Paper WEA2-1

Broadband-Multiband Antennas Enabling Capacity & Security for Mobile Wireless 5G and Beyond

Johnson J. H. Wang
Wang Electro-Opto Corporation (WEO)
Marietta, Georgia USA
email: jjhwang@weo.com

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Broadband-multiband antennas
are becoming necessary and enabling

for

both **capacity and security**

in

Mobile Wireless 5G and Beyond

Antenna requirements for global 5G mobile wireless

- Frequency bands range from **614 MHz to 43.5 GHz** for upcoming global 5G mobile wireless, **and even wider later on.**

System or plan	Freq. (MHz)	Pol	Gain	Pattern	Sat/Ter	Tx/Rx
mMTC	614-1000	LP	Low	Omni	Terrestr	Tx/Rx
3GPP and LTE	@ 1700, 2000, 2500	LP	Low	Omni	Terrestr	Tx/Rx
GNSS	1210-1610	RHCP	Low	Hemi-spheri	Satellite	Rx
MT & others	3300-4200	LP	Low	Omni	Terrestr	Tx/Rx
Japan/China	4400-5000	LP	Low	Omni	Terrestr	Tx/Rx
mmWave	24250-43500	LP	High	Beam-scan	Terrestr	Tx/Rx

[1] J. Lee et al (10 authors from Samsung, Ericsson, Nokia, and Huawei), IEEE Communications Magazine, vol. 56, no. 3, pp. 12-18, Mar. 2018.

Security and crises have become top issues on everyone's mind

- Rampant hacking, spoofing, stealing, monitoring, tracking in *both cyber and physical spaces*
  - For example, both the efforts and the errors in preparing this paper **doubled** due to
    - real-time hacking
    - software degradation and malfunction (WORD, Excel, PDF, PowerPoint, Windows) with each security upgrade, or worse, discontinuance .
- Insurance companies keep accelerating sales efforts yet foot-dragging in paying claims
- Global warming crisis will go beyond point-of-no-return in two years if staying on present course. (This point can be proven with simple vector calculus.)

A Joint Special Session in 2019 IEEE International Symposium and Radio Science Meeting in Atlanta, GA, July 7-12, 2019

Special Session (SS) Topic:

Cybersecurity and Electromagnetic Systems—from DC to Daylight and from Wireless to Wired

