Partnership Between Universities & Industrial Labs

Bobby Brar

Electronics Division
Teledyne Scientific Company
Thousand Oak, CA 91320

Nov 16th 2006

bbrar@teledyne.com

Outline

- Why Darpa is important
- Role of the University
- Role of the Industrial Lab
- Rules of Engagement

Darpa as DoD VC

- Central R&D for the Department of Defense
- Fundamental Discoveries to their Military use
- Military Roles and Missions

DoD VC

- Central R&D for the Department of Defense
- Fundamental Discoveries to their Military use
- Military Roles and Missions
- Everything in the context of a PM

DoD VC

- Central R&D for the Department of Defense
- Fundamental Discoveries to their Military use
- Military Roles and Missions
- Everything in the context of a PM
- High-Risk High-Payoff

DoD VC

- Central R&D for the Department of Defense
- Fundamental Discoveries to their Military use
- Military Roles and Missions
- Everything in the context of a PM
- High-Risk High-Payoff
- Adequate funding…

…And Go/No-Go Milestones

Universities have them – they are called Exams

Recent Programs with University Collaborators

More than 50% of Teledyne programs include Universities

ABCS
TFAST
FLARE
gBECi
MIATA
CSAC
SMART
Sb-SLS
TIFT

Recent Programs with University Collaborators

More than 50% of Teledyne programs include Universities

- ABCS DARPA
- TFAST DARPA
- FLARE DARPA
- gBECi DARPA
- MIATA DARPA
- CSAC DARPA
- SMART DARPA
- Sb-SLS
- TIFT DARPA

And a great majority of those are sponsored by Darpa

Outline

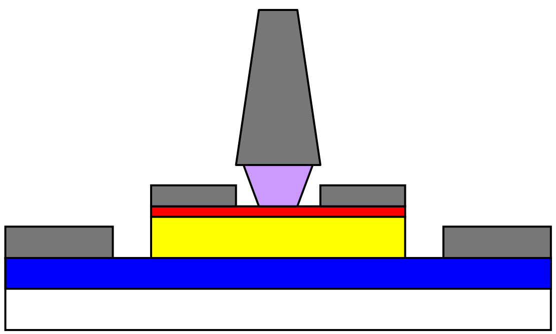
- Why Darpa is important
- Role of the University
- Role of the Industrial Lab
- Rules of Engagement

Role of the University

- They are good at the fundamentals

Collaboration on TFAST

University set the stage: InP HBT Scaling Roadmaps



Parameter	scaling law	Gen. 2 (500 nm)	Gen. 3 (250 nm)	Gen. 4 (125 nm)	Gen 5 (62.5nm)
MS-DFF speed	γ^1	150 GHz	235 GHz	330 GHz	440 GHz
Amplifier center frequency	γ^1	245 GHz	400 GHz	650 GHz	750 GHz
Emitter Width	$1/\gamma^2$	500 nm	250 nm	125 nm	62.5 nm
Resistivity	$1/\gamma^2$	16 Ω-µm²	9 Ω-µm²	4 Ω-µm²	2 Ω-µm²
Base Thickness	$1/\gamma^{1/2}$	300Å	250 Å	212 Å	180 Å
Contact width	$\sim 1/\gamma^2$	300 nm	175 nm	120 nm	70 nm
Doping	γ^0	7 10¹⁹ /cm²	7 10¹⁹ /cm²	7 10¹⁹ /cm²	7 10¹⁹ /cm²
Sheet resistance	$\gamma^{1/2}$	500 Ω	600 Ω	707 Ω	830 Ω
Contact ρ	$1/\gamma^{1/2}$	20 Ω-µm²	10 Ω-µm²	5 Ω-µm²	5 Ω-µm²
Collector Width	$1/\gamma^2$	1.2 µm	0.60 µm	0.37 µm	0.20 µm
Thickness	$1/\gamma$	1500 Å	1060 Å	750 Å	530 Å
Current Density	γ^2	4.5 mA/µm²	9 mA/µm²	18 mA/µm²	36 mA/µm²
$A_{collector}/A_{emitter}$	γ^0	2.4	2.4	2.9	2.8
f_τ	γ^1	370 GHz	530 GHz	730 GHz	1.0 THz
f_{max}	γ^1	490 GHz	801 GHz	1.30 THz	1.5 THz
I_E / L_E	γ^0	2.3 mA/µm	2.3 mA/µm	2.3 mA/µm	2.3 mA/µm
τ_f	$1/\gamma$	340 fs	240 fs	180 fs	130 fs
C_{cb} / I_c	$1/\gamma$	400 fs/V	280 fs/V	250 fs/V	190 fs/V
$C_{cb}\Delta V_{logic} / I_c$	$1/\gamma$	120 fs	85 fs	74 fs	57 fs
$R_{bb}/(\Delta V_{logic} / I_c)$	γ^0	0.76	0.54	0.34	0.39
$C_{je}(\Delta V_{logic} / I_C)$	$1/\gamma^{3/2}$	380 fs	180 fs	94 fs	50 fs
$R_{ex}/(\Delta V_{logic} / I_c)$	γ^0	0.24	0.24	0.24	0.24

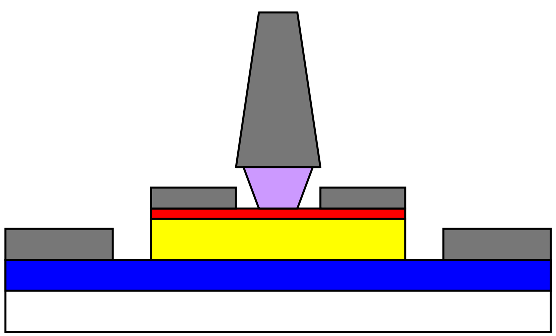
key figures of merit for logic speed

Key scaling challenges
emitter & base contact resistivity
current density → device heating
collector-base junction width scaling
& Yield !

TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

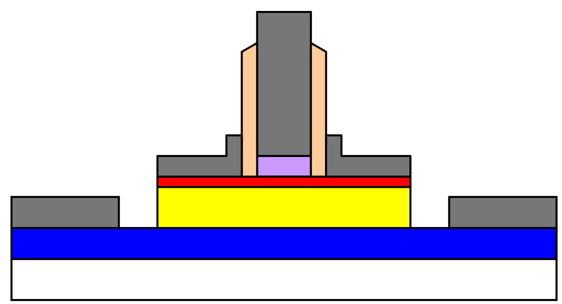
Three+ Versions of Technology

Scaled mesa-HBT



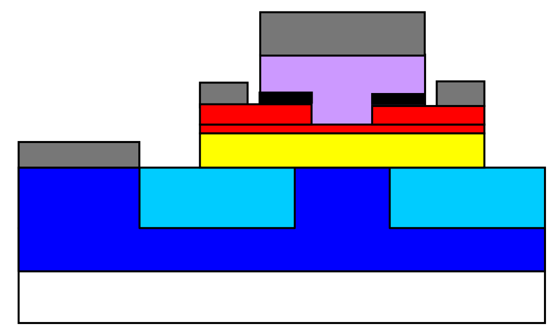
- High performance, low yield technology
- Difficult to scale to W_E < 0.3 um
- Processed for epitaxy and circuit validation
- Record device results obtained at UCSB

S3 Technology



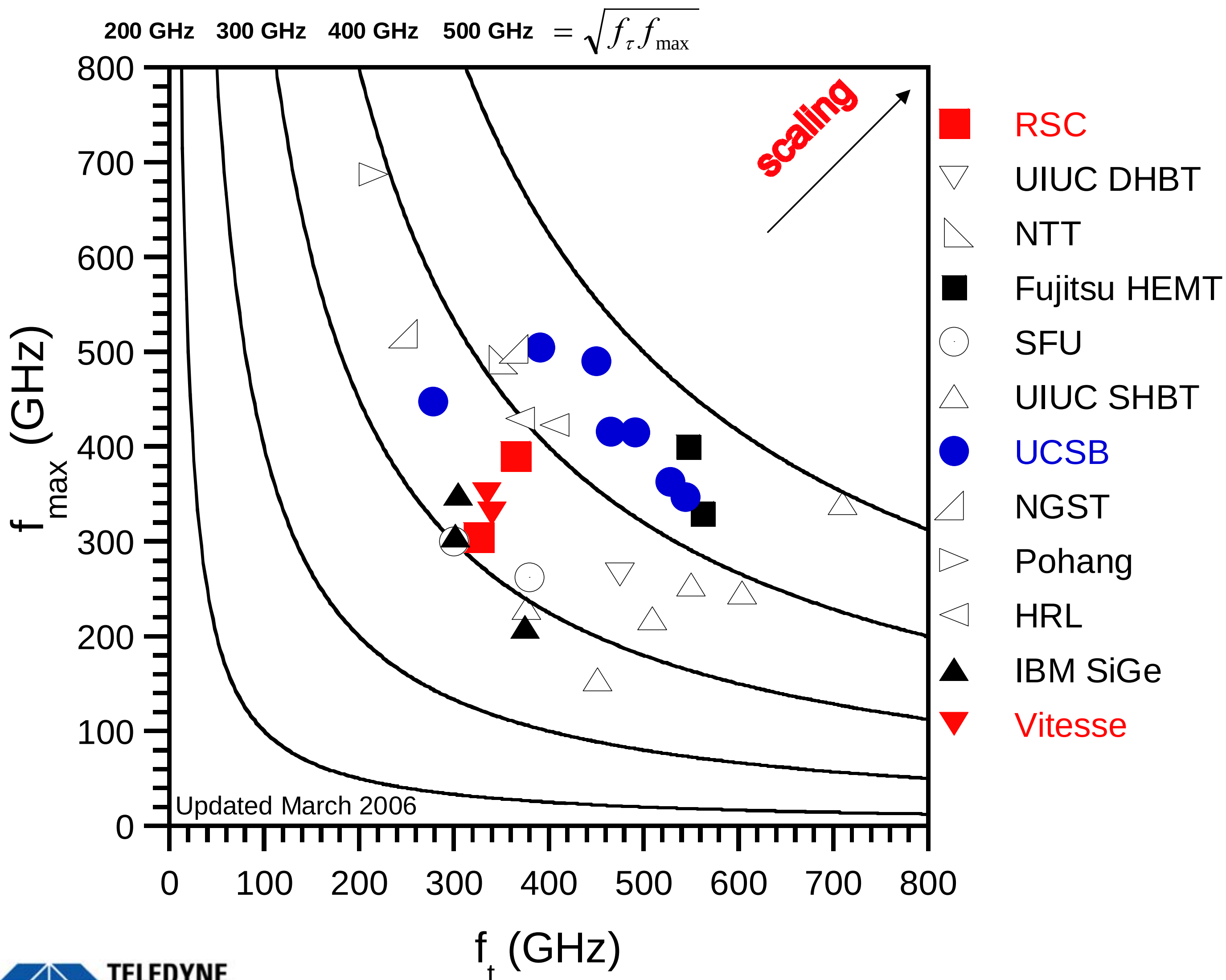
- Eliminate Liftoff from Base-Emitter Junction Formation. High Yield.
- Process scalable to W_E < 0.25 um
- Integrated improved multi-level interconnect process
- Platform for fabrication of DDS and divider circuits

Regrowth Technology



- Process modules that can be added to HBT technology
- Emitter regrowth for high yield, low ρ_{ex}
- Pedestal implant for reduced C_{cb}
- Subcollector implant for reduced C_{cb}
- Process development at UCSB

University Led with Devices and Process Modules
Industry focused on ICs



popular metrics :

f_τ or f_{max} alone

$(f_\tau + f_{max})/2$

$\sqrt{f_\tau f_{max}}$

$(1/f_\tau + 1/f_{max})^{-1}$

much better metrics :

power amplifiers :

PAE, associated gain,

mW/μm

low noise amplifiers :

