.

From 1943

- The State of the Art text book for radio engineering
- Probably the best comprehensive US radio electrical engineering book ever written. Used in all English speaking countries.
- Contains only analog circuitry (Digital technology did not exist at that time)


RADIO ENGINEERS' HANDBOOK

BY

FREDERICK EMMONS TERMAN, Sc.D.

Professor of Electrical Engineering and Executive Head, Electrical Engineering Department, Stanford University (absent on leave); Director, Radio Research Laboratory, Harvard University; Past President, the Institute of Radio Engineers

First Edition
Fourth Impression

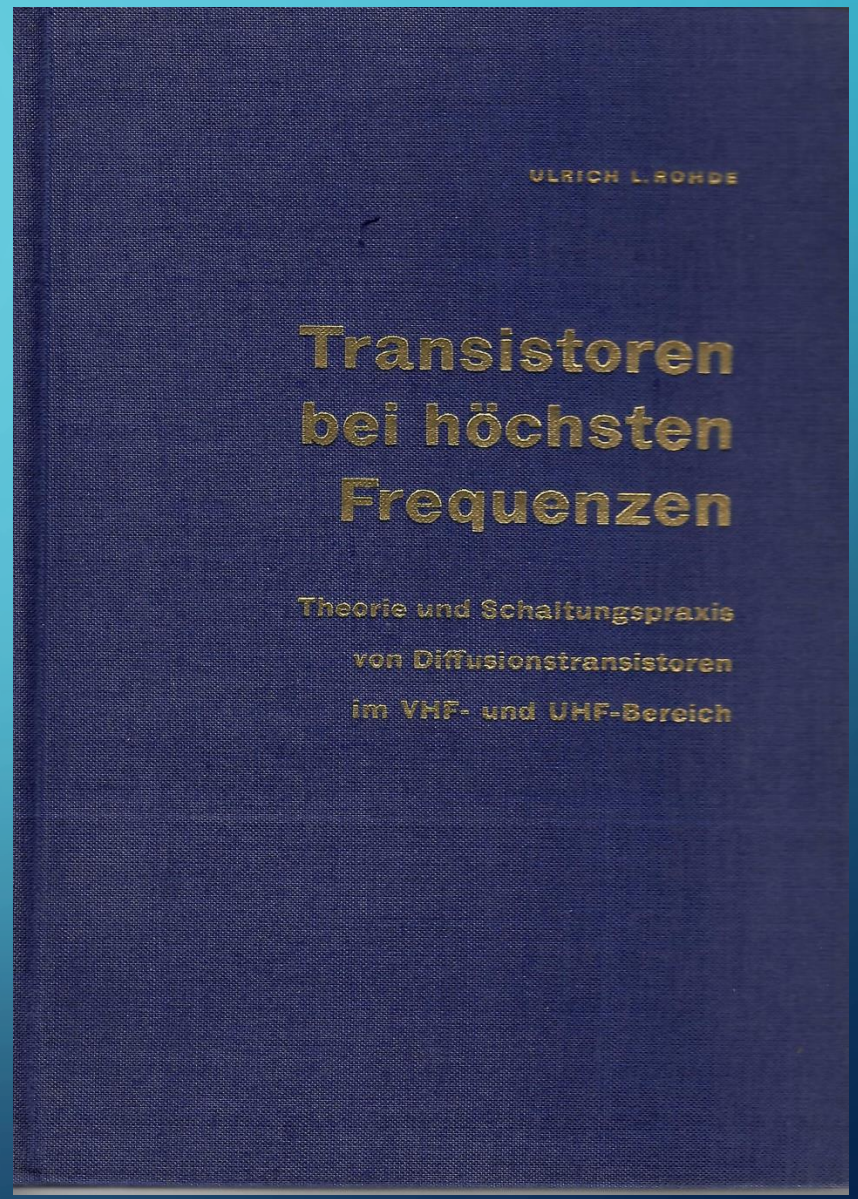
McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK AND LONDON
1943

From 1965/69

Pioneering Publication: First book on microwave transistors.

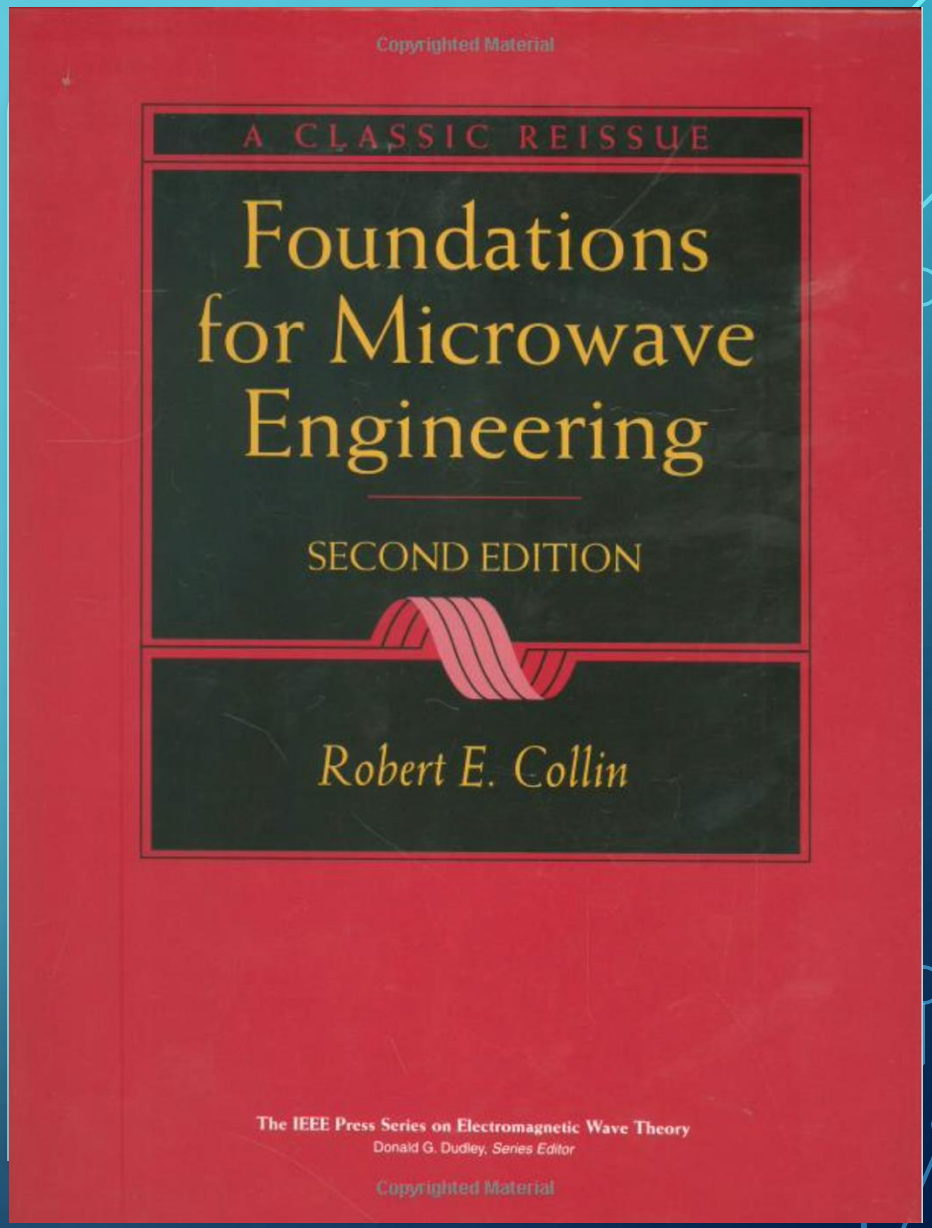
Microwave Focus: Targeted transistor applications above 1000 MHz, a novel field.

