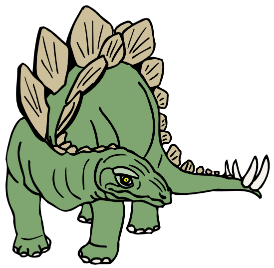
Living the Electronics Revolution: 60 Years of Fun with Radio



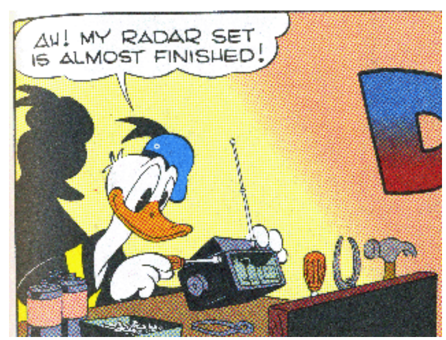
Charles W. Bostian

Alumni Distinguished Professor Emeritus

Bradley Department of

Electrical and Computer Engineering

April 13, 2012

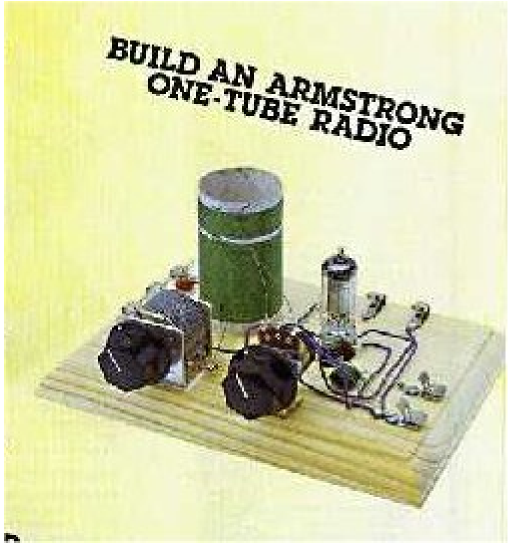


Wireless @ Virginia Tech

“Radio” and Radio Frequency (RF) Engineering

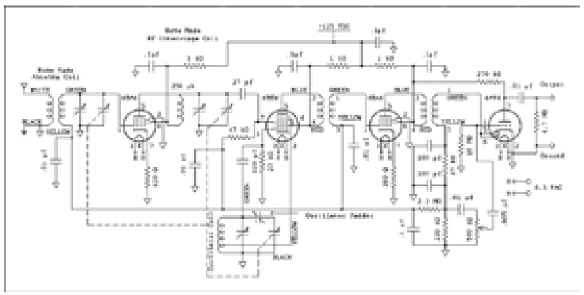
What is it?

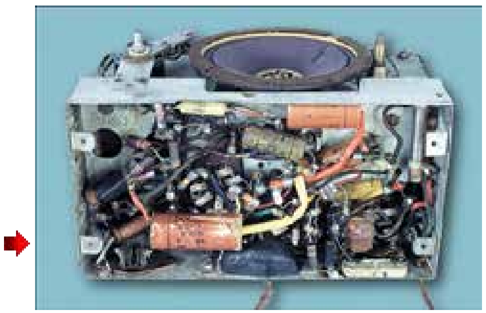
The design of radio transmitters and receivers – electronic devices that send and receive electromagnetic radiation.



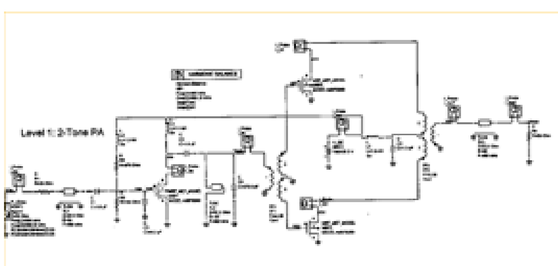
For years, RF was considered a branch of magic!

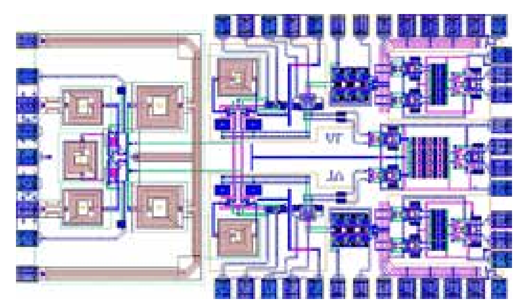
We designed with slide rules and curves, followed by a great deal of cut and try in the laboratory. When a design finally worked, you were not sure why.





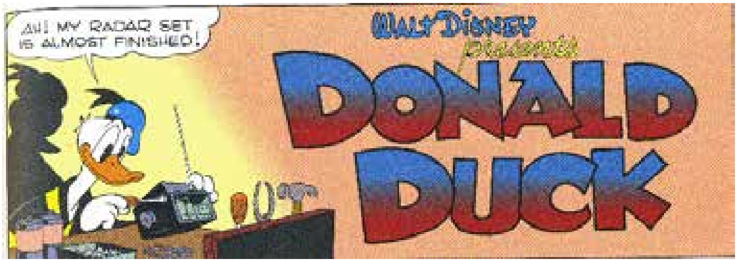
Now we have sophisticated computer aided design tools. When we design and build a radio, it usually works the first time.



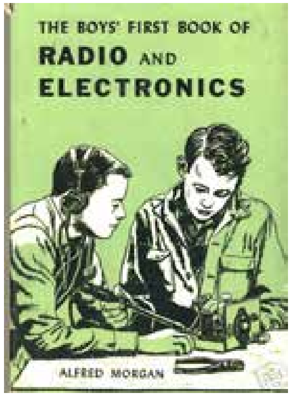


How did I get into radio? Comics, science fiction, and books!

•A 1946 comic book about Donald Duck's radar – I still have my "radar box," where I put the money I was saving to buy a radar when they came on the market.



•Alfred P. Morgan's *A First Radio Book for Boys*



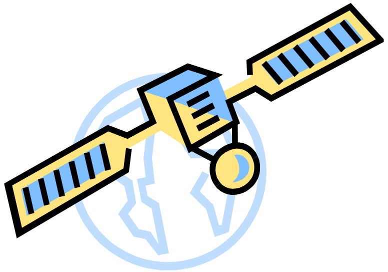
•Early TV science fiction

I developed a lifetime fascination with how radio communication works – transmission over long distances without wires.

During my career radio and ECE have changed from a world of hardwired single-purpose stand-alone stationary analog systems designed by classical mathematical analysis to a world of mobile networked software-driven digital devices designed by simulation and numerical analysis.

This is the electronics revolution as I was fortunate enough to live it! Here is its story from my perspective.

When I started graduate school in 1963, I thought my research career would involve taking radios to new places (outer space!) using new frequencies and new electronic devices.



But the problems would remain the same –
Make analog radios

- Smaller
- More efficient (i.e. longer battery life)
- Higher capacity

A network was either something like NBC or a bunch of police radios with a dispatcher.

But a series of unforeseen things happened!

My Subjective List of Unforeseen Things That Changed the World - 1

How we went from a world of hardwired single-purpose of stand-alone stationary analog systems designed by classical mathematical analysis to a world of mobile networked software-driven digital devices designed by simulation and numerical analysis:

Starting Year	Technology Drivers	Consequences for ECE	Consequences for Radio
1963	Discrete solid state analog devices	• Slow demise of vacuum tubes • Multiple low-cost active devices available to circuit designers	• Portable radios • Satellite communications
1965	Discrete solid state digital devices	• Digital computers became available to researchers • Numerical techniques solved previously unsolved mathematical problems • Simulation became available and accepted as a rigorous analytical tool • Decline in importance of math to ECE research	• Analytical basis for antenna design • Computer Aided Design (CAD) for RF
1971	Microprocessors and digital ICs	• Demise of analog circuitry for most applications • Practical Digital Signal Processing (DSP) • Software rises from nothing to dominance	• Signal processing functions performed digitally • Digital waveforms replace analog

My Subjective List of Unforeseen Things That Changed the World - 2

Starting Year	Technology Drivers	Consequences for ECE	Consequences for Radio
1973	Hand-held cell phone	• Portable devices becomes a driver of employment	• Rebirth of interest in RF • Hand-held devices rise to dominance
1981	Practical optical fiber cables	• Demise of TEM transmission lines for information • Transmission bandwidth a decreasing limitation for information systems • Cellular backhaul becomes practical and cheap	• Demise of radio (including satellites) for long haul communications • Enabled wireless = short-distance radio
1982	TCP/IP	• Everything becomes networked	• Network considerations drive radio design
1990	GHz CMOS logic + all of the above	• "Dumb" digital circuitry running highly intelligent software	• RF functions performed digitally – Software Defined Radio & Cognitive Radio
2000-12	Social networks, open source software, hobbyist electronics	• TBD	• TBD

The result of these developments is the convergence of information technology: from devices that are single-purpose, large stand-alone, and fixed in location to devices that are multi-purpose, hand-held, intensely networked, and portable.

Graduate School 1963-67

M.S. Thesis – *A Procedure for Selecting Germanium Transistors for Use in the Radiation Environment of Space*
Ph.D. Dissertation – *The Loop Antenna Loaded with Active Elements*

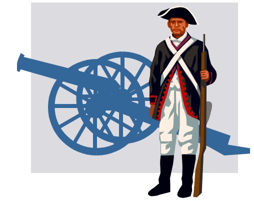
Coursework evenly divided between solid state electronics and electromagnetics. Ph.D. research was in numerical EM. For 80 years it had been impossible to solve analytically for the current distribution on any real antennas. Now numerical techniques and the availability of digital computers ("IBM Machines") made it possible!

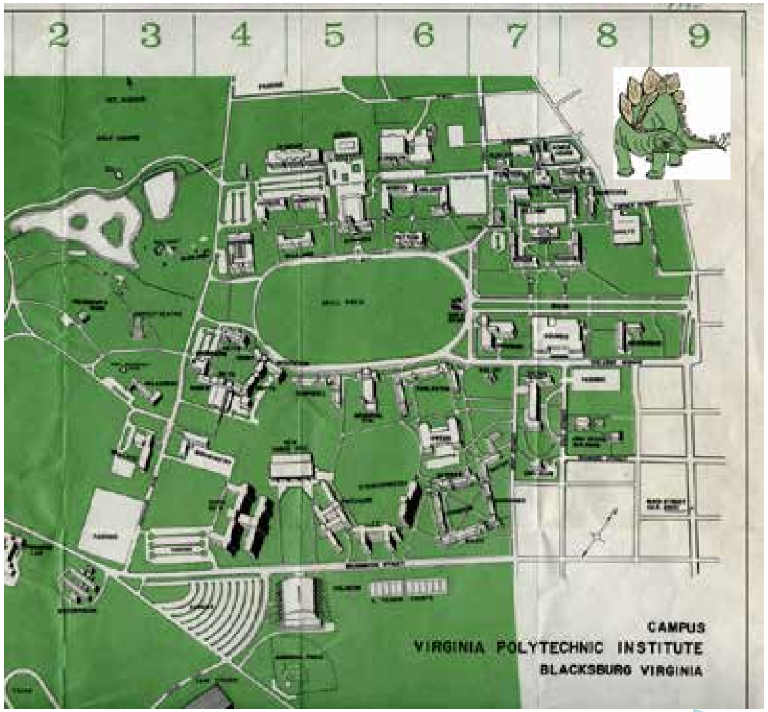
In the years following graduate school I published exactly one more paper in device electronics and one in numerical electromagnetics!