F_{min}, associated gain,

digital :

f_{clock}, hence

$(C_{cb}\Delta V / I_c)$,

$(R_{ex} I_c / \Delta V)$,

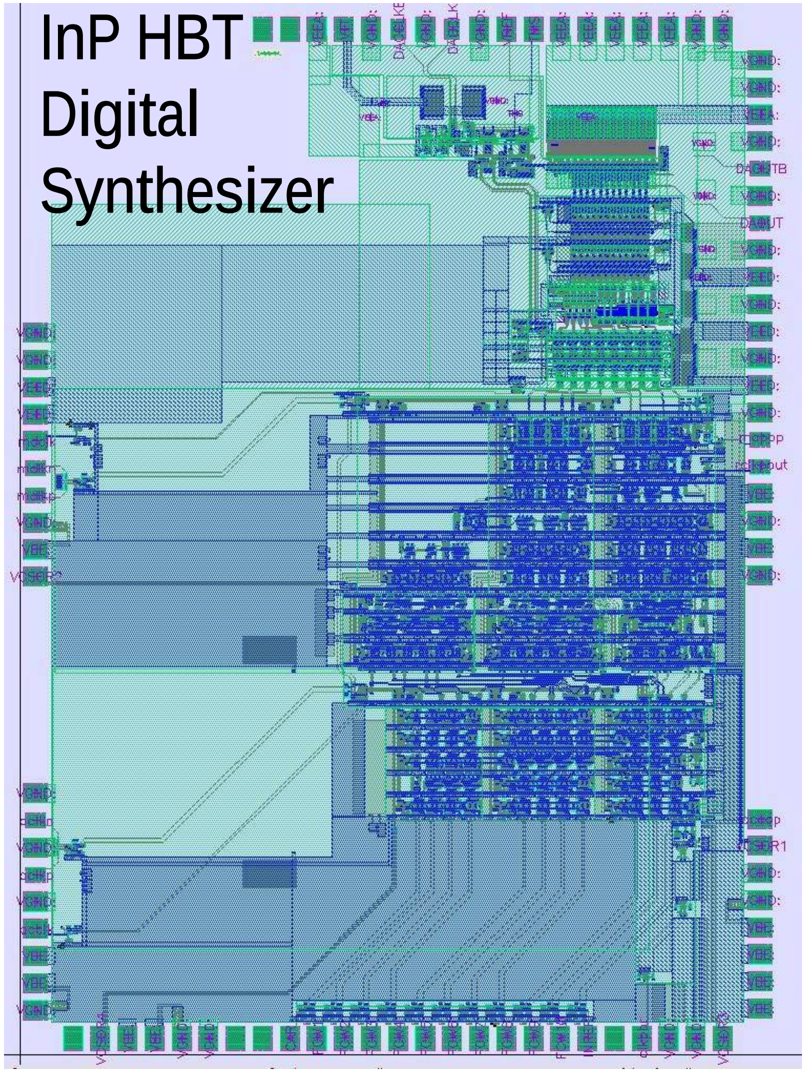
$(R_{bb} I_c / \Delta V)$,

$(\tau_b + \tau_c)$

Multiple circuit Iterations (takes a few years)
The right role for industry

<u>New Technologies require</u>

- Materials development
- Process development
- Process qualification
- Design kit development
- Yield improvement
- Complex circuit demonstrations

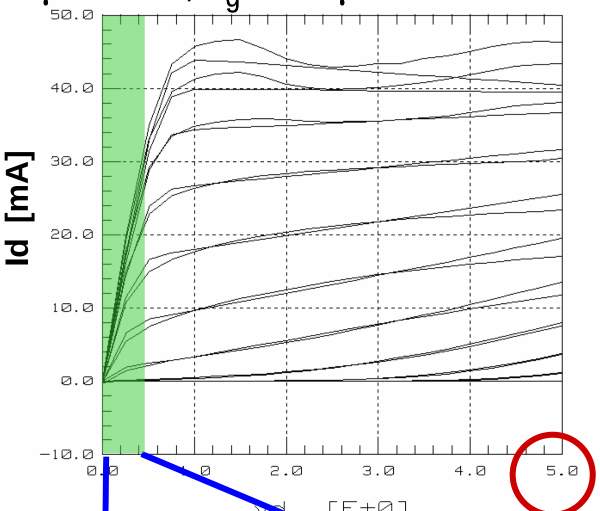


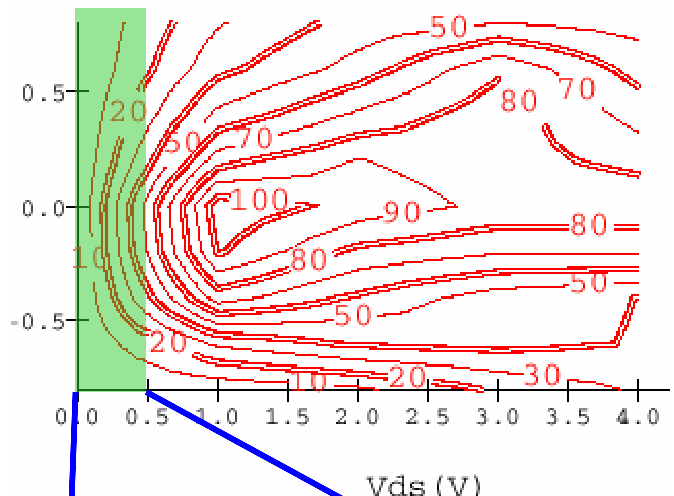
Role of the University

- They are good at the fundamentals
- They are more inclined to be objective

ABCS HEMT technology enables MMW high-performance LNAs at 40x lower power than GaAs

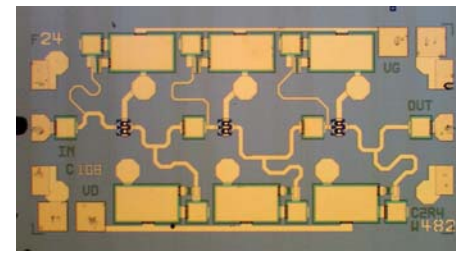
80μm wide, L_g=0.18 μm GaAs PHEMT → 100GHz Ft at Vds>1V → Ka-Band GaAs LNA