Major Impact: Sold 10,000 copies in two editions, despite being written in German.



FROM 2001

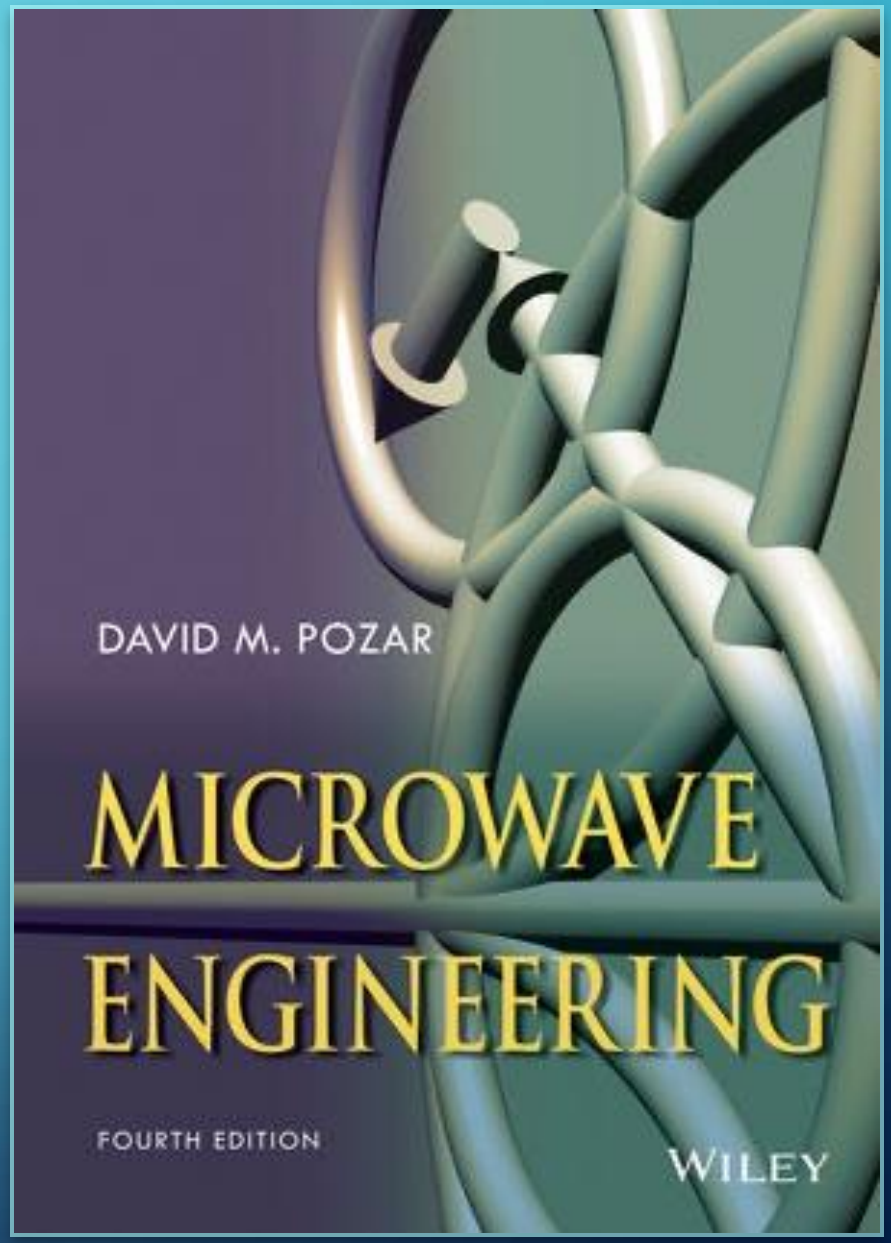
Covers the major topics of microwave engineering. Its presentation defines the accepted standard for both advanced undergraduate and graduate level courses on microwave engineering. An essential reference book for the practicing microwave engineer.