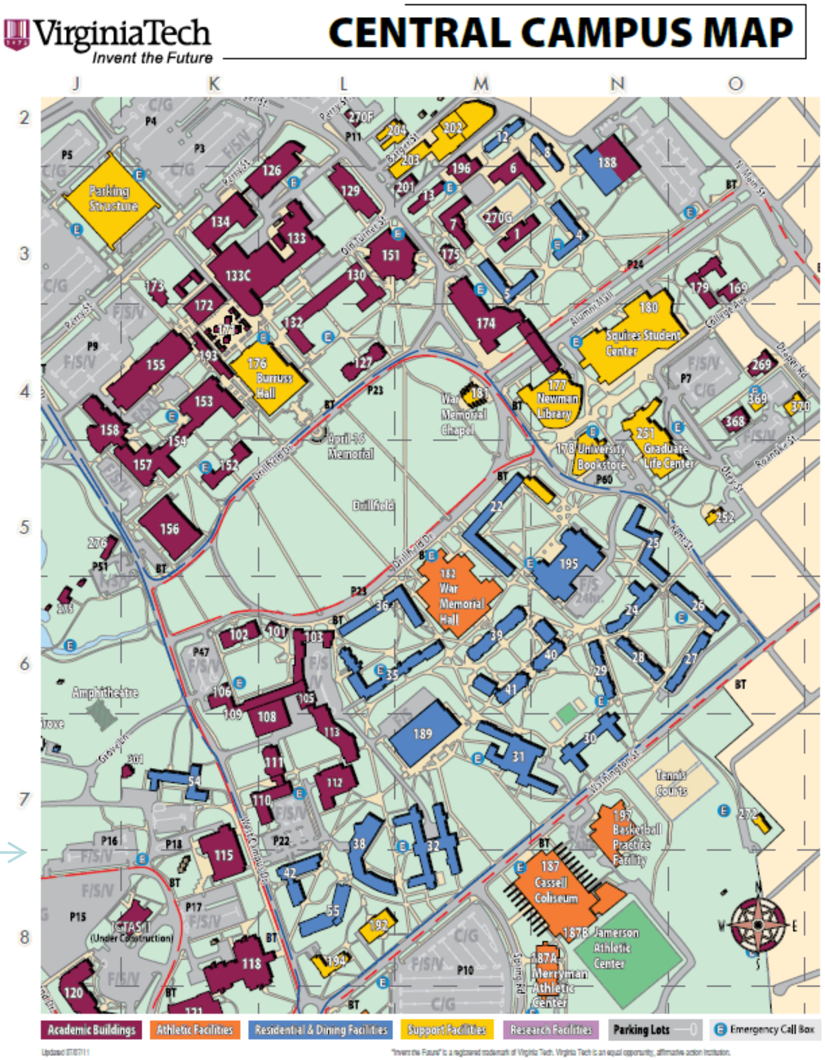
IBM 1620 computer →

My advisor's lab ←

I joined VT in 1969 following service as an army officer

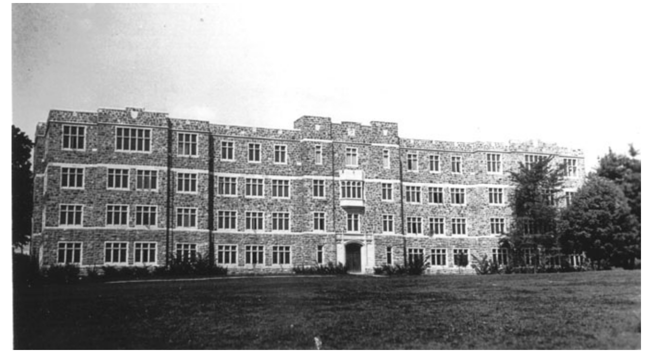


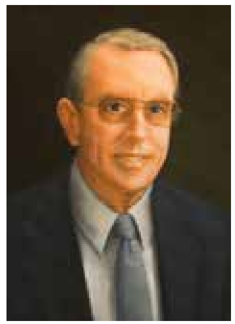




Then

Now





ELECTRICAL ENGINEERING

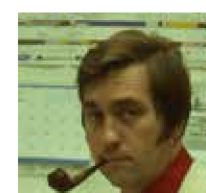
W. A. BLACKWELL, *Head*

Professors: Barnes, Blackwell, Cannon†, Holt, Krauss, Powley, Worcester

Assoc. Prof.: Ebert, Grigsby, Hasdorff, Hopkins, Hull, Manus*, Miller, Phelan, Rhee, Walsh

Asst. Prof.: A. W. Bennett, W. S. Bennett, Bond, Kabaservice, Popovic, Smith, VanLandingham

+ 4 new assistant professors: Bostian, Shah, Stutzman, Yavin



28 names, 24 people actually present in 1969-70

In 2011-2012 we have 72 faculty + 4 open positions

Graduate Courses ~ 40

Electrical Engineering Courses (Graduate)

500	ELECTROSTATICS
501	MAGNETOSTATICS AND MAGNETODYNAMICS
503	ELECTRO-ACOUSTICAL ENGINEERING
505	ADVANCED CIRCUIT ANALYSIS
506	ADVANCED SERVOMECHANISMS
507	OPERATIONAL CIRCUIT ANALYSIS
5012	GRADIENTS AND SURGES
5013	TRANSIENT ANALYSIS OF SYNCHRONOUS MACHINES
5014	INFORMATION THEORY
5015	ANALOG COMPUTER
5016	ANALOG COMPUTER LABORATORY
5017	ELECTRICAL ENGINEERING MATERIALS
5018	ELECTRONIC CIRCUITS
5019	IMPEDANCE MEASUREMENT
5020	RANDOM SIGNALS AND NOISE
5021	DIGITAL POWER SYSTEM ANALYSIS
5022	SAMPLED DATA SYSTEMS
512, 522, 532	POWER SYSTEM STABILITY
513, 523, 533	ELECTROMAGNETIC WAVES
514, 524, 534	CONTROL SYSTEM SYNTHESIS
515, 525, 535	NONLINEAR CONTROL SYSTEMS
516, 526, 536	THEORY AND DESIGN OF DIGITAL MACHINES
517, 527, 537	SEMICONDUCTOR ELECTRONICS
518, 528, 538	SYNTHESIS OF PASSIVE NETWORKS
519, 529	ADVANCED ENERGY CONVERSION
597	INDIVIDUAL STUDY
598	SPECIAL STUDY
599	RESEARCH AND THESIS
601	OPTIMUM CONTROL SYSTEMS
602	STOCHASTICALLY EXCITED ELECTRICAL NETWORKS
611, 621	COMMUNICATION SYSTEM DESIGN
799	RESEARCH AND DISSERTATION

External Research Funding

1969-70 $0

2011-12 $29,235,212

Enrollment Figures. (x) indicates women included in count

Then

ECE
Graduate 39(1)
Ph.D. 16
M.S. 23 (1)
Undergraduate 443 (5)
Senior 164 (2)
Junior 134 (2)
Sophomore 131
Freshmen 114 (1)

VT 10,352
Graduate 1,084
Undergraduate 10,352

Thanks to Tamara Kennelly, Univ. Archivist

Now

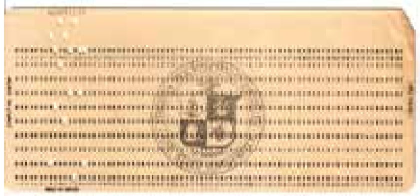
ECE
Graduate 496 (71)
Ph.D. 311 (39)
M.S. & M.Eng. 185 (32)
Undergraduate 677 (66)
EE 404 (46)
CPE 273 (20)

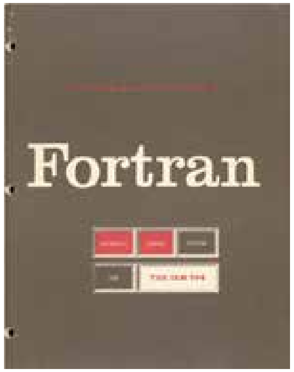
VT 30,936
Graduate 6,856
Professional 380
Undergraduate 23,700

Thanks to Cindy Hopkins, Mary Taylor and Sharon Shrader

These were the research tools we had in 1969-70.

1 Mb!





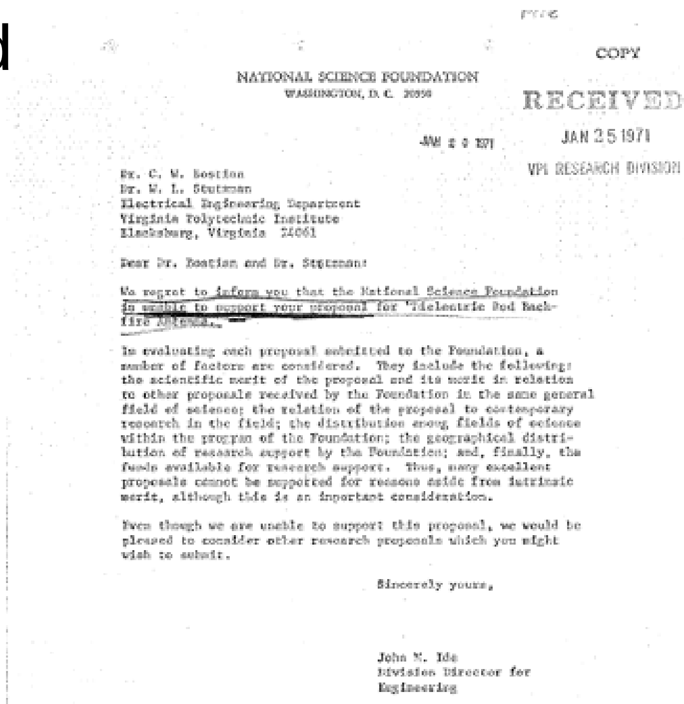
First Proposals

- Dielectric Rod Backfire Antenna
- Dielectric Rod Beacon Antenna

Written in response to Dept. Head mandate that every faculty member who wanted a raise should write a proposal.