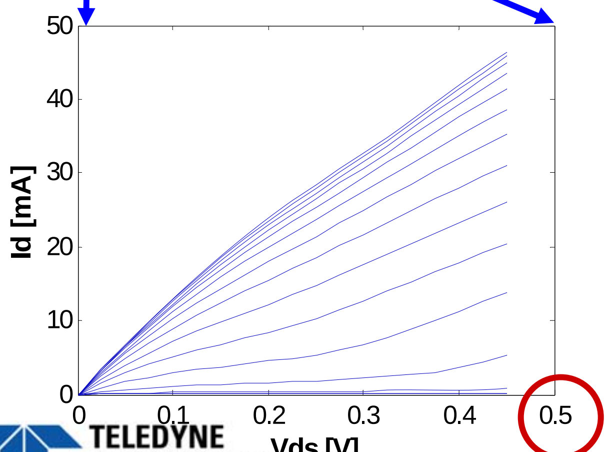


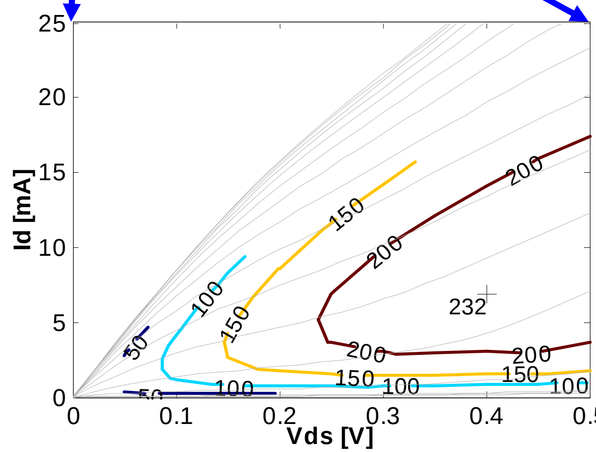
4V, 40mA Fets

Gain = 20-27dB, Power=160mW



40μm wide, L_g=0.2 μm ABCS HEMT → 100GHz Ft at Vds = 0.1V → Ka-Band ABCS LNA

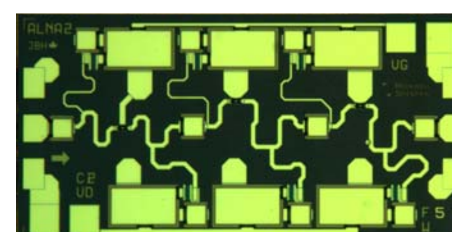




0.35V, 12mA Fets

Gain = 28dB, NF < 2.2 dB

Power=4.2mW



1/10th Voltage scale = same RF performance

TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

Role of the University

- They are good at the fundamentals
- They are more inclined to be objective
- They need to publish, publish, publish

Role of the University

- They are good at the fundamentals
- They are more inclined to be objective
- They need to publish, publish, publish
- They can move fast
- They have students
- (Everything in the University is in the context of a student)

Role of the University

- They are good at the fundamentals
- They are more inclined to be objective
- They need to publish, publish, publish
- They can move fast
- They have students
- (Everything in the University is in the context of a student)

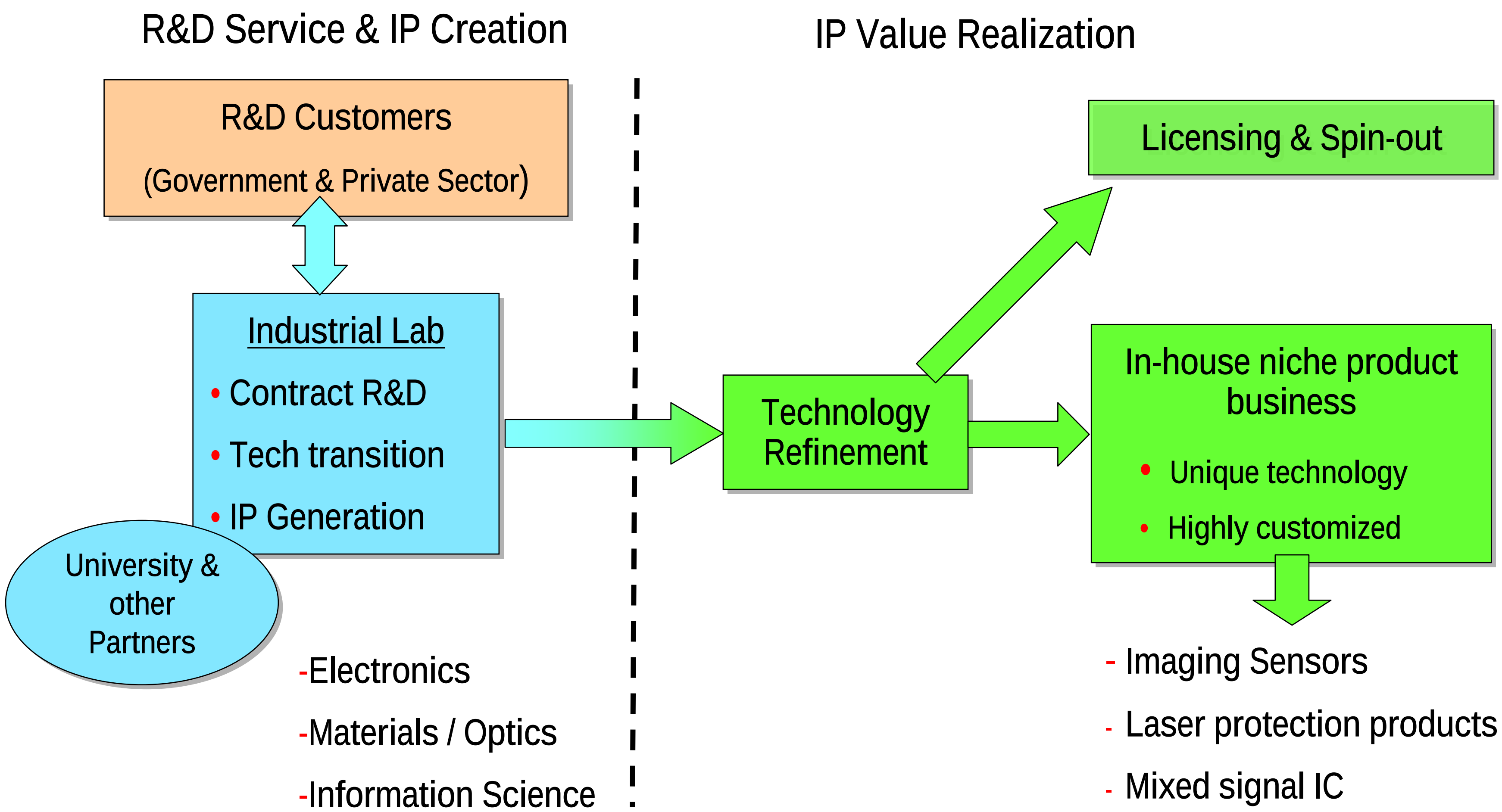
Outline

- Why Darpa is important
- Role of the University
- Role of the Industrial Lab
- Rules of Engagement

