CICC

IEEE Custom Integrated Circuits Conference

IC and Array Technologies for 100-300GHz Wireless

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Acknowledgements

Systems


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Networks, Applications, MIMO, Power


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UC Santa Barbara
MIMO algorithms
Imaging algorithms
Compressive imaging


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MIMO algorithms
VLSI MIMO
digital beamforming


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USC
100-300GHz propagation measurements


Danijela Cabric
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MIMO algorithms (funding via CONIX)

ICs


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mm-wave CMOS: hub
mm-wave arrays
mm-wave MIMO


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efficient PAs
III-V arrays


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140-300GHz SiGe ICs


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high-frequency packaging


Gabriel Rebeiz
UC San Diego
mm-wave CMOS: handset
mm-wave arrays


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Cornell
N-path mixers
MIMO ADCs


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design automation
equalizers


Tim Fisher
UCLA
advanced packaging materials


Andrew Kummel
UCSD
advanced packaging materials

Transistors


Umesh Mishra
UC Santa Barbara
N-polar GaN HEMTs for 140, 210GHz


Huili (Grace) Xing
Cornell
AlN/GaN HEMTs for 140, 210GHz


Susanne Stemmer
UC Santa Barbara
transistors in novel materials


Debdeep Jena
Cornell
GaN HEMTs on Si


Srabanti Chowdhury
UC Davis
Diamond cooling for GaN

SRC®
JUMP
ComSenTer
COMMUNICATIONS SENSING TERAHERTZ

Massive MIMO demo.

Borivoje Nikolic
UC Berkeley
VLSI design automation
VLSI MIMO processors

Compressive imaging

Amin Arbabian
Stanford
140GHz radar chipsets and arrays

140/210/280GHz arrays for demos.

Mark Rodwell
UC Santa Barbara
THz HBTs for PAs
THz HEMTs for LNAs

Also:
Kyocera: D. Kim, H. Horikawa, M. Imayoshi.
Samsung: G. Xu, N. Sharma, S. Abu-Surra, W. Choi
Pi-Radio: A. Dhananjay,
GlobalFoundries: 22nm SOI CMOS ICs

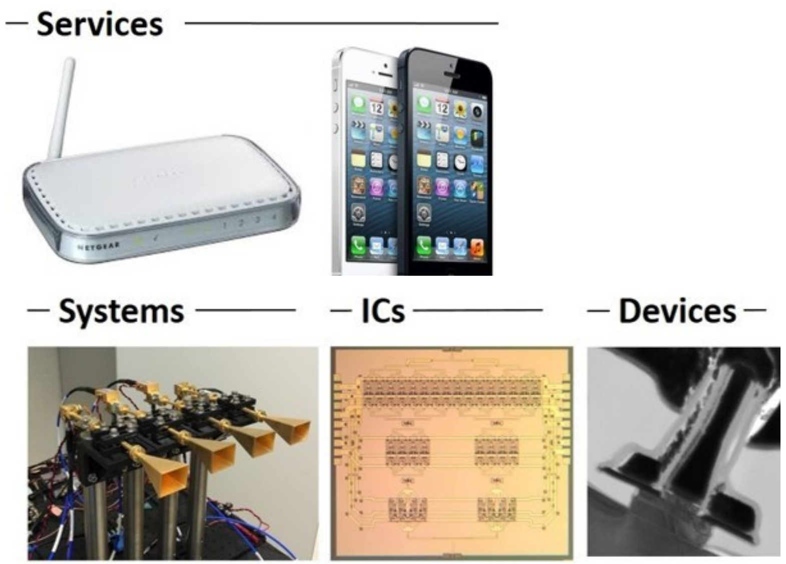
ANALOG DEVICES
IBM
arm
NORTHROP GRUMMAN
NSF
Raytheon Technologies
DARPA
tsmc
EMD PERFORMANCE MATERIALS
LOCKHEED MARTIN
SAMSUNG
SK hynix
Micron
intel
NIST

100-300GHz Wireless

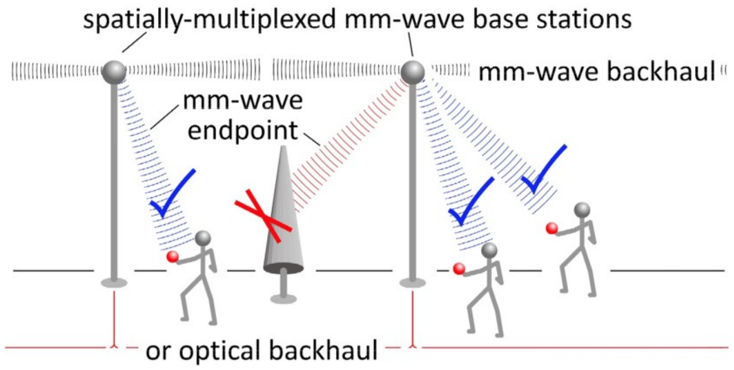
Wireless networks: exploding demand.

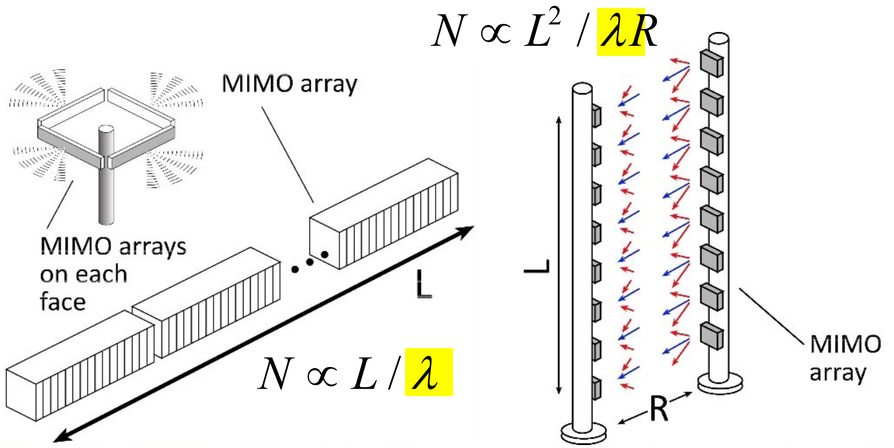
Immediate industry response: 5G.
~1~40 GHz ("5G?")
~40~100GHz ("5.5G ?")
increased spectrum, extensive beamforming

Next generation might be above 100GHz.. (?)
greatly increased spectrum, massive spatial multiplexing



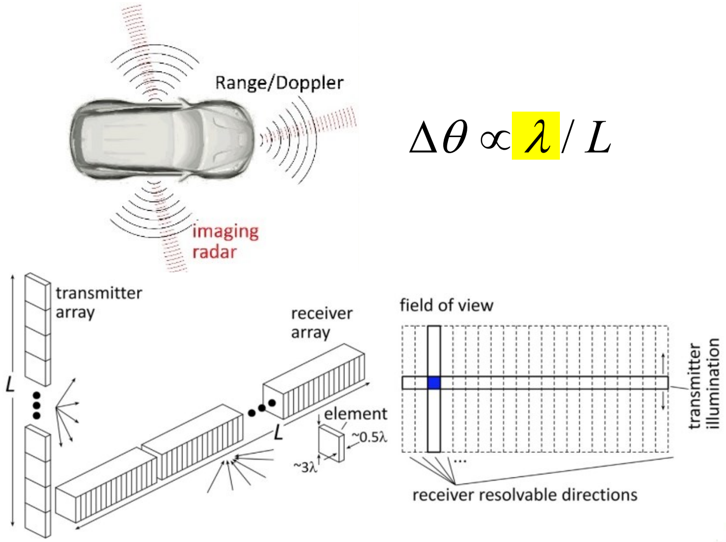
100-300GHz carriers, massive spatial multiplexing
→ **Terabit hubs and backhaul links, high-resolution imaging radar**





$N \propto L^2 / \lambda R$

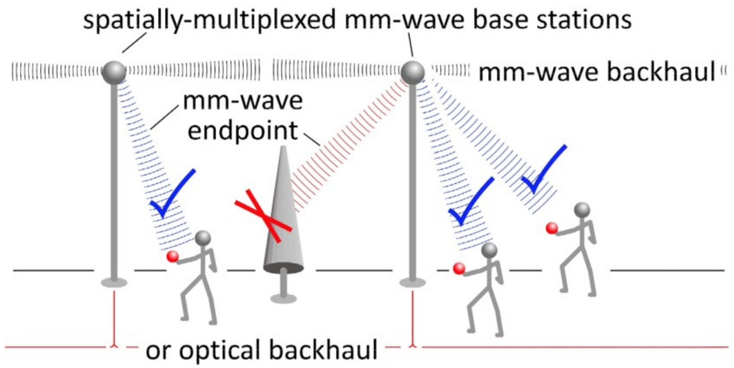
$N \propto L / \lambda$

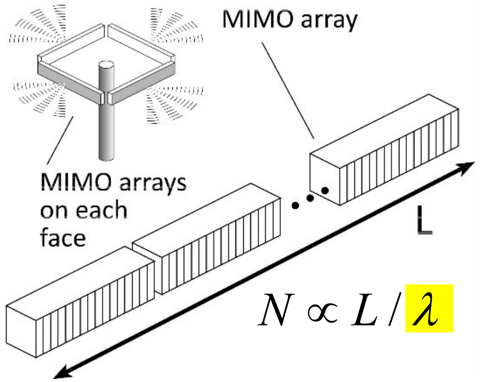


$\Delta\theta \propto \lambda / L$

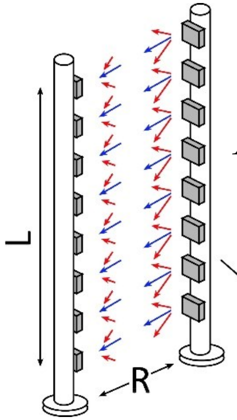
Benefits of Short Wavelengths

Communications: Massive spatial multiplexing, massive # of parallel channels. Also, more spectrum!

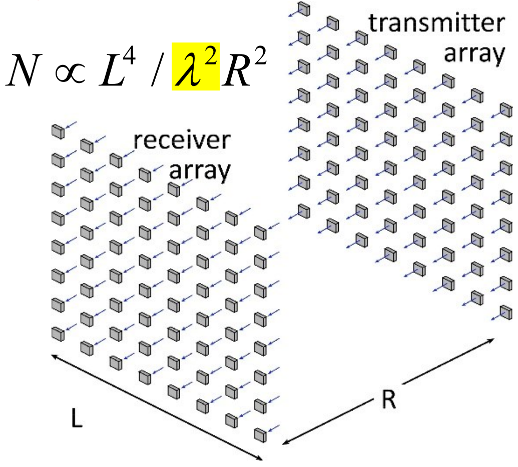




$N \propto L / \lambda$

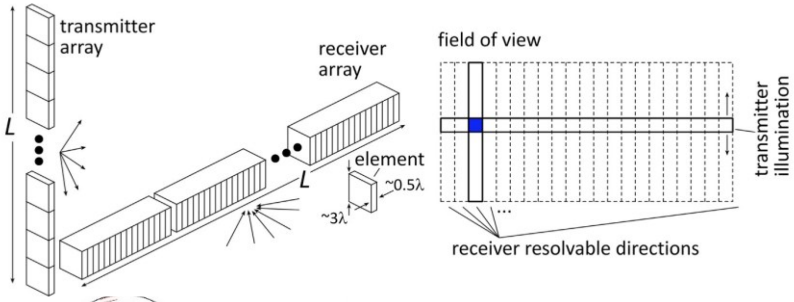


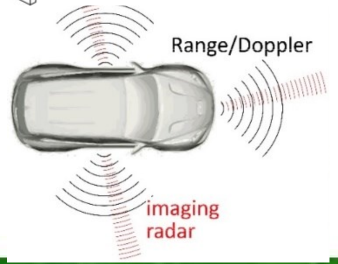
$N \propto L^2 / \lambda R$



$N \propto L^4 / \lambda^2 R^2$

Imaging: very fine angular resolution





$\Delta\theta \propto \lambda / L$

But:

High losses in foul or humid weather.

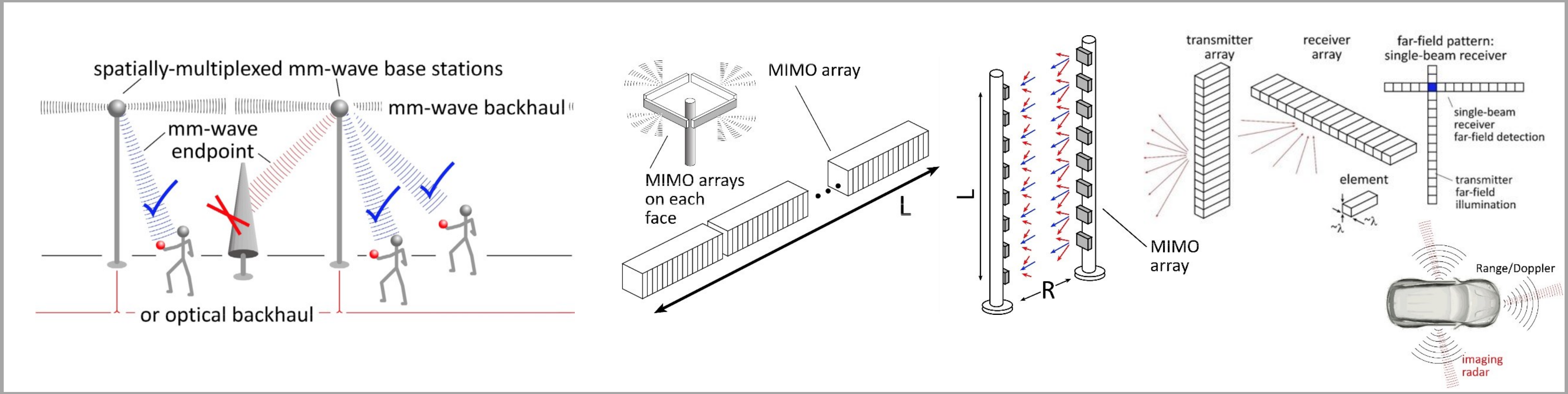
High λ^2/R^2 path losses.

ICs: poorer PAs & LNAs.

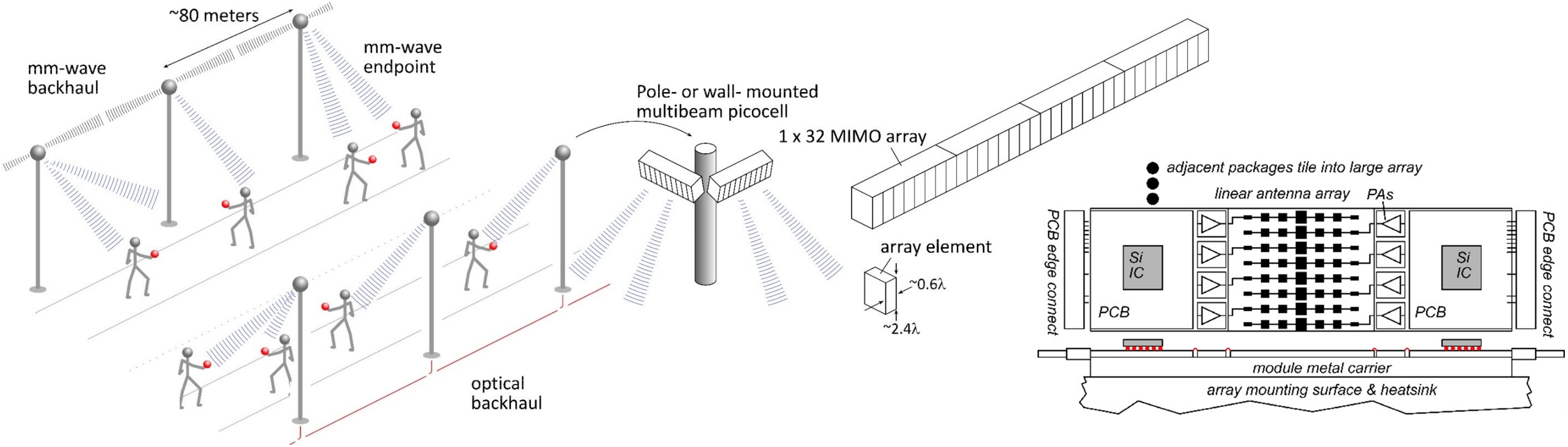
Beams easily blocked.

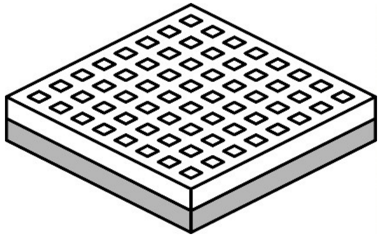
***100-340GHz wireless:
terabit capacity,
short range,
highly intermittent***

Applications



140GHz Moderate-MIMO hub





Handset:
8 × 8 array
(9×9mm)

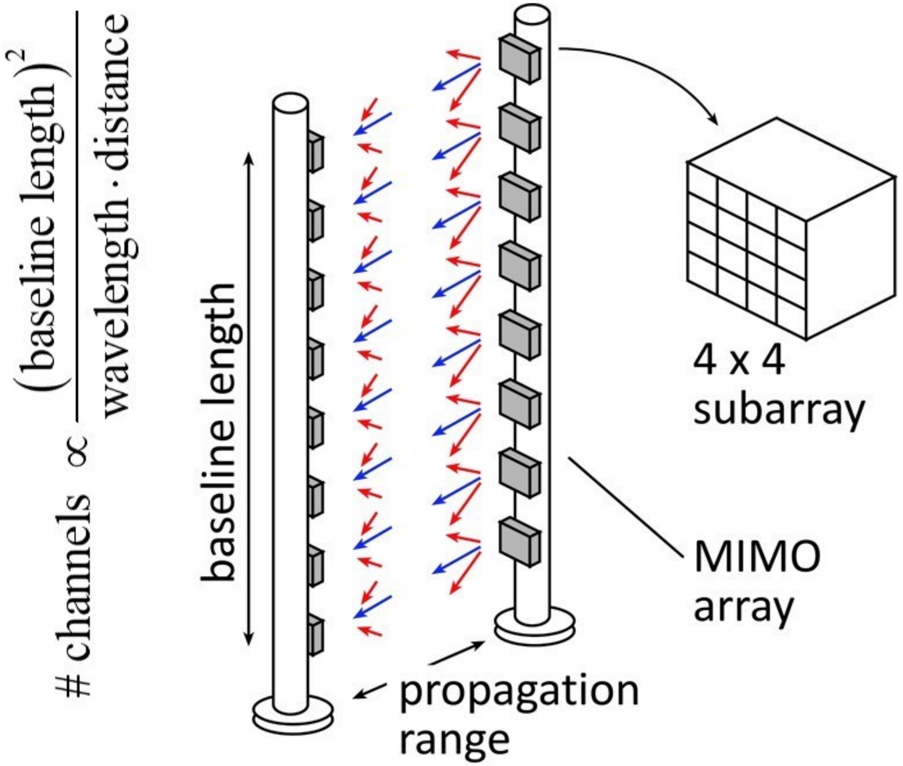
If demo uses 32-element array (four 1×8 modules):

16 users/array. P_{1dB}=21 dB$_m$ PAs, F=8dB LNAs

1,10 Gb/s/beam→ 16, 160 Gb/s total capacity

70, 40 m range in 50mm/hr rain with **17**dB total margins

210 GHz, 640 Gb/s MIMO Backhaul

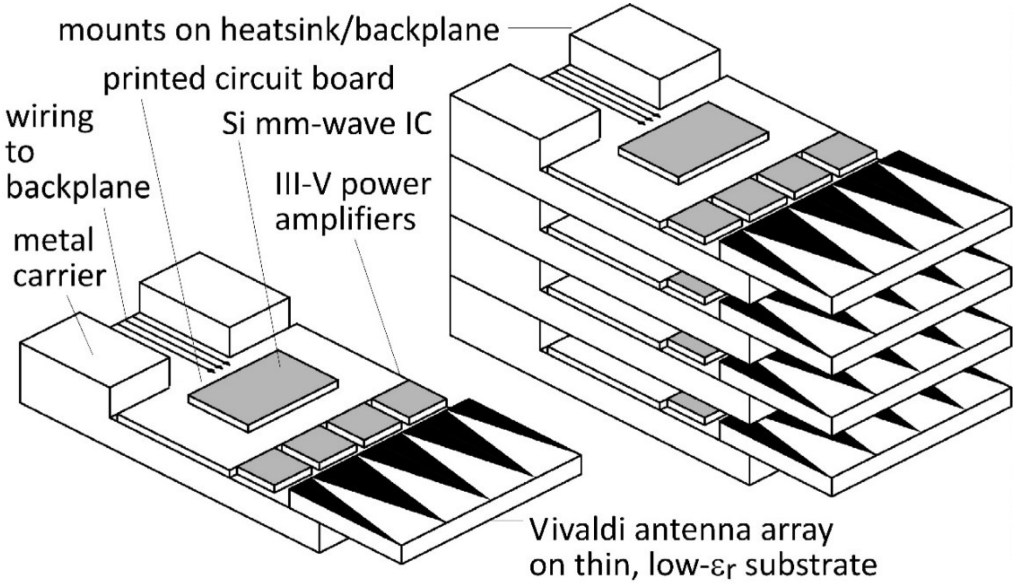


8-element MIMO array

2.1 m baseline.