FROM 2011

Covers

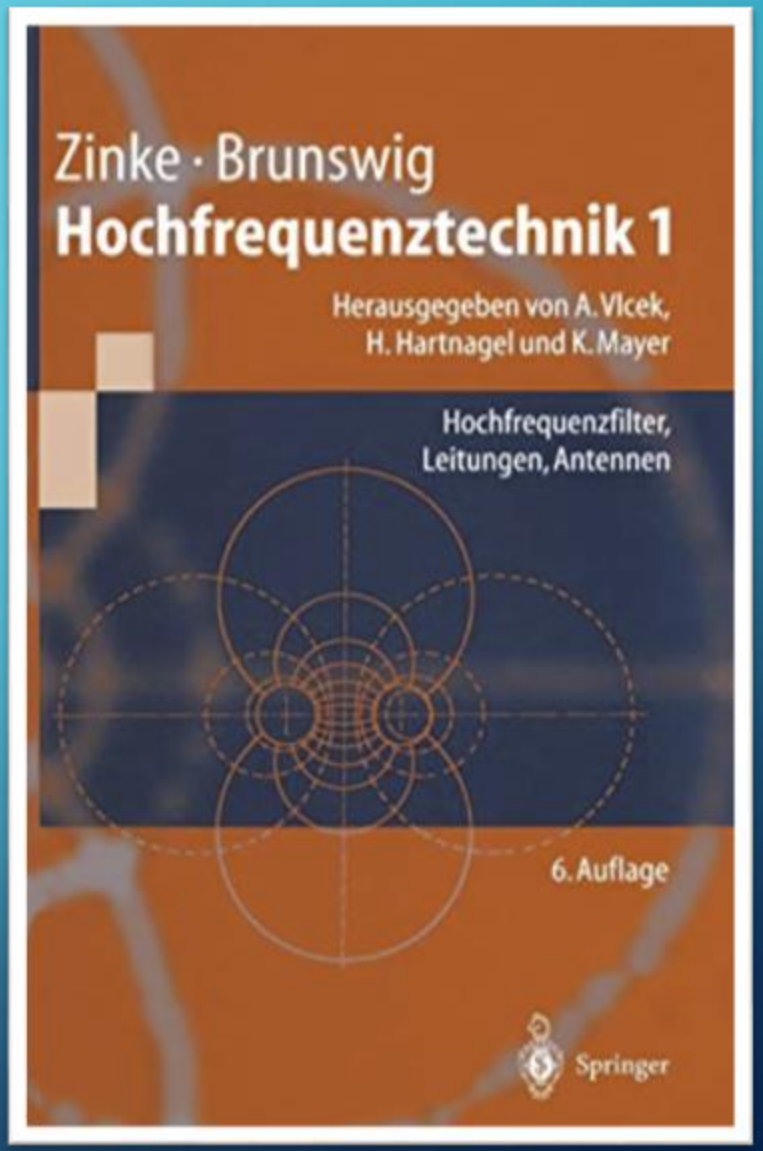
- Design of microwave oscillators, amplifiers, and mixers
- Microwave network analysis, impedance matching, directional couplers and hybrids, microwave filters, ferrite devices, noise, nonlinear effects



FIRST EDITION 1960
THIS TWO-VOLUME STANDARD

Covers the generation, amplification, propagation, radiation, and application of electromagnetic signals over the full frequency range, from a few kHz to optical communications.

Volume 1 addresses resonant circuits, high-frequency transformers and filters, characteristics of coaxial cables, microstrip lines, coplanar and fin lines, directional couplers, optical waveguides, surface acoustic wave filters, waveguides, gyromagnetic media, antennas, and quartz filters.



FIRST EDITION 1960

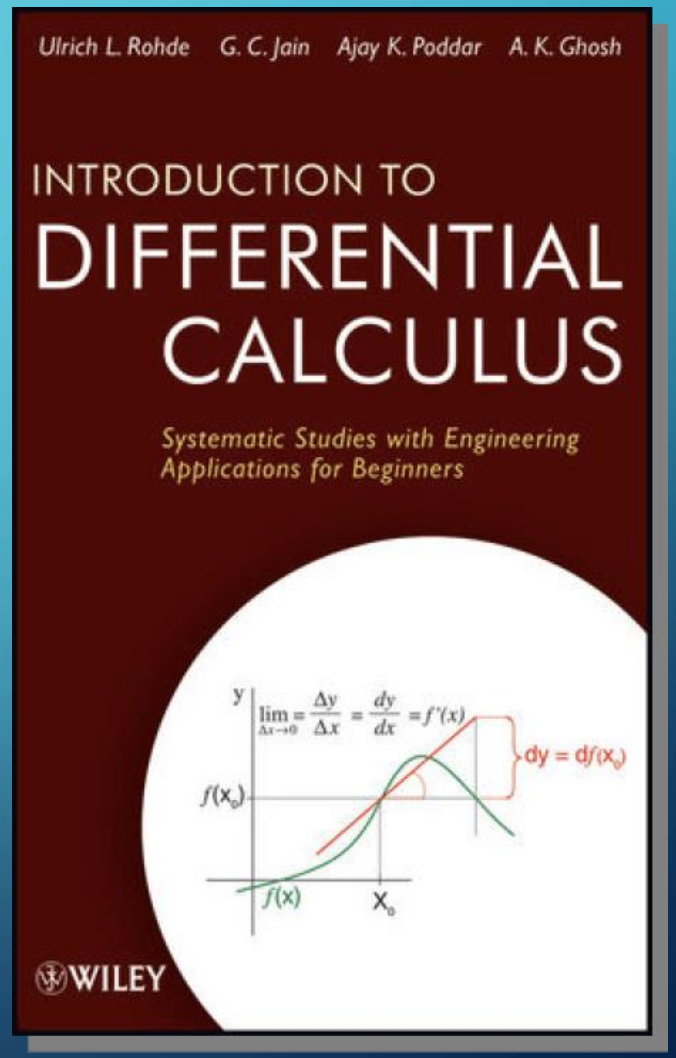
Volume two addresses:

Electron tubes and semiconductors, Interference and Noise, Amplifier, Oscillators, Mixing and Frequency Multiplication, Modulation, Sampling and Demodulation

From 2012

Introduction to Differential Calculus fully engages readers by presenting the fundamental theories and methods of differential calculus and then showcasing how the discussed concepts can be applied to real-world problems in engineering and the physical sciences.

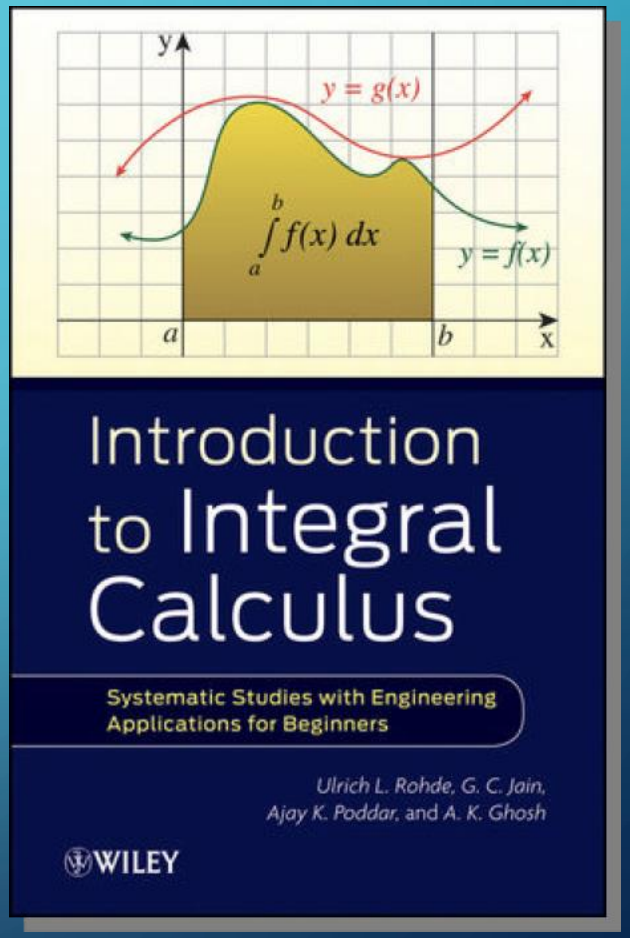
- Concepts of function, continuity, and derivative
- Properties of exponential and logarithmic function
- Inverse trigonometric functions and their properties
- Derivatives of higher order
- Methods to find maximum and minimum values of a function
- Hyperbolic functions and their properties