Role of the Industrial Lab

– Industrial Lab (Teledyne Scientific's) Business Model

Teledyne Business Model



Role of the Industrial Lab

- Industrial Lab (Teledyne Scientific's) Business Model
- Overlap is very important

Teledyne has a long history of relationships with Universities

- Larry Coldren
- Steve Long
- Pochi Yeh
- Jim Harris
- Elliot Brown
- John Bowers
- Dan Dapkus
- Wen-Wang
- David Clark
- Peter Asbeck
- Herbert Kroemer
- Frank Chang
- Dave Rutledge
- …

UCSB

UCLA Bruins

USC

CALTECH

UCSD

STANFORD

CU

SANTA CRUZ

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Role of the Industrial Lab

– Industrial Lab (Teledyne Scientific's) Business Model
– Overlap is very important
– Truth is stranger than fiction

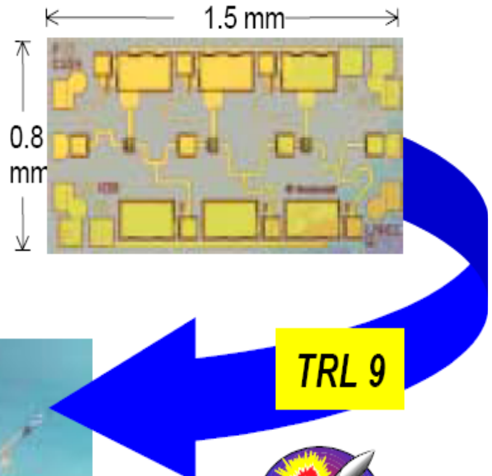
Role of the Industrial Lab

- Industrial Lab (Teledyne Scientific's) Business Model
- Overlap is very important
- Truth is stranger than fiction (profit is not a four-letter word)

Ka-Band GaAs PHEMT LNA Mil-B LRIP

Ka-band LNA MMIC
Mil-Class B Reliability
(0.18 µm GaAs PHEMT)

24 dB Gain
2.5 dB NF
at 35 GHz



LNA for PAC-3 missile

PAC-3 HIT TO KILL

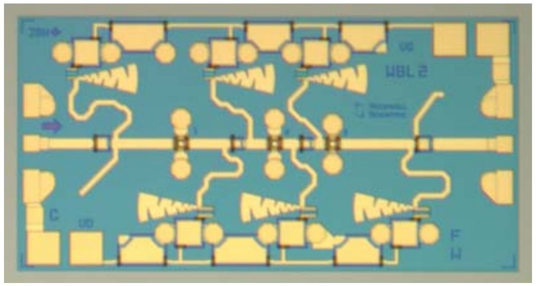
BOEING

LOCKHEED MARTIN

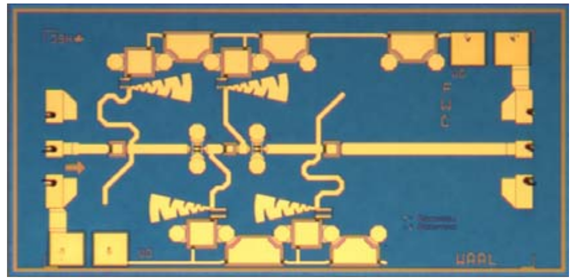
- Supplied MMICs from TSC Fab for 10 years
- Qty 500/year at about $1000/die
- Mil Spec-B
- Last delivery 2003