80Gb/s/subarray→ 640Gb/s total

4 × 4 sub-arrays → 8 degree beamsteering



Key link parameters

500 meters range in 50 mm/hr rain; 23 dB/km

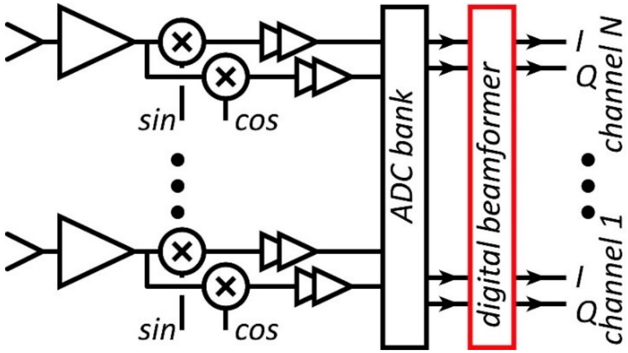
20 dB total margins:

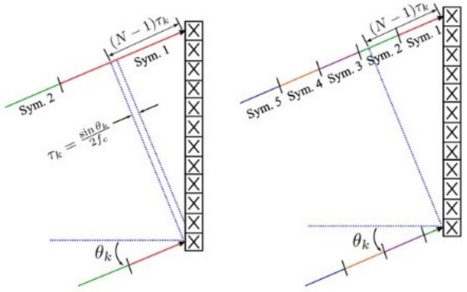
packaging loss, obstruction, operating,
design, aging

PAs: 18dBm $=P_{1dB}$ (per element)

LNAs: 6dB noise figure

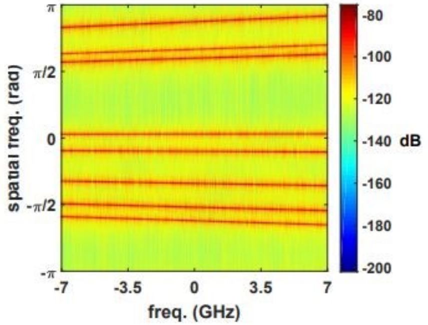
Systems



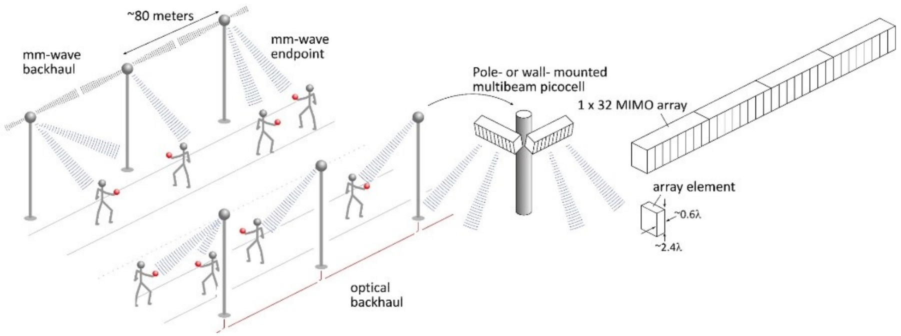


(a) Narrowband scenario.

(b) Wideband scenario.



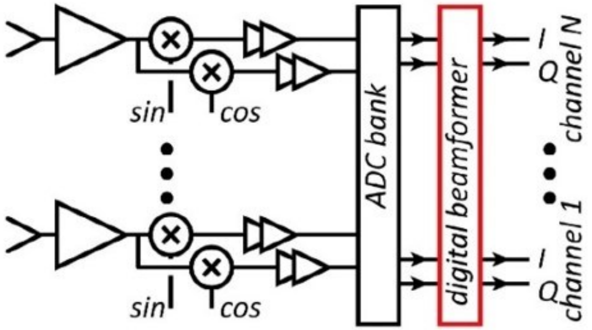
MIMO System Design



ADCs/DACs[1]: QPSK needs only 3-4 bit ADC/DACs

N ADC bits, M antennas, K signals: $\text{SNR}=6N+1.76+10\cdot\log_{10}(M/K)$

3 bits, $(M/K)=2 \rightarrow$ SNR=23 dB. QPSK needs 9.8 dB.



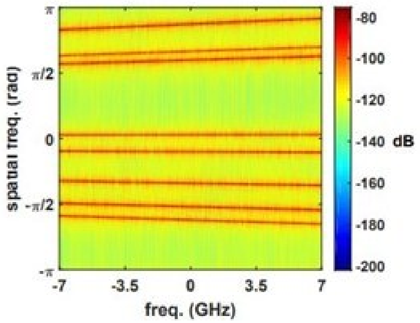
Linearity[1]: Amplifier P_{1dB} need be only 4 dB above average power

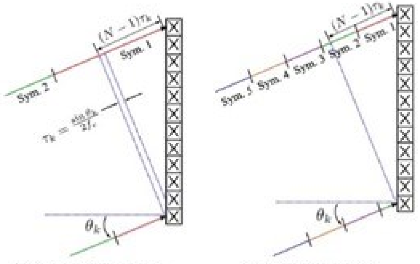
Phase noise[2,3]: Requirements same as for SISO

Efficient digital beamforming[4,5]: beamspace algorithm

Efficient VLSI digital beamformer implementation[6]: low-resolution matrix

Efficient beamforming in broadband arrays[7]: combined spatial & temporal FFTs.





(a) Narrowband scenario.

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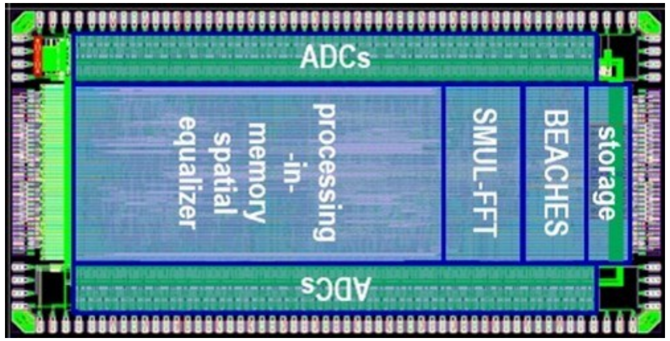
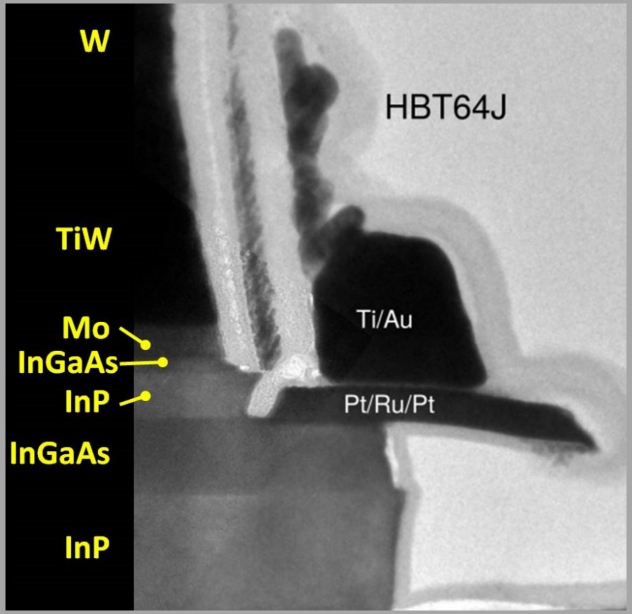
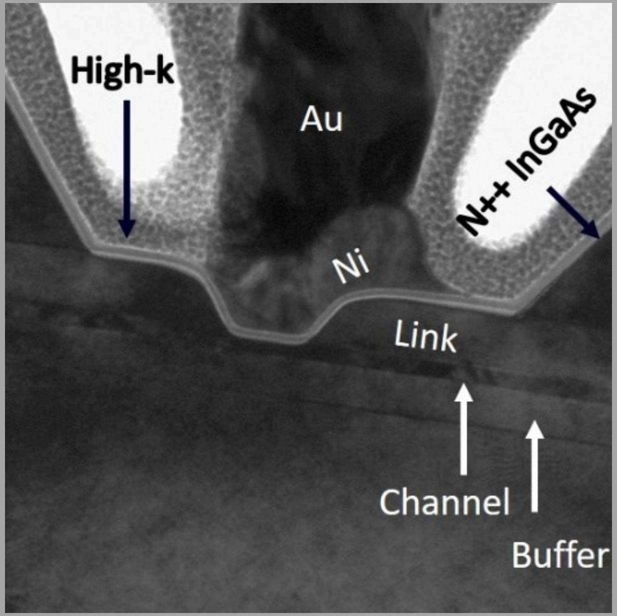
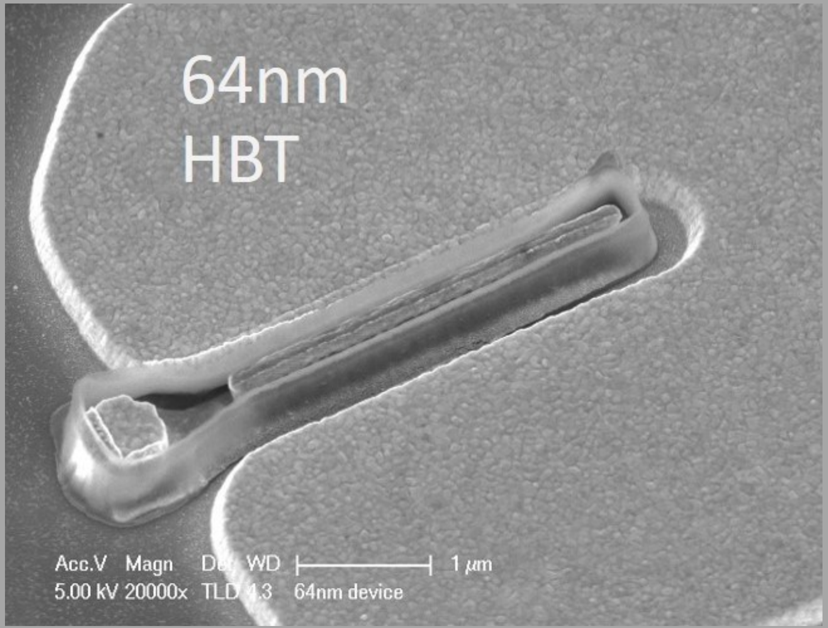


1) M. Abdelghany et al, IEEE Trans. Wireless Comm, Sept. 2021
2) M. E. Rasekh et al, IEEE Trans. Wireless Comm, Oct. 2021
3) A. Puglielli et al, 2016 IEEE ICC
4) M. Abdelghany, et. al, , 2019 IEEE SPAWC
5) S. H. Mirfarshbafan et al, IEEE Trans CAS 1, 2020
6) O Castañeda Fernández et. al, 2021 ESSCIRC
7) M. Abdelghany et al 2019 IEEE GLOBECOM

Transistors







Transistors for 100-300GHz

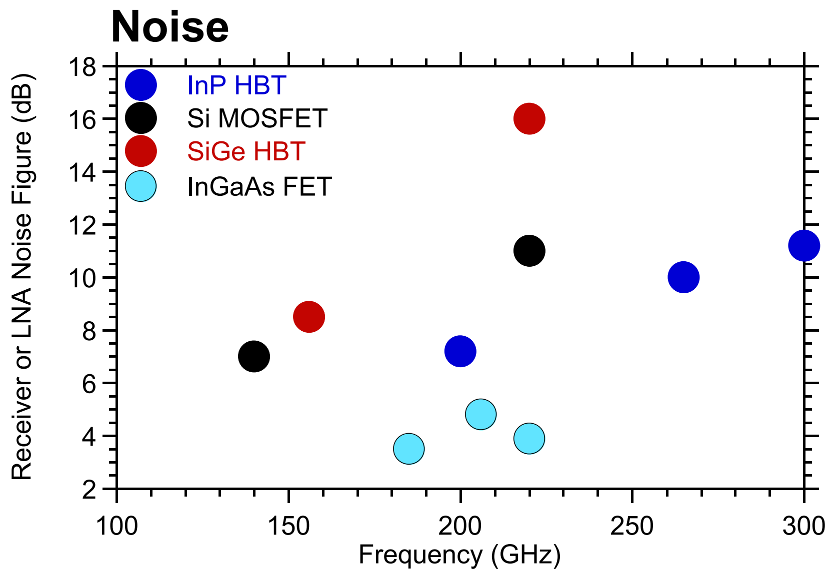
CMOS: good power & noise up to ~150GHz. Not much beyond. 65-22nm nodes are best.

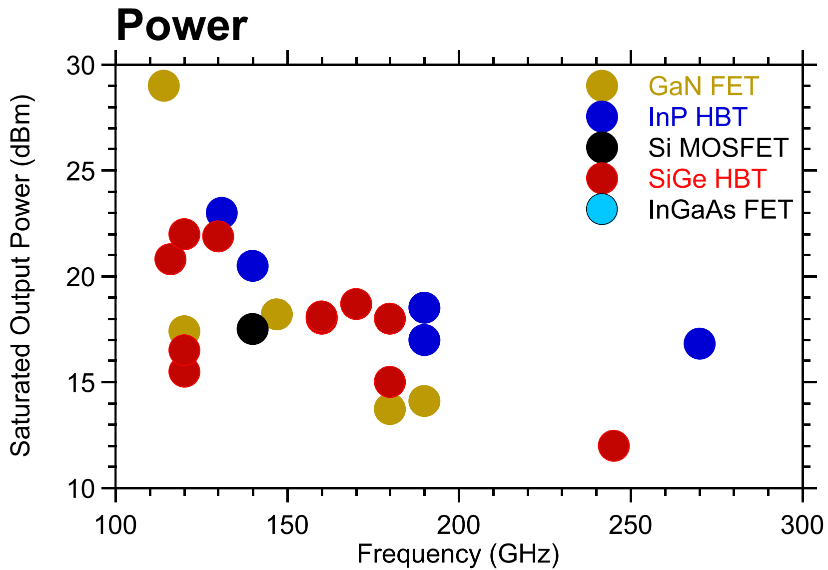
InP HBT: record 100-300GHz PAs

SiGe HBT: out-performs CMOS above 200GHz

GaN HEMT: record power below 100GHz. Bandwidth improving

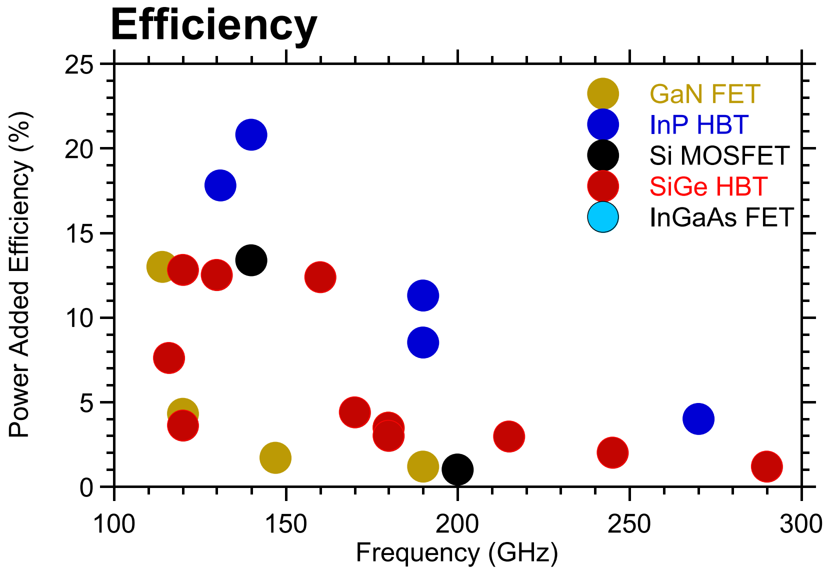
InGaAs-channel HEMT: world's best low-noise amplifiers





Results compiled 9/9/2021

Results with low power but high PAE, or low PAE but high power, are not shown



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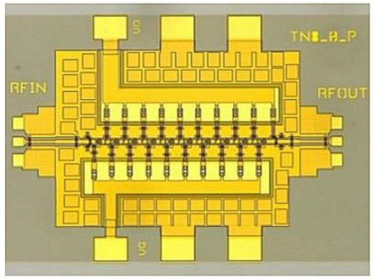
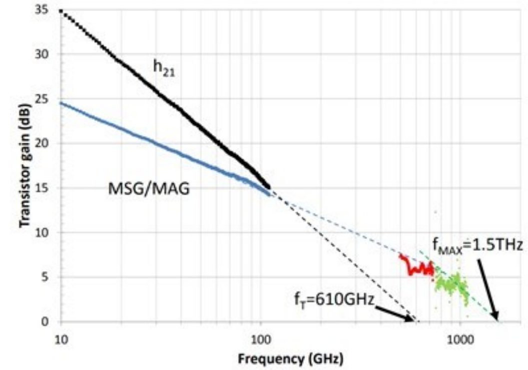
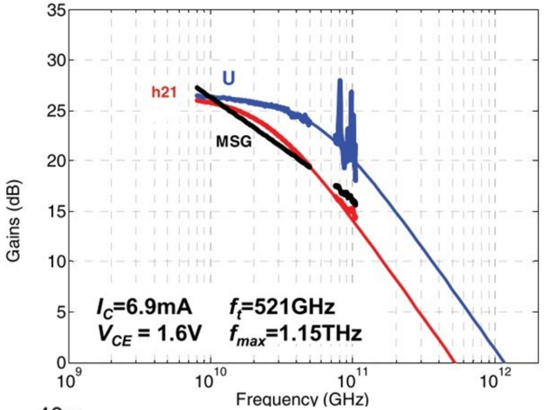
Summary: InP Transistors & ICs





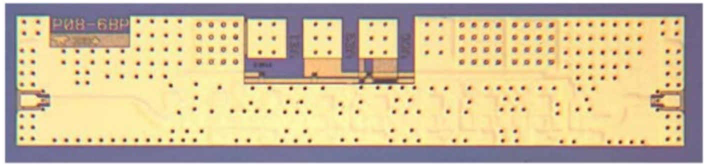
InP HEMTs: 1.5THz f_{max}, 1.0THz amplifiers

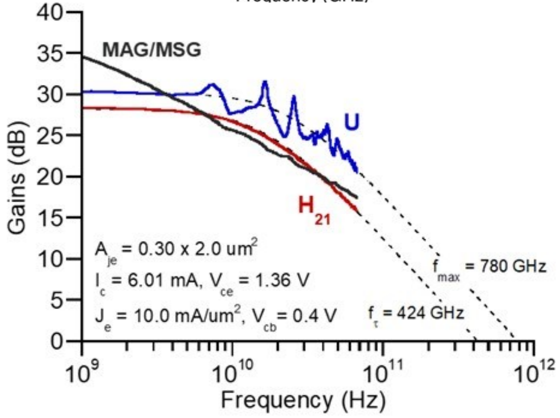
W. Deal et al, 2016 IEDM (Northrop-Grumman)



130nm InP HBTs: 1.1THz f_{max}, **3.5V.** 670 GHz amplifiers

M. Urteaga, et al, IEEE Proceedings June 2017 (Teledyne)

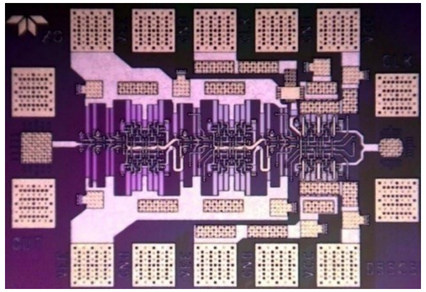




250nm InP HBTs: 650GHz f_{max}, **4.5V.**

Z. Griffith et al, 2007 IPRM conference (UCSB)

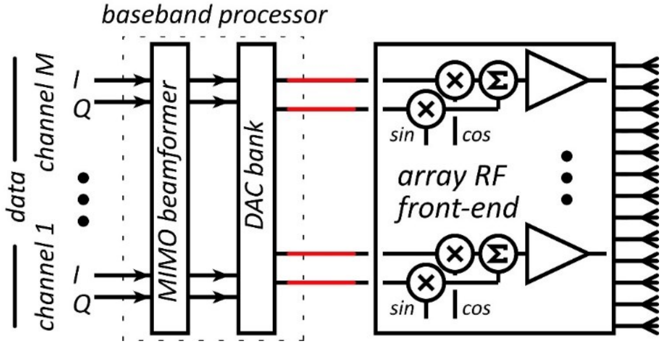
M. Urteaga, et al, IEEE Proceedings June 2017 (Teledyne)



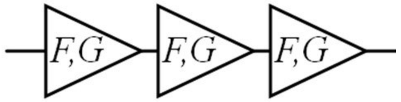
204 GHz static frequency divider
Z. Griffith et al, 2010 IEEE CSICS

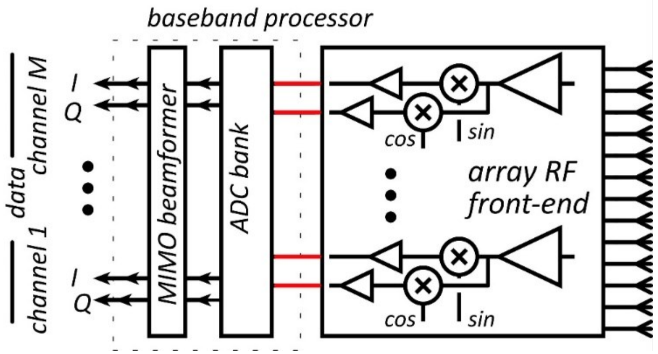
100-300GHz Wireless: Transistor Requirements

Transmitters need:
high power-added efficiency $PAE = (P_{out} - P_{in})/P_{DC}$
high added power density (P_{out}-P_{in})/(gate width, emitter length)

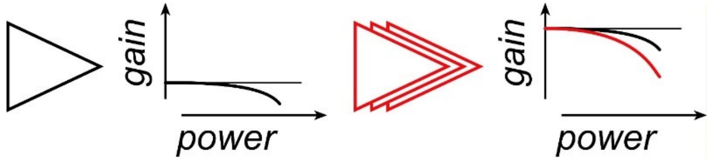


Receivers need:
low cascaded noise $F_{casc} = F + (F-1)/G + (F-1)/G^2 + \cdots$





Need reasonable gain/stage.
die area, power,
accumulated gain compression



(gain in PAs, LNAs is less than MAG/MSG, U, ...)