Turned down by all recipients.

Lesson learned: *People won't fund you because of the beauty of your mathematics. Your proposal must solve a real problem that they have!*



COPY

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

RECEIVED
JAN 25 1971
VPI RESEARCH DIVISION

JAN 20 1971

Dr. C. W. Bostian
Dr. W. L. Stutzman
Electrical Engineering Department
Virginia Polytechnic Institute
Blacksburg, Virginia 24061

Dear Dr. Bostian and Dr. Stutzman:

We regret to inform you that the National Science Foundation is unable to support your proposal for "Dielectric Rod Backfire Antenna."

In evaluating each proposal submitted to the Foundation, a number of factors are considered. They include the following: the scientific merit of the proposal and its merit in relation to other proposals received by the Foundation in the same general field of science; the relation of the proposal to contemporary research in the field; the distribution among fields of science within the program of the Foundation; the geographical distribution of research support by the Foundation; and, finally, the funds available for research support. Thus, many excellent proposals cannot be supported for reasons aside from intrinsic merit, although this is an important consideration.

Even though we are unable to support this proposal, we would be pleased to consider other research proposals which you might wish to submit.

Sincerely yours,

John M. Ide
Division Director for
Engineering

First Proposals

- Dielectric Rod Backfire Antenna
- Dielectric Rod Beacon Antenna

Written in response to Dept. Head mandate that every faculty member who wants a raise should write a proposal

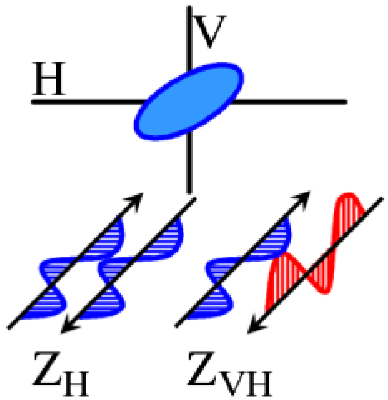
Turned down by all recipients.

But a NASA manager liked my proposal and invited me to work for him over the summer, saying he would fund me to work on a propagation project!

NASA Program in Millimeter Wave Satellite Communications

4 and 6 GHz satellite systems, built to distribute cable TV programming, were hugely successful – it was the era of big backyard satellite dishes.

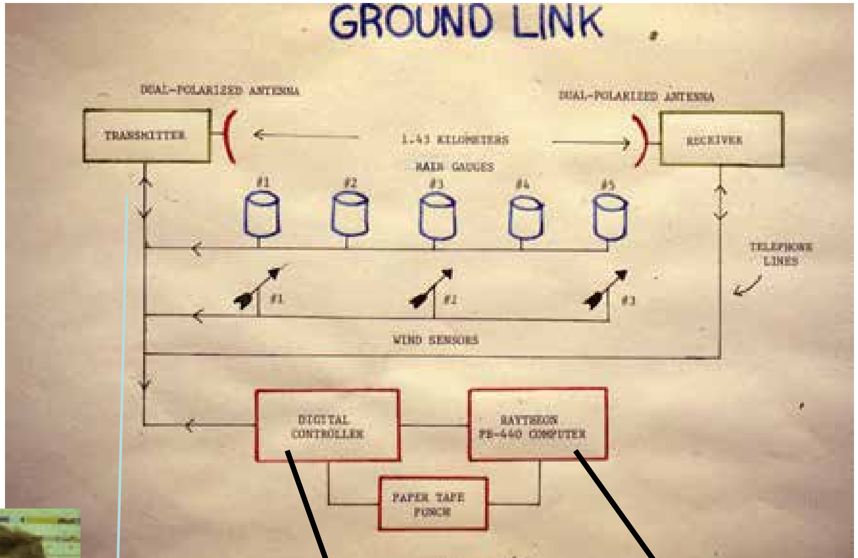
4 and 6 GHz spectrum was full – expansion would come in the 10-30 GHz band.

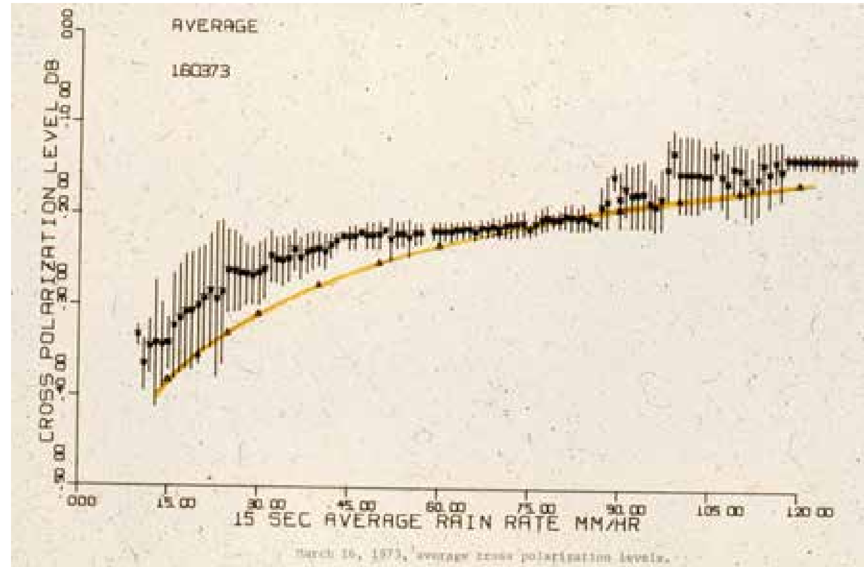


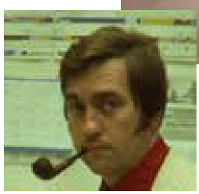
Because of water's high dielectric constant, rain drops are a significant fraction of a wavelength in size above 10 GHz. They attenuate and depolarize. Attenuation in dB/km ~ frequency and rain rate both raised to powers.

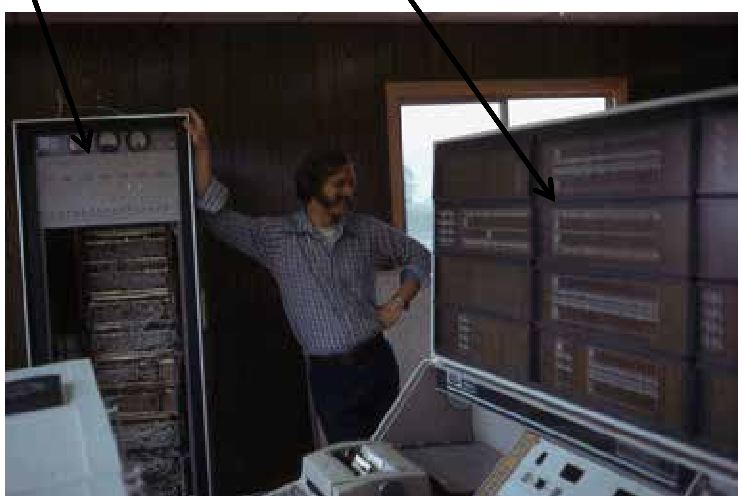
Characterize rain attenuation and depolarization to obtain needed information for design of future systems.

The First Experiment: A 17.65 GHz Terrestrial Link. ECE's First Federally Funded Project.