From 2012

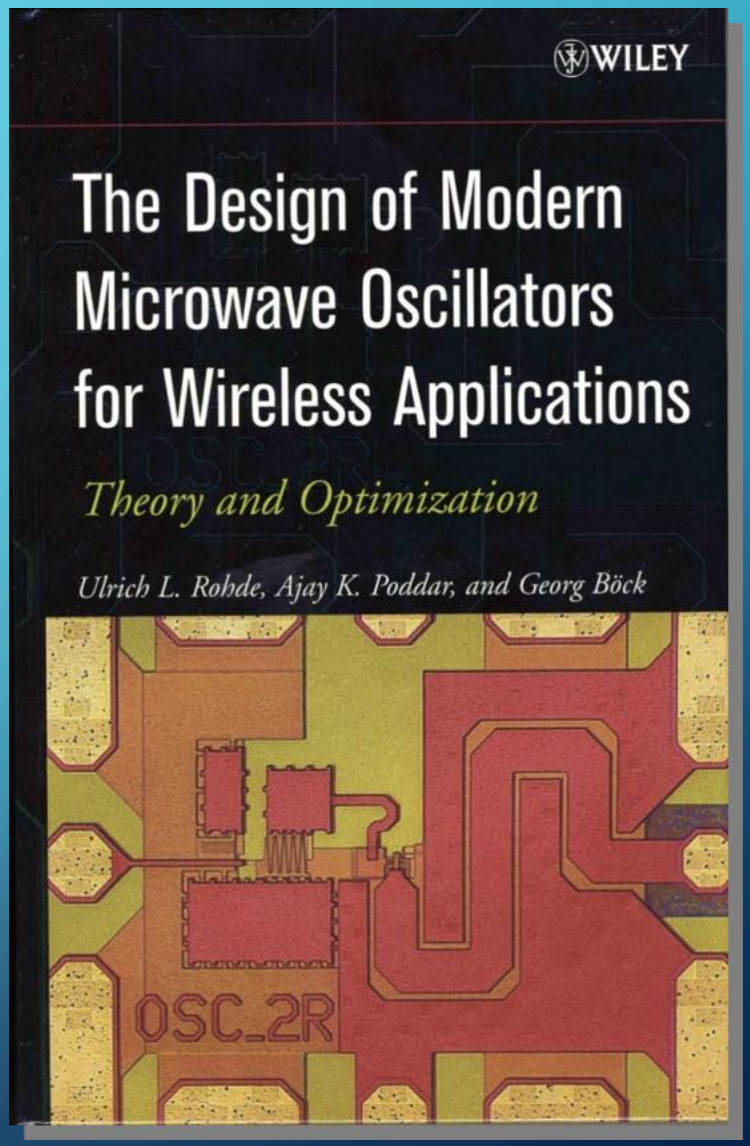
Integration is an important function of calculus, and Introduction to Integral Calculus combines fundamental concepts with scientific problems to develop intuition and skills for solving mathematical problems related to engineering and the physical sciences

- Mastering and applying the first and second fundamental theorems of calculus to compute definite integrals
- Defining the natural logarithmic function using calculus
- Evaluating definite integrals
- Calculating plane areas bounded by curves
- Applying basic concepts of differential equations to solve ordinary differential equations



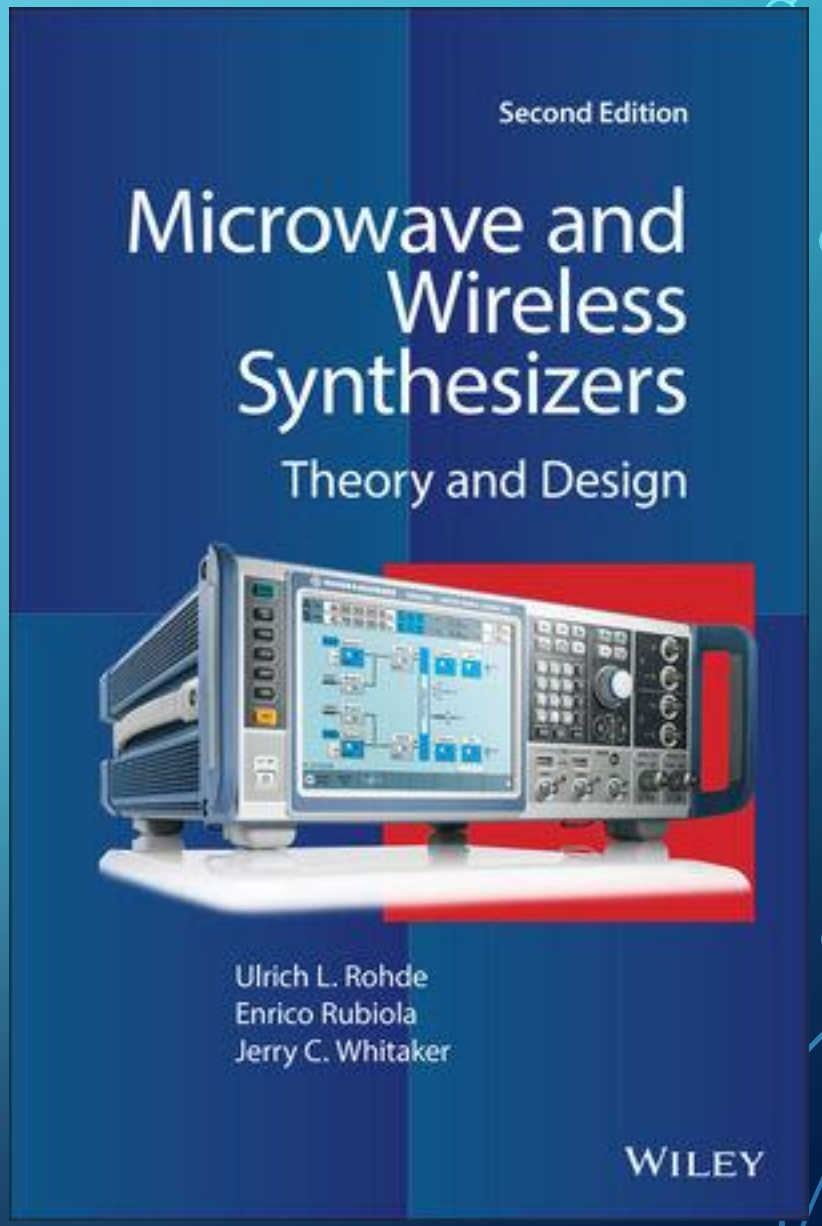
From 2005

- Oscillator performance can make or break a system performance
- Covers RF to millimeter wave circuits
- Most advanced text book on this topic
- Ideal reference material