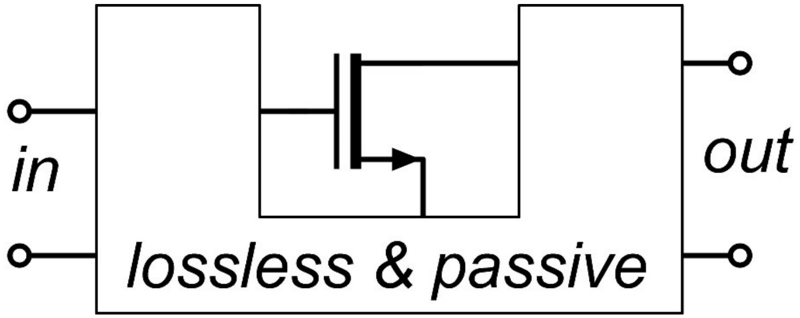
Where the IC designer can't help

mm-wave transistor gain is low: gain-boosting is common
Common-source vs. common-gate.
Capacitive neutralization. Unconditionally stable positive feedback (Singhakowinta, Int. J. Electronics, 1966)

Such circuits don't improve the parameters that matter the most.

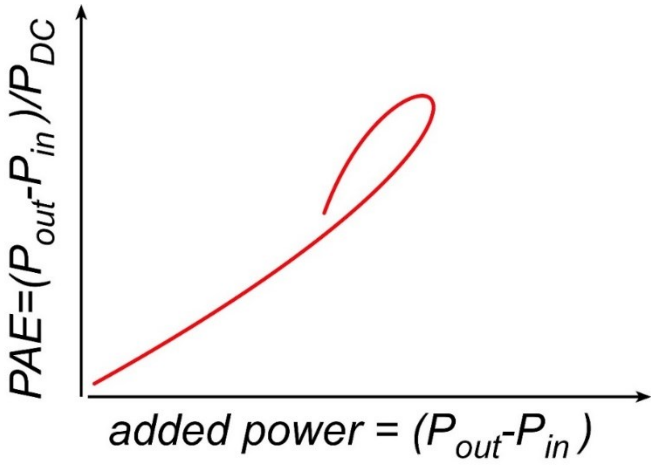
The circuit* doesn't change the transistor minimum cascaded noise figure. (Haus, Adler, Proc. IRE, 1958)

The circuit* doesn't change the transistor maximum efficiency vs. added power curve.

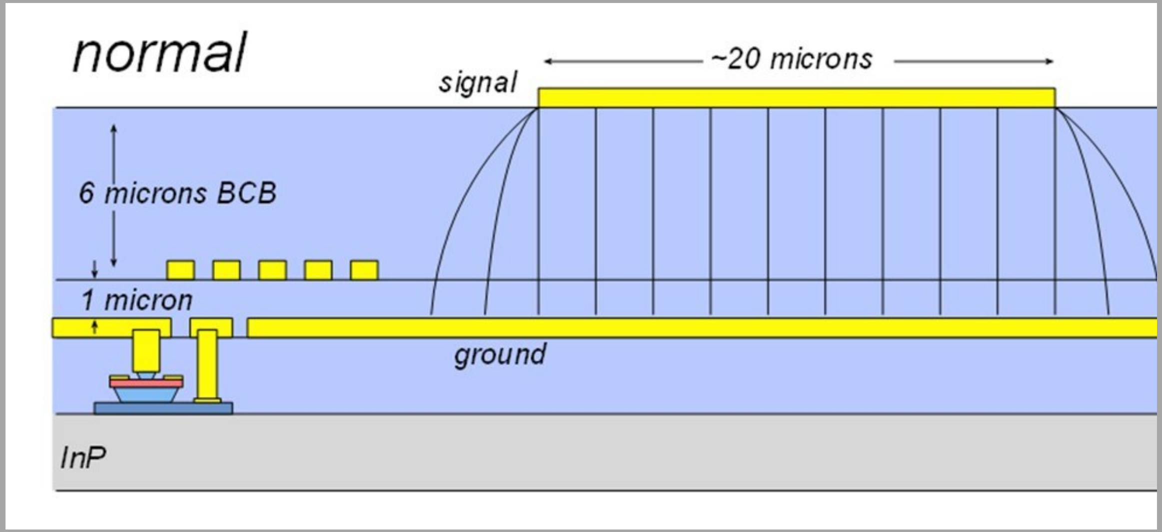


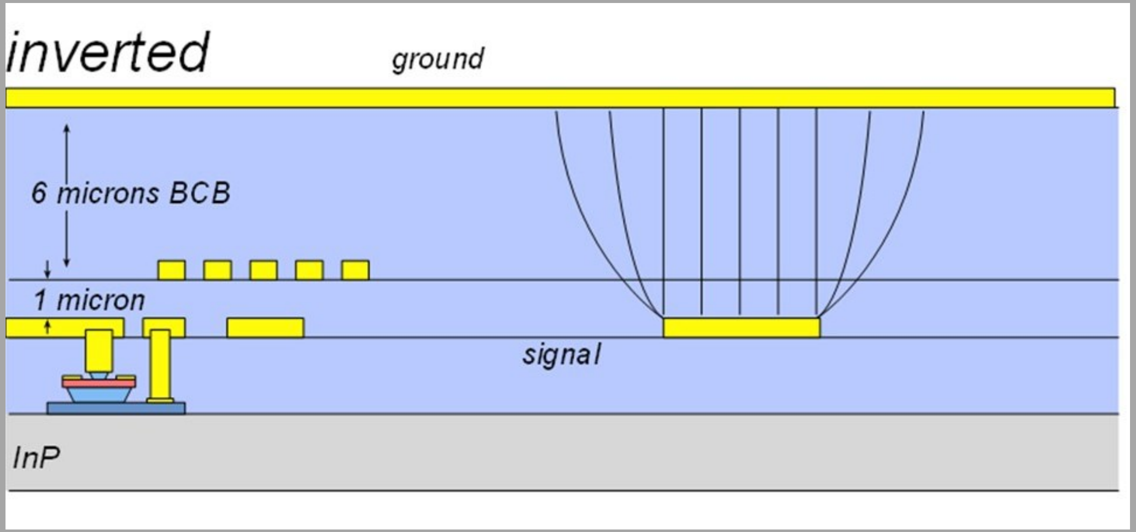
$$F_{casc} = 1 + M = F + (F-1)/G + (F-1)/G^2 + \cdots$$

*If lossless, and given the correct source and load impedances.



Interconnects

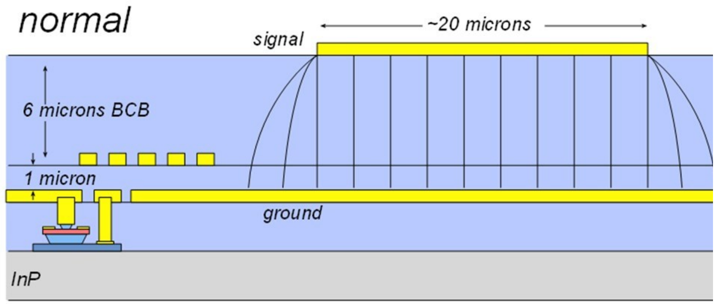


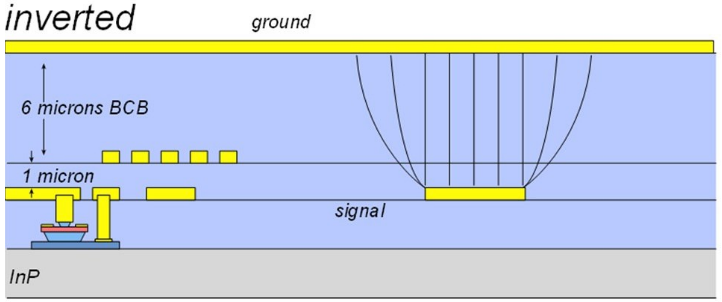


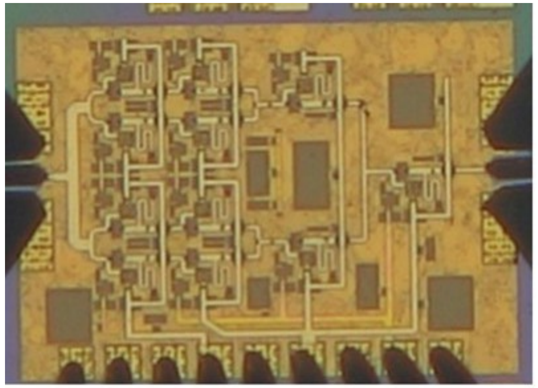
Normal & Inverted Microstrip

Normal: PAs, LNAs
smaller skin-effect losses ✓
ground-plane holes at transistors ✗

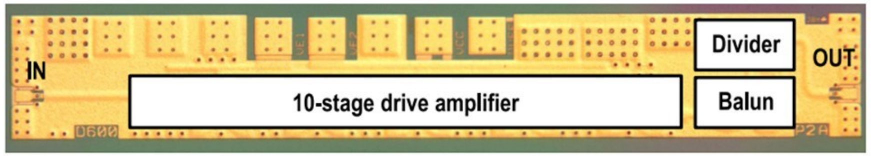
Inverted: high-density blocks (mixers, phase shifters,…)
higher skin-effect losses ✗
no ground-plane breaks: better ground integrity ✓

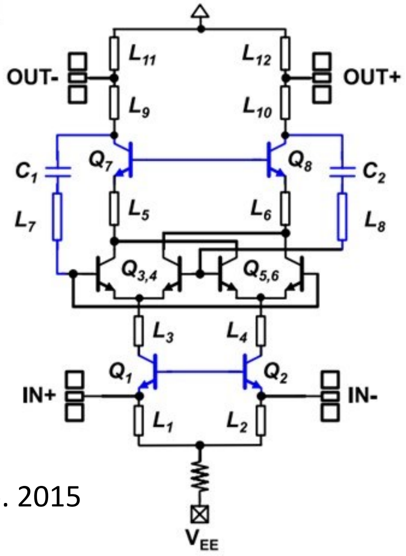






266GHz, 16.8dBm PA: A. Ahmed et. al, 2021 IMS





529GHz dynamic divider: M. Seo et al, IEICE Electronics Express, Feb. 2015

On-Wafer Interconnect Losses

Interconnects in packages and on PCBs:

$H \propto 1/\text{frequency}$ (to control radiation loss)

$\text{loss (dB/mm)} \propto (\text{frequency})^{3/2}$

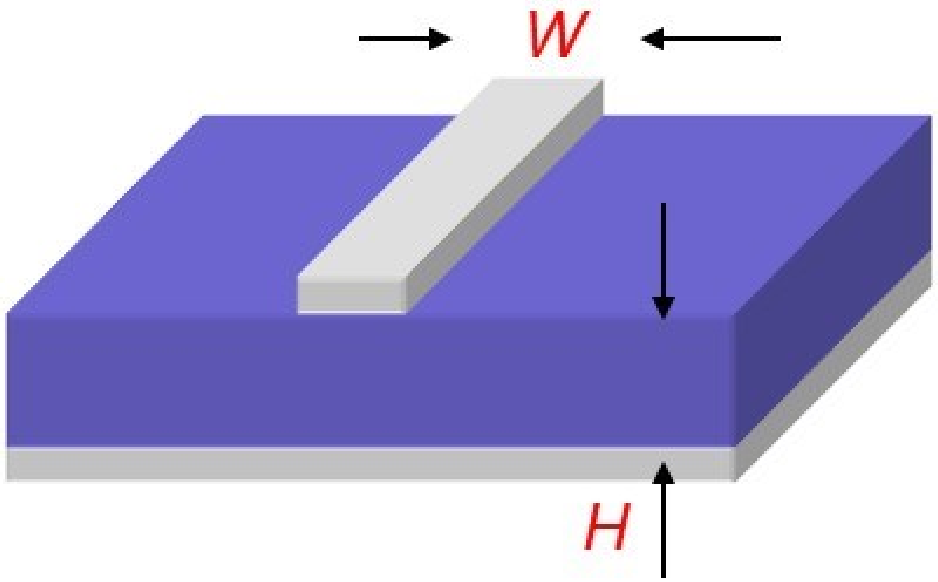
$\text{loss (dB/wavelength)} \propto \sqrt{\text{frequency}}$

Interconnects in ICs:

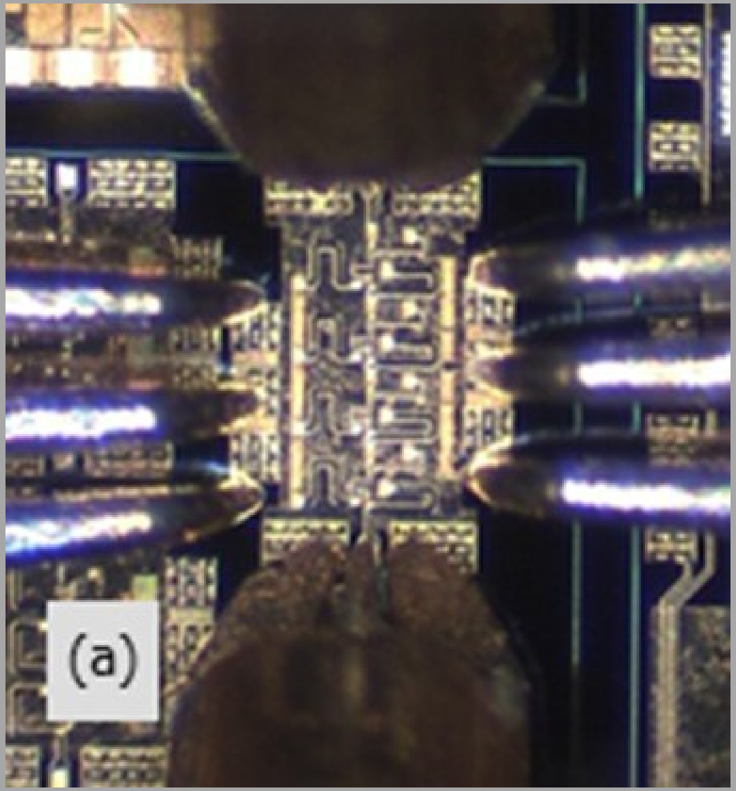
H is independent of frequency

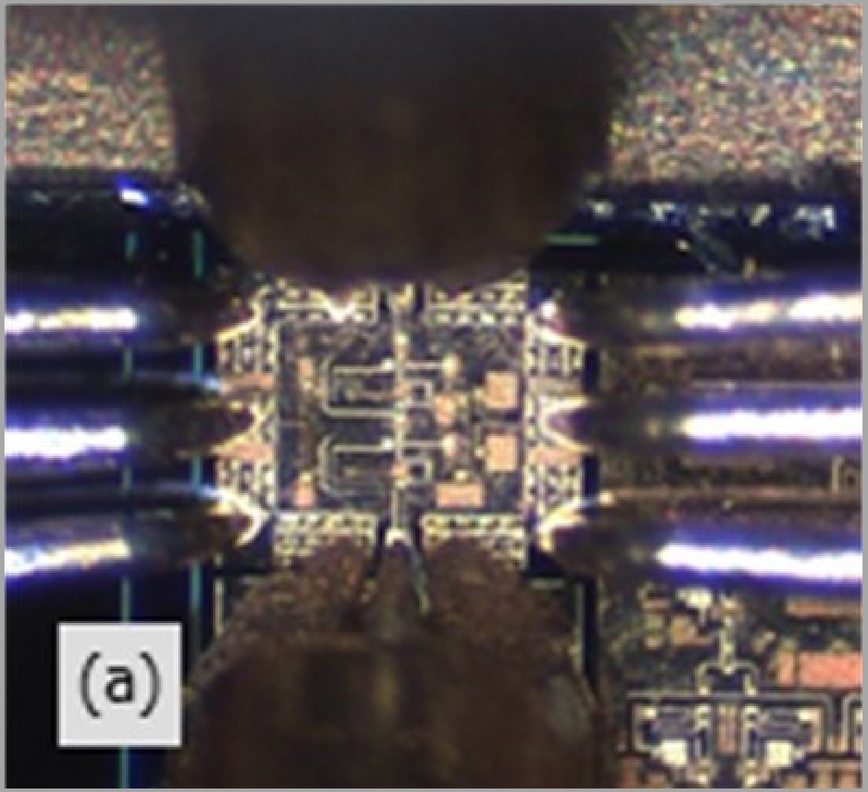
$\text{loss (dB/mm)} \propto \sqrt{\text{frequency}}$

$\text{loss (dB/wavelength)} \propto 1/\sqrt{\text{frequency}}$



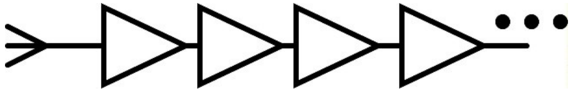
Low-Noise Amplifiers





LNA Design: Noise Close To Transistor Limits

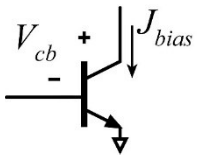
1) Goal: low noise measure, not noise figure

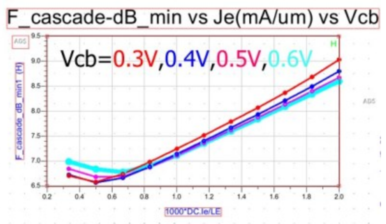


$$F_{\text{cascade}} = M + 1 = F + \frac{F-1}{G} + \frac{F-1}{G^2} + \ldots = \frac{F-1/G}{1-1/G}$$

F = noise figure, M = noise measure

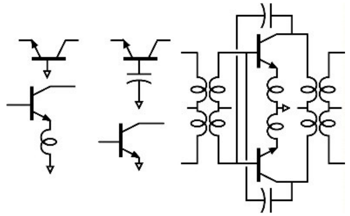
2) Find bias current density for lowest noise measure





@210GHz,
$F_{\text{cascade,min}}$= 6.57 dB
given:
J_e=0.5 mA/um,
V_{cb}=0.3V

3) Minimum M is independent of circuit configuration*; pick for high bandwidth or high gain/stage (= low P_{DC})

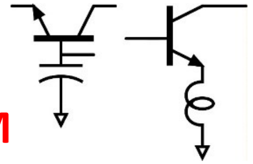


<-- all give the same minimum M…

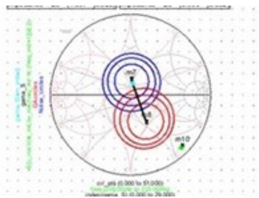
…but common-base gives highest gain (InP HBT @210GHz).

*HA Haus, RB Adler, Proceedings of the IRE, 1958

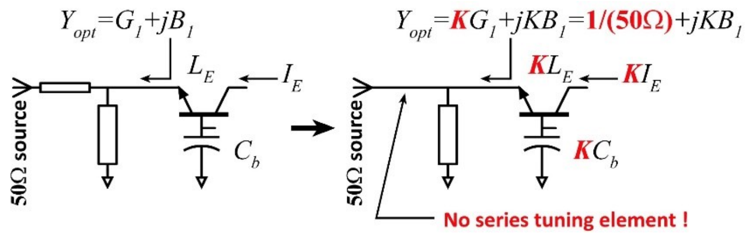
4) Capacitance in common-base; just like inductance in common-emitter, allows simultaneous tuning for zero reflection coefficient and minimum M



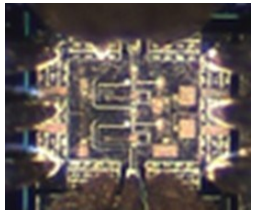
5) Write ADS Python code to display source impedance for minimum M.

