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# Solving Cybersecurity Problem by Symmetric Dual-Space Formulation— Physical and Cybernetic

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This author had

- sounded alarm on the lurching cybersecurity crisis in 2016 IEEE Phased Array Symposium
- notified hacking of 2017 and 2018 APS-URSI Symp. websites!
- presented the theory and solution for Cybersecurity problems in two preceding Special Sessions he organized:
  - J. J. H. Wang, "Wideband Wide-Scan Millimeter-Wave Phased Arrays for Enhanced Security/Privacy and Performance in 5G Mobile Wireless," 2017 IEEE APS-URSI Symp., San Diego, CA, July 2017.
  - J. J. H. Wang, “Wideband Antenna and Phased Array for Performance and Physical Layer Security in Mobile Wireless 5G,” 2018 IEEE APS-URSI Symp., Boston, MA, July 2018.

However, several respectable readers and reviewers find this theory difficult to understand.
As a result, this paper was almost rejected if not for……

***Therefore, we will attempt to illustrate this theory from several different angles, starting by attacking the following remarks of Elon Musk****

We live in a simulation—like characters trapped inside some space alien's video game!

*Elon Musk is a highly accomplished figure well known to most in this audience.

# To show that Musk is wrong, we begin with a review on the underlining Maxwell Equations (ME) and Fourier Transforms (FT)

- Fourier Transform (FT) is the fundamental theory on which most fields of IEEE—even Statistical Mechanics, Quantum Mechanics, Thermodynamics, etc.—are built up.
- Maxwell Equations (ME) and FT in *Symmetric* forms appeared 78 years ago in the classical text of Stratton at MIT.
- Stratton's *Symmetric* ME and FT have rarely been used in practice—yet by this author exclusively.

# Symmetric Maxwell Equations (ME) were already in Stratton in 1941!

**J. A. Stratton, *Electromagnetic Theory*, McGraw-Hill, New York, 1941, p.464**

Let us assume that the field vectors contain the time only as a factor $\exp(-i\omega t)$ and write the field equations in the form

$$\text{(I)} \quad \nabla \times \mathbf{E} - i\omega\mu\mathbf{H} = -\mathbf{J}^*, \qquad \text{(III)} \quad \nabla \cdot \mathbf{H} = \frac{1}{\mu}\rho^*,$$

$$\text{(II)} \quad \nabla \times \mathbf{H} + i\omega\epsilon\mathbf{E} = \mathbf{J}, \qquad \text{(IV)} \quad \nabla \cdot \mathbf{E} = \frac{1}{\epsilon}\rho.$$

The medium is assumed to be homogeneous and isotropic, and of zero conductivity. The quantities $\mathbf{J}^*$ and $\rho^*$ are fictitious densities of "magnetic current" and "magnetic charge," which to the best of our

[1] Sections 8.14 and 8.15 were written in collaboration with Dr. L. J. Chu.

[2] LOVE, *Phil. Trans.*, (A) **197**, 1901; LARMOR, *Lond. Math. Soc. Proc.*, **1**, 1, 1903; IGNATOWSKY, *Ann. Physik.* **23**, 875, 1907

# Symmetric Fourier Transforms (FT) were also already in Stratton in 1941!

**J. A. Stratton, *Electromagnetic Theory*, McGraw-Hill, New York, 1941, p.289**


likewise the transform of $g(u)$. In the more general case of Eq. (14) one may write for the spectral density of $f(x)$ the function

$$g(u) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{-iux}\, dx, \tag{21}$$

and hence for $f(x)$ the reciprocal relation

$$f(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} g(u) e^{iux}\, du. \tag{22}$$

An extensive table of Fourier transforms has been published by Campbell and Foster.[1]

# The Dual-Space Dual System concept is based on FT

This author's numerical analyses used the following symmetric FT pair for problem governed by ME.