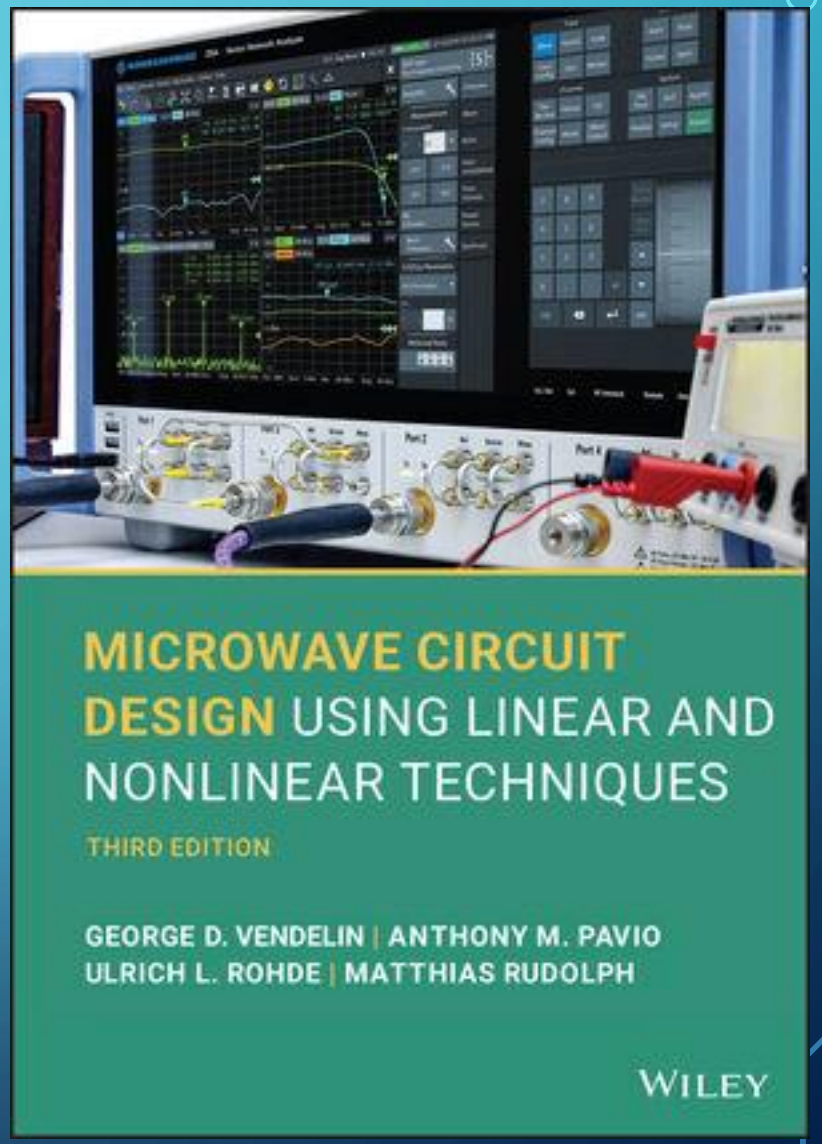
From 1997 > 2021

- Microwave and Wireless Synthesizers-the first book to emphasize both practical circuit information from RF to millimeter-wave frequencies and up-to-date theory.
- In-depth look at the practical side of the phase-lock loop (PLL) in synthesizers-including special loops, loop components, and practical circuits-material
- Second edition 2021