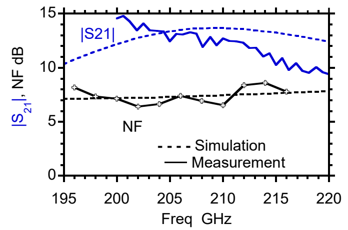


6) Scale transistor size to eliminate series tuning element. Less input tuning→ less noise from passive element loss.



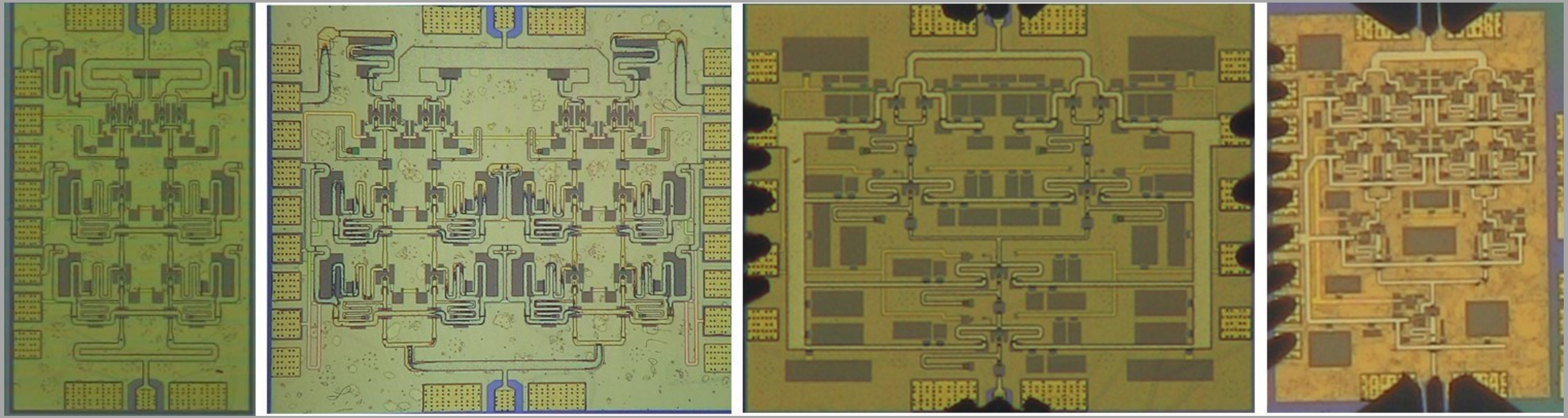
Result: 7.2-7.4dB LNA noise given 6.6dB transistor F_{cascade}.





U. Solyu et. al, to be presented, 2021 EuMIC Conference

Power Amplifiers

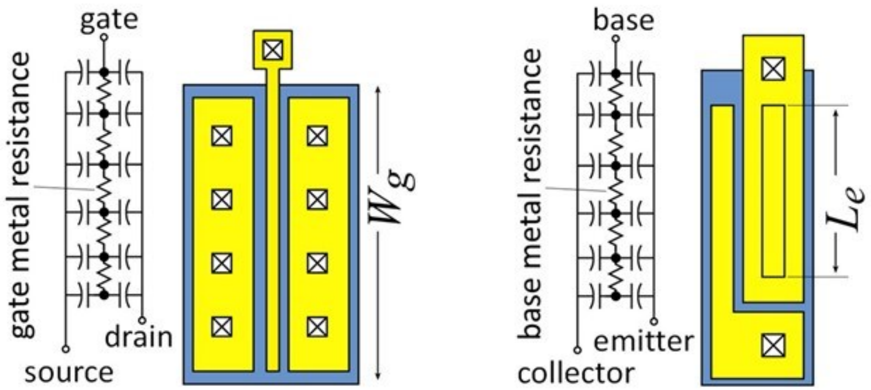


Current density, finger pitch limit cell output power

Electrode RC charging time $\propto$ (finger length)^2

Maximum finger length $\propto 1/\sqrt{\text{frequency}}$

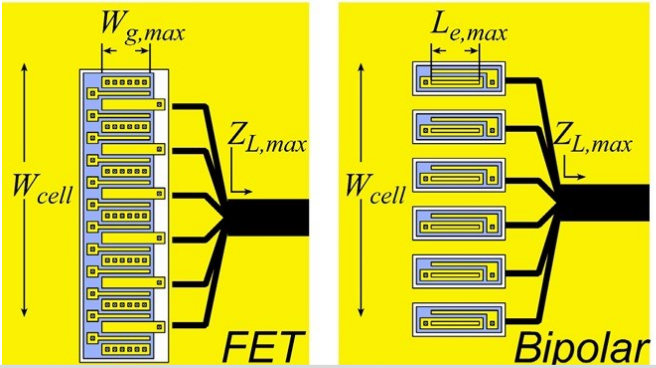
Current per finger $\propto 1/\sqrt{\text{frequency}}$



Maximum cell width $\propto$ 1/ frequency

Maximum number fingers $\propto$ 1/ frequency

Maximum current per cell $\propto 1/\text{frequency}^{3/2}$



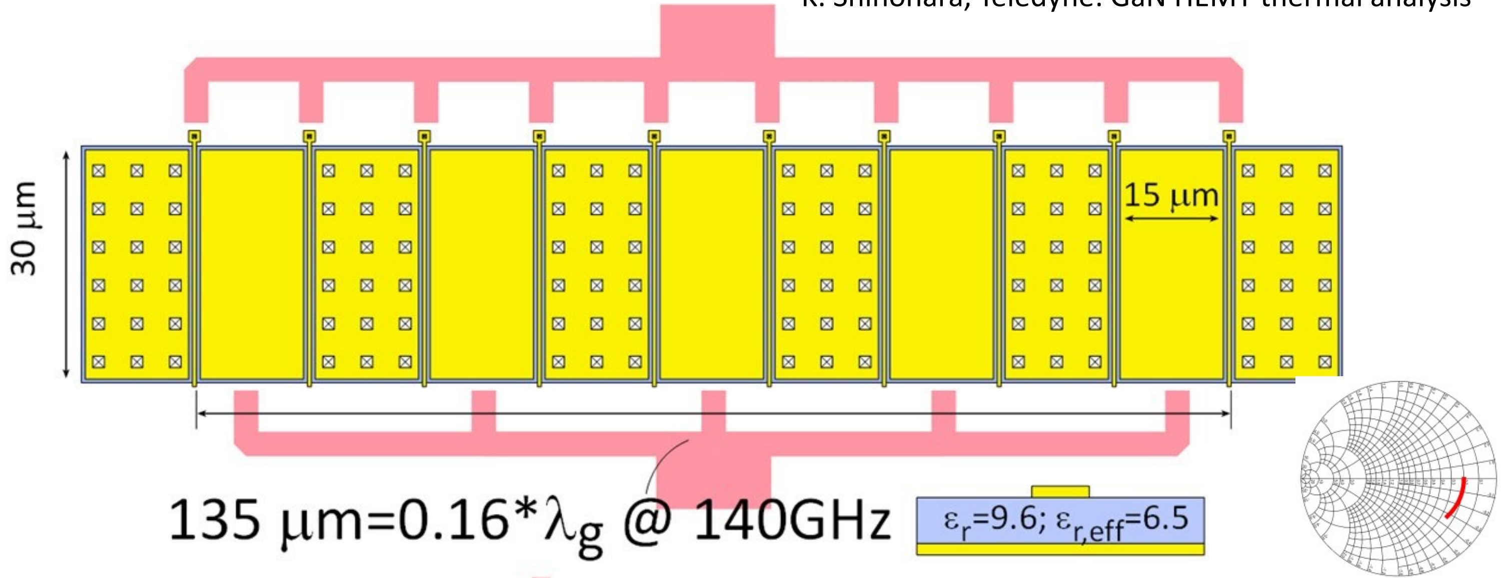
Maximum RF power per cell $\propto (\text{maximum load resistance}) \cdot (\text{maximum current})^2 \propto 1/(\text{frequency})^3$

Compare to Johnson F.O.M.: maximum power per cell $\propto (\text{maximum voltage})^2/(\text{minimum load resistance}) \propto 1/(\text{frequency})^2$

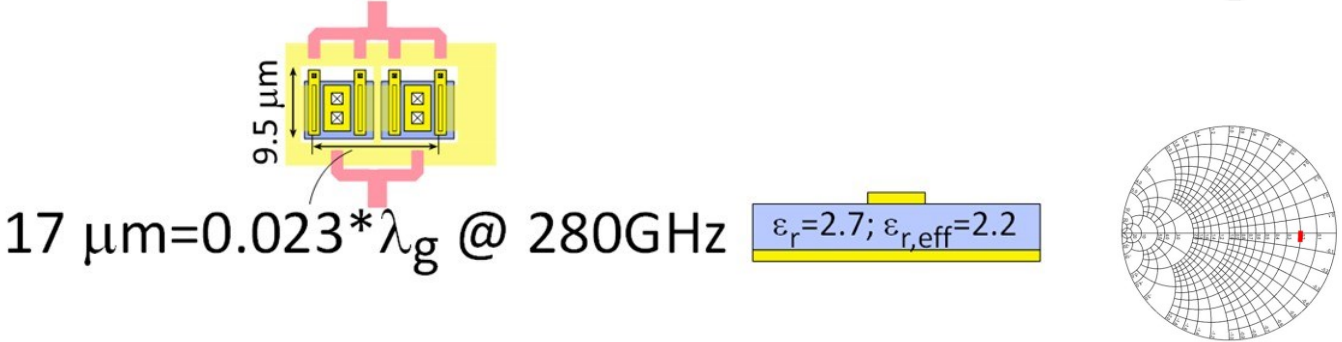
Current density, finger pitch limit cell output power

50Ω GaN PA cell @ 140GHz (1.6W)
25V swing, 1.67mA/µm,
gates: 30 µm width, 15 µm pitch

K. Shinohara, Teledyne: GaN HEMT thermal analysis



50Ω InP HBT PA cell @ 280GHz (40mW)
4V swing, 3.3mA/µm,
emitters: 6 µm length, 6 µm pitch

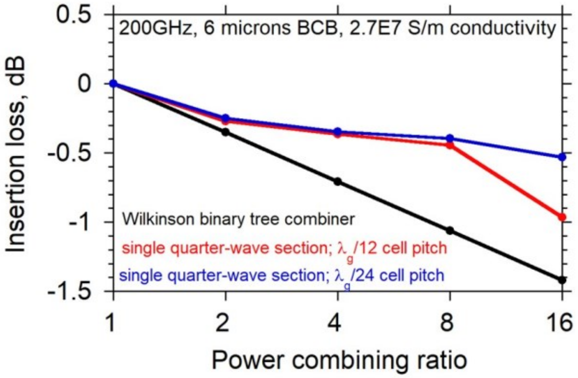


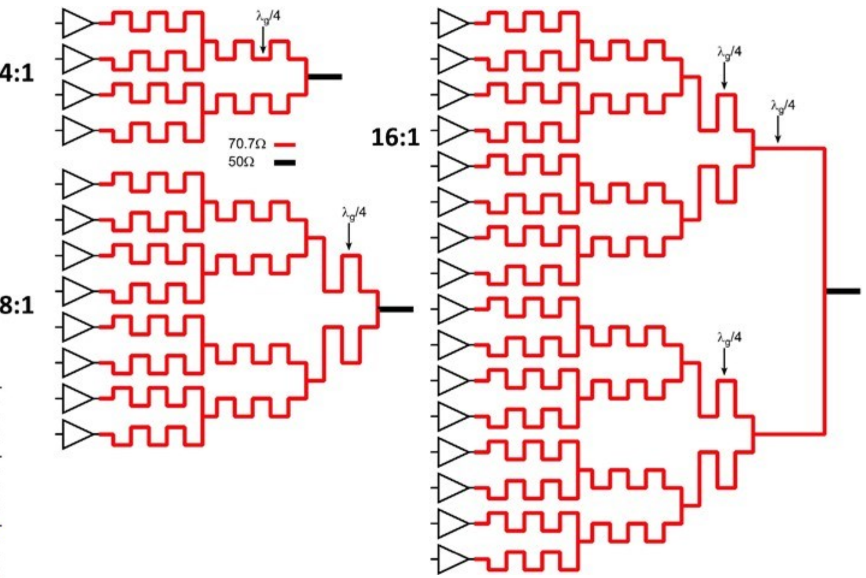
High V_{br}, low I_{max} ? Device sized to drive 50Ω might approach $\lambda_g/4$ width.
Small finger pitch is critical; limited by thermal design

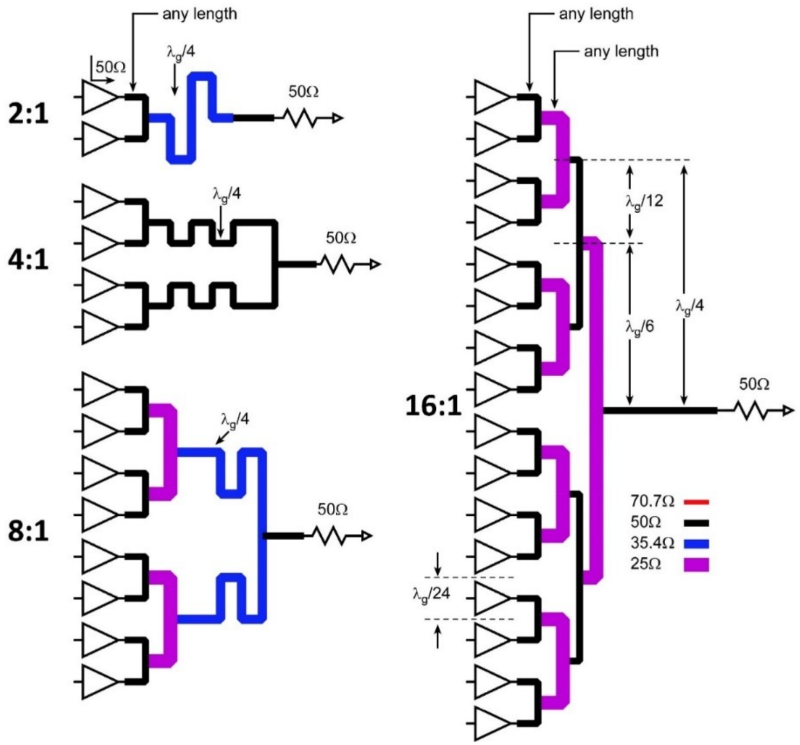
Low-Loss 100-300GHz Corporate Combining

Wilkinson trees are lossy:
Signal passes through *many* 70.7Ω, λ/4 lines.
λ/4 lines are long.
70.7Ω lines are narrow…and lossy→ High loss.

Single-(λ/4) combiners are much less lossy
Each design uses a single *effective* λ/4 section.
Shorter lines, low-Z_o lines → lower loss
But, low loss only if transistor cells fit.

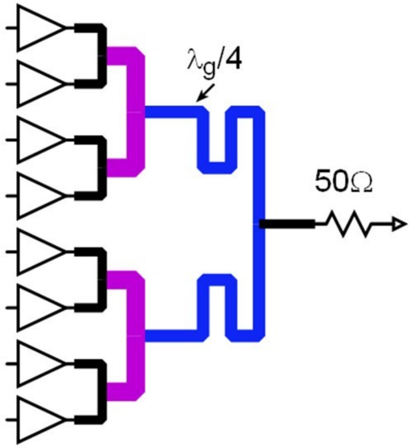






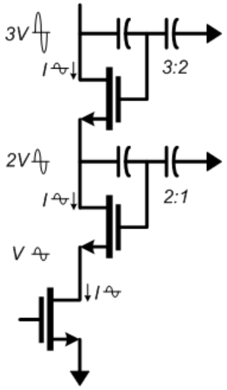
100-300GHz Power combining: what is best ?

Corporate T-line



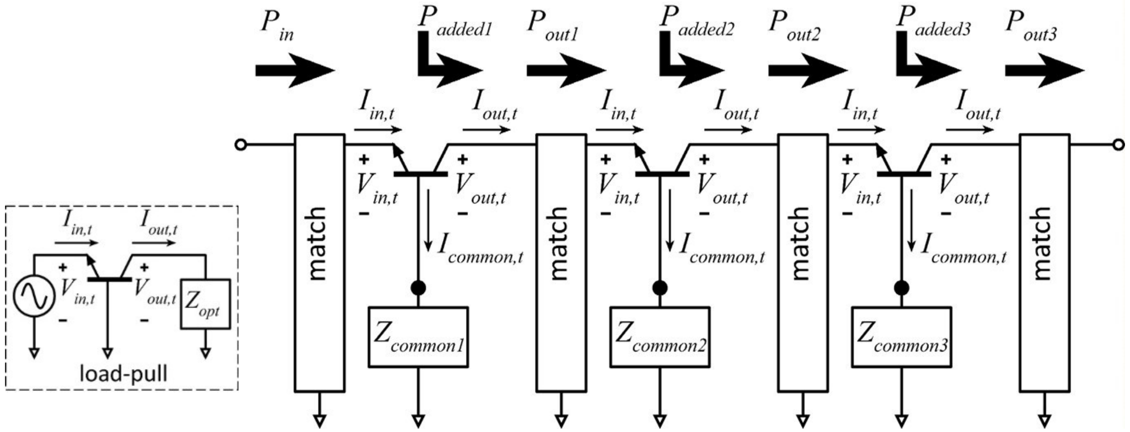
Direct series-connected

M. Shifrin: 1992 IEEE μWave/mmWave Monolithic Circuits Symp. **(Raytheon)**



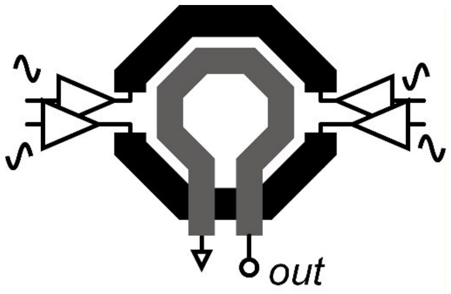
Cascaded combining

A. Ahmed 2018 EuMIC, 2021 RFIC **(UCSB)**



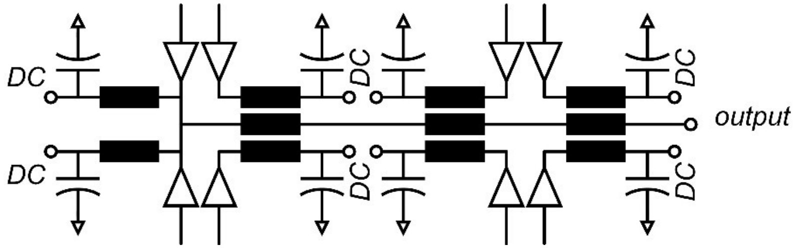
Distributed Active Transformer

I. Aoki, IEEE Trans MTT, Jan. 2002 **(CalTech)**

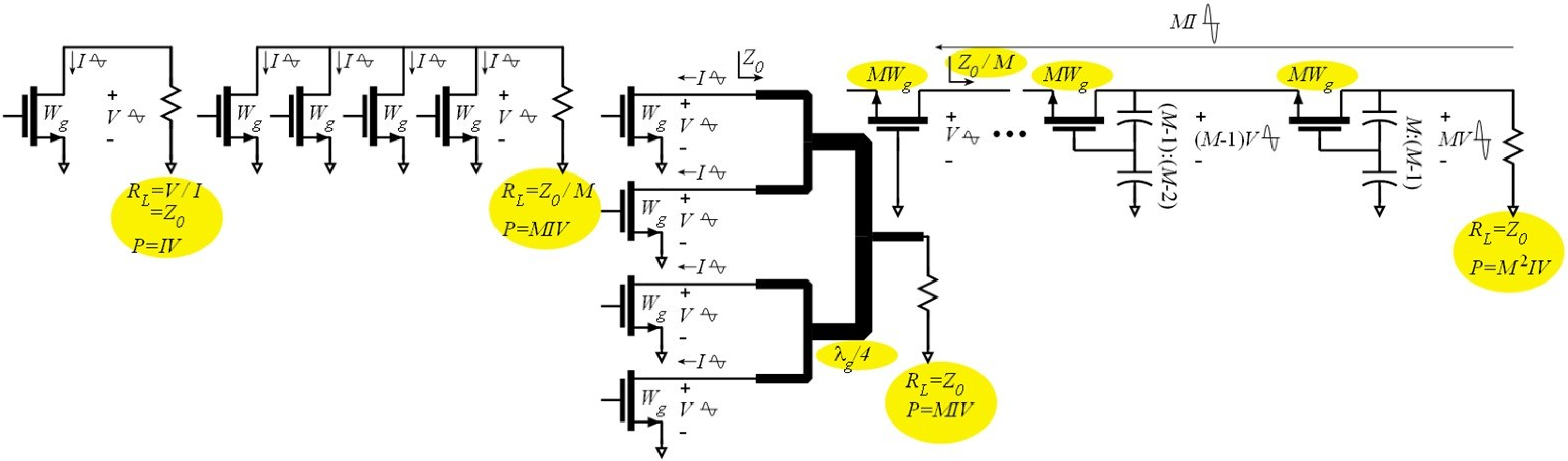


Balun series-connected

λ/4 baluns: Y. Yoshihara, 2008 IEEE Asian Solid-State Circuits Conference **(Toshiba)**
sub-λ/4 baluns: H. Park, et al, IEEE JSSC, Oct. 2014 **(UCSB)**

