Optical Emulator of complex RF systems with nanophotonics

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Electromagnetic (EM) properties such as antenna gain or radar cross section are often measured in anechoic chambers. However, for very large structures such as a Navy ships or other highly complex platforms, this could be expensive or impractical due to the sheer size of the structure. Computer simulation is a very helpful tool, but the processing time increases exponentially with the scale of the model, making the solution intractable for large systems. Also, these complex codes can easily diverge or present artifacts that should be identified by other means. Considering Maxwell's equations are invariant under dilatation transformation, it is possible to make the measurement on reduced size models at a higher frequency. In the past, such scale models had a reduction factor ranging from 10 up to few hundreds, and were kept into the radio-frequence (RF) domain.

Today, with the emergence of nanophotonics and the access to sub-micron 3D printing machines, it is possible to measure all the EM properties of complex RF systems in the near infrared (1 micron) by reducing the size by a factor 10^5. The vision for this system is presented in Figure 1. At that scale, an entire cruiser ship ($\approx$100 meters) is reduced to a length of 1 mm and easily fit in a tabletop measurement setup (see figure 2). The advantage of this approach is to be faster than computation, and much cheaper than full-scale measurement. Using 1 micron wavelength also leverages the many optical components that are readily available either for telecommunication (fast transceiver, laser diode, integrated optics) as well as consumer electronics (large 2D array sensor, lens assembly).

Our team has already demonstrated a setup capable of measuring the classical RCS of structures with the relevant feature size.[1] Calibration of the setup has shown identical behavior with similar RF systems, and a excellent agreement when compared with rigorous simulation for simple objects (see Figure 3). In addition, our setup is capable to immediately identify the location and the nature of the strongest scatterers and glints (see Figure 4). This ability allows for an intuitive interaction with the model to eliminate these sources and minimize the RCS.

We also used a femtosecond pulsed laser to perform holographic time-of-flight measurements which allows to retrieve the 3D information of the model.[2] This type of measurement is similar to the ranging mode of operation of RADAR.

We are working on the inclusion of multi materials models. RF permittivity of conductors and dielectrics like concrete and vegetation will be reproduced by engineered materials such as aerogel and polymer loaded with TiO_2 nanoparticles.

We are also developing plasmonic nano-antennas that behaves as their RF counterpart. With such antennas, our benchtop emulator can include active emitters, so that antenna placement as well as interferences can be studied. 200 nm size split dipoles have already been manufactured, and their far field emission measured.

Our long term vision is an electromagnetic “wind tunnel” system where, from a CAD model of the structure of interest, a scale model is manufactured by 3D printing. By integrating different materials, conductor and dielectrics, the model will accurately reproduce the RF properties of the original structure. Active antennas will then be added to specific locations to test for obstruction and interferences. The electromagnetic signature will be obtained with 2D sensors all around the model for a fast and high resolution measurement. Turnaround time from CAD file to measurement has been proven to be less than a day.

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1 P.-A. Blanche et al., “A 100,000 Scale Factor Radar Range“, Scientific Reports, 7, 17767, (2017).

2 P.-A. Blanche et al., “A 300 THz tabletop radar range system with sub-micron distance accuracy“, Submitted to Scientific Reports, (2018).

