FURTHER READING

Page ***,
'A programmable metasurface based RF chain-free 8PSK wireless transmitter.'
W. Tang, J.Y. Dai, M. Chen, X. Li, Q. Cheng, S. Jin, K-K. Wong and T.J. Cui.

the future of wireless?

Wankai Tang‡, Junyan Dai‡, Mingzheng Chen‡, Xiang Li‡, Qiang Cheng‡, Shi Jin‡, Kai-Kit Wong§, and Tie Jun Cui‡

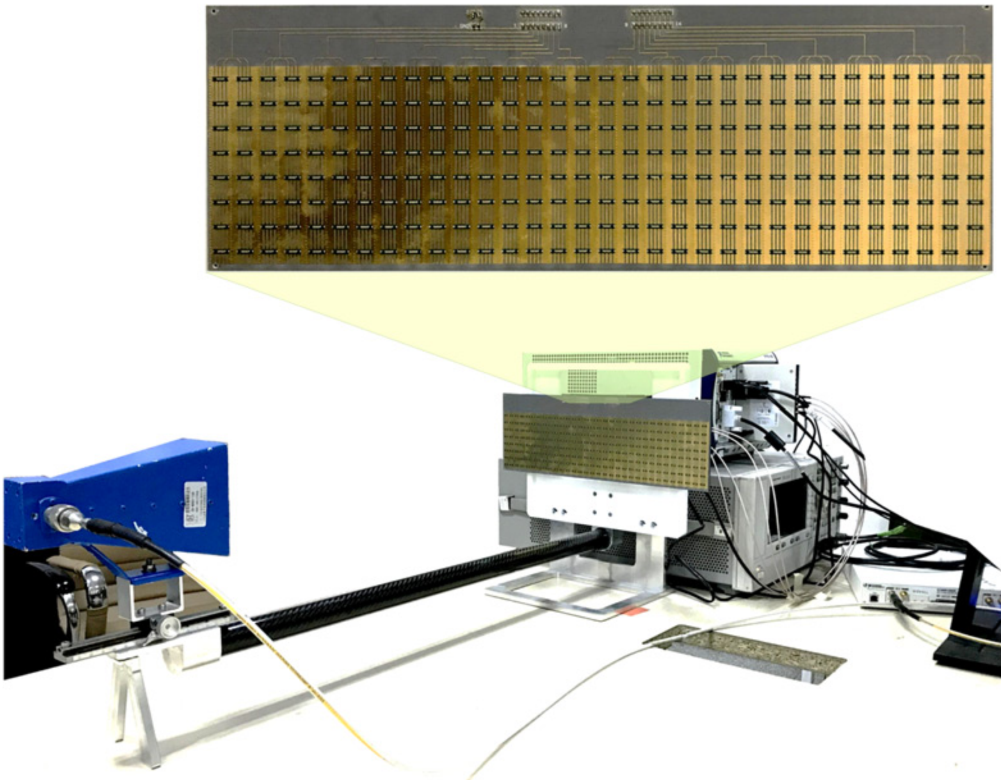
‡School of Information Science and Engineering, Southeast University, China
§Department of Electronic and Electrical Engineering, University College London, United Kingdom

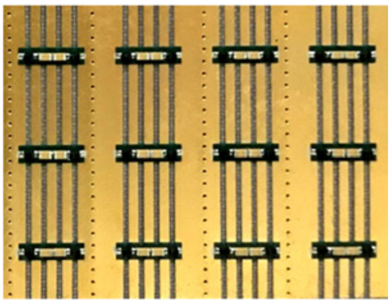
Mobile communication has come a long way from analogue to digital, from voice-only to multimedia, from cellular-only to cellular plus machine-to-machine (M2M), now reaching the modern day challenges presented by the internet-of-things (IoT). The main focus has also shifted from bit-error-rate (BER) reduction to maximising the capacity and most recently to ultra-reliable low-latency communications (URLLC) in fifth generation (5G) mobile communication which will gradually come into service worldwide in 2019. Over the years, we have witnessed several leaps in technology enabling upgrades to all previous generations. Mobile communication networks today are also much more intelligent and powerful, and will look to benefit from the rise of artificial intelligence (AI) for years to come.

However, as great as these advances in mobile communications technology are, there is a growing feeling that mobile technologies have now matured to a point where another breakthrough may be impossible, with the last big thing being multiple-input multiple-output (MIMO) antennas. There may be some truth to this, as MIMO was introduced in 3G, and has made an enormous impact in 4G. The currently emerging 5G still relies on the massive deployment of MIMO antennas to deliver the much-needed upgrade. With that being said, researchers are endeavouring to explore new directions to seek another game changer that will shape our future.

One promising area which emerged in the late 90s but is yet to make a real impact is metamaterials. First demonstrated as practically possible by Pendry in 1999, metamaterials are artificial materials that can be engineered to have properties that do not exist in naturally occurring materials. Negative-index metamaterials are of particular interest and for example one application allows small-sized antennas to be made that are impossible using conventional materials. The recent concept of coding metamaterials, also known as metasurfaces, further empowers signal processing methods in information science to be applied to physical metamaterials. Now, after 20 years of research, there is good evidence to suggest that metasurfaces may be the next disruptive technology.

This article reports some preliminary experimental results from a team of researchers at Southeast University (SEU) and University College London (UCL) that have studied the use of programmable metasurfaces for achieving the key functionalities of wireless communication in an unconventional way. The results are remarkable in that they demonstrate the possibility of replacing RF chains and antennas, all with a single programmable metasurface. The design also requires only a single narrowband power amplifier (PA), revealing an attractive low-cost alternative, compared to conventional RF transceiver architectures.