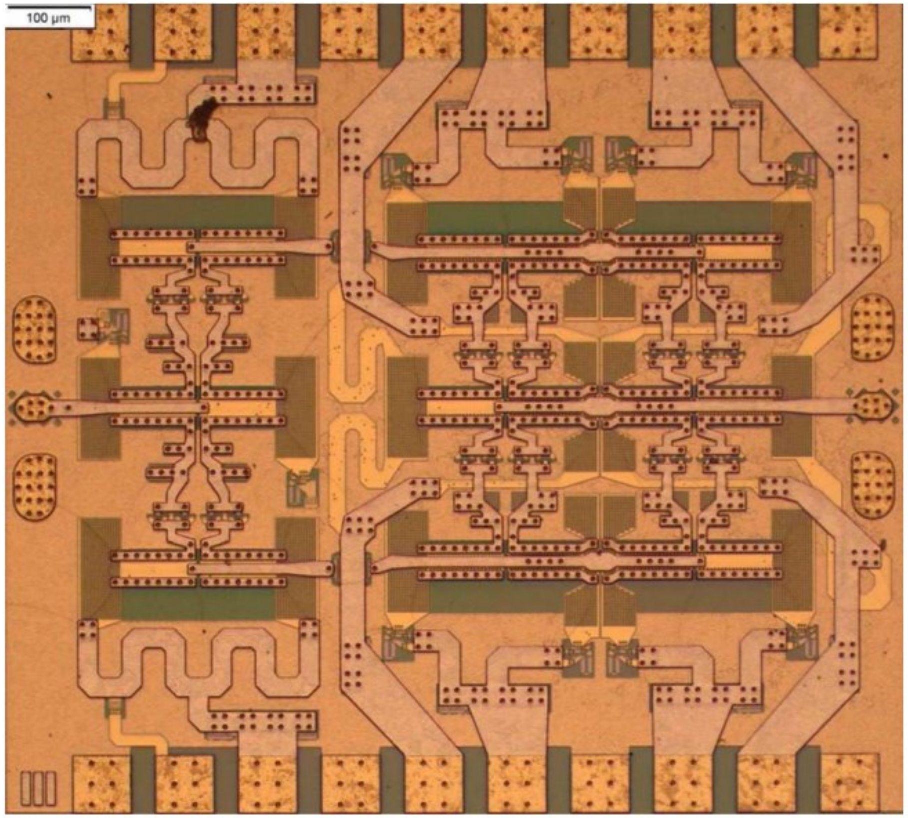


Transistor stacking. Why ? Why not ?



	Lower frequencies	Higher frequencies
Corporate combining	length $\propto 1/f \rightarrow$ large die area ✗ dB loss $\propto 1/\sqrt{f} \rightarrow$ high loss ✗	length $\propto 1/f \rightarrow$ small die area ✓ dB loss $\propto 1/\sqrt{f} \rightarrow$ low loss ✓
Series-connected	more transistor fingers per cell → ok ✓	more transistor fingers per cell→ parasitics ✗

Series combining using sub-$\lambda/4$ baluns



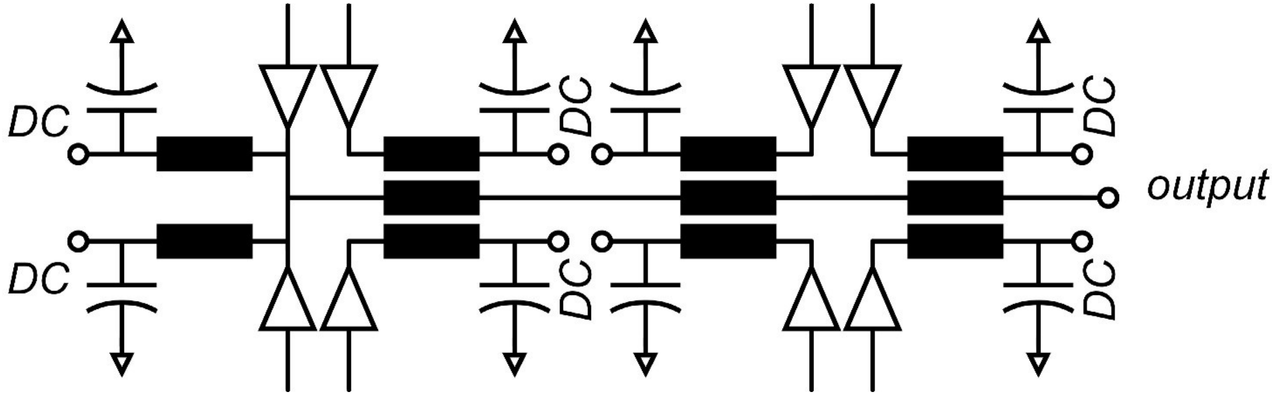
81GHz, 17 dB Gain

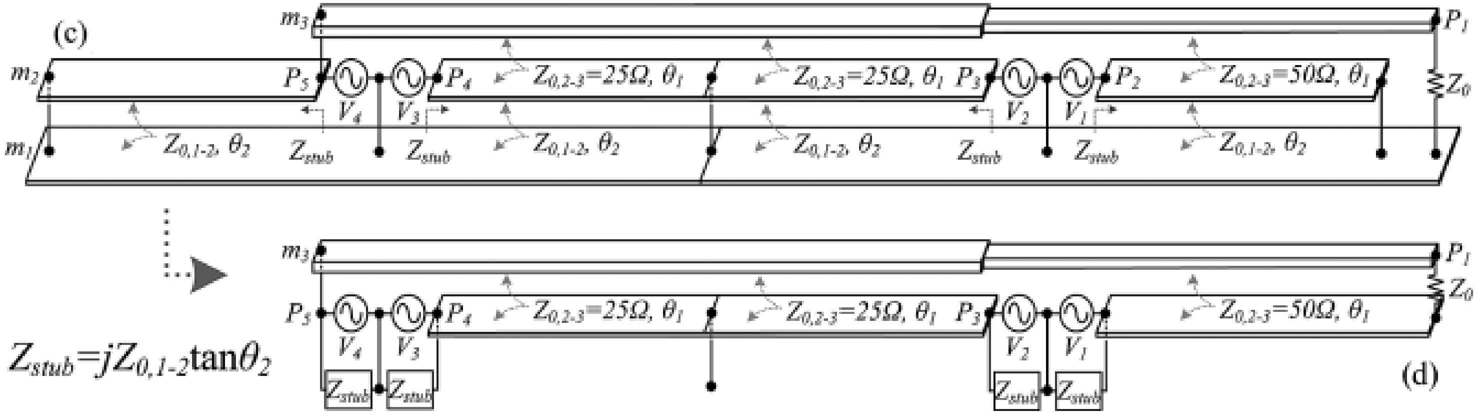
470 mW P_{sat} , 23% PAE

Teledyne 250 nm InP HBT

2 stages, 1.0 mm^2(incl pads)

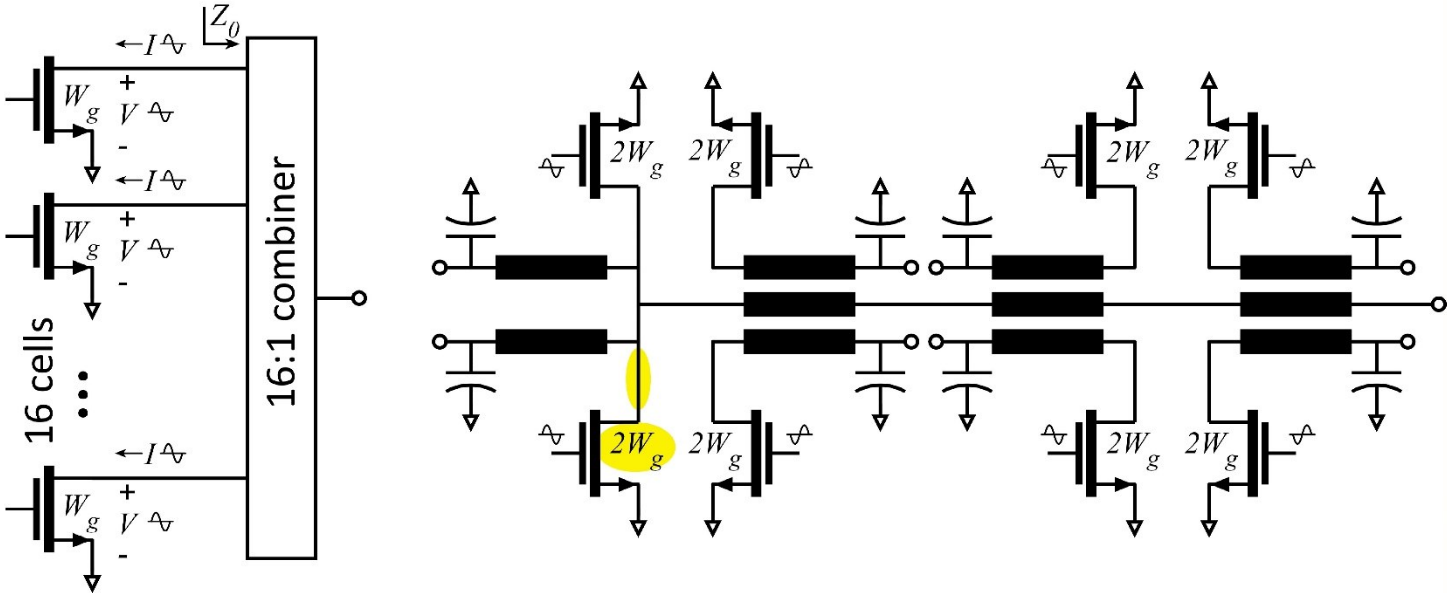
$\lambda/4$ baluns: Y. Yoshihara, 2008 IEEE Asian Solid-State Circuits Conference **(Toshiba)**
sub-$\lambda/4$ baluns: H. Park, et al, IEEE JSSC, Oct. 2014 **(UCSB)**





$Z_{stub}=jZ_{0,1\text{-}2}\tan\theta_2$

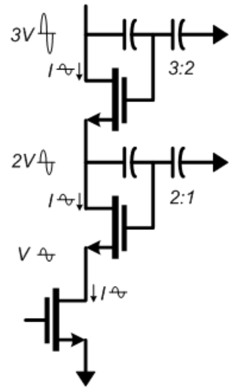
Sub-λ/4 Balun Combiners. Why ? Why not ?

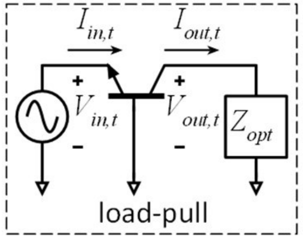


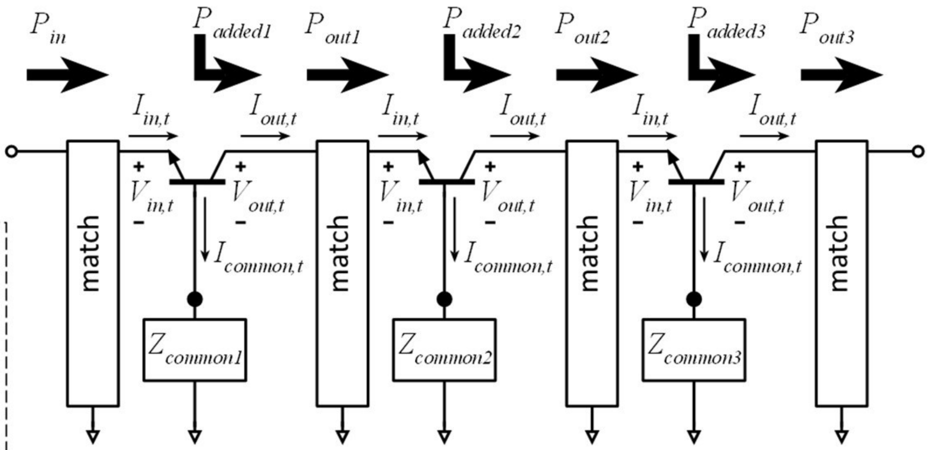
	Lower frequencies	Higher frequencies
Corporate combining	length ∝ $1/f$ → large die area ✗ dB loss ∝ $1/\sqrt{f}$ → high loss ✗	length ∝ $1/f$ → small die area ✓ dB loss ∝ $1/\sqrt{f}$ → low loss ✓
Sub-λ/4 Balun	more transistor fingers per cell → ok ✓	more transistor fingers per cell → parasitics ✗ impedance shift of transistor-balun interconnect ✗

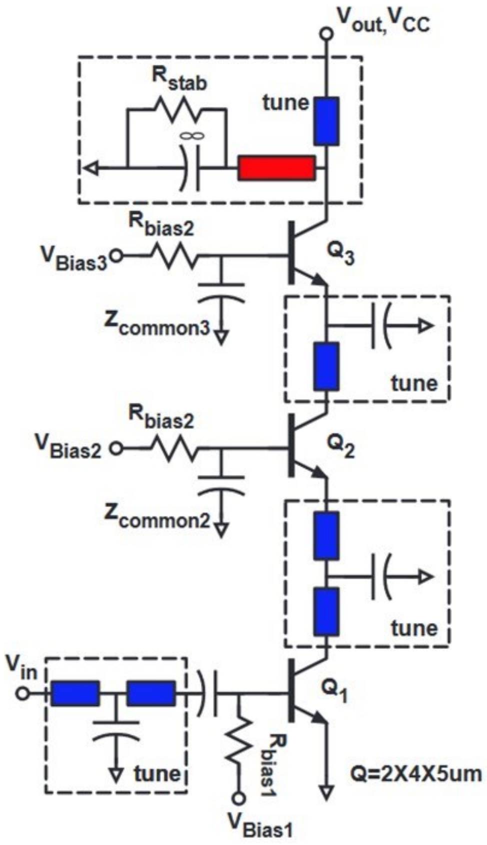
Cascade combining as stacking plus matching

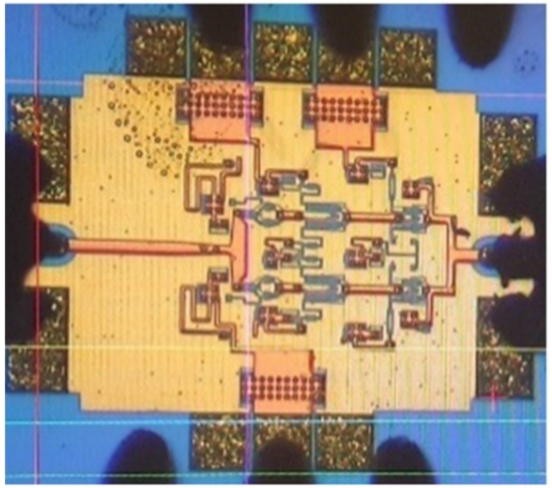
A. S. H. Ahmed et al, 2018 EuMIC (UCSB)