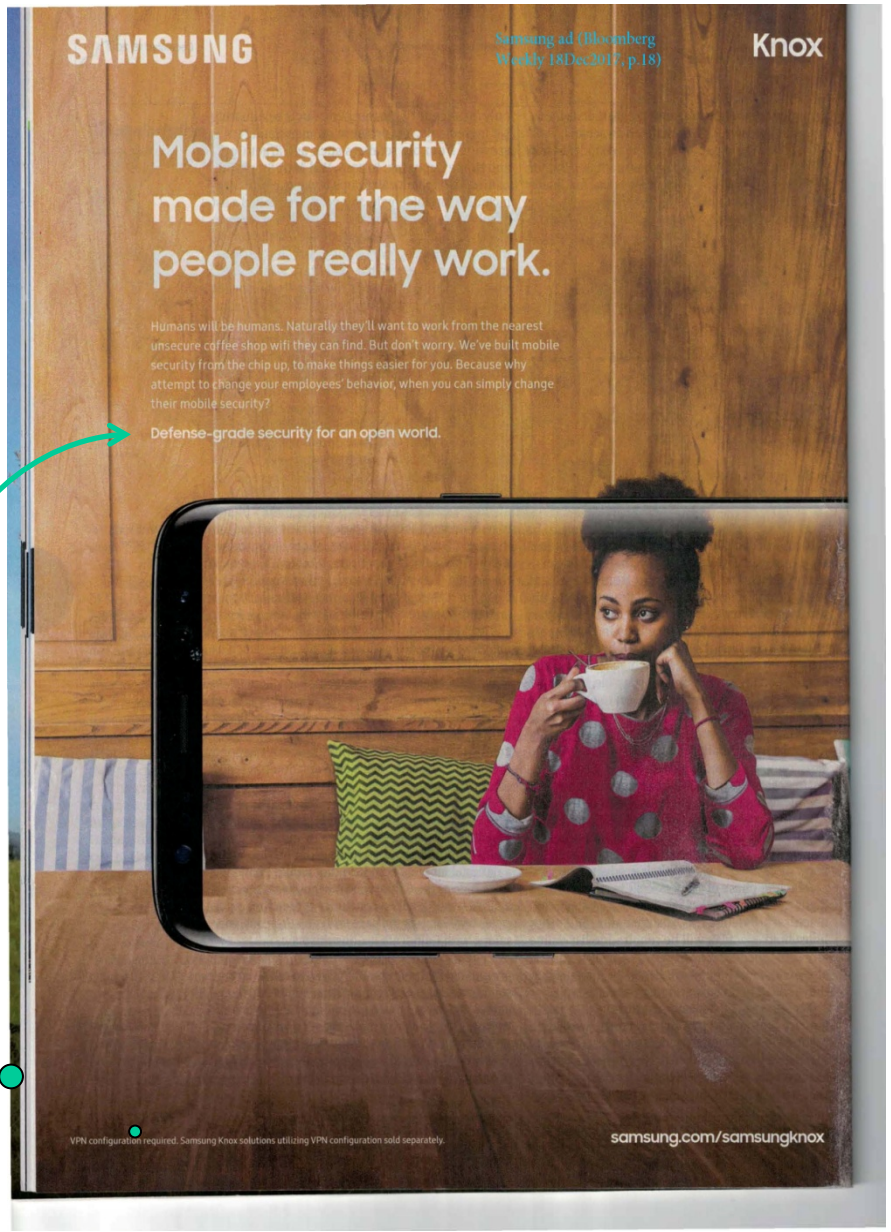
Co-Organizers: Drs. Johnson J. H. Wang and Andrew Peterson

This planned Joint Special Session (SS) follows the theme of two preceding SS's:

TH.SP.1P "Wideband Phased Arrays for Wireless of 5G and Beyond" (2017);
TU-SP.1P "Wideband Antenna and Phased Array to Enable Performance and Physical Layer Security for Mobile Wireless 5G" (2018).

Cellphone industry leader began to follow the footsteps of defense industry by promoting "Defense-grade security for an open world"

Defense-grade security for an open world



Samsung ad, *Bloomberg Businessweek,* 18 Dec 2017, p.18

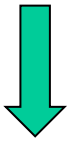
Warning on network security and antivirus on protective sheet covering the screen of new Anritsu VNA (VectorStar)

For engineers, GNSS (Global Navigation Satellite System) has tough security problem to solve

- As a wireless system, GNSS operation is inherently vulnerable to jam, spoof, and other hostile cyber attacks.

  S. Lo et al, "Consumer mass market accelerometers for GNSS anti-spoofing," Inside GNSS, Sept/Oct 2017.

- ***Countermeasures available for GNSS?***
  - ***Frequency filtering and spatial filtering (meaning directional antenna) both indispensable.***



  - ***The wider the bandwidth and more adaptive pattern nulls for the antenna system, the more secure the GNSS receiver!***

Proposed antenna arrangement on smartphone, consistent with the concept of Samsung, Ericsson, Nokia, and Huawei [Lo et al]

Broadband-multiband handsets

- In the US, 30-year R&D under SpeakEasy and later JTRS led to production of broadband-multiband military smartphone handsets.
- For the first 100,000 units fielded worldwide, the cost including NRE is over $30,000 per unit.
- The newest model Army AN/PRC-152A handset covers six functions over 30-2000 MHz, contiguously.
  - A body-wearable antenna suitable for field operations has been developed by WEO.
- A handheld receiver Icom IC-R30—covering 0.1-3305 MHz—is available at $600.