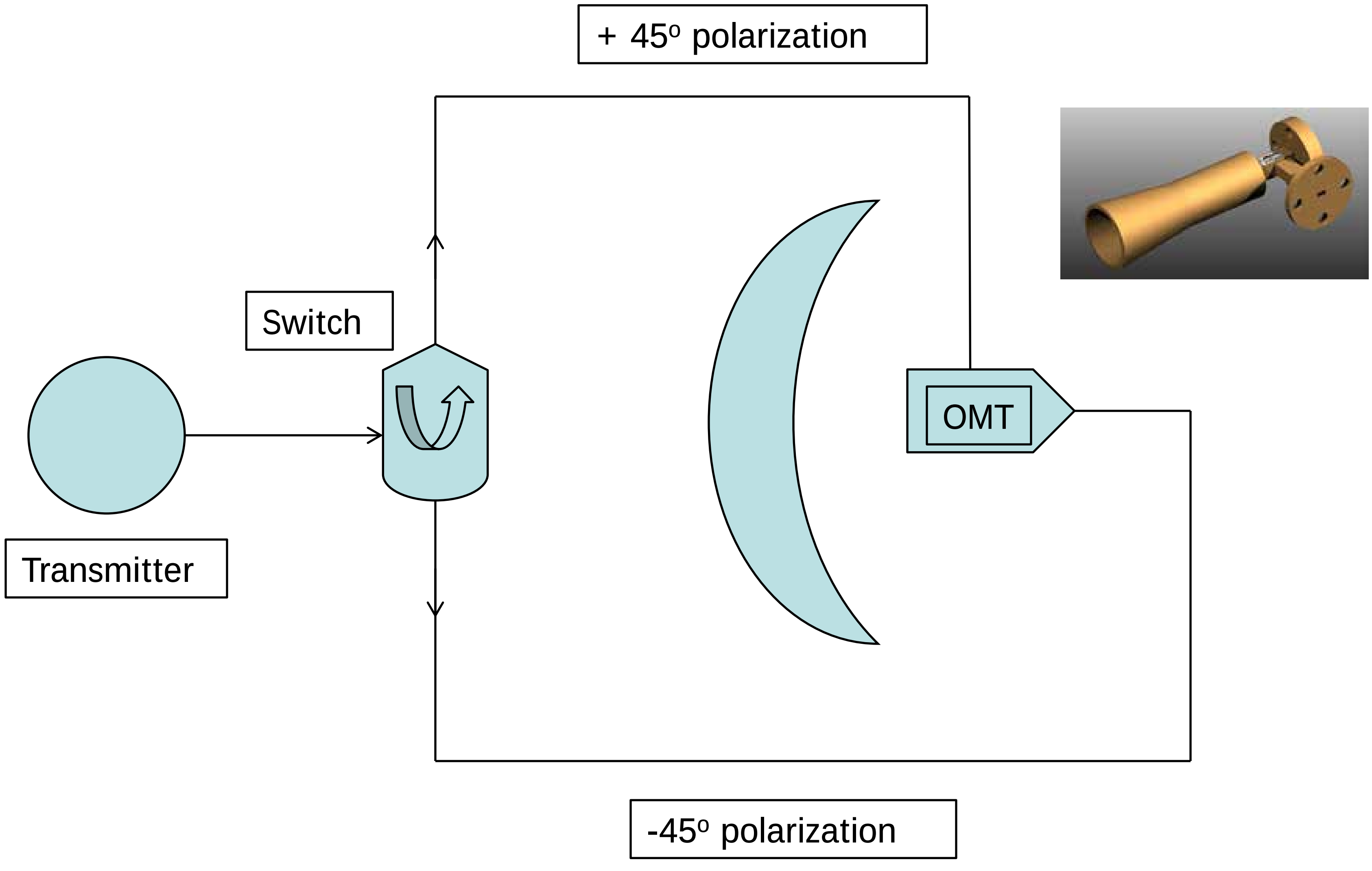




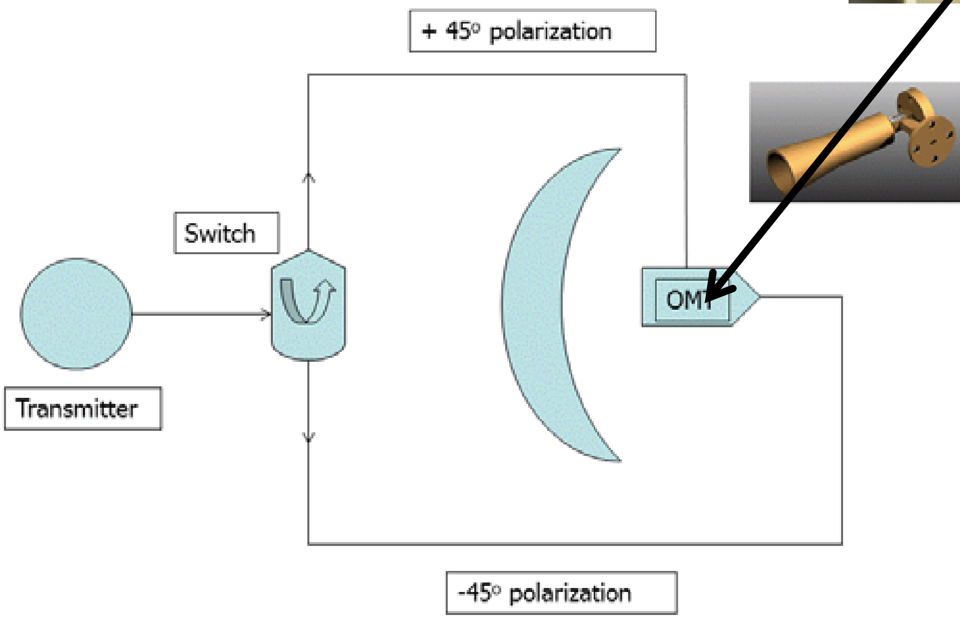




First digital recording of propagation experiment data – Strip chart recorders had been the standard.


+ 45^{o} polarization
Switch
Transmitter
OMT
-45^{o} polarization

The Culprit!


+ 45º polarization
Switch
Transmitter
OMT
-45º polarization

The ground link led to many years of experiments with a variety of NASA and commercial satellites.

We obtained a lot of data like this sample.

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. AP-34, NO. 1, JANUARY 1986

Results of a Three-Year 11.6 GHz Low-Angle Propagation Experiment Using the SIRIO Satellite

CHARLES W. BOSTIAN, SENIOR MEMBER, IEEE, TIMOTHY PRATT, SENIOR MEMBER, IEEE, AND WARREN L. STUTZMAN, SENIOR MEMBER, IEEE

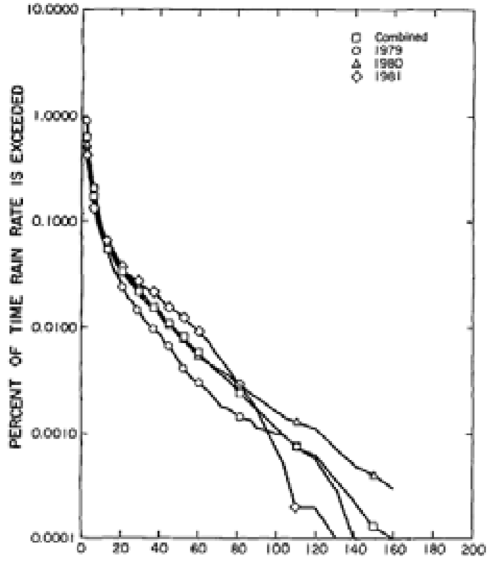


Fig. 1. A comparison of the three-year rain rate distribution with that for each calendar year.

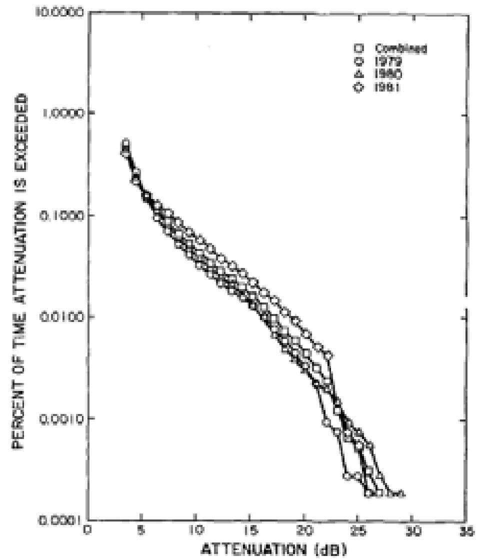


Fig. 4. A comparison of the three-year cumulative distribution of beacon attenuation with that for each calendar year.

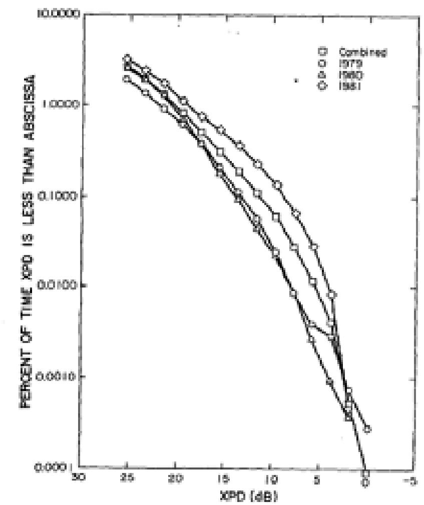
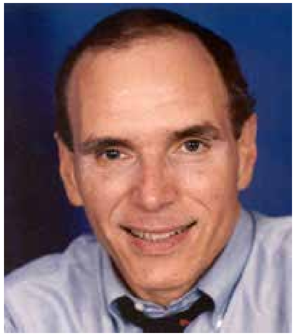


Fig. 5. A comparison of the three-year cumulative distribution of beacon XPD with that for each calendar year.

Our measurements and models provided the basis for the link design of the 10-30 GHz systems that are in wide use today.

I took a year's leave from research in 1989 and served as an IEEE Congressional Fellow, working in the office of Rep. Don Ritter (R-PA), an MIT Ph.D. in physical metallurgy and a former Lehigh professor.

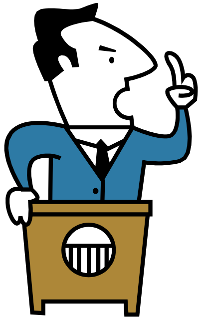


IEEE TRANSACTIONS ON PROFESSIONAL COMMUNICATION, VOL. 34, NO. 4, DECEMBER 1991

Technical Information and the 1989 Debate About High Definition TV

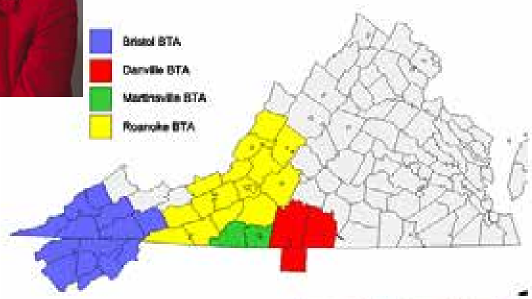
Charles W. Bostian and Frieda F. Bostian

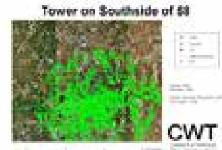
Afterwards, VT thought I knew a lot about talking to politicians! (Actually, they talk and you just listen!)



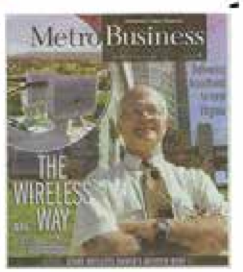
I developed a strong interest in the intersection of ECE and radio with business. It led to the formation of CWT and a valuable 10 year collaboration with faculty from Business and Geography.

Virginia
WiNS
Wireless Network Services with LMDS



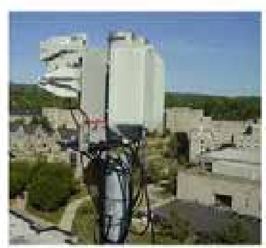


LMDS: Broadband Access for Southwest and Southside Virginia



Virginia Tech

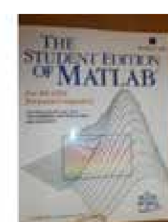
Charles W. Bostian,
Director
The Center for Wireless Telecommunications
December 12, 2000



CWT

This was the great dot com and telecomm boom, when everyone wanted wireless!

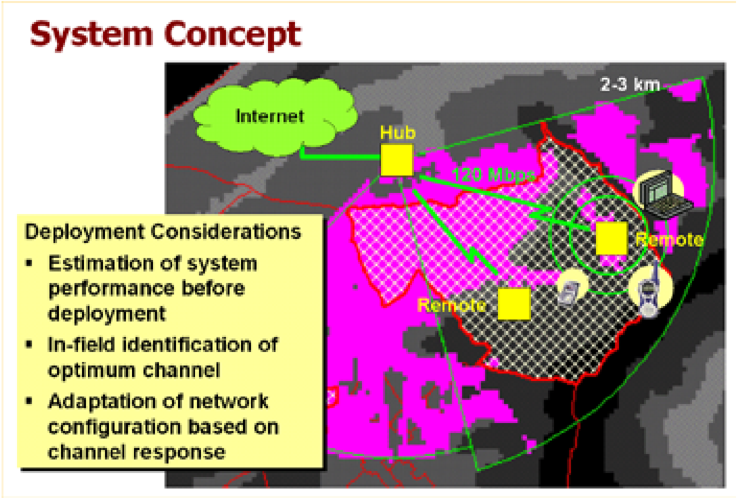
We did a lot of work in developing fixed wireless technology, which was obviated by the desire for broadband mobile access and the ability to deliver it by OFDM.



