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Flat Panel Antennas – State of the Art

Nov 15, 2017 / Patrick Gannon

Introduction

Interest in flat panel antennas is growing, as new products begin to be deployed or come closer to the market. Flat panel antennas (FPA) are of increasing importance as the demand for Communication on the Move (COTM) continues to grow. Even automobiles (link to connected car article?) are connecting to the internet, while cruising across the country. With the rapid pace of development there is some amount of confusion over the competing technologies being used to develop the new products. We will take a look here at the technology and a couple of the vendors driving it.

Gimbal Antenna

The typical or conventional mobile antenna that most people are familiar with, primarily for maritime applications, are Gimbal antennas with a parabolic dish. A gimbal is a mechanism, typically consisting of rings pivoted at right angles, originally designed to keep an instrument such as a compass or chronometer horizontal in a moving vessel or aircraft. A typical Ku/Ka-band antenna is multi-gimbal, that is, the antenna is mechanically manipulated to point directly at a satellite using azimuth and elevation axis, i.e. gimbals, to rotate, raise and lower the antenna to face the satellite. Polarization on most gimbal antennas is automatically and mechanically controlled by motors.

There are two areas, in particular, that are a challenge for mobile antennas. The first problem, is called skew, and it is of greatest concern as one approaches the equator. Picture an airplane leaving Chicago headed west. At the time of its departure, it is locked on to a satellite directly south, over the Galapagos Islands at 900 West. Picture an imaginary string that connects the airplane antenna to the satellite. As the airplane heads west, the angle of the line between the airplane and the satellite out over the Galapagos changes. The line gets longer, and the angle gets smaller. It started at 90 degrees in Chicago, pointing due south, and had an elevation of about 42 degrees above the horizon; but in California, the line between the satellite and the airplane is longer (which means the signal had to go through more atmosphere), and more importantly, the angle to the satellite has changed. Now the line from the antenna to the satellite is pointing southeast, and the elevation is lower, around 34 degrees. When the plane started, the line between the airplane antenna and satellite did not come close to any other satellites. Now, from the new position, the line is passing close to other satellites that are located nearby (20 of separation); that means there is the potential for interference from those satellites, or to those nearby satellites. This is called ASI or adjacent satellite interference, and it worsens as you approach the equator and attempt to connect to satellites on the horizon.

To address the problem, authorities have created acceptable limits for the amount of power that can be directed to nearby satellites causing interference, and the terminal equipment automatically adjusts the amount of power being radiated, in order to stay in compliance. This loss of power, however results in loss of throughput, Gimbal antennas are limited in what they can do to address this problem, which is why customers may find their internet service going away on equatorial flights.

Another concern is scanning. Gimbal antennas may work better in low elevation applications, such as when the satellite is very low on the horizon. A FPA, because of its flat design, will be limited in how low it can see on the horizon, whereas a 3-axis Gimbal antenna may be able to remain connected to these satellites, particularly when faced with pitch and roll on the seas, or on airplanes that roll the antenna away from the

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targeted satellite, while turning in the air. Gimbal antennas will perform better on polar routes, because they can maintain connectivity with the satellite longer as it dips below the horizon with respect to an airplane flying over the poles. There are limitations, of course. Raising the antenna, will allow the dish to dip or tilt lower, but that raises the profile of the entire antenna assembly.

Some of the obvious downsides to Gimbal antennas include weight which can run around 125 kg (275 lbs.), and height, which can be as much as 140 cm (55 in). These higher profile antennas produce a lot of drag in aircraft applications, they leave little room for clearance on trains, and they make vehicles top-heavy, not to mention aesthetically unattractive. Gimbal antennas are power hungry, requiring Peak Power over 300 W, to manage a complicated Positioner. Reliability is also an issue. If the Positioning system fails, connectivity to the satellite cannot be maintained if there is any movement.

FPA - Phased Array Antennas

Currently the most popular alternative to Gimbal antennas are Phased Array Antenna flat panel antennas, which are composed of many radiating elements that can be thought of as numerous, tiny, fixed antennas. Each one has a phase shifter which forms beams by shifting the phase of the signal emitted from each of the radiating elements (tiny antennas). This provides a constructive/destructive interference which may be used to steer the beam(s) in a particular direction. This entire process is all electric, so the beam direction can be controlled and pointed instantaneously in any direction. It is able to track the movement of a satellite in the sky, regardless of the movement of the car, boat, airplane, or train.