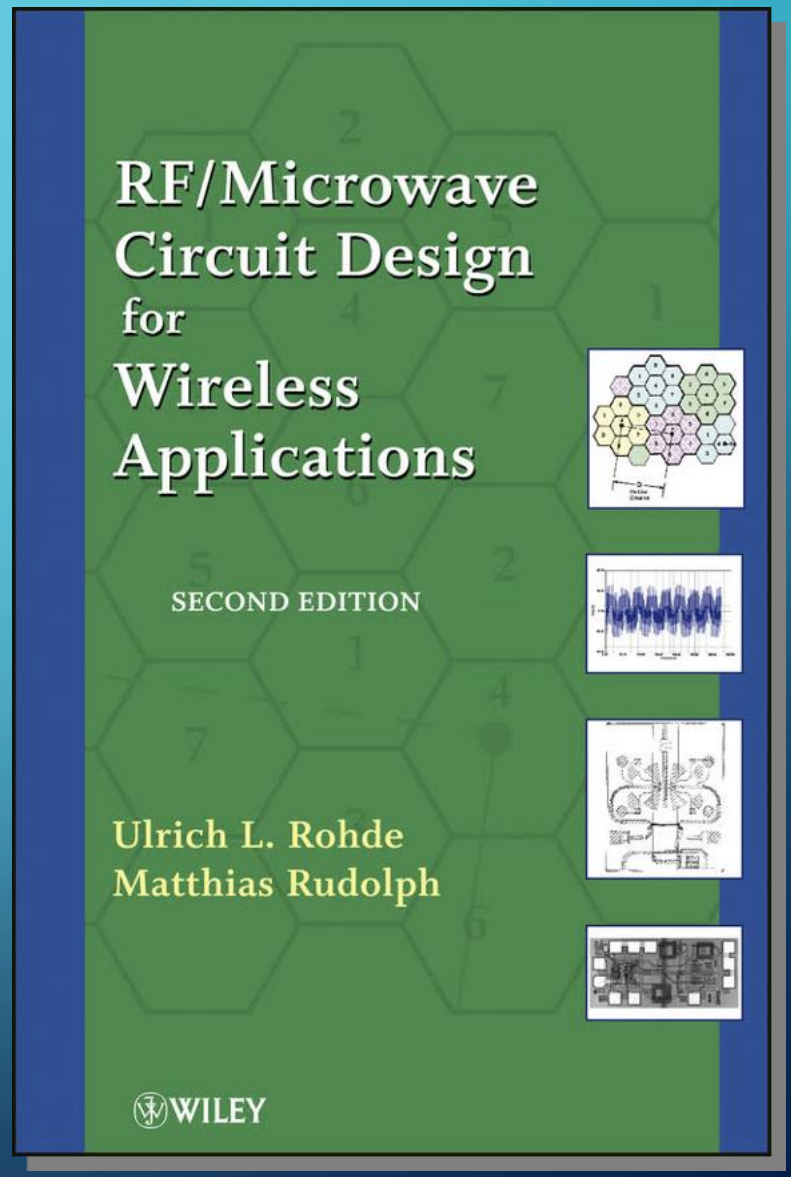
From 2005 > 2021

- Linear and nonlinear circuit analysis treatment 3rd edition 2021
- Best in class
- Covers all relevant material
- Ideal reference material



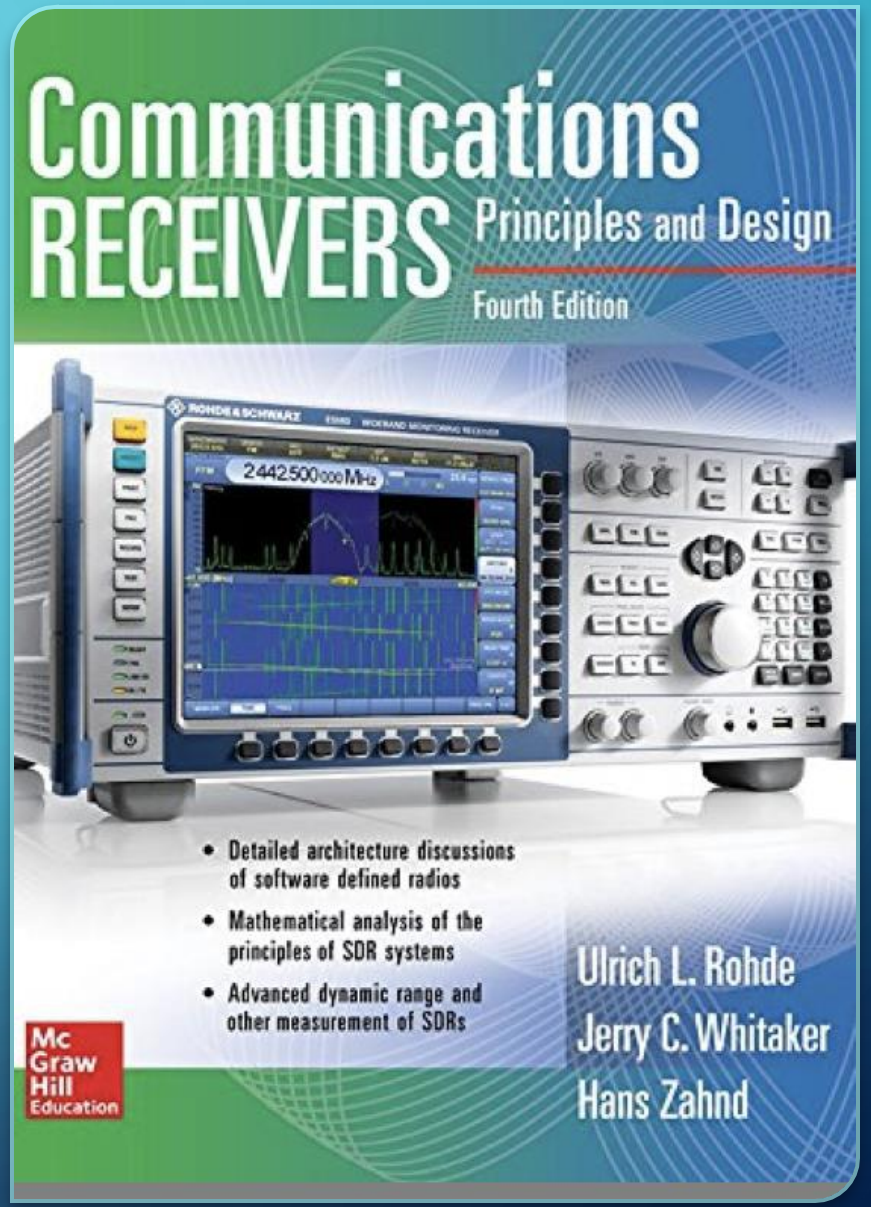
From 2013

- Education in English international technology language
- Focus on theory and real life application
- Material presented at international conferences
- Result of technology exchange or transfer
- Covers modern cellular radio technology, analog and digital



FROM 1988>2017

- State of the art communication technology
- Covers high performance application
- Good reference for past and modern design