NSF Disaster Communications Project 1998

Overall Objective: Develop a rapidly deployable high capacity backbone radio system bringing high speed Internet service to a disaster site.

Technical Challenges: **find** short-lived radio paths of opportunity and **compensate** for the shortcomings of these paths at both the radio and the network levels to deliver optimum performance.



Wireless LAN Technology at This Time

No OFDM
802.11 was a low-data rate intra-office system
Cell phones were barely 2G with at best Cellular Digital Packet Data.

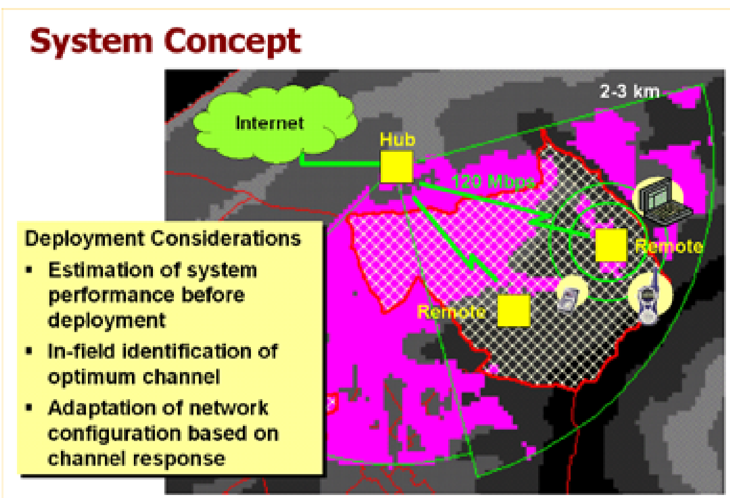
The only way to get OC3 (155 Mbps) data rates was by using millimeter wave frequencies with QPSK modulation.

VT held 28 GHz LMDS licenses and had the needed equipment.

NSF Disaster Communications Project 1998

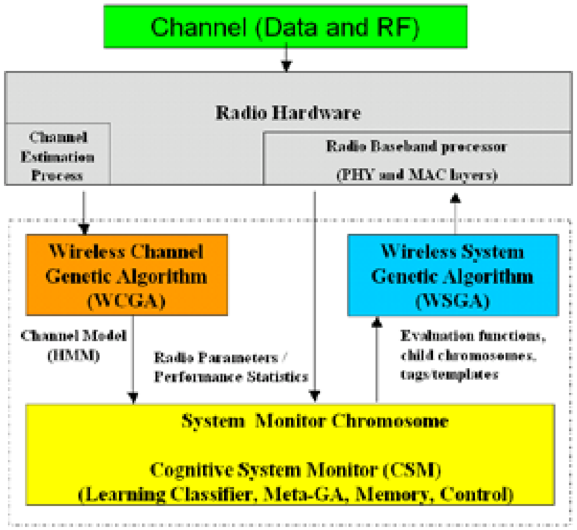
Overall Objective: Develop a rapidly deployable high capacity backbone radio system bringing high speed Internet service to a disaster site.

Technical Challenges: **find** short-lived radio paths of opportunity and **compensate** for the shortcomings of these paths at both the radio and the network levels to deliver optimum performance.

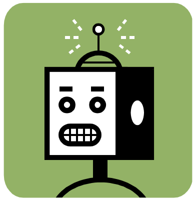


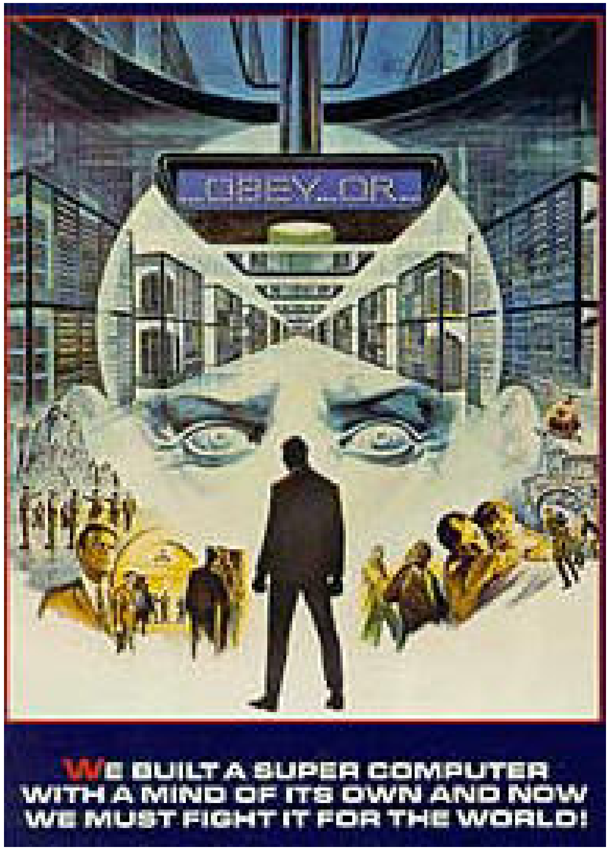
The radio must think for itself. Emergency responders emphatically do not want a radio that requires hands-on adjustment by an expert. They need a radio that is smart enough to find the best path of opportunity, configure itself and communicate, all with minimal human intervention.

My students concluded we needed a **cognitive radio** – radio engineering plus **a**rtificial **i**ntelligence.



I said no! Artificial intelligence has a history of hype followed by failure – it was for science fiction movies! I wanted something that would work!





But **the students** were right.

They ignored my protests and pulled me into an entirely new area of research – at a time when I could have coasted into retirement!

Christian Rieser

Tom Rondeau

Tim Gallagher

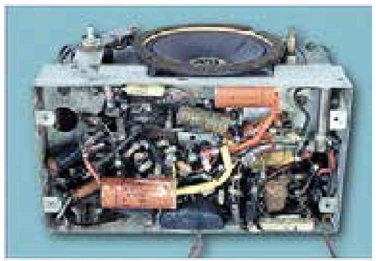
Cognitive Radio Engine Based on Genetic Algorithms in a Network. US Patent 7,289,972. Filed June 25, 2004, Granted October 30, 2007.

Walling Cyre

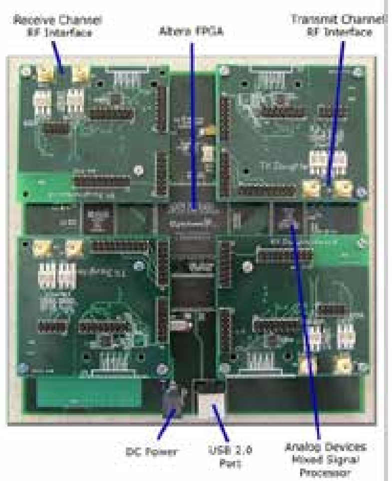
Working Definitions

Software Defined Radio – how the radio is constructed and controlled

Legacy radios– function is defined in hardware.



Software defined radios – function is defined by software.

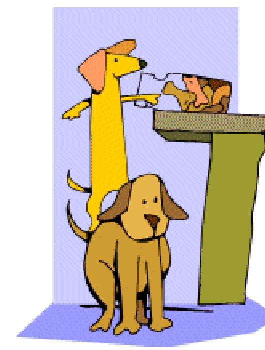


An SDR is essentially a computer that generates and understands radio signals.

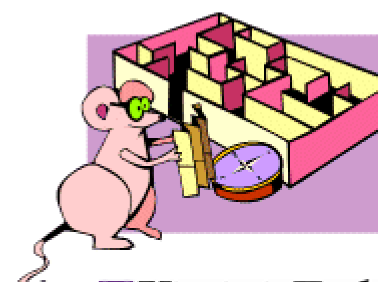
Cognitive Radio – how the radio behaves

Fixed radios– set by operator

Adaptive radios- adjust themselves to accommodate anticipated events.

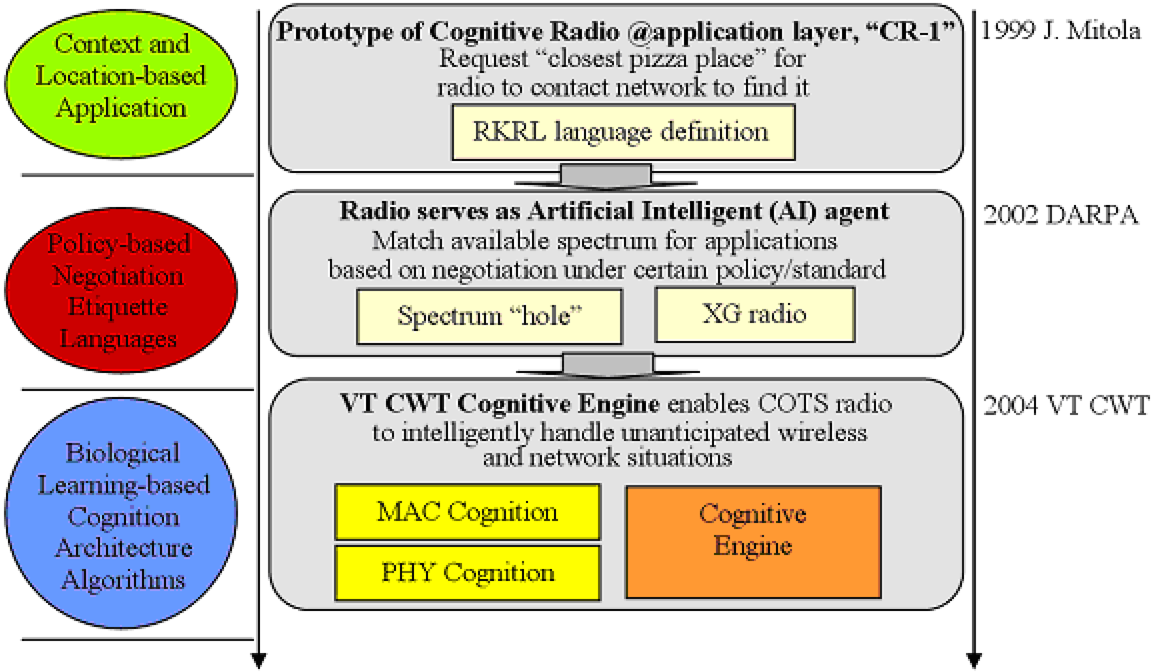


Cognitive radios- sense their environment and learn how to adapt.