Military wideband handsets covering 30 MHz to 2000 MHz

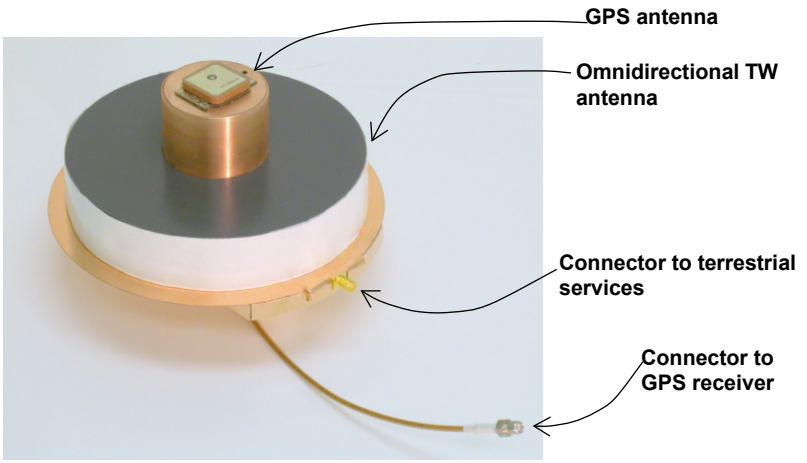
- Defense industry has produced Army AN/PRC-152A wideband network handset, among others, covering 30 MHz to 2000 MHz .

The newest model can cover six functions ranging from 30 MHz to 2000 MHz in a contiguous way

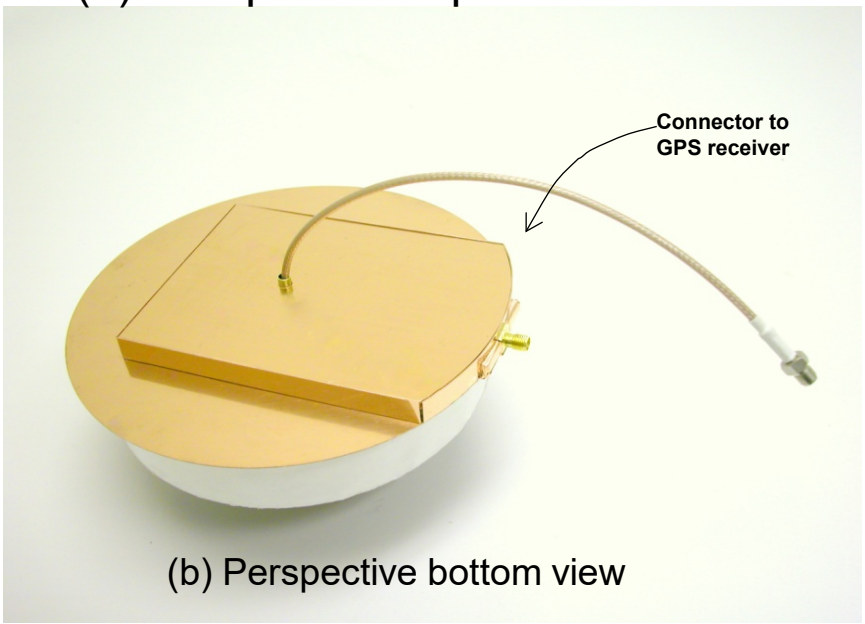
System served	Freq. (MHz)	Pol	Gain	Pattern	Sat/Ter	Tx/Rx
SINCGARS band	30-88	LP	TBD	Omni-diretional	Terrestrial	**Tx/Rx**
Air & Marine band	116-174	LP		Omni-diretional	Terrestrial	**Tx/Rx**
UHF Comm.	225-450	LP	TBD	Omni-diretional	Terrestrial	**Tx/Rx**
UHF-Public Safety	450-512	LP	TBD	Omni-diretional	Terrestrial	**Tx/Rx**
UHF SATCOM	225-318	**RHCP**	TBD	Hemi-spherical	Satellite	**Tx/Rx**
L-Band (Soldier Radio Waveform)	1000-2000	LP	TBD	Omni-diretional	Terrestrial	**Tx/Rx**

Antenna solution: multioctave Traveling-Wave Antenna (TWA)

- Body-wearable version for handsets has been demonstrated [8].
- For 5G the 3D TWA will be shrunk to about 1/5.
- Fortunately, like other cellphone antennas, for lower frequencies it serves essentially as a launcher; the body of the cellphone is the actual radiator.