A Phased Array Antenna is a flat panel antenna, usually with a very low profile just a few inches high. It has no external moving parts like a Gimbal antenna. Weight can vary depending on the type of design, and power requirements can be very high as well, 1000’s of watts in some cases. Depending on design, a phased array antenna can be more reliable, because if one of the small antenna elements fails, the remainder continue to function, and the collective pattern of the whole is modified slightly to overcome the loss. This is sometimes referred to as a graceful degradation.

Fixed phase array antennas have been in use, including by the military, since the 1950s and have progressed significantly in the decades since then, graduating from mechanically steered models to far more efficient and reliable electrically steered flat panels. There are two basic designs. The passive phased array or passive electronically scanned array (PESA) system has elements connected to a single transmitter and/or receiver. The PESA phased array is the most common type.

Active phased arrays, known as active electronically scanned arrays (AESA) are those in which each antenna element has an individual transmitter/receiver unit, all of which are controlled by a computer. This second generation of phased array technology is currently used in some military applications. An AESA phased array can radiate multiple beams of radio waves in different directions, at multiple frequencies, at the same time.

One issue with electronically scanned antennas is that they are expensive, high tech devices that have to solve the problem of making thousands of tiny, individually tuned elements work together as one, unified antenna. This process has to operate over time, often in extreme temperature ranges, and in harsh environments. The power supply has to be capable of actively controlling power-hungry phase shifter components and amplifiers.

Phased array antennas are growing in popularity for the airline industry, but there are some limitations. Above 60 degrees latitude, flying a polar path that many transcontinental flights take, flat panels lose efficiency due to the scan issue mentioned above. Envision an airplane with a flat panel antenna mounted on top. The flat part of the antenna is pointed straight up, and the edge of the antenna is pointed at the satellite out over the equator. The flat panel antenna can’t “see” the satellite. A three axis Gimbal antenna might be

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able to tilt enough to see the satellite, where a flat panel cannot. This is because the mechanical satellite may tilt far enough so the entire antenna aperture (face of the dish) is able to collect the signal from the satellite. With a phased array FPA the physical design of the FPA means that the edge of the panel – a few inches – is facing the satellite, so there is very little, if any, surface area for the antenna elements to collect a signal. It should be noted, however that the concept of the phased array antenna allows for design elements in which the antenna may be placed on a curved surface, providing more of the panel surface with a line of sight to a GEO (Geosynchronous Earth Orbit) satellite over the equator, when the aircraft with the FPA is flying over the north pole, for example.

On the other hand, FPAs generally offer an advantage when it comes to skew. Elliptical gimbal antennas, by tilting them with regard to the plane of the satellites along the equator, are able to offer some limited measure of control over how much of their radiated beam will interfere with adjacent satellites, but as a mechanical process, this is limited, and power inevitably has to be reduced to avoid interference with near-by satellites, affecting throughput in the process. Phased array antennas can electronically form the beam to ensure that power is directed at the target satellite with much less spillover to adjacent satellites. This means maintaining throughput at higher levels.

Industry researchers suggest that when MEO (Mid-Earth Orbit) and LEO (Low-Earth Orbit) satellites become more ubiquitous, this problem will go away, as there will always be a satellite overhead. They anticipate that the growth of the LEO/MEO market and flat panel market, will go hand-in-hand. The market appears poised to transition from one in which satellites are fixed in the sky to one where they are moving in the sky and there must be a hand-off between satellites. How the satellites are tracked, how the beam is pointed, how quickly the beam can be moved to another satellite, will all be design considerations for new products.