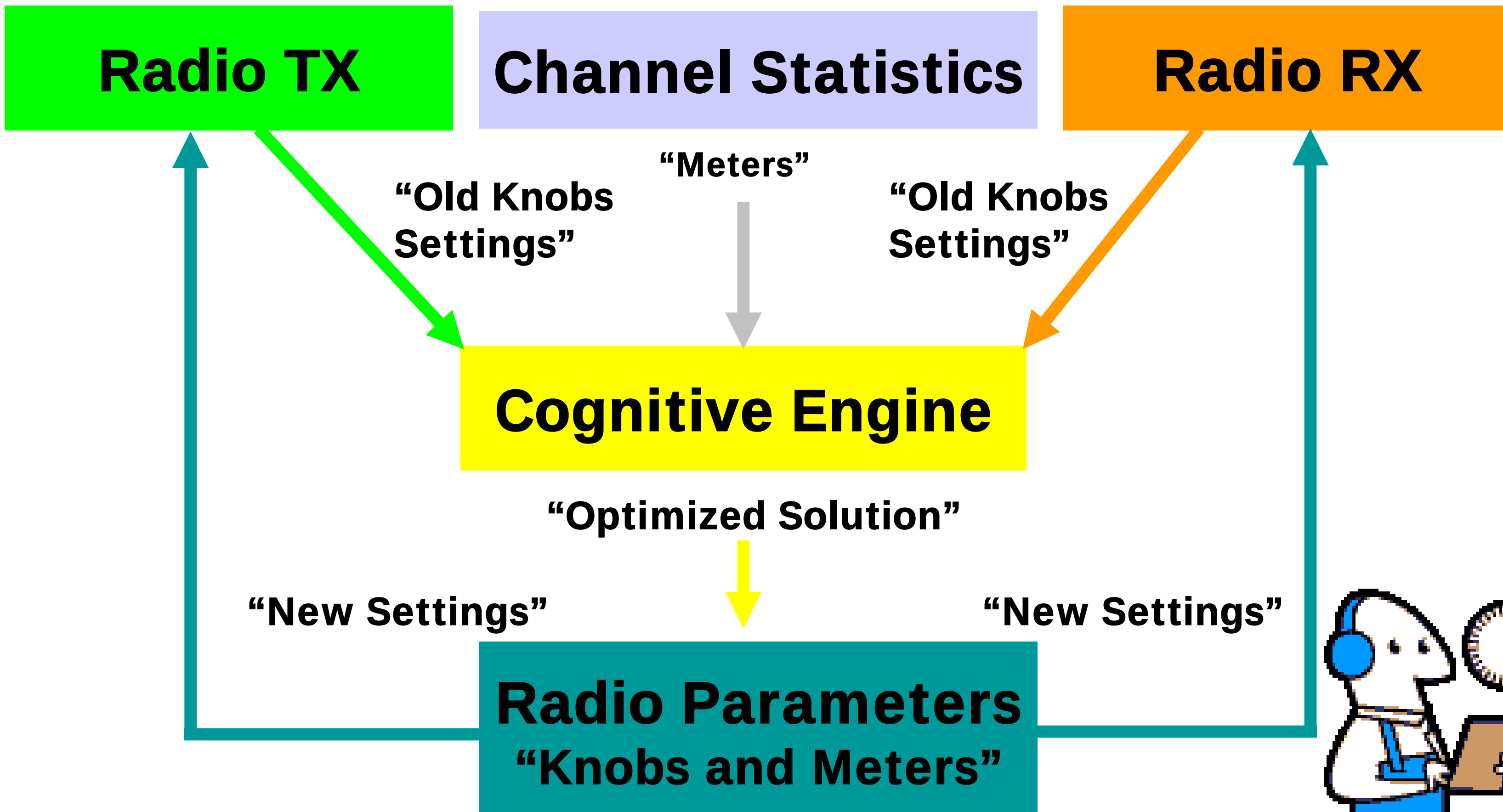


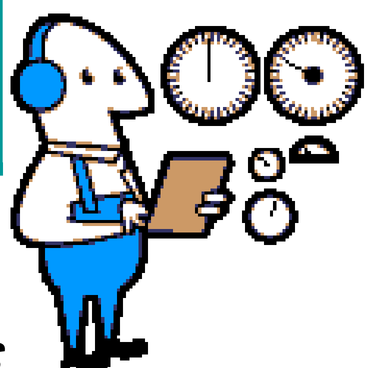
Cognitive Radio History

Cognitive radio began with Joseph Mitola's work in the late 1990's, where he visualized cognition running in the application layer. Our work extended it downwards into the MAC and PHY layers. PHY = hardware settings. MAC=access to the radio spectrum.



A cognitive radio can be realized as a **cognitive engine** (intelligent software package) controlling a software defined **radio platform**.

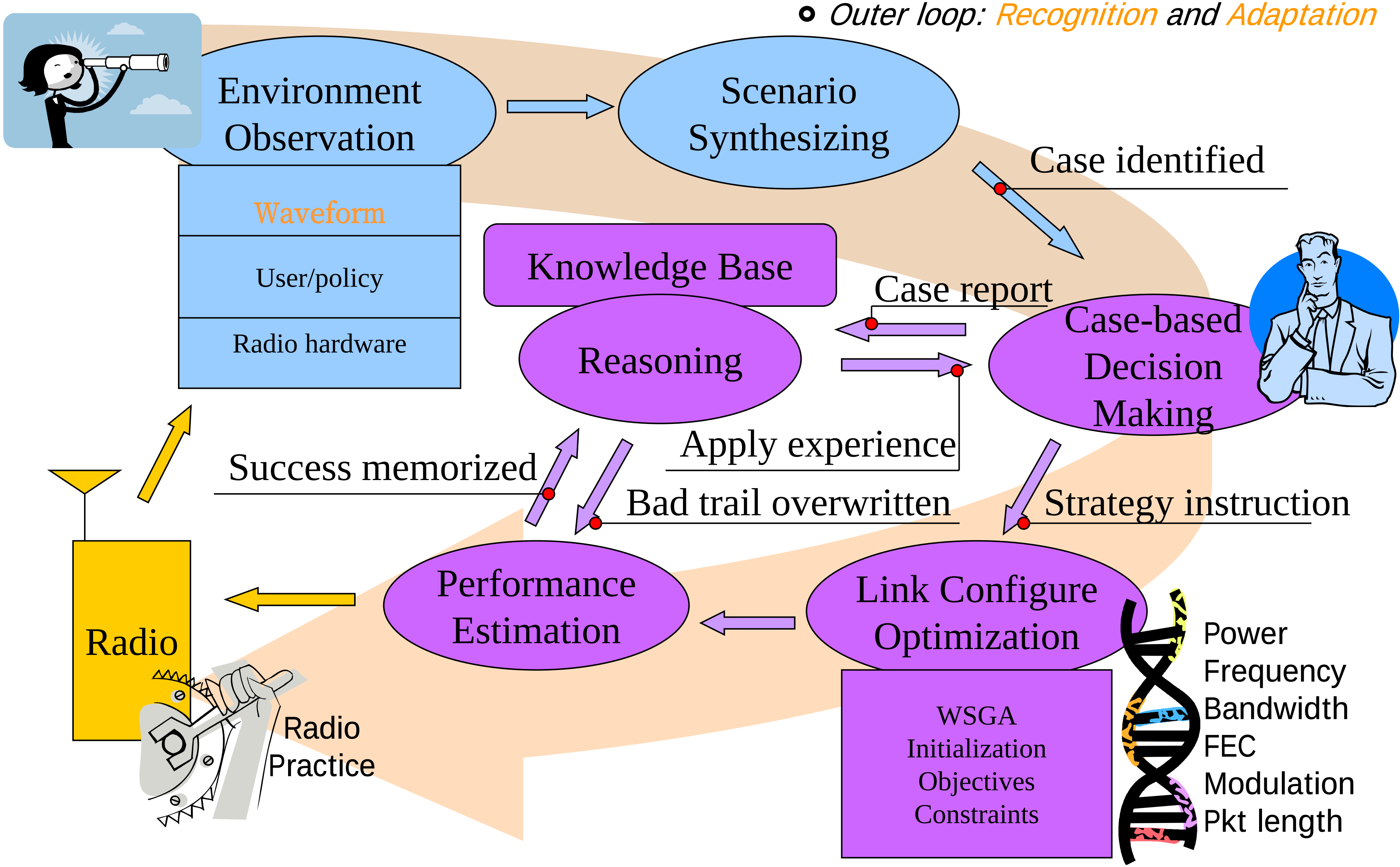




CR reads the meters and turns the knobs.