(a) Perspective top view



(b) Perspective bottom view

History of three-dimensional (3D) Traveling-Wave Antenna (TWA)

- First published in ISAP 2011 and later for a more advanced model with more details.
- Several patents awarded in 2013-2016.
- For its antenna, a cost-effective breadboard Multi-band Body Wearable Antenna (MBWA) covering all functions has been developed and tested successfully*.

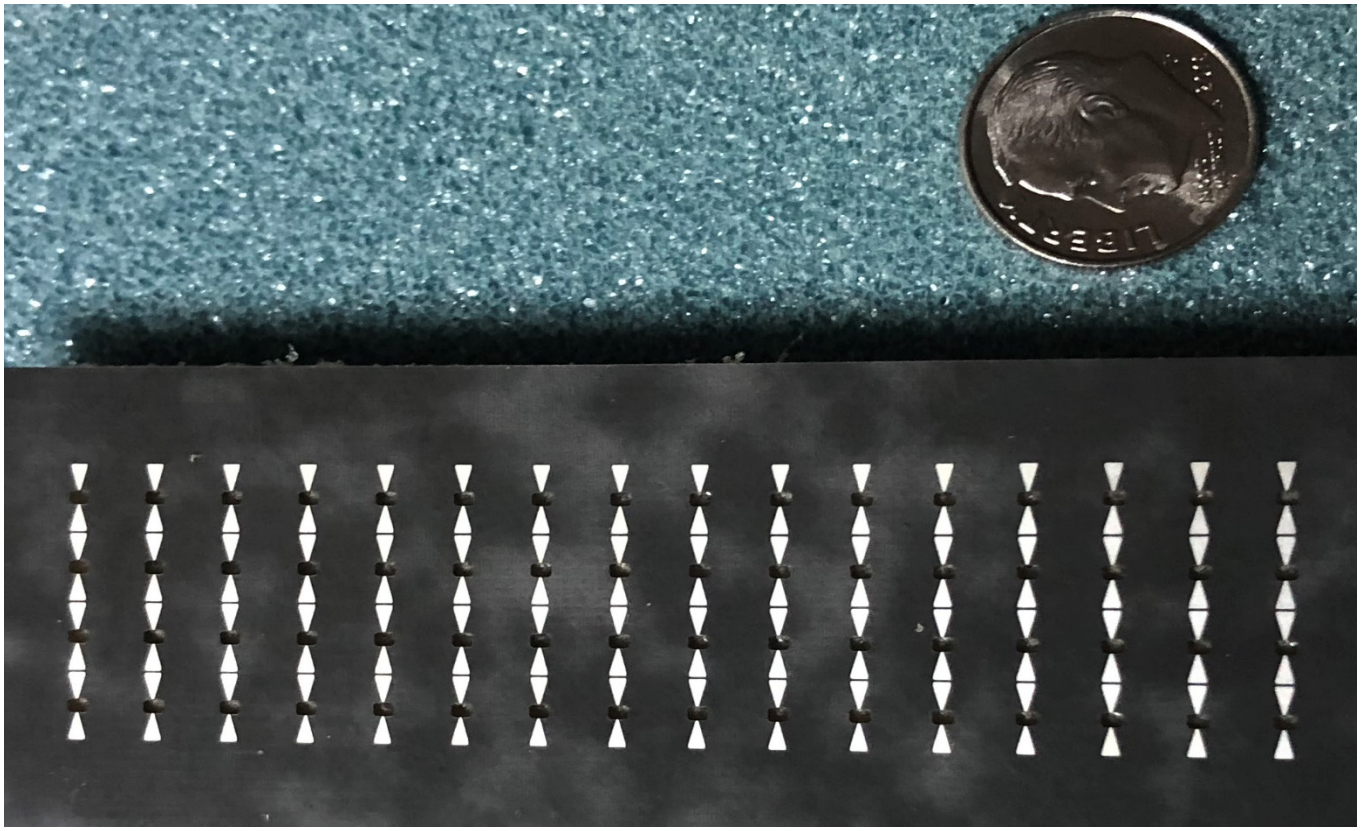
*J. J. H. Wang and J. C. Adley, "30-2000 MHz Multi-band Body Wearable Antenna (MBWA)," *2017 IEEE International Symposium on Antennas & Propag. and Radio Science Meeting*, San Diego, CA July 9-15, 2017.