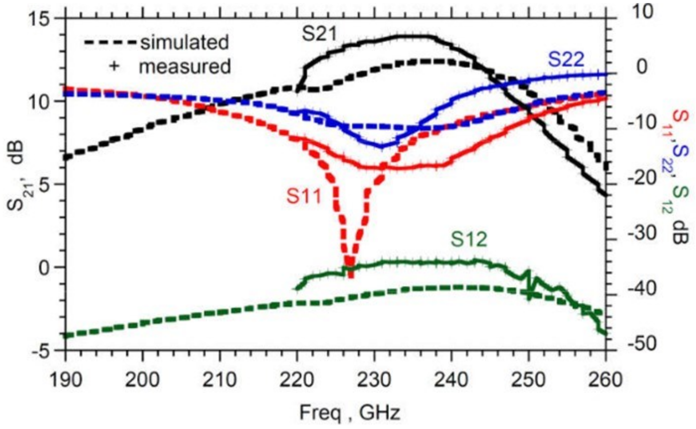


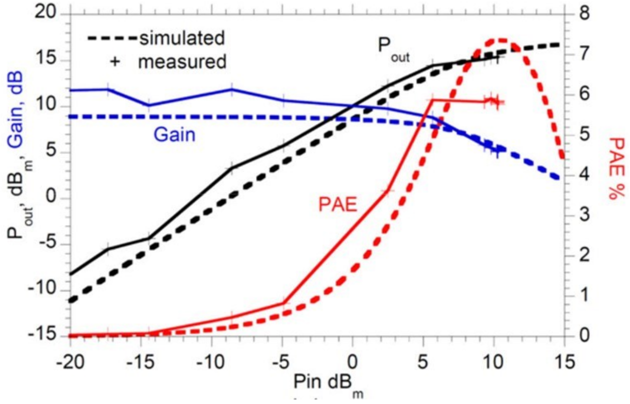








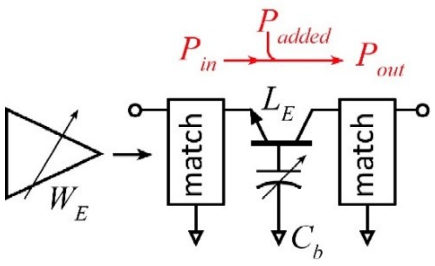




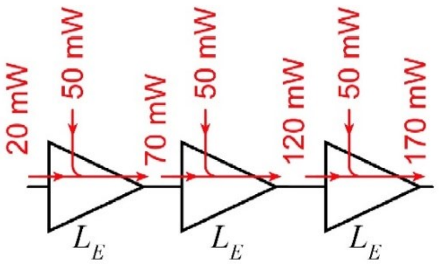
Generalized cascade combining

A. S. H. Ahmed et al, 2018 EuMIC (UCSB)
A. S. H. Ahmed, et al, 2021 RFIC Symposium

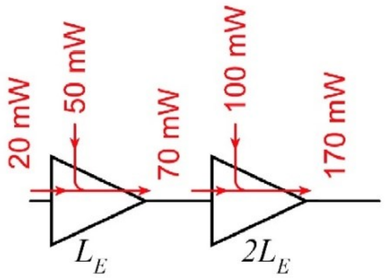
adjustable power summation



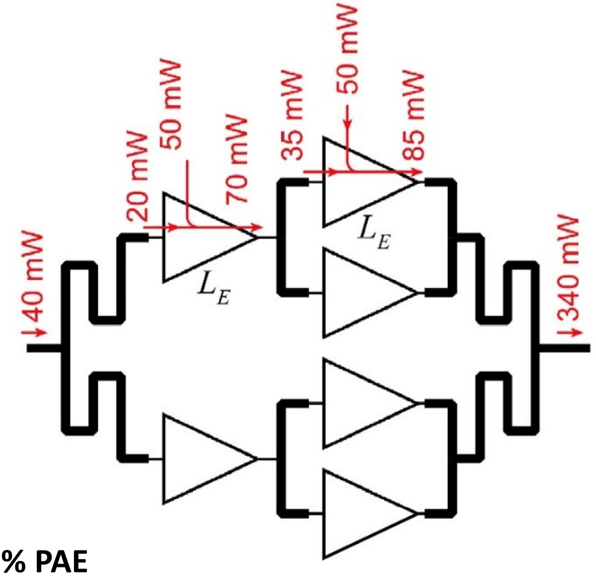
=stacking + matching

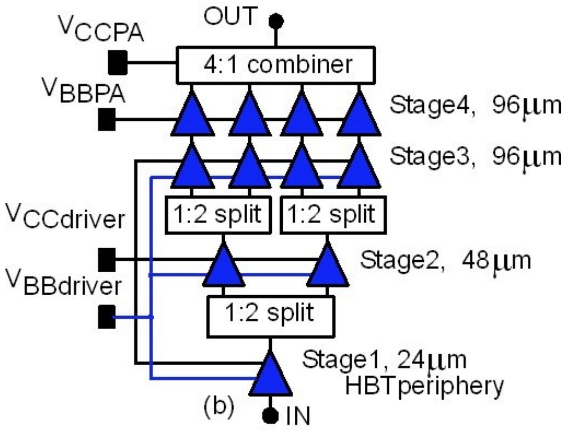


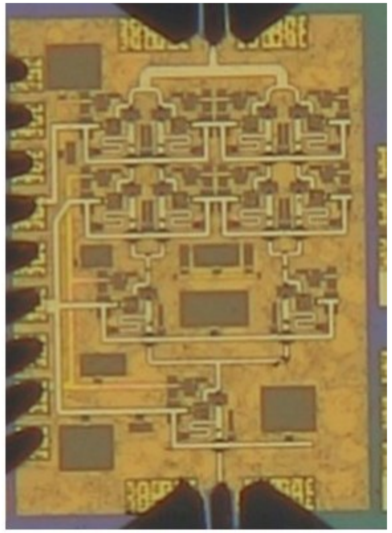
nonuniform



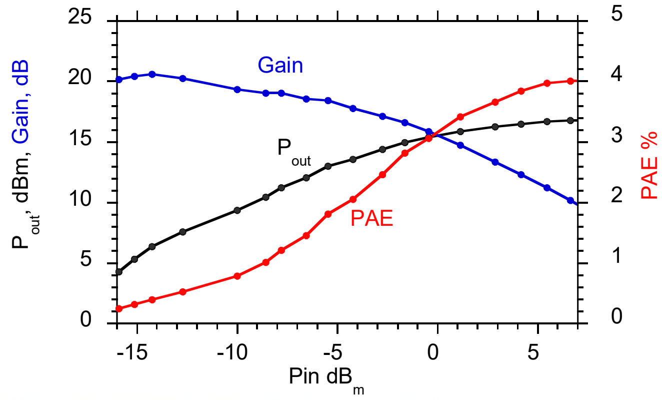
with spittling or combining

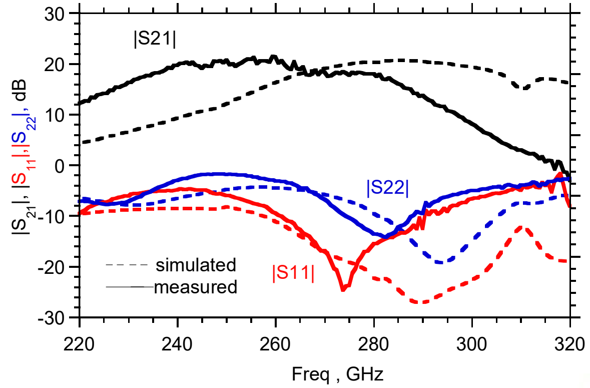




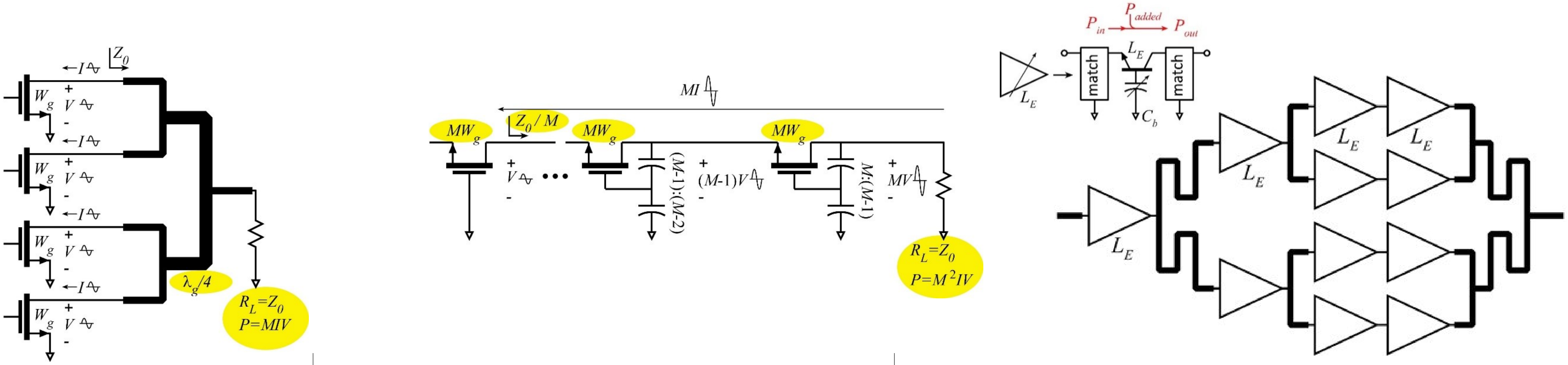


266GHz, 16.8dBm, 4.0% PAE





Cascade Combining: Why ? Why not ?



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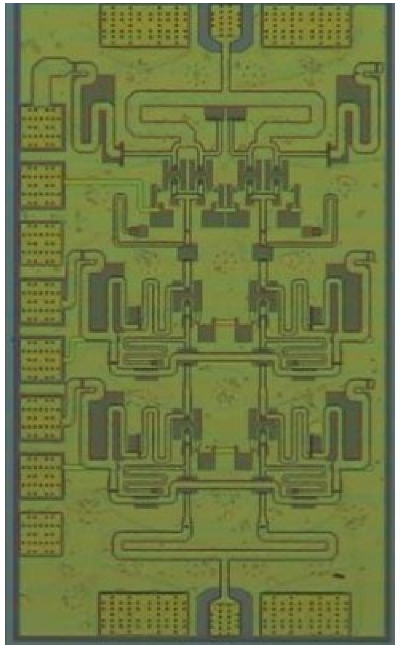
Series-connected	more transistor fingers per cell → ok ✓	more transistor fingers per cell→ parasitics ✗
Cascade combining	large interstage matching networks ✗	small interstage matching networks ✓ small # transistor fingers per cell → ok ✓ cascade cell pass-though losses ✗

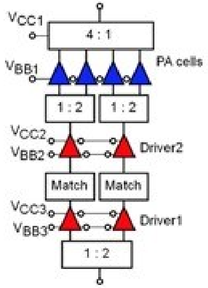
Recent high-efficiency 100-300GHz PAs

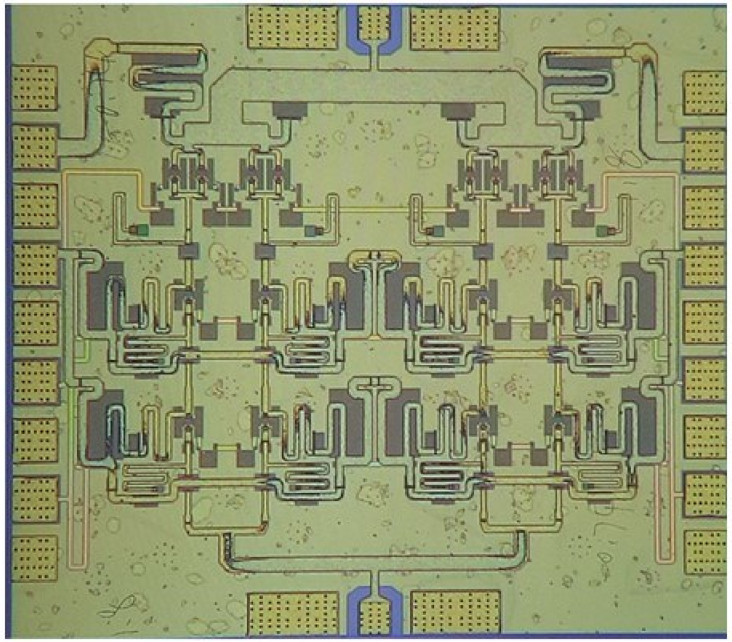
Teledyne 250nm InP HBT technology

Ahmed et al, 2020 IMS, 2020 EuMIC, 2021 IMS, 2021 RFIC

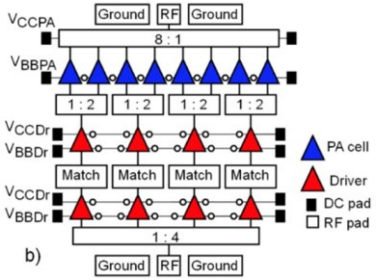


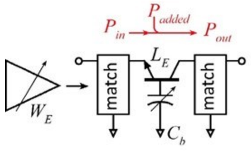
140GHz, 20.5dBm, 20.8% PAE

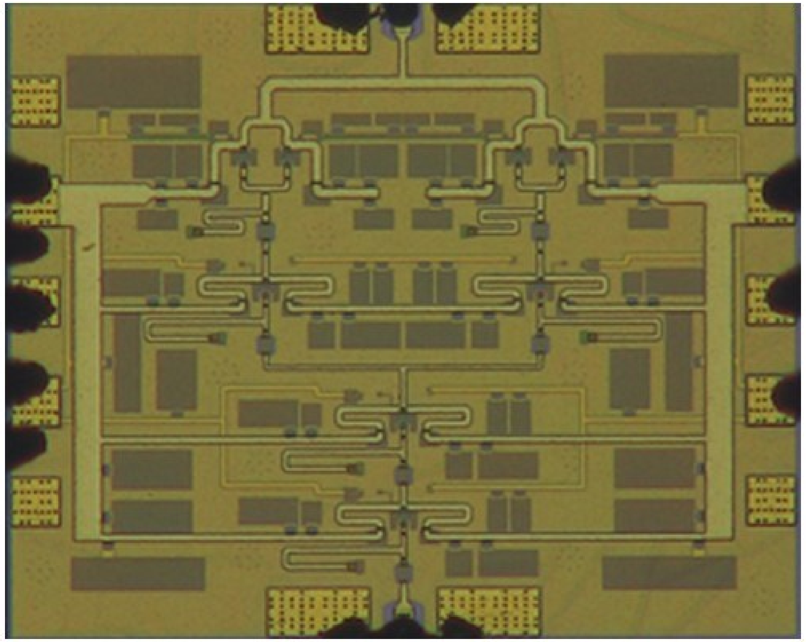




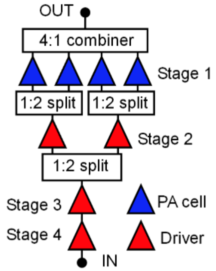
130GHz, 200mW, 17.8% PAE

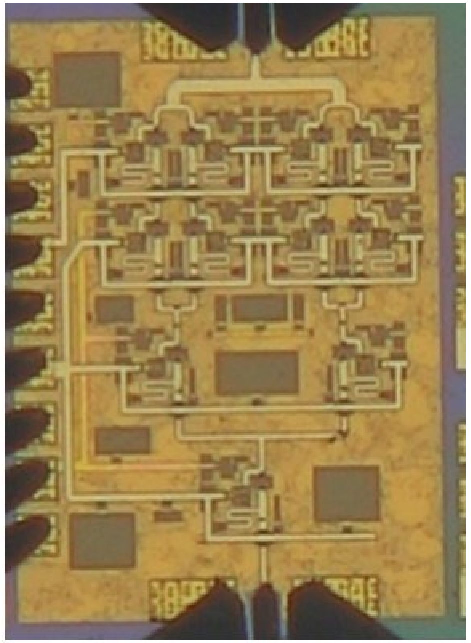




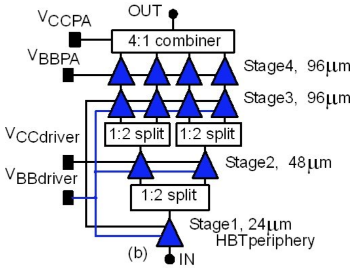


194GHz, 17.4dBm, 8.5% PAE

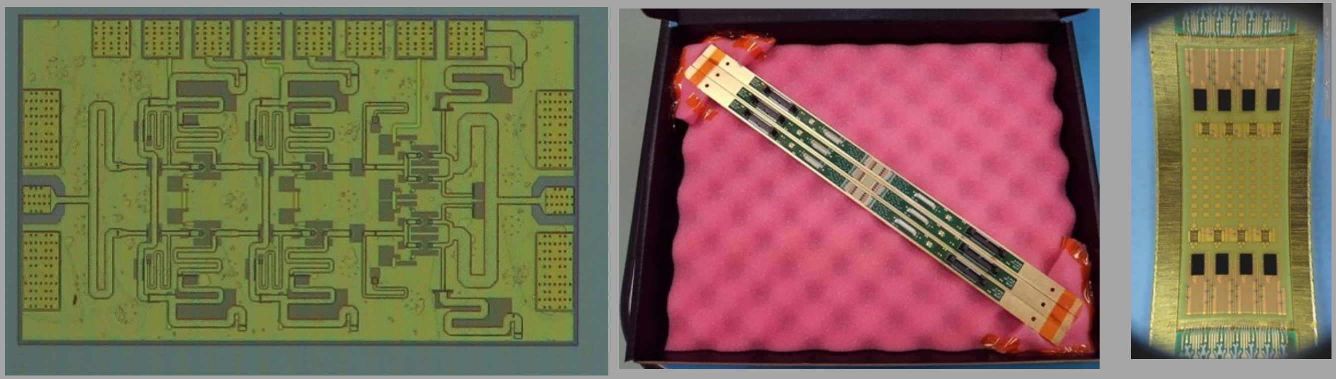




266GHz, 16.8dBm, 4.0% PAE

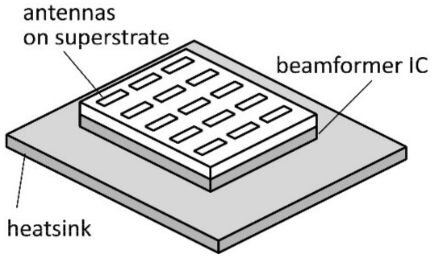


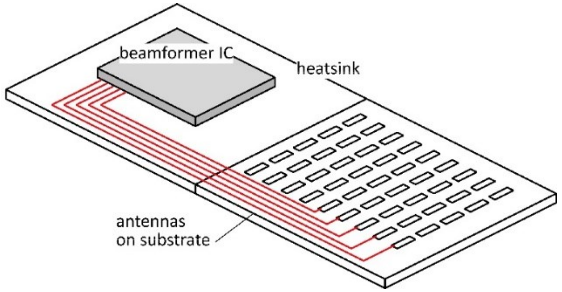
140 GHz
Array Modules



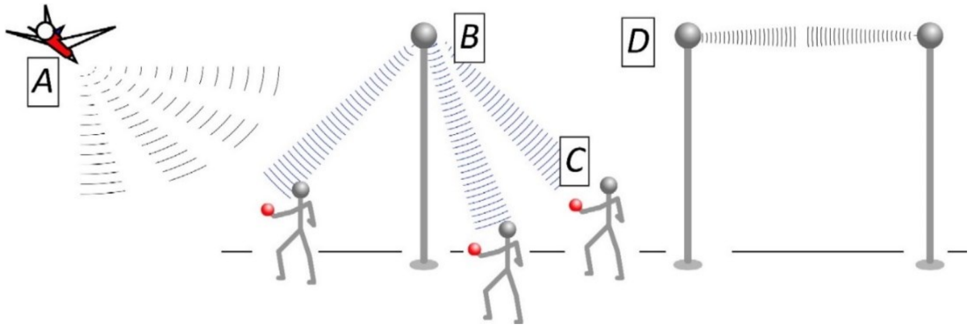
The mm-wave module design problem

How to make the IC electronics fit ?
How to avoid catastrophic signal losses ?
How to remove the heat ?

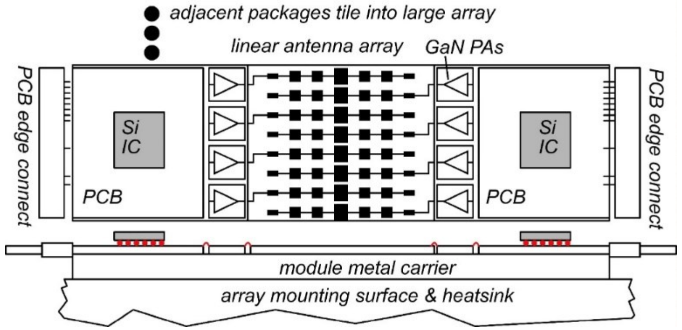


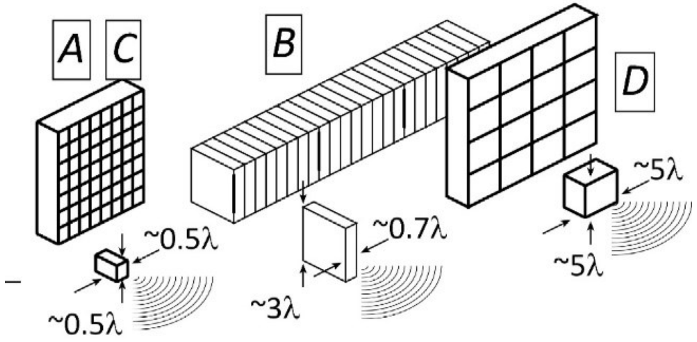


Not all systems steer in two planes...
    ...some steer in only one.



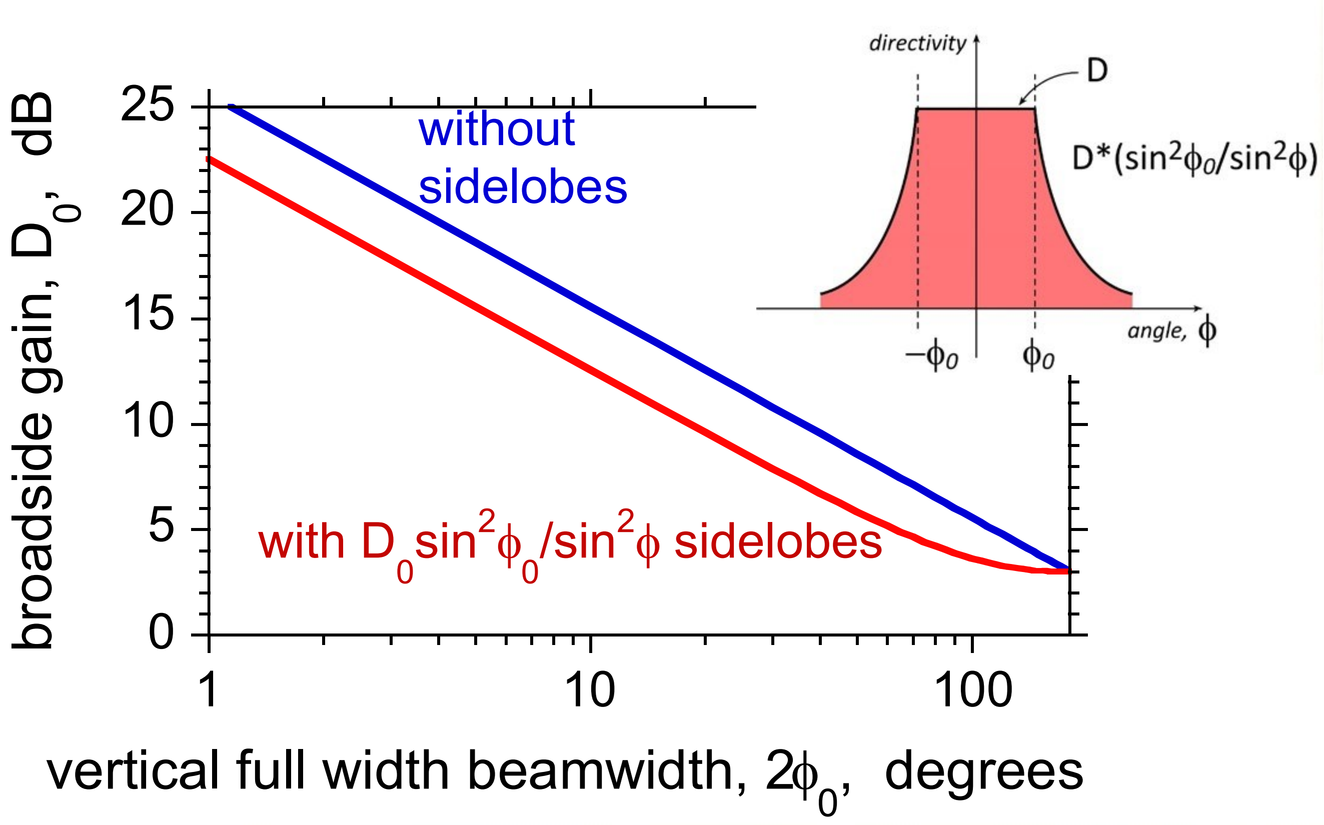
Not all systems steer over 180 degrees...
    ...some steer a smaller angular range

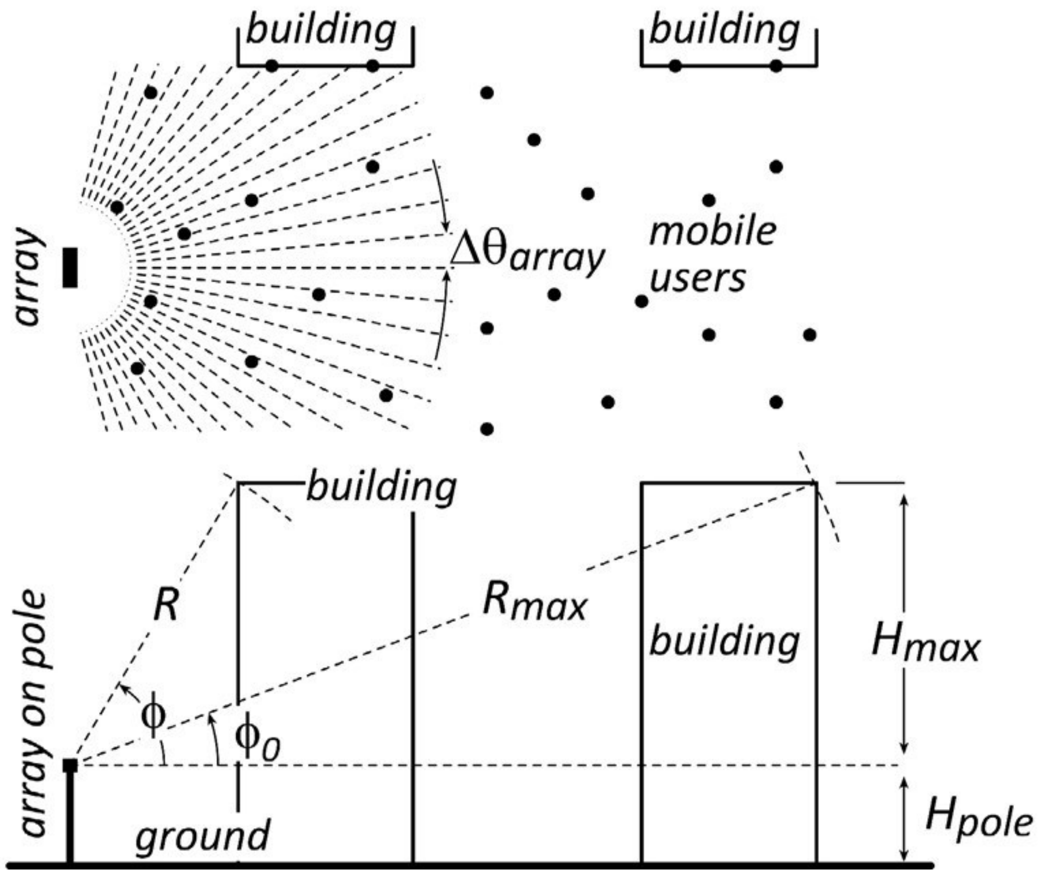




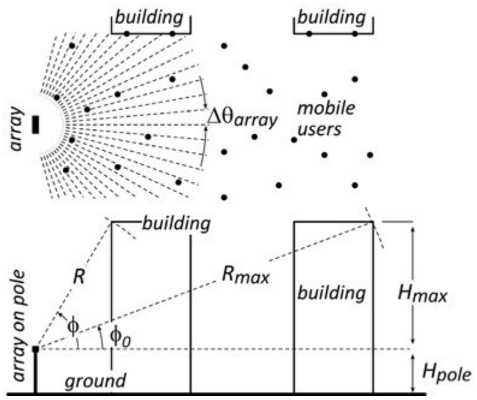
Do we need 2D arrays ? 1D steering might be fine.