**$E\ (r, t)$ : Time domain** ***Real space*** ⟸ **We are here!**

$$\bar{E}(\mathbf{r},t) = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{\infty} \mathbf{E}\,(\mathbf{r}, \omega)\, e^{j\omega t}\, d\omega \equiv \mathbf{F}^{-1}[\,\mathbf{E}(\mathbf{r}, \omega)\,]$$

**$\mathbf{E}\ (r, \omega)$ : Frequency domain** ***Virtual space***

$$\mathbf{E}(\mathbf{r}, \omega) = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{\infty} \bar{E}\,(\mathbf{r}, t)\, e^{-j\omega t}\, dt \equiv \mathbf{F}\,[\,\bar{E}(\mathbf{r}, t)\,]$$

*J. J. H. Wang, Generalized Moment Methods in Electromagnetics —Formulation and Computer Solution of Integral Equations, p. 404, John Wiley & Sons, New York, 1991.*

# Our theoretical approach takes advantage of the *transform relationship between* cyberspace & physical space *(like Fourier Transform)*

- By focusing on *observables*, one can transform the abstract *information* in cyberspace to a *physical space problem* by narrowing
  - *information* to *electronic information*
  - *communication* to *telecommunication*
- The present methodology is similar to several well-established *dual-space/dual-system* concept in modern physics.
- The process requires that Maxwell Equations (ME) and Fourier Transforms (FT) have *symmetric mathematical features!*

During 1940-1960 application of symmetric FT to mechanical waves achieved astounding success, as Blackman and Tukey described with excitement in the preface of their book:

> **"…we were able to discover....a very weak low-frequency peak which would surely have escaped our attention without spectral analysis. This peak, it turns out, is almost certainly due to a swell from the Indian Ocean, 10,000 miles distant. Physical dimensions are: 1 mm high, a kilometer long."**

***This historic discovery of the magic power of spectral-space observation—in contrast to the inadequacy of the physical-space observation—heralded in the digital age!***

Strangely, after 1960….in the open literature

-symmetric ME and FT were replaced by asymmetric ME and FT

-dual-space/dual-system was pursued only in the cyberspace.

***One might think the culprit was the US government maneuvering this change as part of its Cold War tactics, as their applications for the Defense and Aerospace Industry (DAI) were obvious.***

***Actually the changes were made by leading textbook authors since 1960.***

***Notably, asymmetric FT was introduced by authors at Brooklyn Institute of Technology, the leading institution in microwave theory and technology during 1960-1980. (Papoulis 1962 did it "because it is commonly used in the engineering literature").***

# Numerical experimentation

- This author was fortunate to arrive at Georgia Tech in 1975 when a most advanced CDC Cyber-74 digital computer had just been installed.
- In 1975, there were only two dozen people worldwide doing modern numerical analysis in electromagnetics, all residing in the U.S.—this author was a new comer of the club—because:
  - high-performance computers were not available outside USA due to U.S. export control until the end of Cold War around 1990.
- CDC Cyber-74 computer was available to Tech faculty at near zero cost for five years. Such opportunity is like free use of the 17-mile-long particle collider for physicist.
- Thus this author had the **unique** opportunity to pursue numerical experimentation on a wide range of electromagnetic problems*, while others had no access to, or could not afford, high-performance* computers (mainframe nor mini).

# Many long-standing puzzles and mistakes were resolved during that rare window of opportunity

- For example, errors in commonly used equation on radiation from thin circular annular slot were corrected.
- As another example, deficiencies in widely used equation on planar near field radiation via Fast Digital Fourier Transform were rectified.

  J. J. H. Wang., D. J. Triplett, and C. J. Stevens, "Broadband/Multiband Conformal Circular Beam-Steering Array," *IEEE Trans. Antennas and Prop*. Vol. 54, No. 11, November 2006.

  J. J. H. Wang, "An examination of the theory and practices of planar near-field measurement," *IEEE Trans. on Antennas and Propagation*, Vol. 36, June 1988.

- Controversy of the singularity in dyadic Green's function.

# Why symmetric ME and FT have been rejected or even absent in almost every textbook and computation since 1941?

- IEEE engineers have followed physicists' rigid view that magnetic charge and current are "fictitious" and "have no physical existence."
  - **Which were likely influenced by L. J. Chu**
- Fortunately, Stratton himself apparently envisioned the value and power of the dual-space/dual system methodology, as shown in the next slide.

# Preface of Stratton pointed out clearly shortcomings of MEs in 1941!

- "The pattern set nearly 70 years ago by Maxwell's *Treatise on Electricity and Magnetism* has had a dominant influence *on* almost every English and American text, persisting to the present day."
- "In fact only a dozen pages are devoted to the general equations of electromagnetic field…." out of Maxwell's 1000-page document.
- "For an exploration of the fundamental content of Maxwell's equations one must again turn to the Continent. There the work of Hertz, Poincare, Lorentz, Abraham, and Sommerfeld,.."