For frequencies 6 GHz to 30 GHz

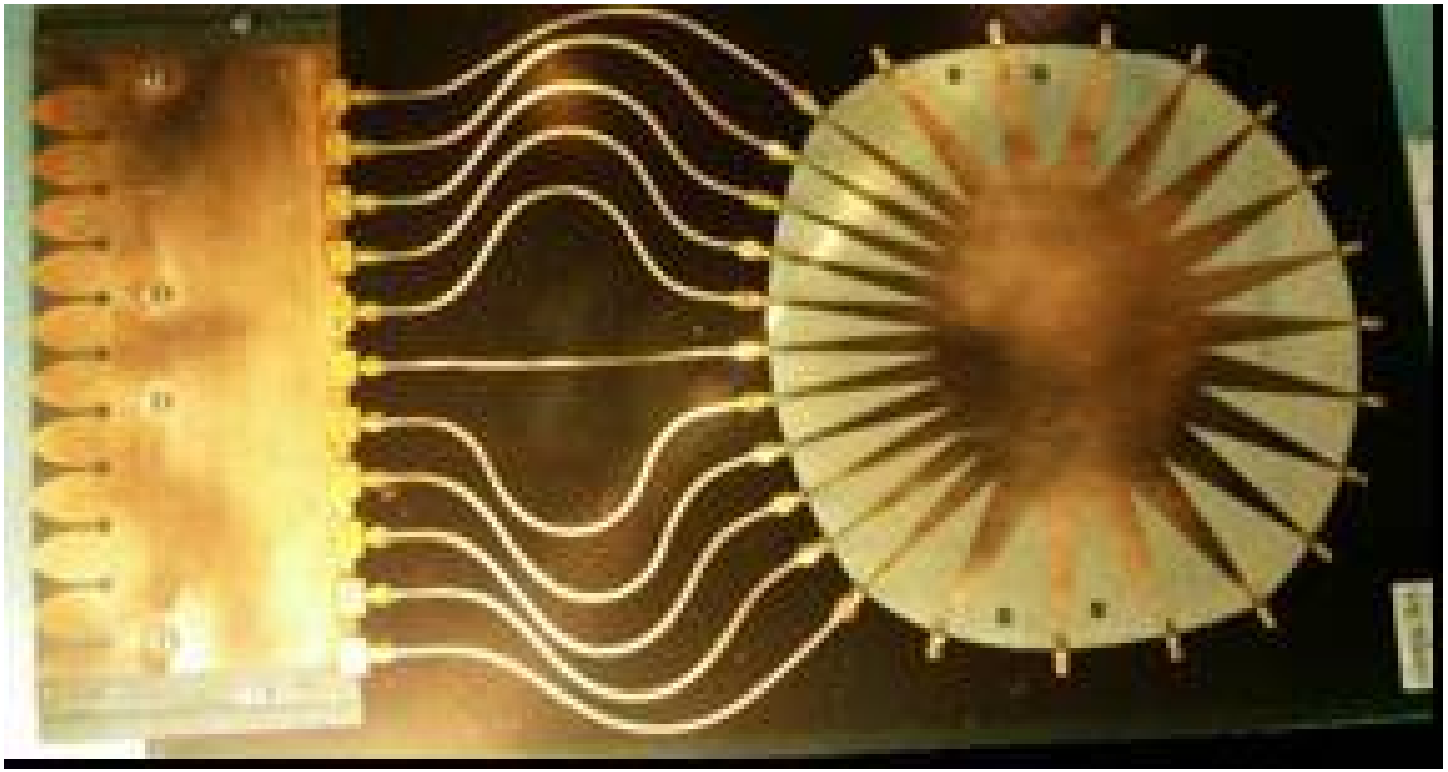
- Research ongoing using wideband wide-scan TWAA phased arrays.
- Beam forming:
  - Transmit (Tx): Analog Beam Forming with Rotman lens.
  - Receive (Rx): Massive MIMO (Multiple-Input Multiple-Output)
- Our difficulties are mainly in scaling up from microwave frequencies to mmWave frequencies.