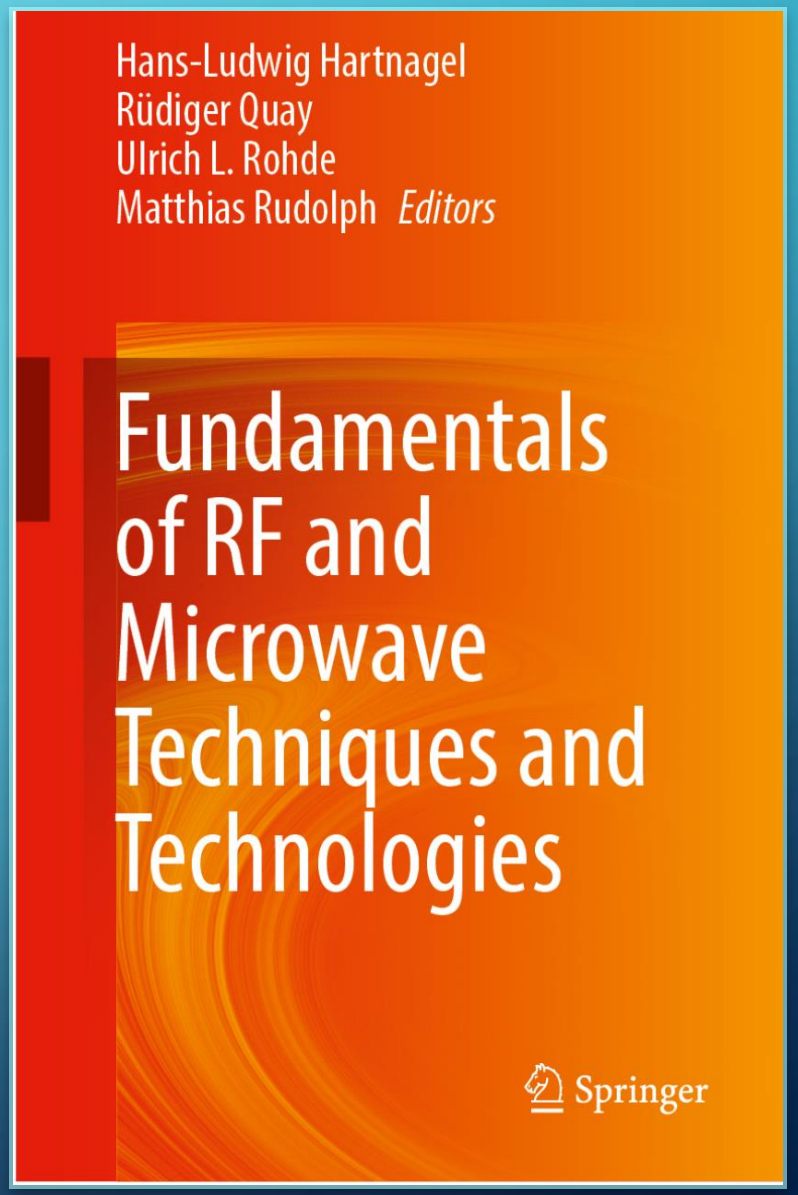


From 2023
Successor of Zinke – Brunswig textbook, now in English

Starting with the fundamentals it provides state-of-the-art theory, design, and applications of all RF and Microwave Techniques and Technologies

Covers:

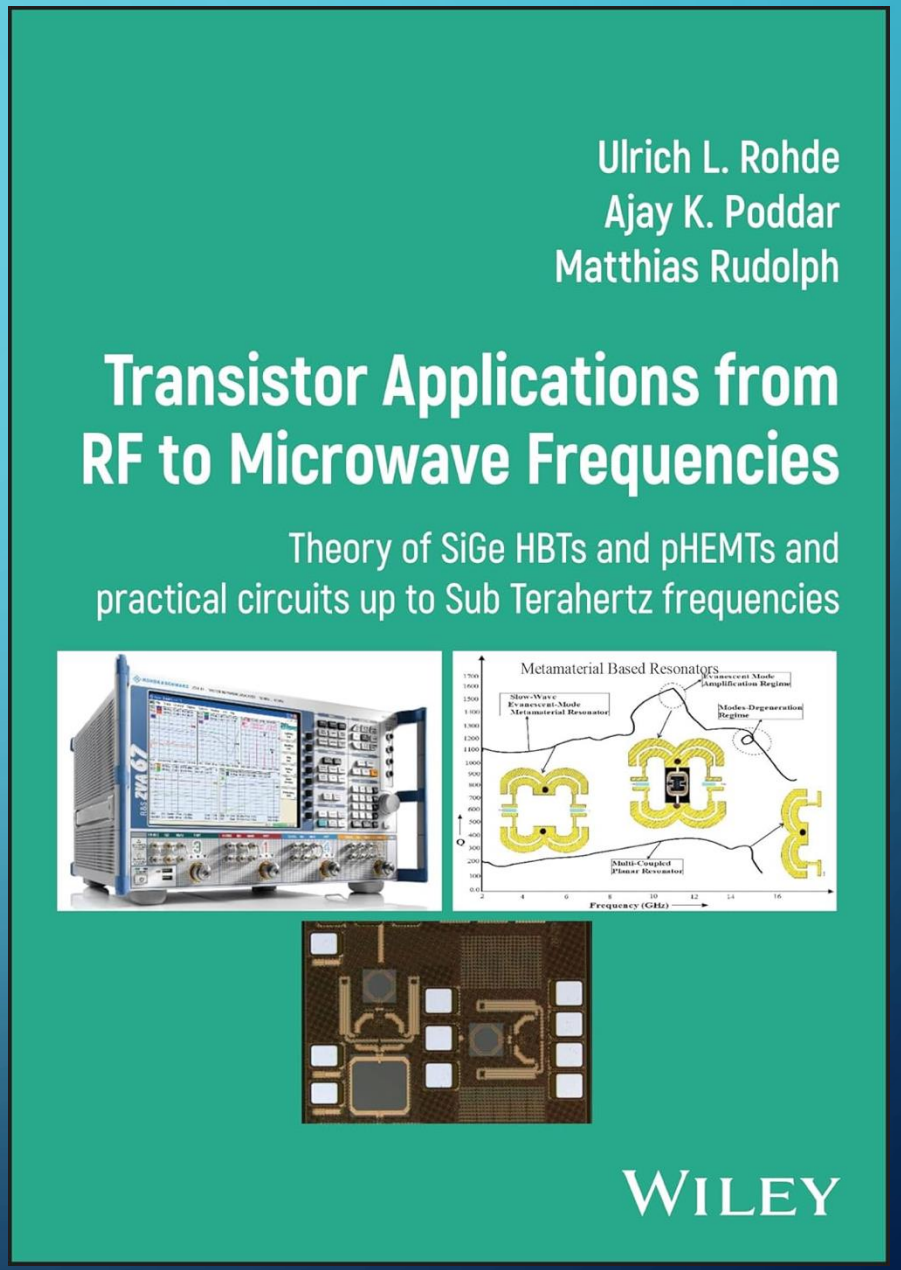
- RLC circuits, transmission-line theory, antenna theory and noise statistics and physics
- Active microwave semiconductors, amplifier, mixer and oscillator circuits and SDR based systems
- Digital signal modulation schemes.