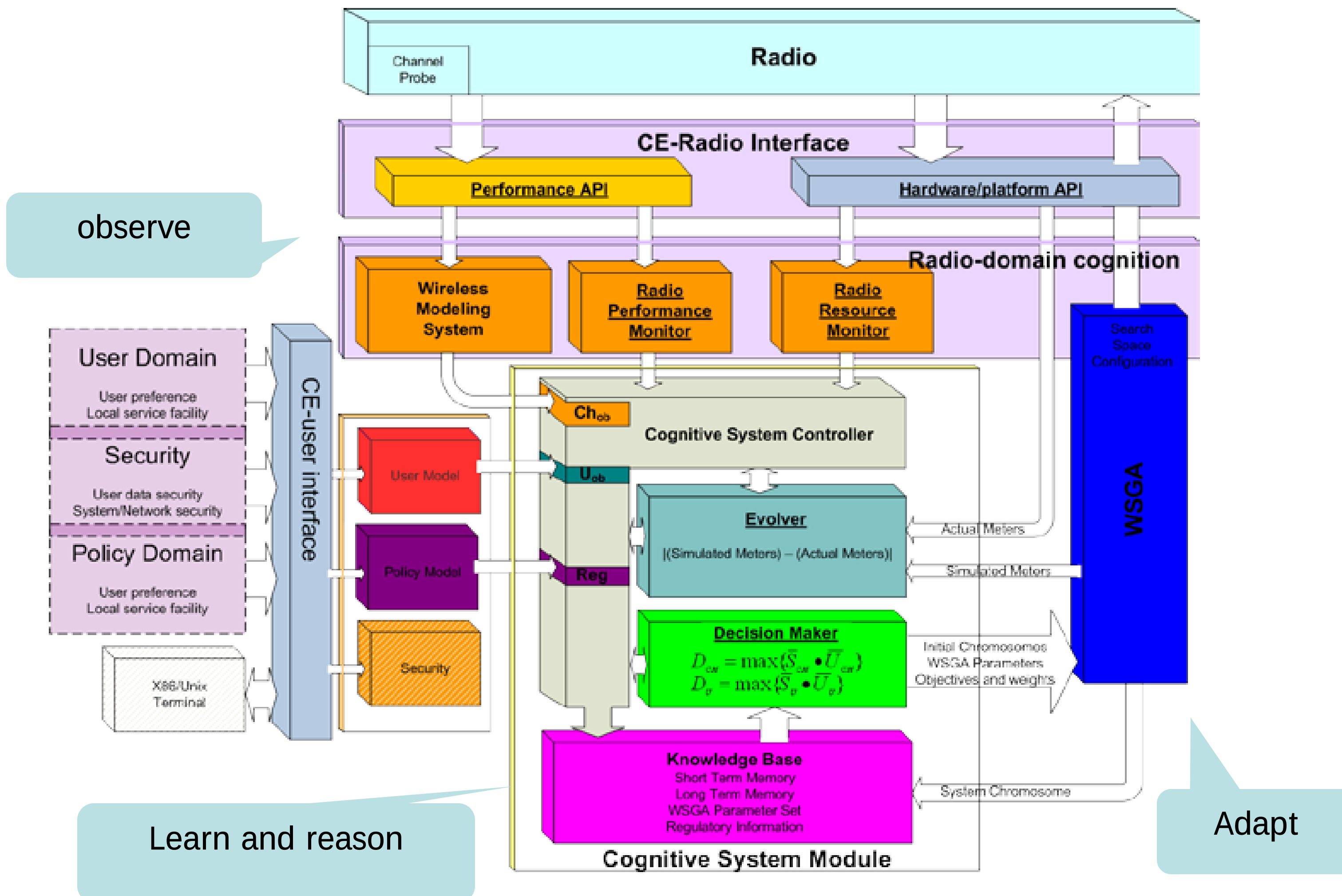
CWT² Cognition Cycle with Two Loops

- *Inner loop: Learning*
- *Outer loop: Recognition and Adaptation*



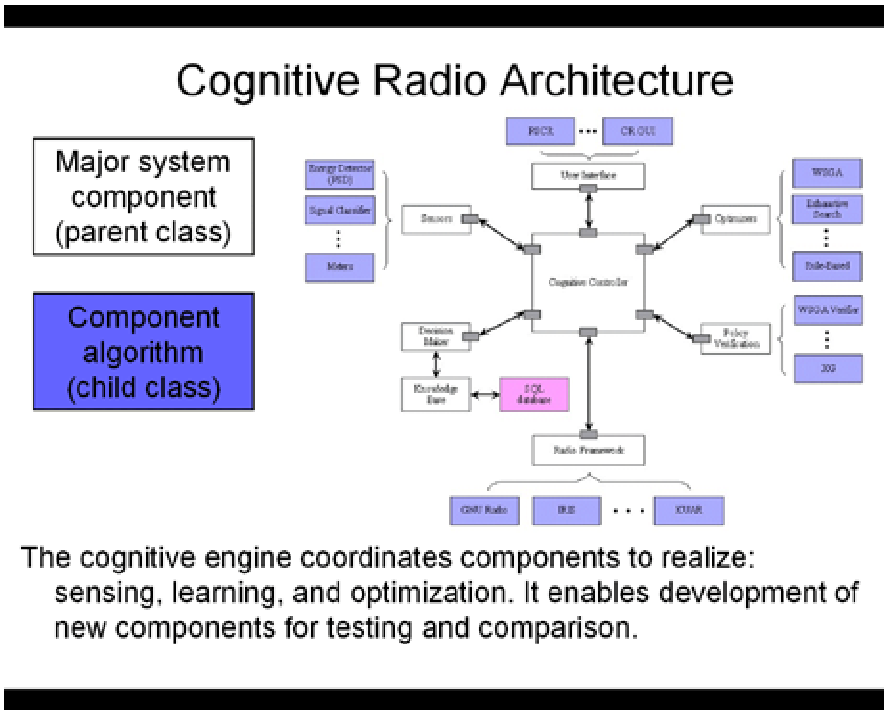
Environment awareness and evolving knowledge lead to optimal radio reconfiguration

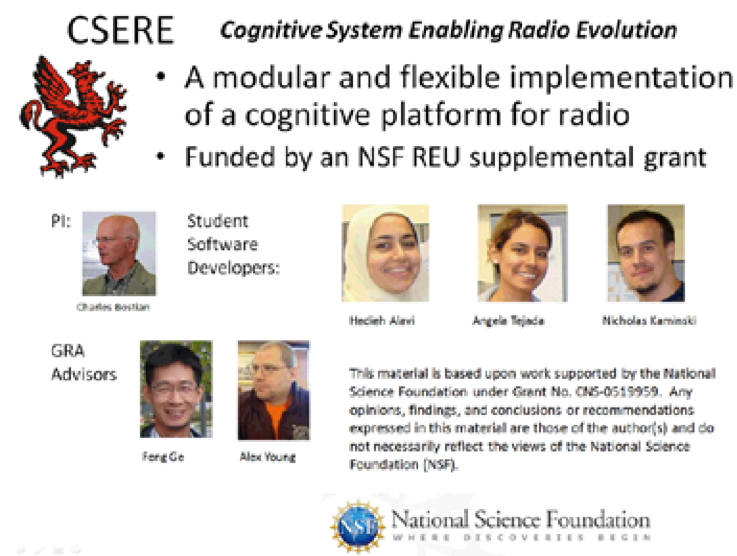
Cognitive Engine – Software Architecture



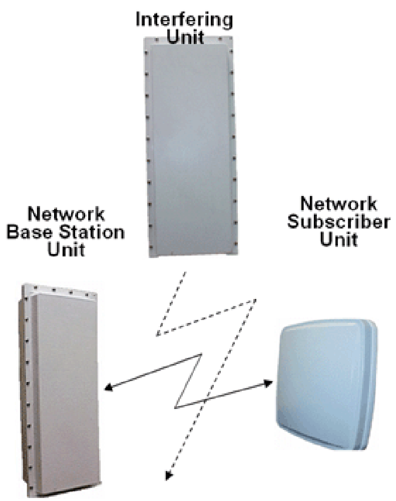
United States Patent 7,289,972 ***Cognitive Radio Engine Based on Genetic Algorithms in a Network***

Our distributed cognitive architecture allows a cognitive radio to incorporate modules from any source.





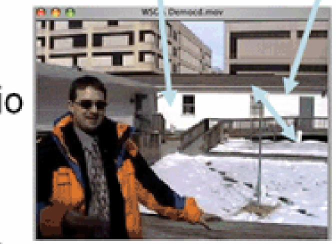
First Working Cognitive Radio Prototype 2004

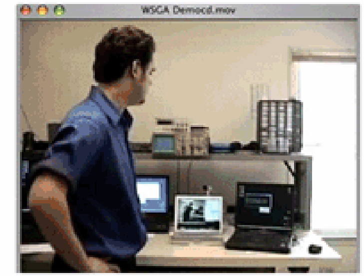


Interference Test setup

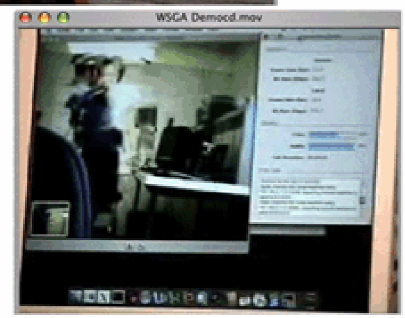
- Cognitive Radio Testbed Link

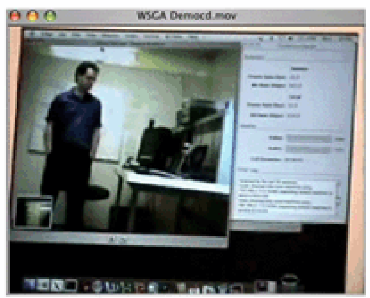
Interferer
Broadband Wireless Link





- Interferer Degrades Broadband Wireless Link



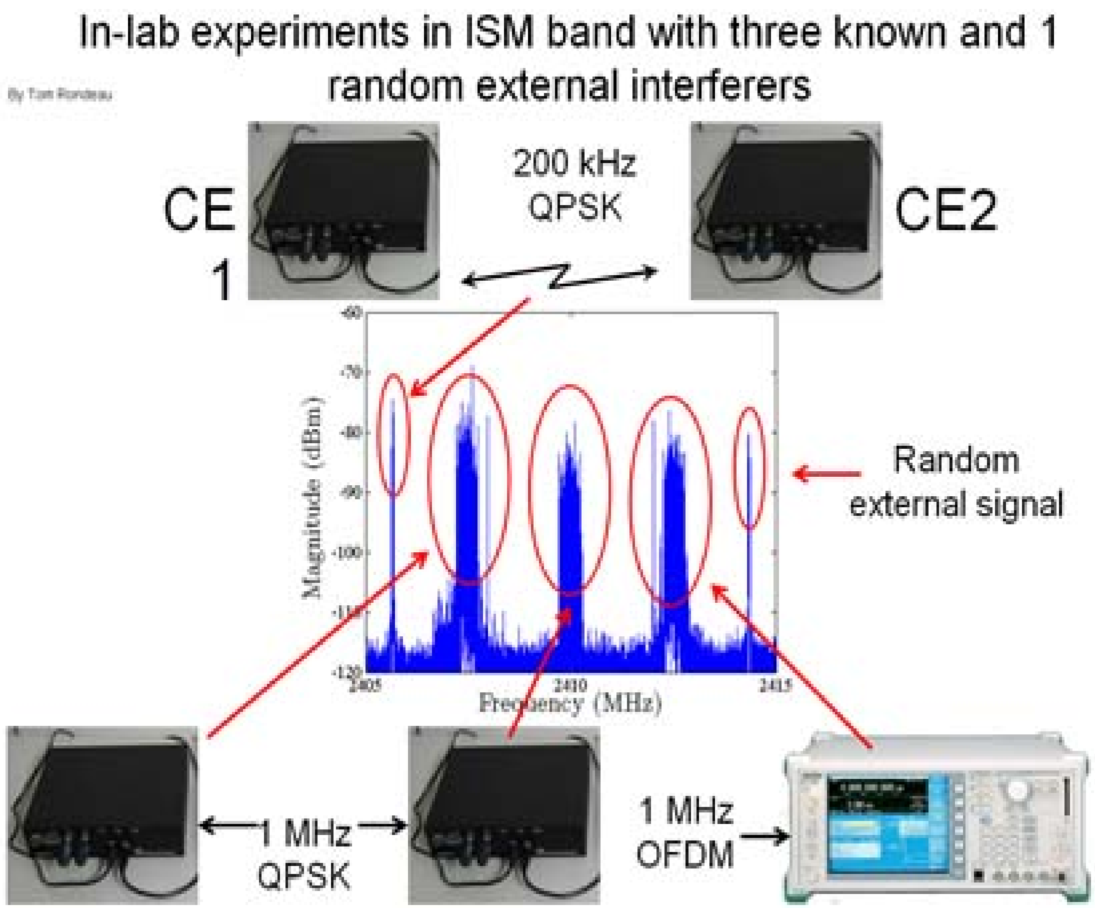


- Link quality of service (QOS) is restored.
- WSGA evolves radio operation

Interferer	Link	→ Link
Tx=11dBm	Tx=6dBm	Tx=16dBm
QAM 16	QAM 16	QPSK 4
Fibs 12	Fibs 22	Fibs 4
3/4 FEC	3/4 FEC	1/2 FEC
Freq=b-5	Freq=a-5	Freq=a-5

VirginiaTech
Invent the Future

Cognitive Radio Demonstration at DySPAN 2007



The VT Public Safety Cognitive Radio (PSCR)

Objective: To solve the interoperability problem by providing intelligent and affordable all-band all-mode radios that find and identify public safety networks and configure themselves to interoperate with them.