# Why our APS-URSI community has ignored these astounding views of Stratton for the past 80 years? Why we lavish Maxwell with so many fanfares in the past two decades?

- Nearly everyone of us was taught by physicists and mathematicians, or their followers, and then strive to emulate them.
- For the past two decades, we are increasingly sensitive of being viewed as belonging to “a subversive group of engineers” (Stratton, Preface, p. vii, para. 4) or one of those characters depicted in the 2015 cartoon in APS Magazine.

# Cybersecurity is a physical-space problem!

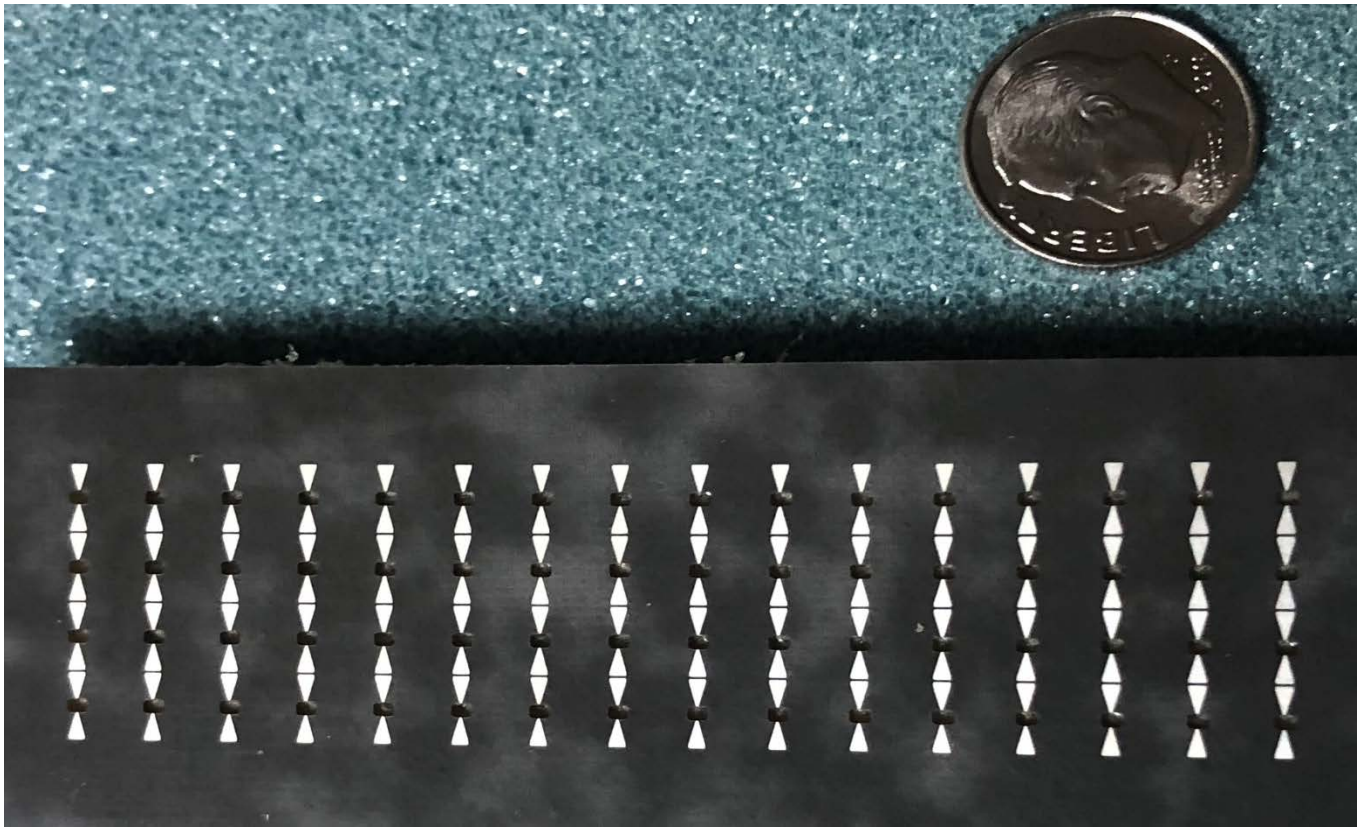
- Focusing on Observables, one can realistically formulate the transmission of electronic information as a physical problem of particle/wave packets that obey the laws of macroscopic electromagnetics and quantum mechanics, etc.
- The wireless channel includes the RF front ends of both transmit and receive systems. The channel, wireless or wired, is a physical entity, without which there is no communication.