FPA – ThinKom

Let's take a look at what is arguably a successful and popular phased array FPA available in the commercial market today. ThinKom produces a mechanically phased array antenna, referred to as their 2Ku Technology. The current Ku-band product includes two beam-forming antennas, one for transmitting, and one for receiving. ThinKom claims their solution is unique. They create beams by mechanically rotating a series of internal plates that have precise resonance characteristics, designed to amplify and direct the signal in a specific way. ThinKom's patented technology moves internal disks mechanically but unlike a gimbal antenna, the entire antenna face is not pointed directly at the satellite, instead small changes in plate position are used to adjust the scan angle in the elevation and azimuth direction. This capability provides some advantages at high altitudes on airplanes. ThinKom claims mechanically steered antennas can provide better broadband service at higher latitudes that electronic phased arrays that generally reduce data rates going over the poles. However, at some point, even ThinKom FPAs will lose connectivity over the North Pole as it loses panel surface area to face the satellite.

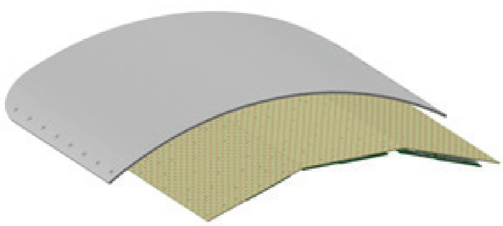
ThinKom's solution has been tapped by Gogo, Inc., a provider of in-flight broadband Internet service and other connectivity services for commercial and business aircraft. Gogo says the ThinKom 2Ku technology can achieve data rates up to 70 Mbps on the download and 15 Mbps on the upload. This capacity is expected to increase to speeds as high as 100 Mbps as new spot-beam satellites become more available. It has been reported that Gogo placed an order for more than 500 antenna units with ThinKom, which are destined for eight airlines and more than 550 aircraft that have agreed to trial or implement the 2Ku technology.

FPA – Phasor

An example of an electronically steered, low profile, high throughput phased array antenna under development, and priming for commercial release comes from Phasor Solutions. Their product, through a collaboration with Kepler Communications, a Canadian satellite company is developing a solution for Non-Geostationary Satellite Orbit (NGSO) applications, in anticipation of LEO and MEO fleets being readied. Phasor took all the supporting electronics like BUCs (Block Upconverters) and amplifiers, and compressed them into ASICs (Application-Specific Integrated Circuit," with the goal of reducing costs through manufacturing efficiency and high volumes.

Rather than using phase shifters, Phasor's solution uses a large number of ASICs, each connected to a small patch antenna. The ASICs allow satellite signals to be separated from noisy background signals. The microprocessors embedded in the electronics dynamically control signal phases of all the individual elements, combining and steering transmit or receive beams in any direction.

Because there are no moving parts, the system is compact and reliable. The vendor claims they can withstand the vibration and environmental conditions on trains, aircraft, vehicles and ships. They are resistant to failure and damage, maintaining service through built-in redundancy.



The antenna is very thin, with an inch between the control board at the bottom and antenna board at the top. On the underside of the antenna board are the rows of ASICs connected to rows of element patch antennas on top. A unique feature is the ability to combine multiple control/antenna boards in order to increase the capacity. They may also be shaped to fit curved surfaces, contributing to aesthetics, reduced wind drag, and the ability to scan for satellites lower on the horizon.

Phasor claims to be frequency agnostic, with the current product aimed at Ku-band, but with development in Ka and X-band underway. The company recently (Oct 30, 2017) announced that it had raised $16 million from investors including satellite communications mobility companies, financial investors and shareholders.

Phased Array technology is not the solution for all FPA manufacturers. Kymeta begins by noting the cost of electronically scanned, high tech antennas. The complexity of getting thousands of individually tuned elements (mini-antennas) operating in harmony is very high. Thousands of small elements have to be in phase alignment with each other, and they have to do it in harsh environments and varying temperatures, for a long time. Contributing to the cost, are all the individual components such as phase shifters, amplifiers and other power-hungry components. It should be noted that many, but not all, phased array antennas require separate antennas for transmit and receive, which also adds to the cost.