High Performance Technologies at Teledyne

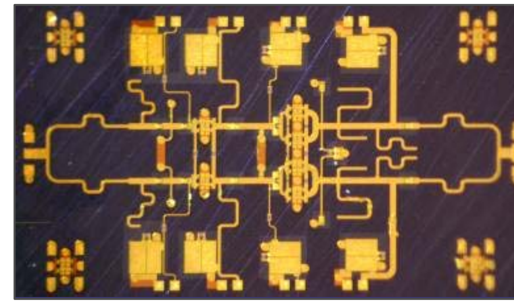
InP HEMT



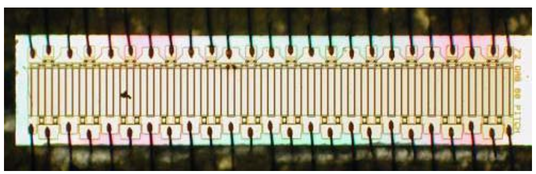
ABCS HEMT



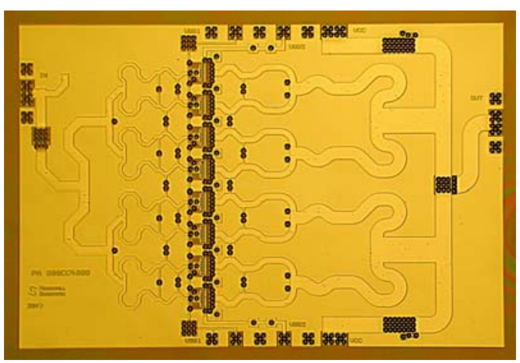
GaN HEMT



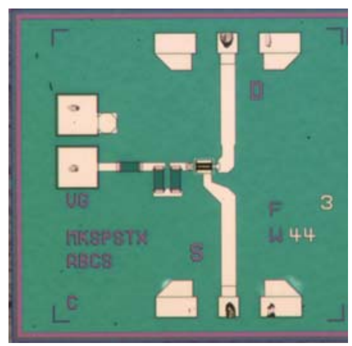
SiC MESFET



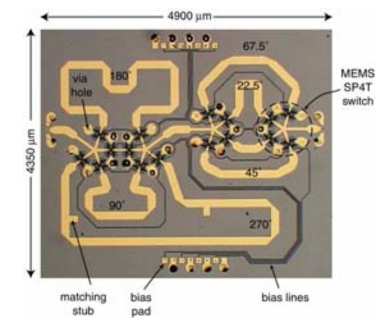
InP HBT

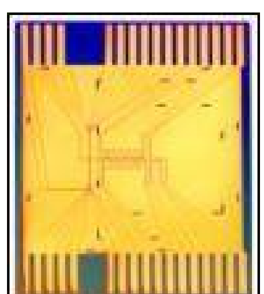


ABCS HEMT Switches



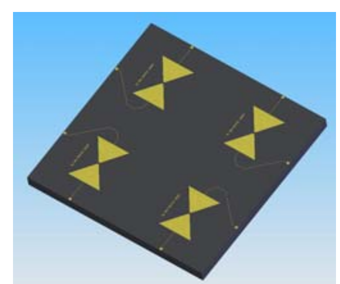
MEMS Switches





Atom Chips

mmW Detectors



SiC Schottkys and FETs

TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

Mixed-Signal Integrated Circuits

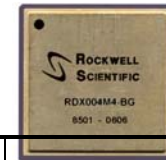



TH	Fclk (GHz)	Bandwidth (GHz)	Hold Time (ns)	FSR (V)	Supply (V)	Power (W)	Availability	Notes
RTH010	1	9	10	1.0	-5.2/5.0	1.6	Now	Dual Track and Hold
RTH020	1	12	10	1.0	-5.2/5.0	1.6	Now	Dual Track and Hold
RTH030	1	8	60	1.0	-5.2/5.0	1.9	Now	Low Noise
RTH040	1	11	50	1.0	-5.2/5.0	1.6	Now	Longer Hold Time
RTH050	1	15	50	1.0	-5.2/5.0	1.6	Now	Dual Track and Hold
RTH060	4	16	5	2.0	-5.2/5.0	1.5	Now	Dual Track and Hold

DAC	Resolution (Bit)	Fclk (GHz)	Bandwidth (GHz)	SFDR (dB)	Supply (V)	Power (W)	Availability	Notes
RDA012	12	1	0.5	65	-5.2	1.8	Now	ECL inputs
RDA012LP	12	1.5	0.75	60	3.3	0.7	Now	Low Power
RDA012M4	12	1.3	0.65	50	-5.2/3.3	3.4	Now	4:1 MUXDAC
RDA012M4MS	12	1.3	0.65	50	-5.2/3.3	3.4	Now	4:1 Master Slave MUXDAC
RDA012RZ	12	1	1	55	-5.2/3.3	3.6	Now	Return to Zero
RDA112RZ	12	1.5	1.5	50	-5.2/3.3	3.6	Now	Return to Zero



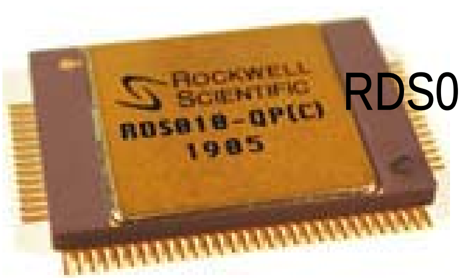

ADC, DDFS and Logic



ADC	Resolution (Bit)	Fclk (GHz)	Bandwidth (GHz)	SFDR (dB)	Supply (V)	Power (W)	Availability	Notes
RAD004	6	4	6	30	-5.2/3.3/5.0	6.0	Samples	6Bit 4GS/s Grey Code Output

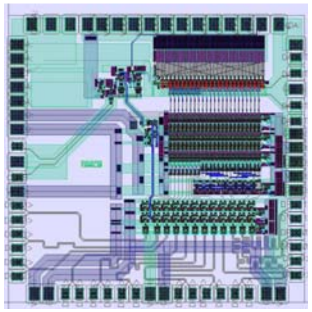
DDFS	Resolution (Bit)	Fclk (MHz)	Tunning Word (Bits)	I/O Interface	Supply (V)	Power (W)	Availability	Notes
RDS010	12	900	32	Parallel	3.3	2.5	Now	32Bit FCW, 12Bit PCW

LOGIC	Bus Width (Bit)	Fclk (GHz)	Control Interface	I/O	Supply (V)	Power (W)	Availability	Notes
RDX004M4	10	4	Parallel	LVDS	-5.2/3.3	6.0	Samples	1:4 10Bit Demultiplexer

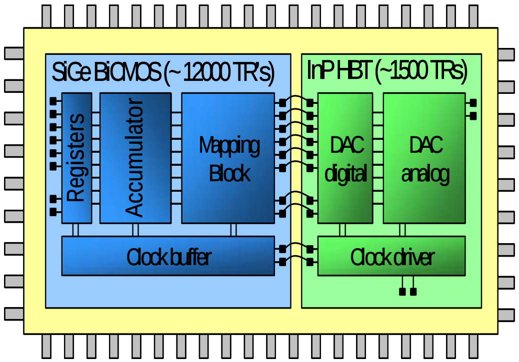


RDS010

Present State of the Art
60dB SFDR at 1GHz



4GS/s InP DAC



4GS/s Hybrid DDS

Role of the Industrial Lab

- Industrial Lab (Teledyne Scientific's) Business Model
- Overlap is very important
- Truth is stranger than fiction (profit is not a four-letter word)
- Industrial users provide specifications