# One easy route for secure communications for 5G is to crossfertilize with military handheld radios!

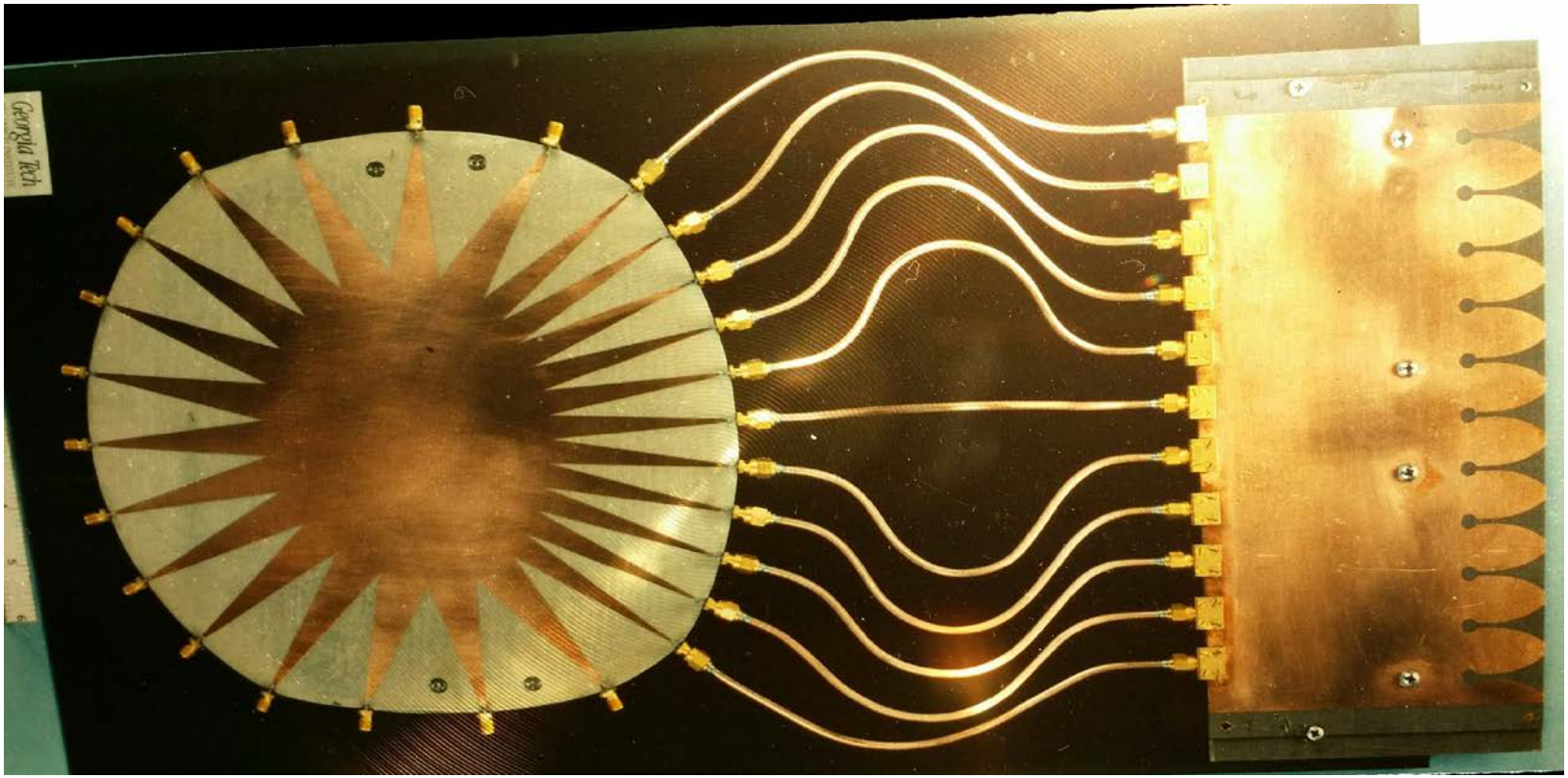
- US military recently deployed 100,000 handheld radios for secure Communications, Command, Control, Computer, Intelligence & Electronic Warfare (C5IRS), under two contiguous DoD Technology initiatives:
  - SpeakEasy: 1980-2000 (DARPA & Army CERDEC)
  - JTRS: 2000-today (mainly Army CERDEC).
- They are software-defined radios (SDR) using antennas with
  - Ultra-wide and multiple bandwidths
  - Sophisticated radiation properties (patterns, polarizations, multimode, smart, etc.)