8-30 GHz ±60°-scan planan array

- Three-dimensional (3D) Traveling-Wave Antenna Array (TWAA) discussed in [6]-[7], scaled up to cover X through Ka bands. Picture shows array aperture.



True Time Delay (TTD) Analog Beam Forming (ABF) is based on a dielectrically-loaded (K~10) Rotman-lens developed in 1992 shown below, to be frequency-scaled upward.



Results Are Highly Promising

- A feasibility study on the proposed antenna solution for 5G and beyond shows that is highly promising, mainly due to the maturity of TWA and TWAA technologies, which have achieved estimated TRL-7 and MRL-7.
- There are some uncertainties on the space available and gain requirement in [1] even though they apparently reflect the consensus of four leading cellphone manufacturers: Samsung, Ericsson, Nokia, and Huawei.

Engineering and Implementation Issues

- The theoretical discussions in treating the cybersecurity as a physical problem are intuitively obvious to some, and have been practiced in the defense & aerospace industry (DAI).
- Since 1980 the U.S. has been developing software-defined radios (SDR), first under the SpeakEasy thrust around 1980, later transitioned to JTRS around 2000.
- In DAI, the security of a high-end wireless system fundamentally depends on its antenna, which ideally is **broadband/multiband, has desired diversity in radiation patterns and adaptive to threat RF power, etc.**

Therefore, the easy route for secure communications for 5G is to crossfertilize with military handheld radios!

- US military recently deployed 100,000 handheld radios for secure Communications, Command, Control, Computer, Intelligence & Electronic Warfare (C4I&EW), under two contiguous DoD Technology initiatives:
  - SpeakEasy: 1980-2000 (DARPA & Army CERDEC)
  - JTRS: 2000-today (mainly Army CERDEC).
- They are software-defined radios (SDR) using antennas with
  - Ultra-wide and multiple bandwidths
  - Sophisticated radiation properties (patterns, polarizations, multimode, smart, etc.)

Regulatory issues

- In late 2017, US FCC dismantled Net Neutrality regulations, thus removed regulatory barrier to broadband internet.

How to transform a $30K military radio to $400 5G phone?