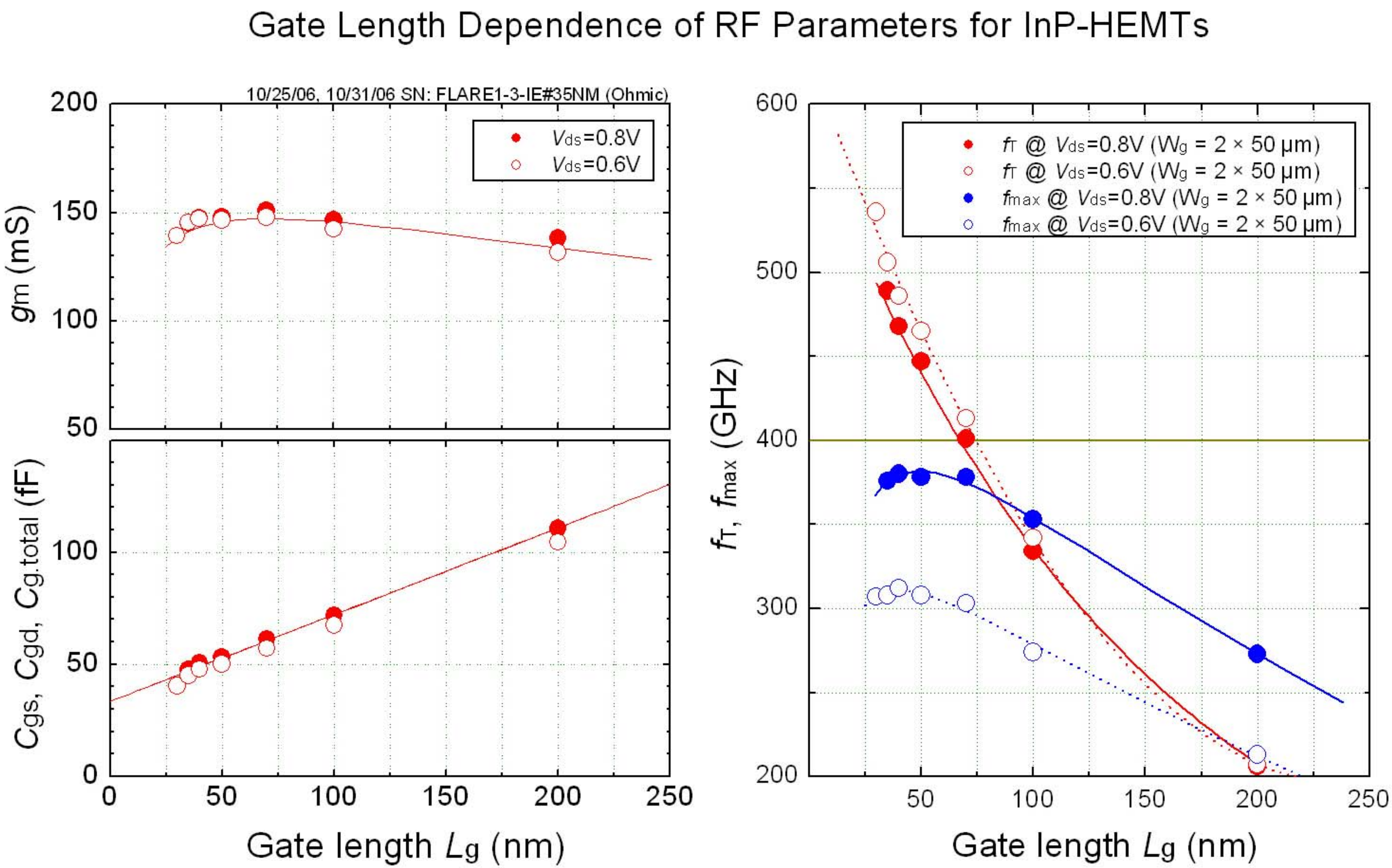
Role of the Industrial Lab

- Industrial Lab (Teledyne Scientific's) Business Model
- Overlap is very important
- Truth is stranger than fiction (profit is not a four-letter word)
- Industrial users provide specifications
- Technology transition is paramount

Role of the Industrial Lab

- Industrial Lab (Teledyne Scientific's) Business Model
- Overlap is very important
- Truth is stranger than fiction (profit is not a four-letter word)
- Industrial users provide specifications
- Technology transition is paramount

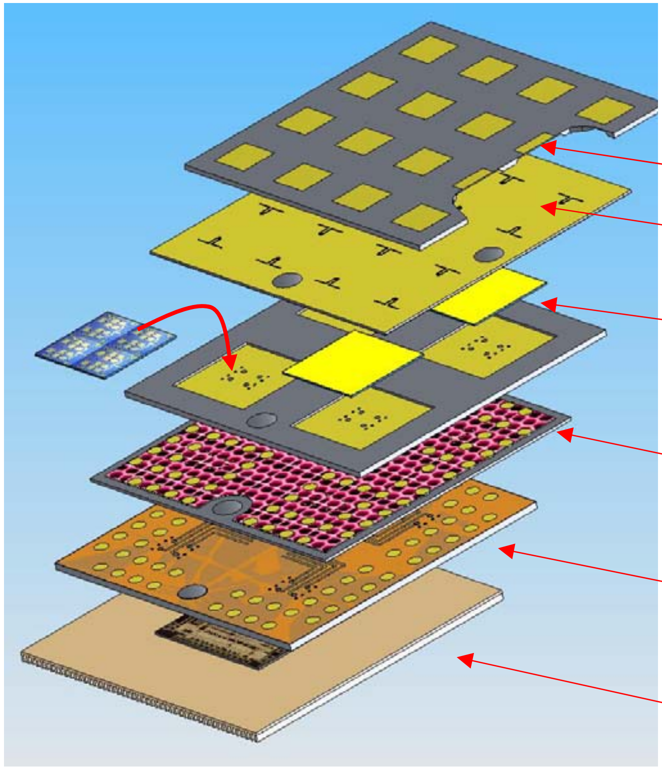
Precise process control enables understanding of scaling behavior through Lg-dependence



TELEDYNE
SCIENTIFIC COMPANY
A Teledyne Technologies Company

Scalable Millimeter-wave Architectures for Reconfigurable Transceivers (SMART)

Our goal is to demonstrate a 44-GHz Transceiver Array that integrates all required functionality from Silicon digital beam control and rf beamforming electronics to InP ultra-high power amplifiers and sensitive receivers, with wide-scan apertures, into a compact, rugged, micromachined three-dimensional structure.