# WEO is developing 8-40 GHz ±60°-scan planar array

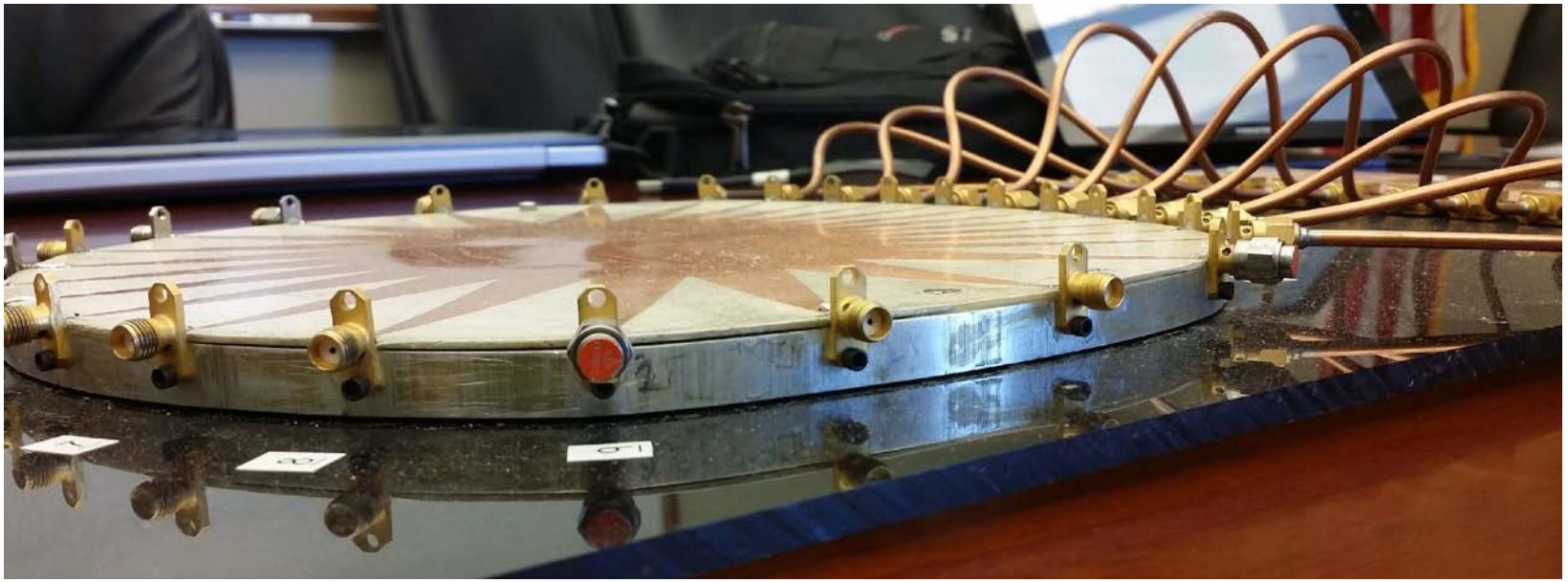
- Three-dimensional (3D) Traveling-Wave Antenna Array (TWAA) discussed earlier, scaled up to cover X through Ka bands. Picture shows array aperture.



# Analog Beam Forming for transmit (Tx) with Rotman lens to be **scaled up** to mmWave from model shown (3-12 GHz) developed by this author at GIT (1992)



# Side perspective view



Note: This work has never been published —until recently— since the report date of 1992.

# Progress So Far 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, even though they apparently reflect the consensus of four leading cellphone manufacturers: Samsung, Ericsson, Nokia, and Huawei.