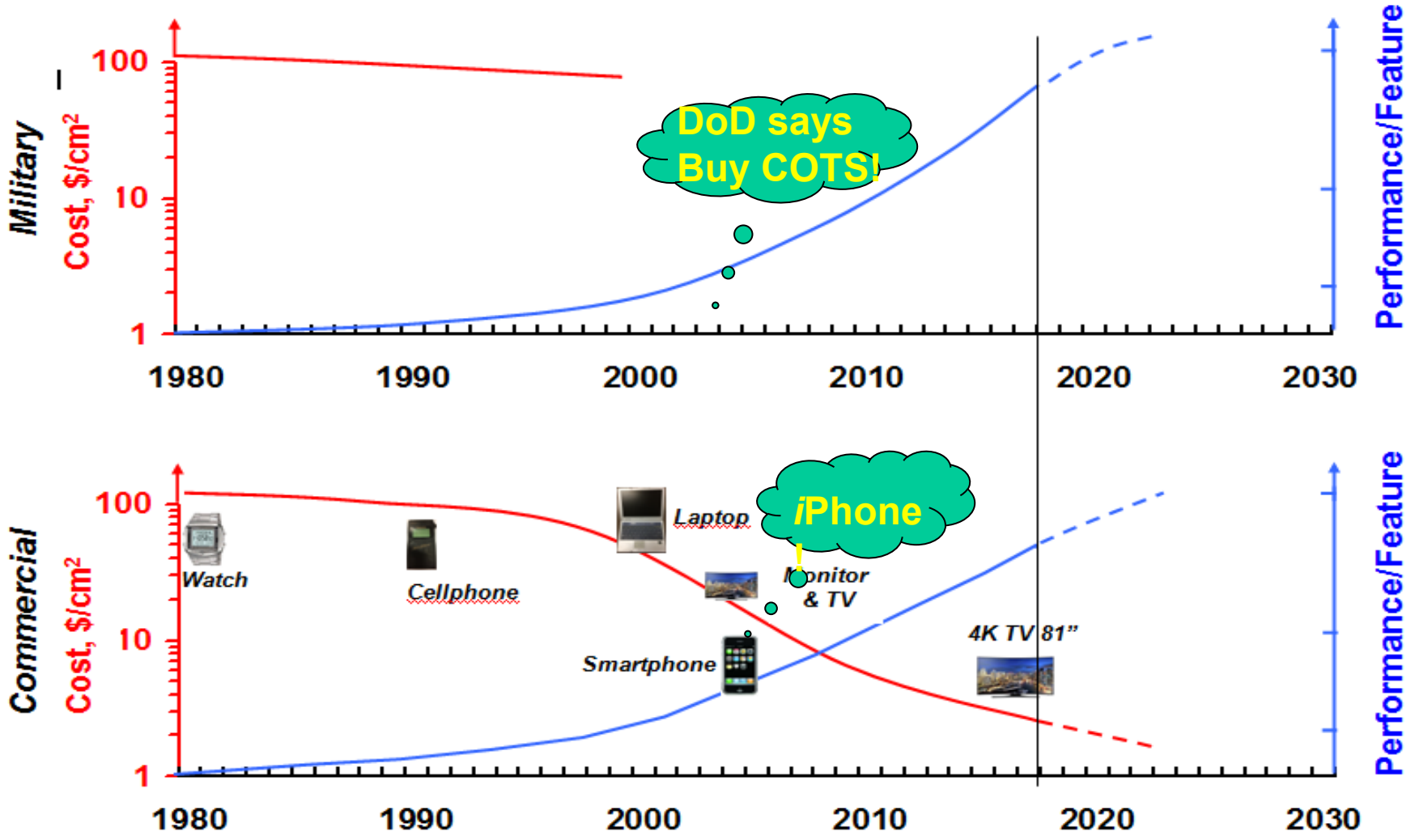
- Overcome humongous cost and complexity
  - start with realistic scaled-down versions
  - teaming, joint or collaborative R&D efforts
- Engineering approaches
  - Downgrade, relax, and redefine specifications
  - Employ Massive MIMO (Multiple-Input Multiple-Output)
- Learn from *i*Phone history from Apple/Foxconn/Cingular?
  - Military radios : $3 Billion total (first 100,000 radio at $30,000 each including R&D & tooling cost costs).

  - 5G phones : $40 Billion total (first 100 million secured phones at $400 each including 10% R&D & tooling costs)

Cost/benefit Study

- Huge cost reduction can be achieved by following the historical path of Flat Panel Display (FPD) in Electronic Viewing (next slide).
- Slide #28 showed that collective and competitive efforts on 5G should lead to success. For example,
  - Foxconn is investing $10 Billion in Wisconsin and $3 Billion in Michigan to build factories in 8K PFD and 5G smartphone.
  - President Trump attended the ground-breaking ceremony in Wisconsin with strong endorsement on June 28, 2018.

Huge reduction in costs can be achieved by following historical path of Flat Panel Display (FPD) in Electronic Viewing



If the 5G spirit remains high, collective and competitive efforts on 5G should lead to success!