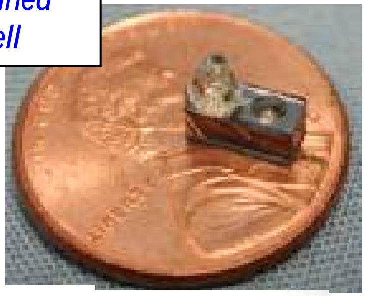
SLIC Stack	Function
Planar antenna layer	Compact multi layer patch antenna provides high isolation from each element with large bandwidth and multiband functionality. Antenna efficiencies of 75% is possible due to multi-stack coupling design.
III-V Chip Interposer	SMMW InP DHBT transistors are used at Q-band to provide the heart of a highly efficient compact power amplifiers with 10W/cm^2 power density. This is achieved by multistack low profile 3D BCB stripline transmission line impedance matching
Heat Spreader	The generated heat throughout SLIC is transferred through strategically located thermal vias to the heat spreader. This is a novel passive two-phase micro-channel array covered with a micro/nano wick structure increasing the effective surface area by > 10x
IC Interconnect layer	The Interposers integrate all the components together. Impressive array of via technologies will be used to deliver RF, bias and control signals to the entire SLIC stack. Low resistance multistack connections will be used to eliminate cross talk and improve efficiency of the SLIC
Silicon beam forming IC	Digital beam forming eliminates long transmission line phase-shifting networks within the beamsteerer, and exploits active transistor circuits for all functions. This is enabled by switching an efficient array of MxM mixers fabricated by Jazz SiGe process.

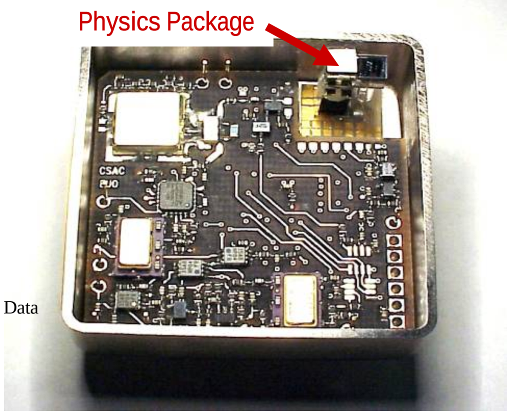
TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

RSC Chip Scale Atomic Clock Program

- RSC team developing compact, high-performance atomic time/frequency standard for DoD system insertion
- Aggressive program goals:
  - Fractional frequency stability $<10^{-11}$ (@1hr integration time)
  - Size $<1cm^3$
  - Power consumption <30mW
- Interim prototypes demonstrate excellent performance:
  - Size <10cc, power <200mW, Allan Deviation <6x10-11 (100sec)

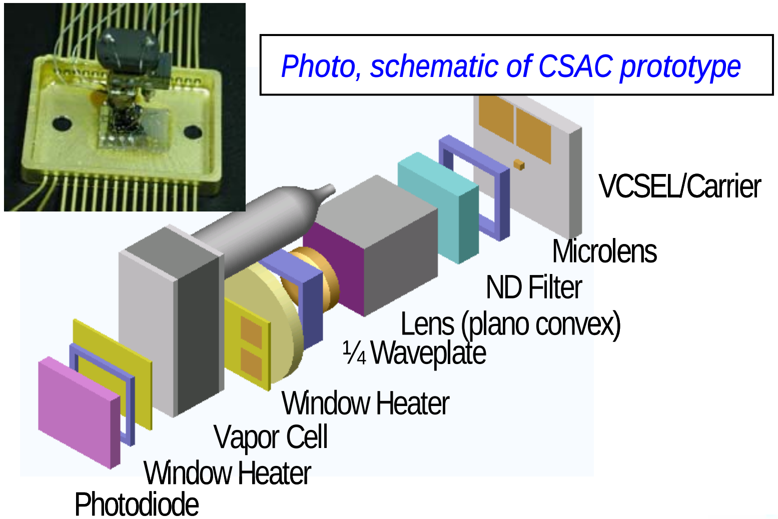
Micromachined Vapor Cell

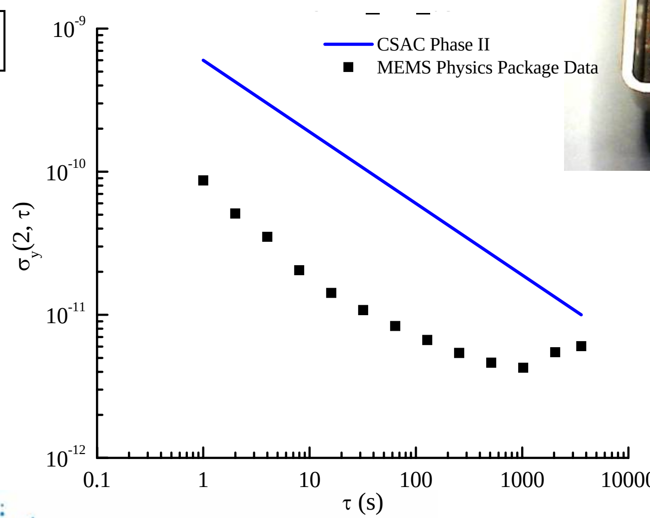




Compact Control Electronics

Photo, schematic of CSAC prototype





Measured Allan Deviation of CSAC

TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

Agilent Technologies

Rockwell Collins

Outline

- Why Darpa is important
- Role of the University
- Role of the Industrial Lab
- Rules of Engagement

Rules of Engagement (Univeristy + Industry)

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes

Rules of Engagement

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes
- Think long-term – put it on the shelf

Rules of Engagement

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes
- Think long-term – put it on the shelf

- Keep it simple (distill or drown)

Rules of Engagement

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes
- Think long-term – put it on the shelf

- Keep it simple (distill or drown)

Rules of Engagement

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes
- Think long-term – put it on the shelf

- Keep it simple (distill or drown)
- No shopping lists

Rules of Engagement

- Partner with industry (different roles)
- Who is in the critical path?
- Who is the prime contractor?
- Watch out for stovepipes
- Think long-term – put it on the shelf

- Keep it simple (distill or drown)
- No shopping lists
- Don’t beat a dead horse

Summary

University + Darpa + Industry

Summary

University + Darpa + Industry

= A ~perfect partnership

bbrar@teledyne.com
805-373-4709 (W)