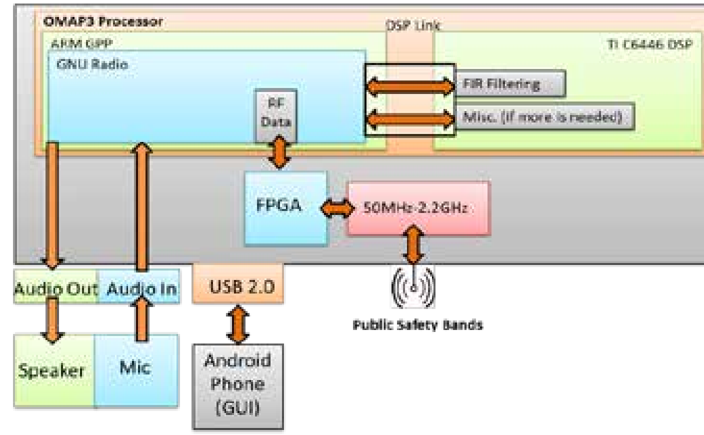
Vehicular Version: 2009

PSCR Capabilities:

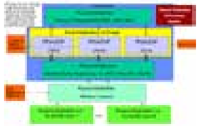
- Recognize all public safety waveforms 50 MHz – 2.2 GHz
- Interoperate with all public safety radios
- Provide a gateway between incompatible networks
- Serve as a repeater when desired

Hand-held Version: 2010-2011

Long-term Concept: Universal Interoperability



VT Cognitive Radio Milestones



- 2002 Origination of Cognitive Engine concept

- 2003 First Demonstration of a Working Cognitive Radio – capable of learning and autonomous adaptation. *Outstanding Paper Award* for SDR04.

- 2005 Start of NSF and NIJ funding for cognitive engine radio development

- 2006 Start of DARPA WNaN funding

- 2007 Demonstration of working prototype *Public Safety Cognitive Radio*

- 2007 SDR07 Grand Prize for 2007 *Smart Radio Challenge* student competition

- 2008 Demonstrations at NTIA, DySPAN, SDR08

- 2009 Prototype Vehicular Public Safety Cognitive Radio delivered.

- 2010 CSERE modular cognitive engine developed

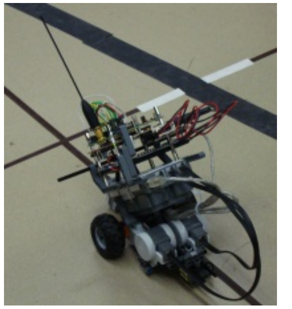
- 2011 Start of AF funding for integrating cognitive radio with autonomous vehicles

- 2012 Public Safety Cognitive radio running on Beagleboard and E100 delivered

VirginiaTech
Invent the Future

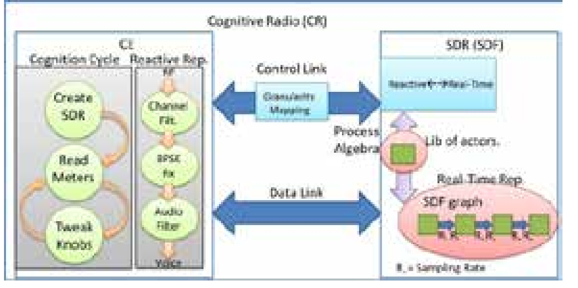
Current Projects

- Integrating cognitive radio with autonomous vehicles



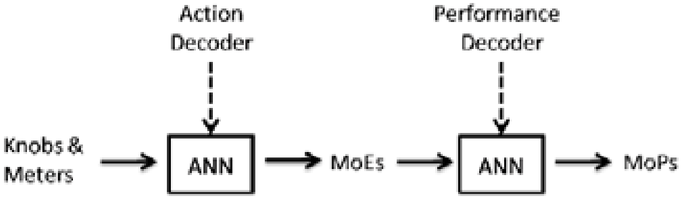
Alex Young

- Computational models for cognitive radio

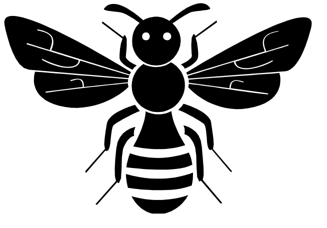


Al Fayez

- Evaluating cognitive radio performance



- Swarm intelligence for cognitive networks

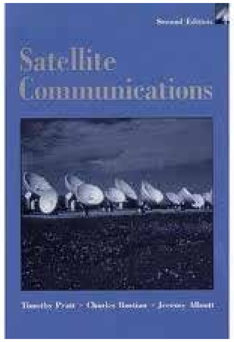


Nick Kaminski

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 41, NO. 12, DECEMBER 1993

A Deterministic Approach to Predicting Microwave Diffraction by Buildings for Microcellular Systems

Thomas A. Russell, *Member, IEEE*, Charles W. Bostian, *Fellow, IEEE*, and Theodore S. Rappaport, *Senior Member, IEEE*



This research was fun and led to many publications

A Configurable Architecture for High-Speed Communication Systems

Visvanathan Subramanian, Joseph G. Tront, Charles W. Bostian, Scot F. Midkiff

WORST-MONTH RAIN ATTENUATION AND XPD STATISTICS FOR SATELLITE PATHS AT 12 GHz

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 40, NO. 3, MARCH 1992

The Dynamics of Rain-Induced Fades

Dennis G. Sweeney and Charles W. Bostian, *Fellow, IEEE*

Dispersion in the 10–30 GHz Frequency Range: Atmospheric Effects and Their Impact on Digital Satellite Communications

W. L. STUTZMAN, T. PRATT, D. M. IMRICH, W. A. SCALES, AND C. W. BOSTIAN

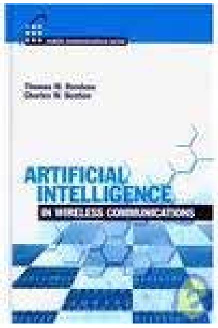
RANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 4

Rain Side-Scatter Interference in the Satellite Links of the 1990's

Fatim Haidara and Charles W. Bostian

Using Site-Diversity Reception to Overcome Rain Depolarization in Millimeter Wave Satellite Communications Systems

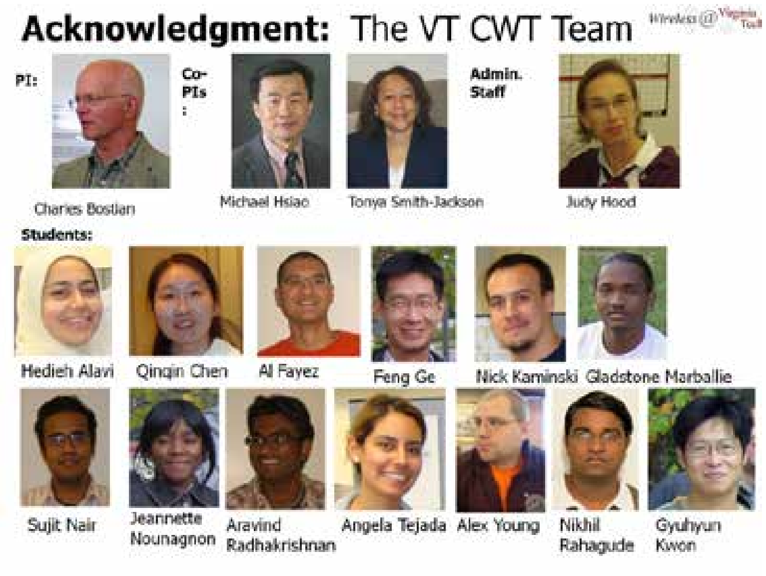
ROBERT E. MARSHALL AND CHARLES W. BOSTIAN, SENIOR MEMBER, IEEE



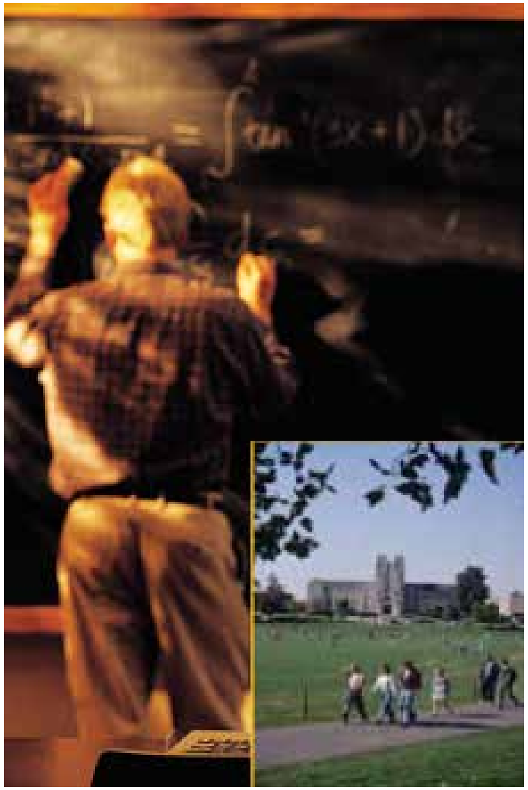
Software Radio-Based Decentralized Dynamic Spectrum Access Networks: A Prototype Design and Experimental Results

Feng Ge*, Aravind Radhakrishnan†, Mustafa Y. ElNainay‡, Qinqin Chen†, Charles W. Bostian†, Allen B. MacKenzie†

BUT the faculty, students and staff members I have worked with are the best part of all! They have taught me a lot – particularly the students!



Of all our activities, the results of teaching last the longest. Some of your former students may remember your teaching 30, 40, or even 50 years from now.



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Center for Wireless Telecommunications

Wireless @ Virginia Tech