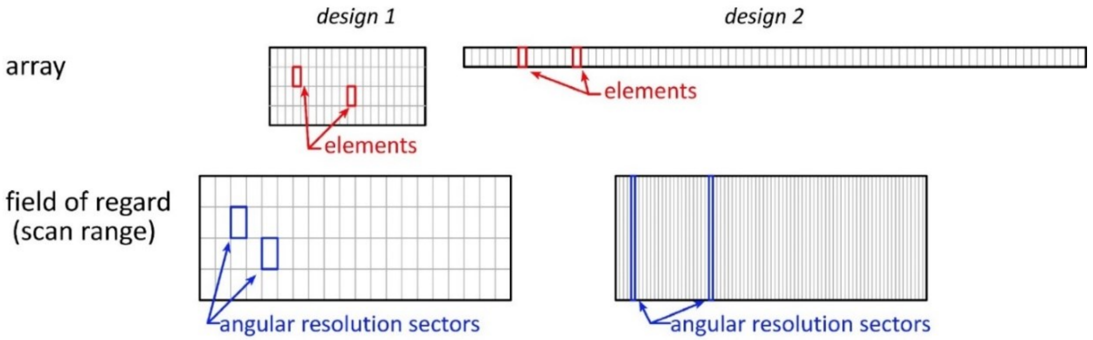
$1/\sin^2\phi$ sidelobes provide strong signals to tall buildings.
Providing sidelobes reduces broadside gain by less than 3dB.
→ Don't need 2D arrays to serve tall buildings





2D vs. 1D: user spatial distribution

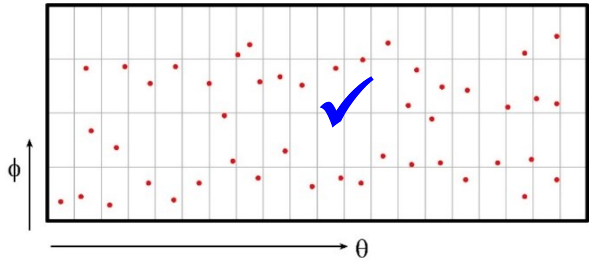


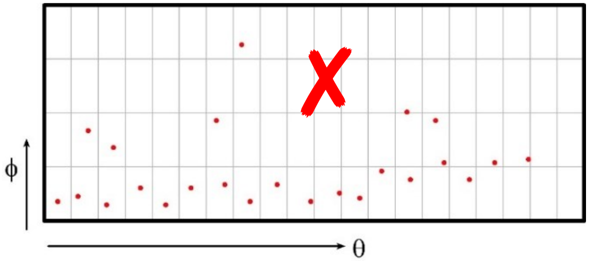


uniform horizontal & vertical user distributions

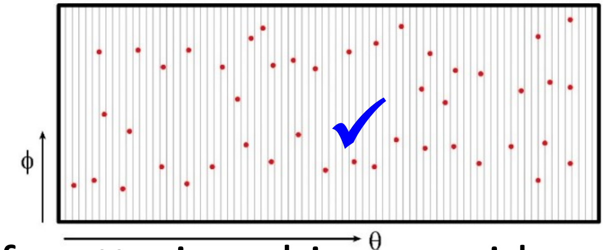
uniform horizontal, nonuniform vertical

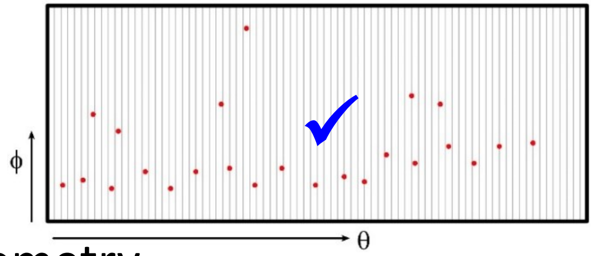
design 1: 2D array





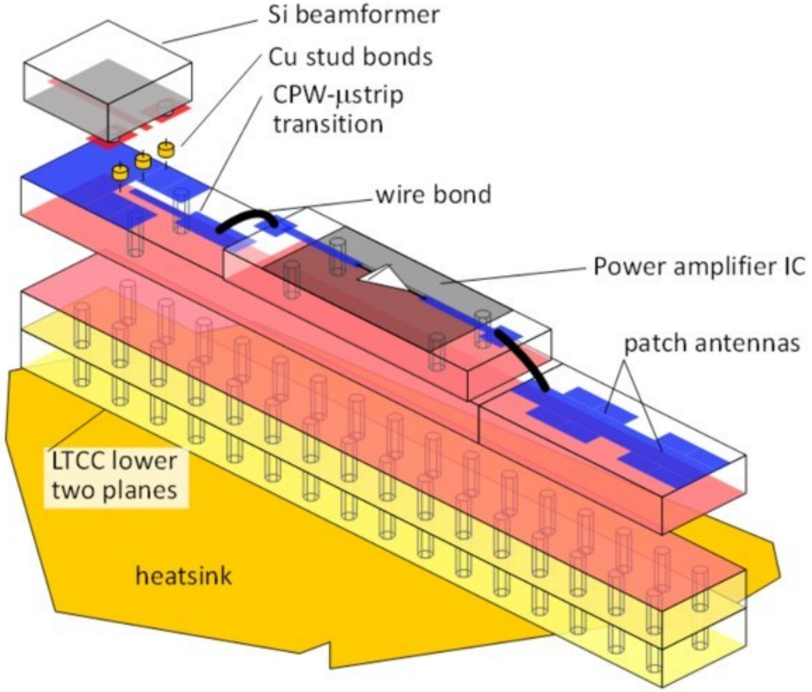
design 2: 1D array



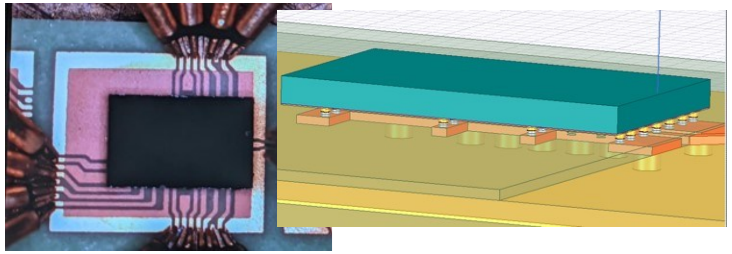


Spatial distribution of users, and of scattering objects, guides choice of array geometry.

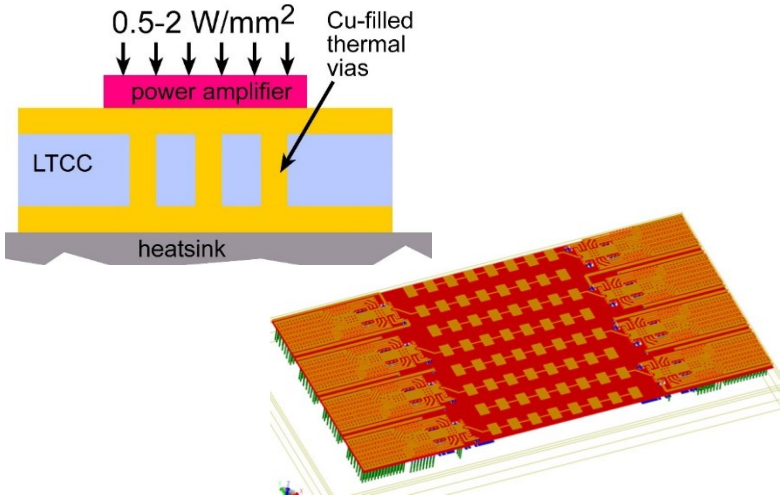
140GHz hub: packaging challenges



IC-package interconnects
Difficult at > 100 GHz



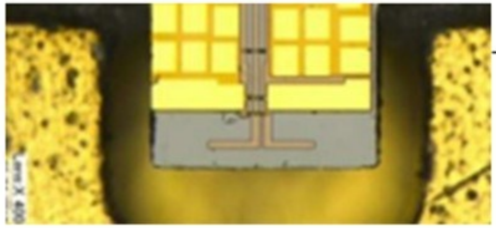
Removing heat
Thermal vias are marginal



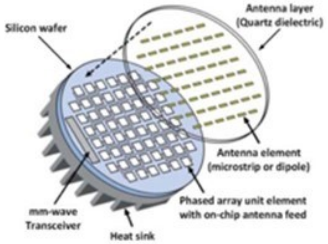
Interconnect density
Dense wiring for DC, LO, IF, control.
Hard to fit these all in.

Economies of scale
Advanced packaging standards require sophisticated tools
High-volume orders only
Hard for small-volume orders (research, universities)
Packaging industry is moving offshore

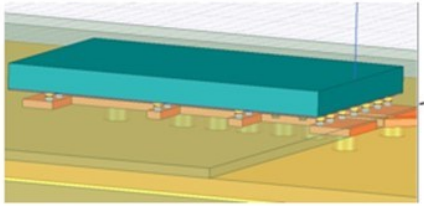
100-300GHz IC-package connections

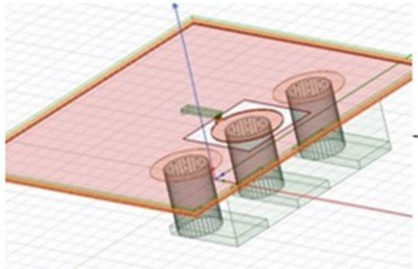


Deal, IEEE Trans THz, Sept 2011



G. Rebeiz

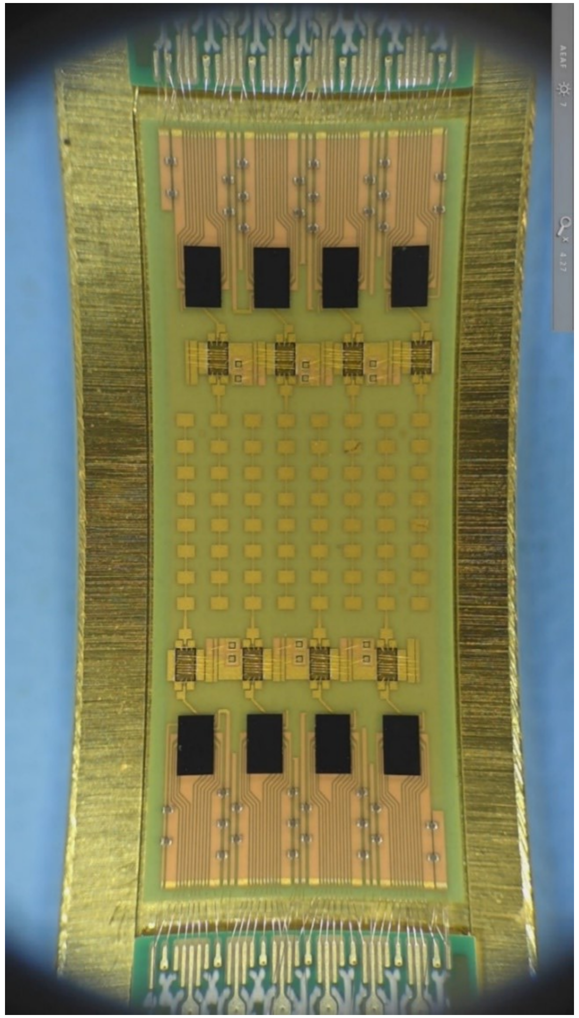




type	Frequency	technology	cost	heatsinking
micromachined waveguide interface	1000 GHz	Research. Cheap one day ?	high ✗	good
ribbon, mesh bond	200 GHz	Handcrafted.	high ✗	good
patch antennas on superstrate	1000 GHz	Straightforward	low	good
Cu stud flip-chip	>200 GHz	Industry standard	low	ok, marginal for PA ✗
hot vias	200 GHz	Development	low ?	good
(ball) wirebonds	100 GHz ✗	Industry standard	low	good

140GHz hub: ICs & Antennas

Receiver: A. Farid et. al, 2021 IEEE BCICTS; Transmitter: A. Farid et. al, 2022 IEEE Trans. MTT 10.1109/TMTT.2022.3161972

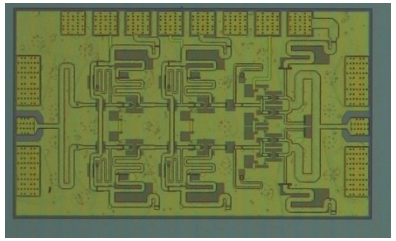


135GHz 8-channel MIMO hub array tile modules

140GHz MIMO hub receiver array modules,
4-element, 8-element
MIMO beamforming
Data transmission up to 1.9Gb/s

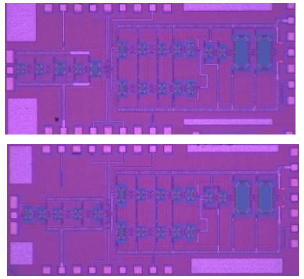
140GHz MIMO hub transmitter array modules,
8-element
38.5dBm EIRP
Data transmission up to 1.9Gb/s
Performance limited by assembly yield.
Data rate limited by connector.

110mW InP PA
20.8% PAE

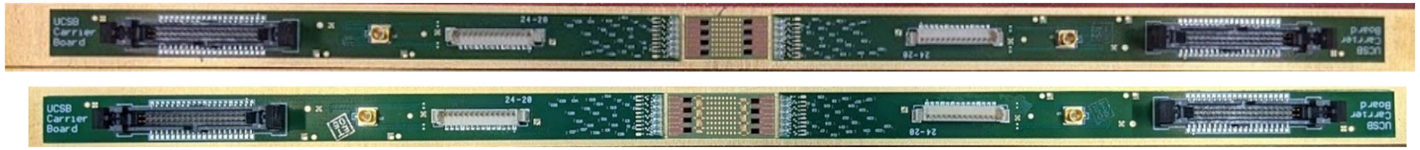


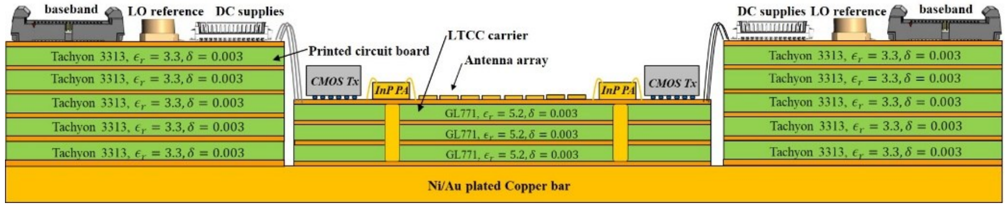
Teledyne 250nm InP HBT

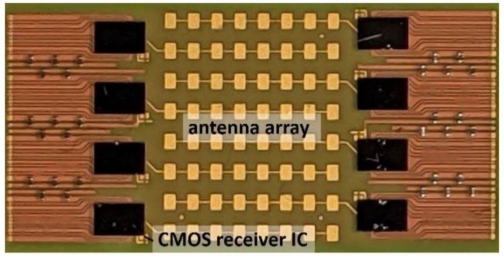
CMOS TX, RX ICs
GlobalFoundries
22nm SOI CMOS.