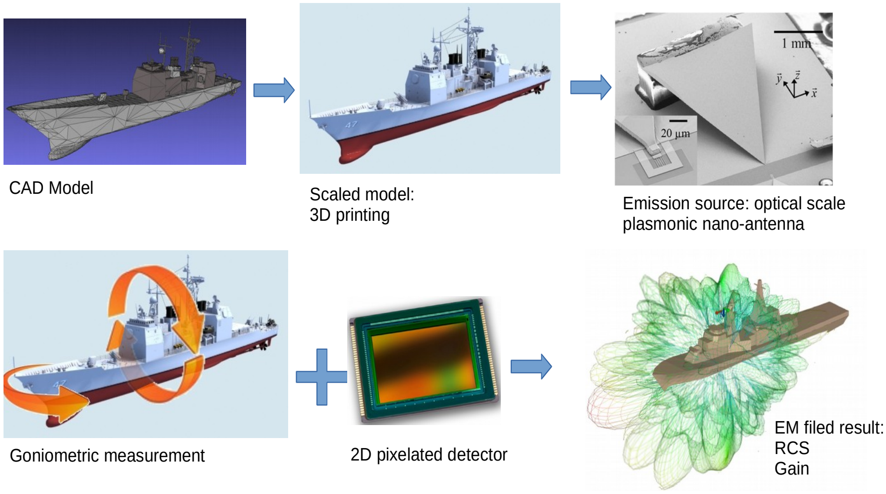

Figure 1: Vision for an optical emulator of RF system.

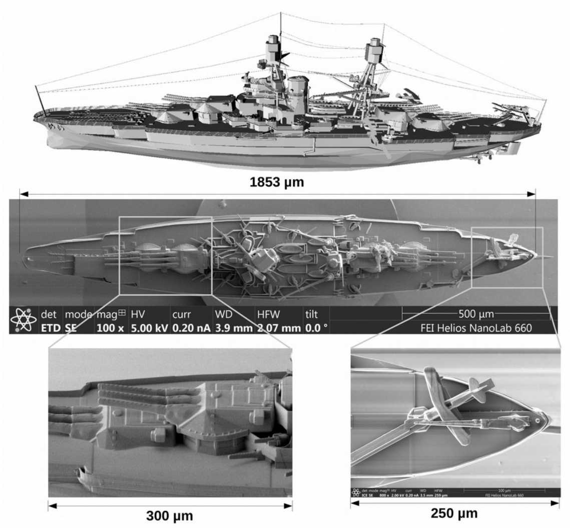

Figure 2: 3D printing of the USS Arizona at a 1/100,000 scale (150 nm resolution).

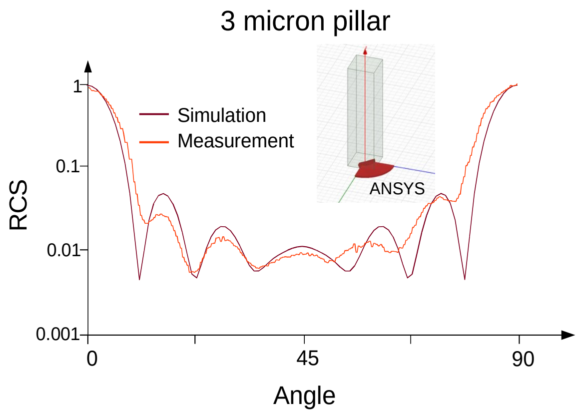

Figure 3: Comparison between the RCS simulation and experimental measurement on a 3 micron pillar.

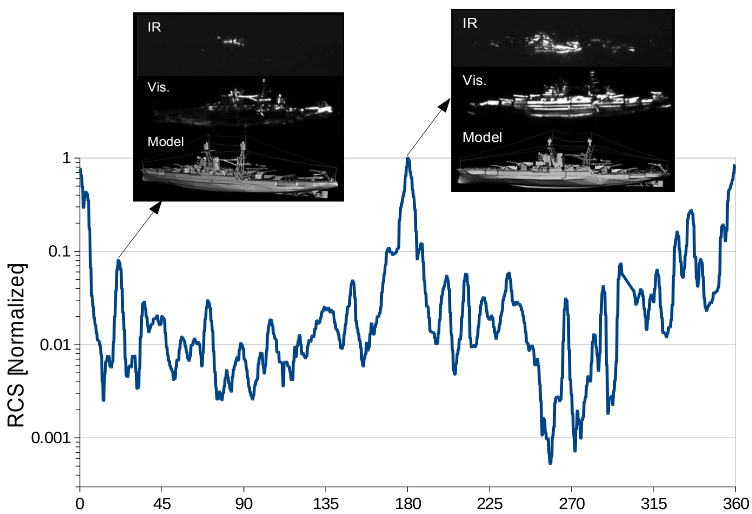

Figure 4: Measurement of the USS Arizona RCS and identification of the scatterer for two peaks.