TOP: Figure 1: A metasurface-based transmitter with a zoomed-in view of the programmable metasurface. **BOTTOM**: Figure 2: A zoomed-in photo of the unit cells on a programmable metasurface.

What is a programmable metasurface?

A metasurface is an artificial sheet of metamaterials with sub-wavelength thickness, in which the electromagnetic properties over the sheet can be manipulated. Conventionally, once the metamaterials are designed and fabricated, their electromagnetic properties, such as their reflection coefficients, are fixed. However, recent advances in this technology see the sheet partitioned into a number of unit cells, each of which contains tuneable components such as varactor diodes. In so doing, the metamaterials in a metasurface can be characterised by the digital coding particles of “0” and “1” and can produce opposite phase responses. The coding particles provide the interface with the physical world of metamaterials and by changing the coding sequence of “0” and “1”, extreme control of the electromagnetic properties of the metasurface can be achieved.

Being programmable in real-time is revolutionary, as it allows the metasurface to alter its electromagnetic properties to achieve a variety of functionalities that traditional metamaterials cannot. In particular, it is possible to control and manipulate electromagnetic waves on the metasurface by programming the coding particles, or programming the phase responses on the unit cells of the metasurface. Various electromagnetic parameters including phase, amplitude, frequency and even orbital angular momentum can be controlled in real-time by an external signal applying changes on the coding particles of the programmable metasurface. Figure 1 is a photo illustrating the metasurface-based transmitter built by the team and housed at SEU. Also, a zoomed-in view of the unit cells on the programmable metasurface is provided in Figure 2.

What we have achieved so far

2019 is the year of 5G and it is anticipated that 5G will bring us high-resolution videos and 4K virtual reality (VR) livestreams without delay. Two underlying technologies that enable 5G are massive MIMO and the use of millimetre wave (mm-wave) bands. Looking beyond 5G, these two technologies can always be scaled up to meet new demands, by using more antennas and tapping into unused higher frequency bands. However, the next hurdle lies in implementation. The hefty hardware costs due to the large number of RF chains, expensive PAs as well as the heat dissipation problem with large-scale integrated RF and analog devices, to name a few, all dampen the prospect of further upscaling these technologies. It is of paramount importance that new hardware architectures and technologies are sought, and if found, could redefine future generations of mobile communications technologies.

This has been the objective of the team at SEU and UCL, which is investigating the feasibility of using programmable metasurfaces for accomplishing wireless communication. The latest result by the team has seen an 8-phase-shift-keying (PSK) transmitter built with a phase-programmable metasurface.

In the setup, a programmable metasurface (see Figure 1) was used to directly modulate the RF carrier signals, without the need of components such as mixers, filters, phase shifters and antennas that are necessary in conventional wireless transmitters. The results illustrate that a metasurface-based 8-PSK transmitter with 8×32 unit cells can achieve a data rate of 6 Mbps at 4.25 GHz, with BER comparable with conventional wireless transmitters, without channel coding. While more research is certainly needed to refine the design, it is worth stressing that in the metasurface-based design, the baseband signal is directly mapped to the control signal of the programmable metasurface to achieve modulation of the incident electromagnetic carrier signal, greatly simplifying the hardware complexity. In addition, the PA in this transmitter is only required to amplify the single tone carrier signal without amplifying the modulated wideband signal because the metasurface directly modulates and radiates the air-fed carrier signal, revealing the possibility of solving the nonlinearity issue of PAs completely. Furthermore, the thin surface physical structure of a programmable metasurface avails heat dissipation.

More to come

Programmable metasurfaces open a new door for the design and optimisation of wireless communications systems that were not considered possible before. In particular, the software-defined nature of the physical metamaterials facilitates the integration between signal processing algorithms in information science and hardware resources made of metamaterial unit cells, permitting fully adaptive hardware use. Research in this area will be interdisciplinary, requiring expertise in wireless communications, RF engineering and metamaterials and their synergy will be important.

Further to the reported 8-PSK results, it would be interesting to look at the implementation of higher-order modulation and other control design methods. In current reported results, the data rate is limited to the phase control response speed of the programmable metasurface, which is then determined by the charge and discharge time of capacitances on the unit cells. The team has already begun to investigate new control methods for the unit cell to avoid capacitance-induced charging and discharging effects. Also, it is more difficult for programmable metasurface to achieve independent regulation of amplitude and phase of the incident carrier signal simultaneously. Therefore, realizing high-order modulation is a big challenge.

Nevertheless, a recent attempt by the team suggests that independent and simultaneous manipulation of amplitude and phase can be achieved by designing digital baseband control sequences, which makes it possible to realise high-order modulation and MIMO transmission with a programmable metasurface.

Is metasurface the future of wireless?

It remains to be seen if metasurfaces will take over the future world of wireless but so far the evidence is encouraging and does suggest that programmable metasurfaces offer something that has not been possible before. Being able to influence electromagnetic waves in the sub-wavelength scale has already given metamaterials a unique advantage for miniaturising wireless systems. The programmability of metasurfaces further provides the engine to adapt and optimise the metasurface in real-time to achieve wireless functionality in a holistic fashion. Though further enhancement of the design will be needed if programmable metasurfaces are to replace current approaches, the advantage in terms of hardware is already obvious. The research team at SEU and UCL is hopeful that future efforts can unlock the full potential of programmable metasurfaces for wireless communications and bring mobile technologies to a new height.