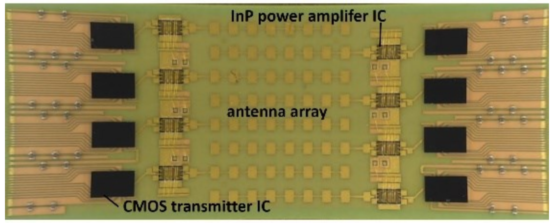


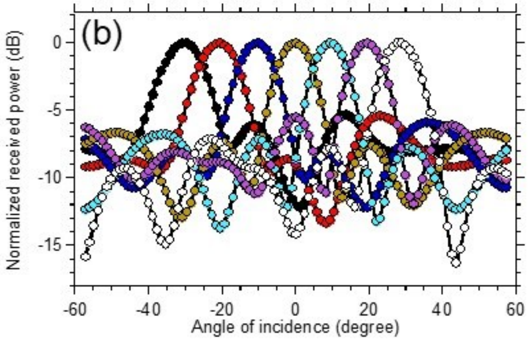
Receiver: A. Farid et. al, 2021 IEEE BCICTS; Transmitter: A. Farid et. al, 2022 IEEE Trans. MTT 10.1109/TMTT.2022.3161972

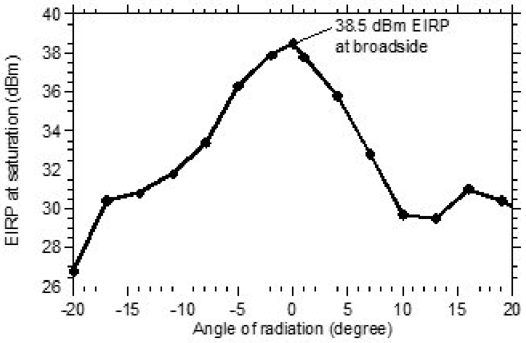


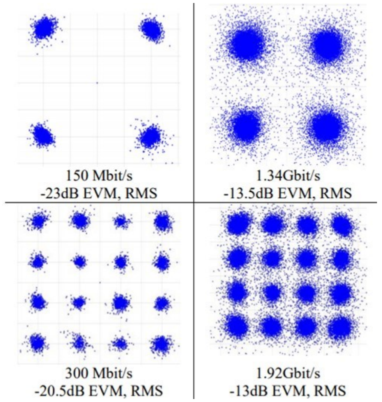




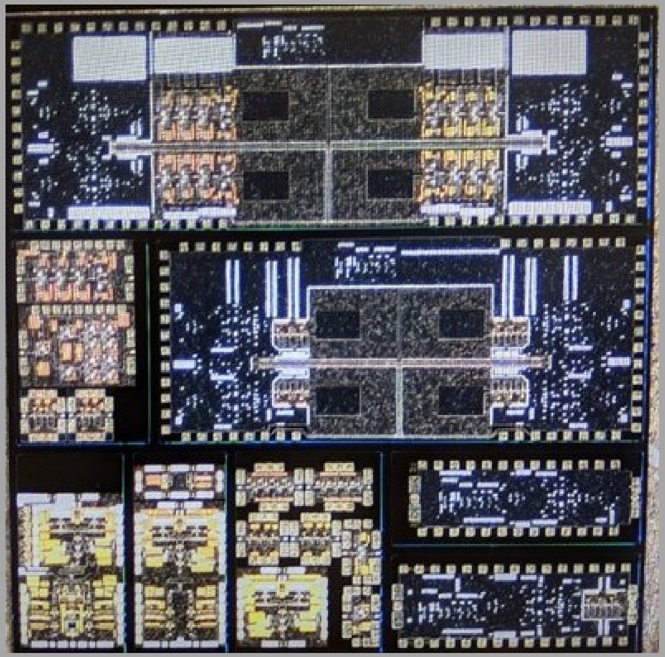


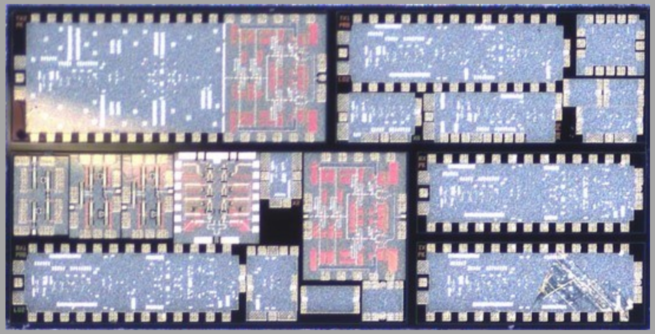




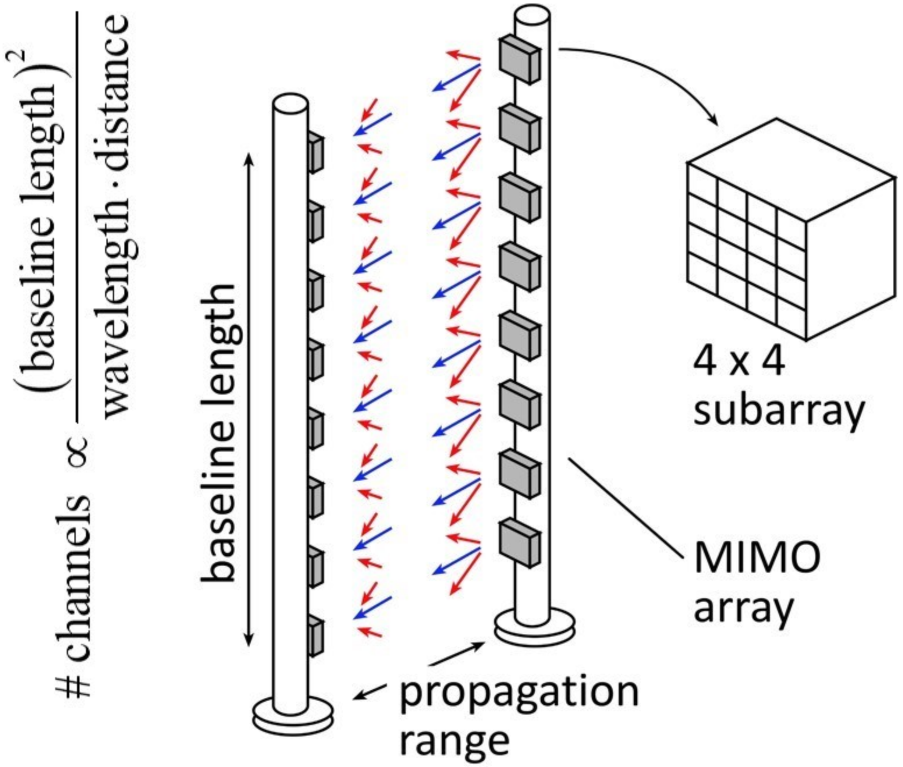


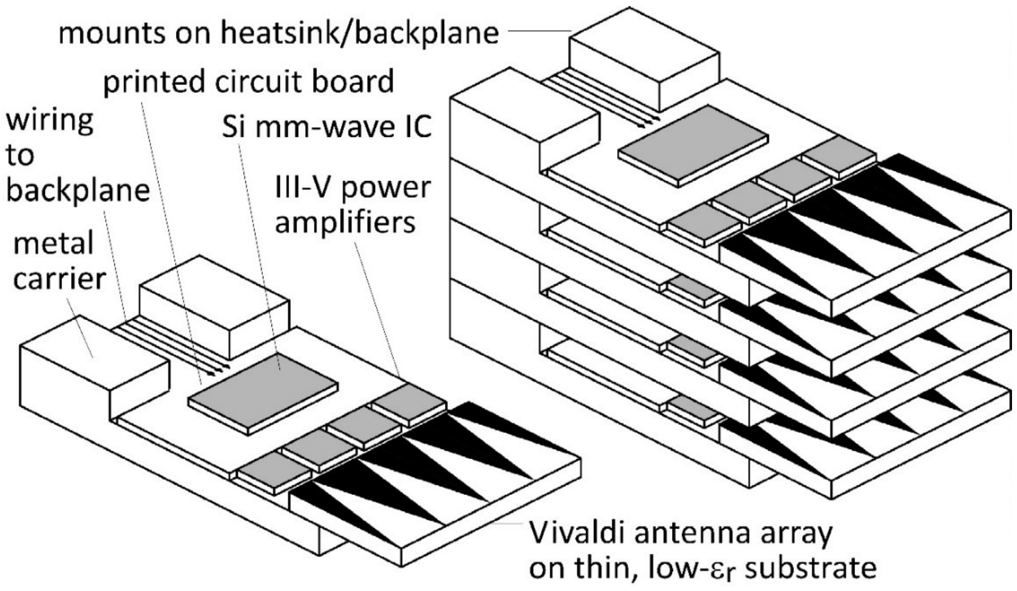
210 GHz and 280 GHz Array Modules





210 GHz MIMO backhaul modules



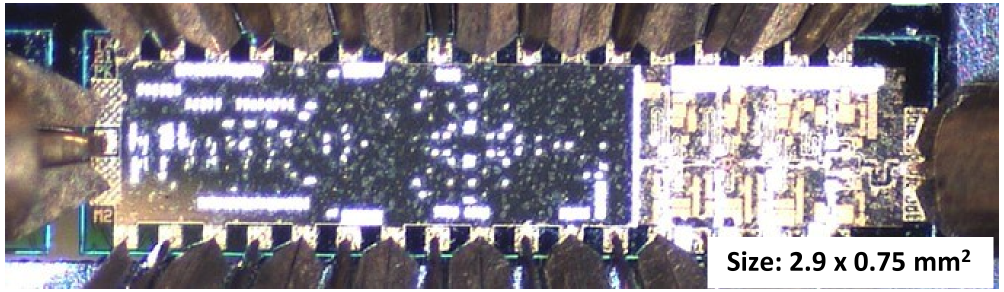


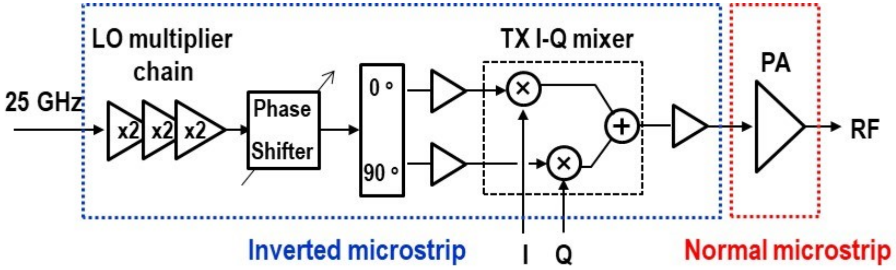
8-element MIMO array
3.1 m baseline for 500m link.
80Gb/s/subarray→ 640Gb/s total
4 × 4 sub-arrays → 8 degree beamsteering

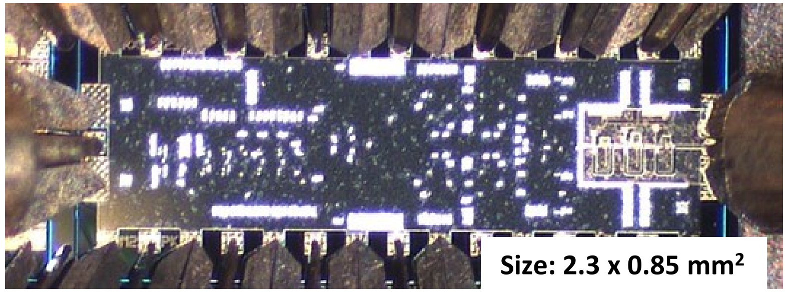
Key link parameters
500 meters range in 50 mm/hr rain; 23 dB/km
20 dB total margins:
packaging loss, obstruction, operating, design, aging
PAs: 63mW $=P_{1dB}$ (per element)
LNAs: 6dB noise figure

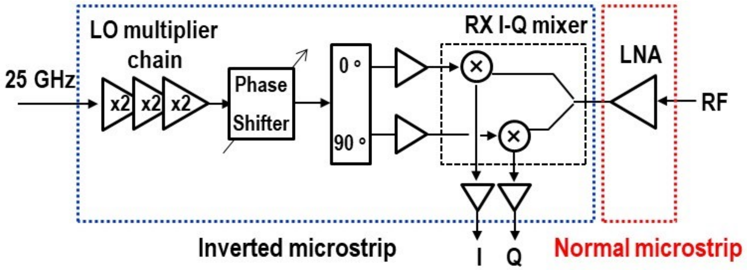
210 GHz Transmitter and Receiver ICs

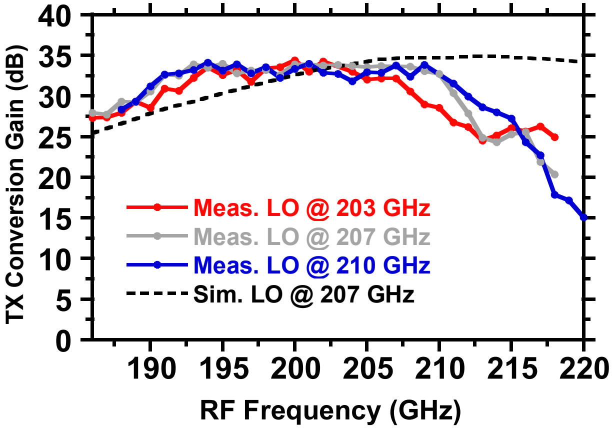
M. Seo et al, 2021 IMS; Teledyne 250nm InP HBT

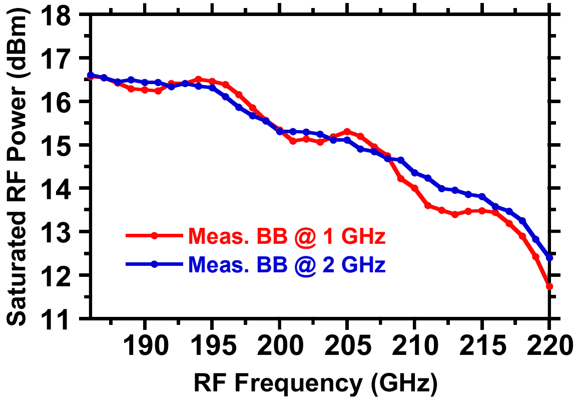


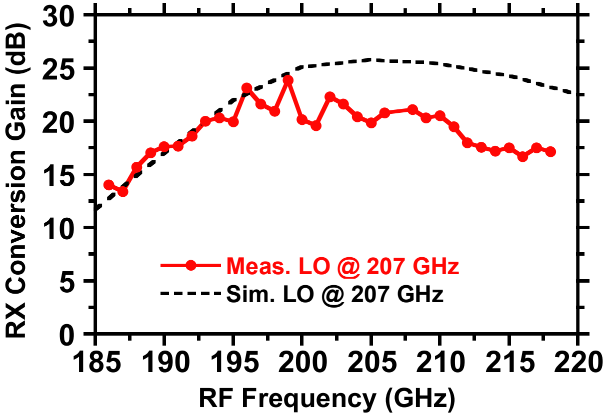


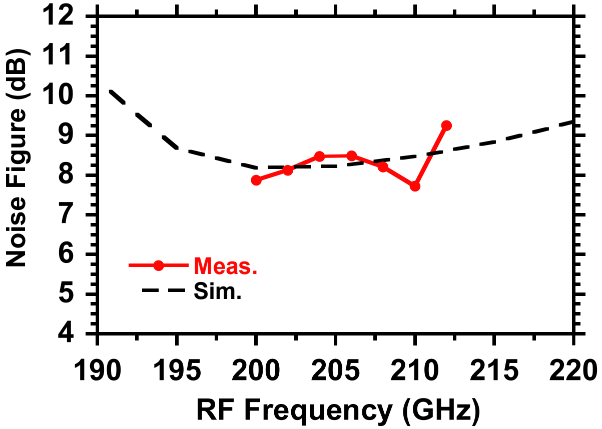








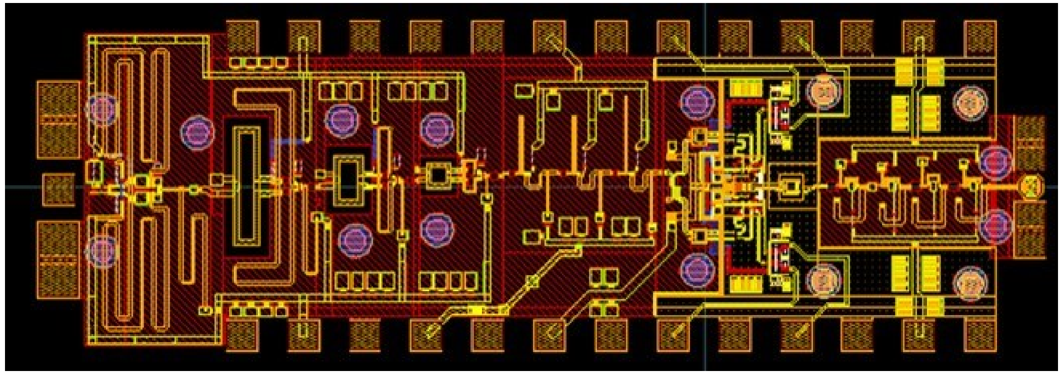




280GHz Transmitter and Receiver IC Designs

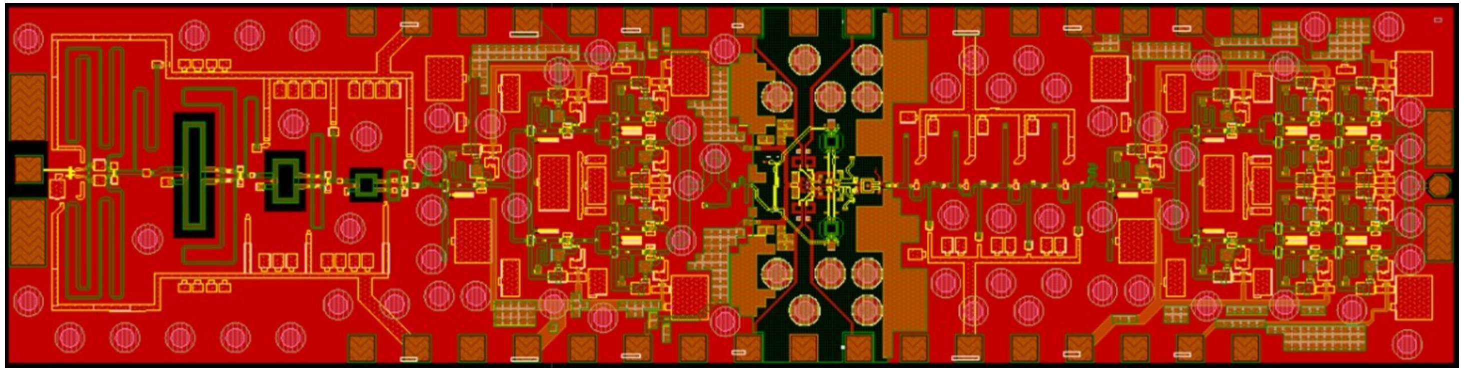
Solyu, Alz, Ahmed, Seo; UCSB/Sungkyunkwan
Teledyne 250nm InP HBT technology

Receiver



simulations: 11dB noise figure, 40GHz bandwidth

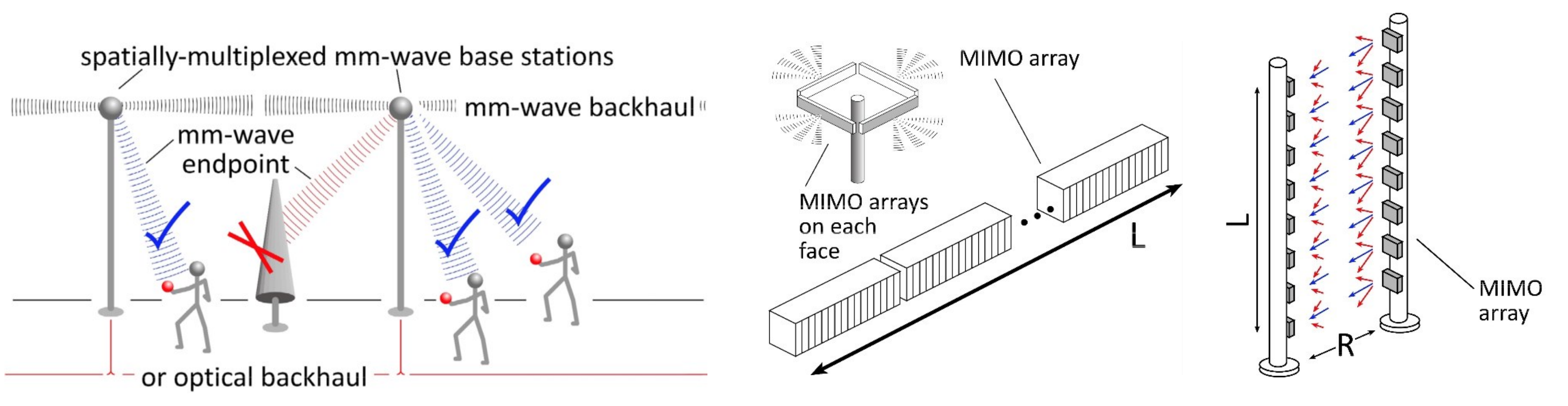
Transmitter



simulations: 17dB saturated output power.

Application: point-point MIMO backhaul links

100-300GHz Wireless



Wireless above 100 GHz

Massive capacities
large available bandwidths
massive spatial multiplexing in base stations and point-point links

Very short range: few 100 meters
short wavelength, high atmospheric losses. Easily-blocked beams.

IC Technology
All-silicon for short ranges below 200 GHz.
SiGe or III-V LNAs and PAs for longer-range links. Just like cell phones today
III-V frequency extenders for 340GHz and beyond

The challenges
computational complexity
packaging: fitting signal channels in very small areas
mesh networking to accommodate beam blockage
driving the technologies to low cost


OBRIGADO
gracias
どうも
ARIGATO
hvala
DANK U
takk
MERSI
merci
謝謝
obrigado
danke schön
köszi
سپاس
PALDIES
muchas gracias
ありがとう
TEŞEKKÜR EDERIM
MOLTE GRAZIE
GO RAIBH MAITH AGAT
danke
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THANKS
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TAK
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vielen dank
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NA GODE
muchas gracias
obrigado

In case
of questions

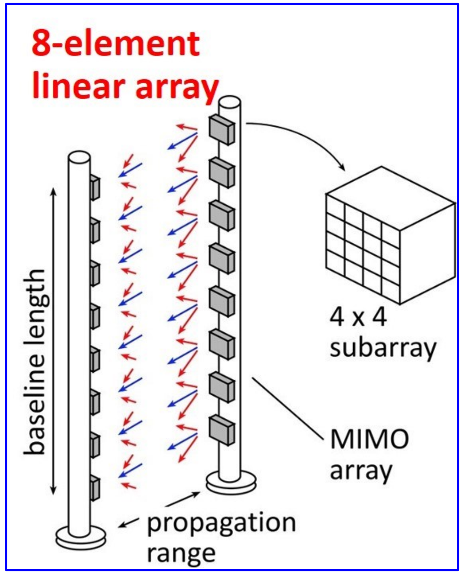
70 GHz spatially multiplexed base station

If we use instead a 70GHz carrier,
the range increases to **70 meters** (vs. **40 meters**)
but the handset becomes **16mm×16mm** (vs. 8mm×8mm),
and the hub array becomes 19mm×612mm (vs. 10mm×328mm)

Or, use a 4×4 (**8mm×8mm**) handset array,
and the range becomes ..**about 40 meters**.

Same handset area (more handset elements)→ same link budget
Easier to obtain license for 140±2.5GHz than 70±2.5GHz

75 GHz, 640 Gb/s MIMO backhaul (16QAM)



Why not use a lower-frequency carrier, e.g. 75 GHz ?

Must use at least 16QAM, given 80Gb/s/channel…

8-element 640Gb/s linear array:

requires 16dB$_m$ transmit power/element (P$_{out}$)

requires 3.5m linear array

Similar RF power output, physically larger