2026

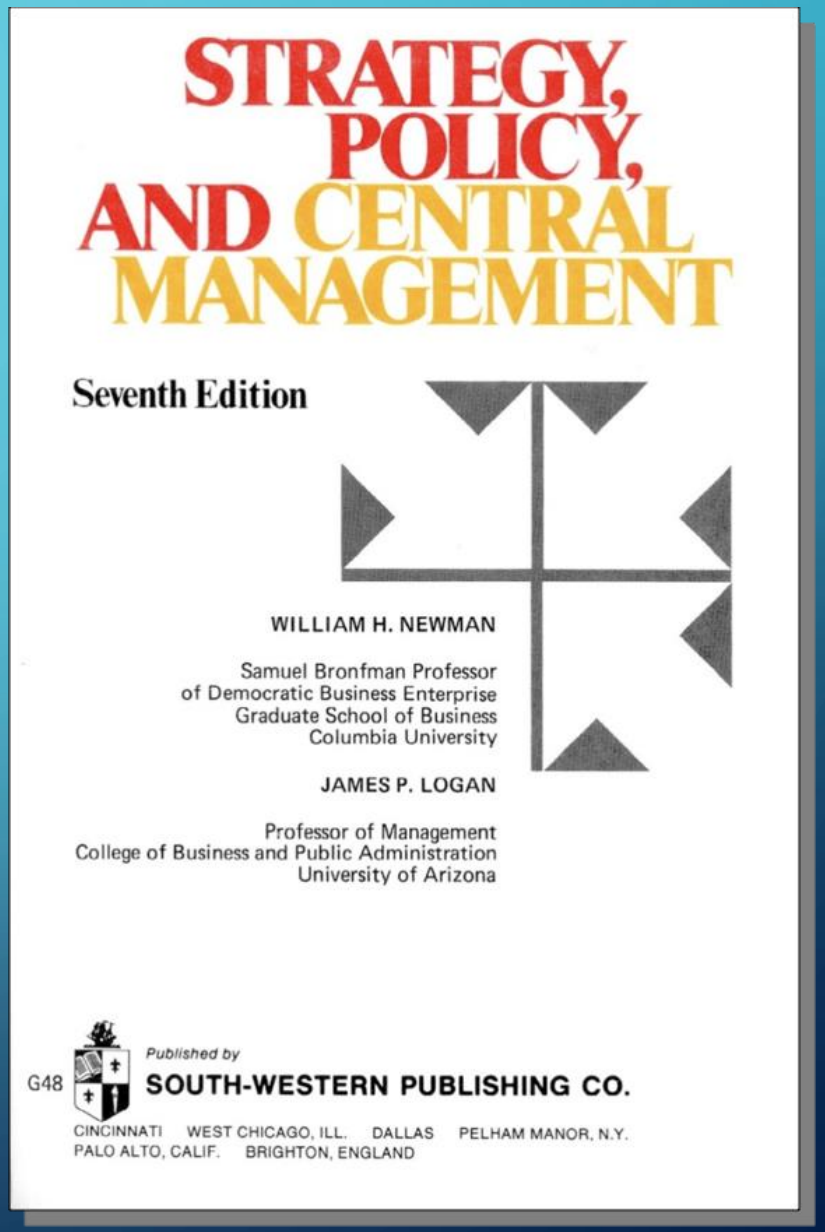
High end text book for engineers studying to become microwave engineers

- Covering top material close to Terahertz frequencies



From 2009

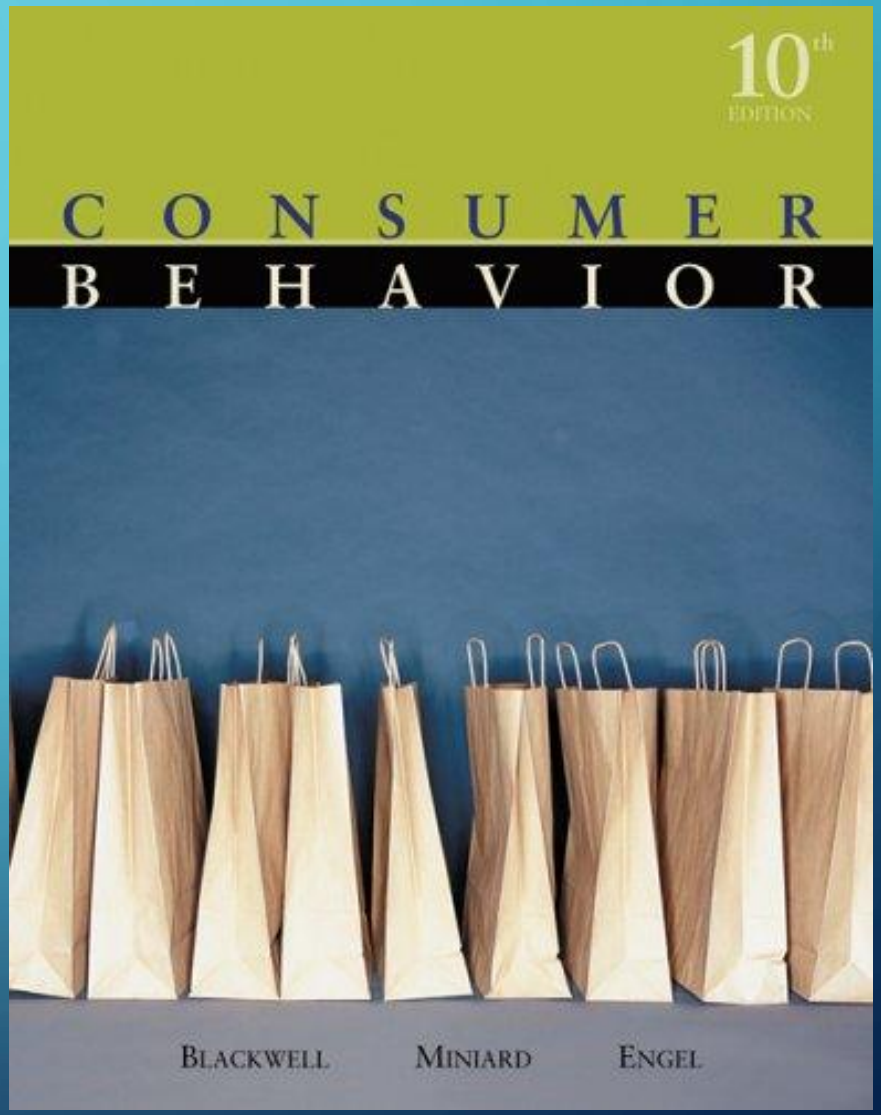
- Success by implementing strategy, policies and central management
- Focus on market needs and cost effective manufacturing
- Watch your competitors at international conferences and adapt products
- Learn from technology exchange



Models of consumer behaviour: The state of the art

BLACKWELL, MINARD AND ENGEL
From 1981 > 2009

- Success by watching consumer behavior
- Listen to the customers needs
- Decisions are made on perceptions more often than reality
- Compatibility with existing technologies or products is key to success



Thank You

- You need a good mix between tradition and society demands
- Students come from all countries and become global professionals
- Country barriers are disappearing
- Success lies in education and commitment to excellency
- Good luck with all the Pomp and Circumstances !