FPA - Kymeta

Kymeta has taken a different approach that does not rely on expensive, power-consuming components. Instead of large numbers of phase shifters and amplifiers, or fitting separate BUCs and LNBS into ASICs for each element, Kymeta has a single LNB and BUC, similar to any other antenna in the VSAT industry. The antenna itself is passive, with no mechanical parts, and no requirement for rows of actively controlled phase

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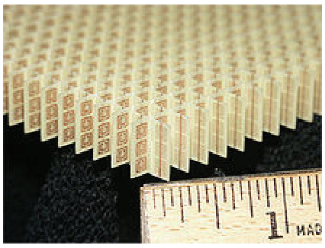
shifters. The result is a lighter weight, smaller sized system with vastly reduced power consumption requirements. Kymeta, like other phased array antenna vendors, is interested in the airplane, and boat market, but hopes that its less expensive platform will provide a large opening to the connected car market. Kymeta has partnered with Intelsat and Toyota to explore this market.

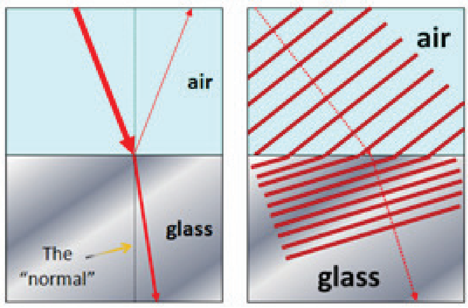
Kymeta's "mTenna Technology" provides a number of benefits. Unlike ThinKom, it can transmit and receive using a single aperture. It offers wide angle scanning to see to the edge of the horizon, and delivers excellent beam performance. The pointing and polarization are all electronically controlled. The unique design, leveraging metamaterials, results in extremely low power consumption and the design lends itself to mass production, which will drive costs down with increased volumes.

Metamaterial / NIM Technology Discussion

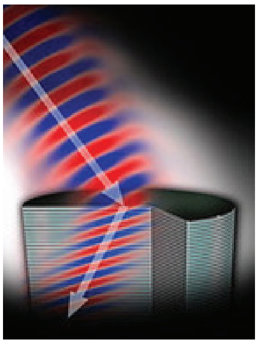
Metamaterials are materials engineered to have a property not normally found in nature. Composite materials such as metals or plastics are used to fashion multiple elements into an assembly in repeating patterns.



The elements are designed to be smaller than the wavelengths of the signals they are influencing. It is not the base properties of the materials used to construct the structures, but the design of those structures, that make them capable of manipulating electromagnetic waves. The metamaterial acts, not like the wires, metals and dielectrics of which it is made from, but rather like a brand new material. It becomes an effective medium like air, glass or water, which carry light and electromagnetic waves, all of which react in predictable ways as the rays pass from one to the other. The precise shape, layout, size and orientation of the metamaterial provides the smart properties such as blocking, absorbing, enhancing or bending waves, producing results not possible with conventional materials. In particular, negative-index metamaterials (NIM) are of interest here.



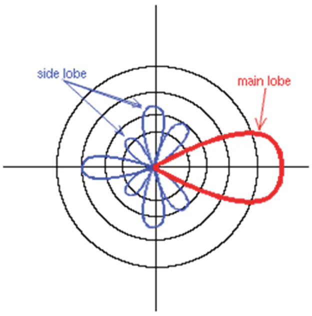
Negative-index material or metamaterial is a metamaterial whose refractive index for an electromagnetic wave has a negative value over some range of frequencies. This is not normal in nature. We know for example that when a ray of light passes from air to glass or water, the heavier density of the water, causes the light, which normally travels in straight lines, to appear to bend. What is happening is that the light is interacting with the atoms in the denser water, being absorbed and re-emitted in ways that can be described in both classical and quantum physics, with the net result that the light slows in the denser medium. This process of bending when the ray passes from one substance to another is called refraction. Think of the light as a bundle of waves – a wavefront – in which the leading edge strikes the glass first, and is already being slowed, before the other side strikes. The ray of light is slowed down by the denser material and this causes the ray of light to change direction, because the speed of the light has been decreased a little. When the ray passes from a less dense material (like air) to a more dense material (like glass or water) the ray is bent away from the surface between the two materials, which means, in this example that the angle of refraction is less than the angle of incidence (the angle the ray came from). When going the other direction, from less dense to more dense, it is bent towards the surface that separates the two materials. This is the behavior we are used to seeing in nature.

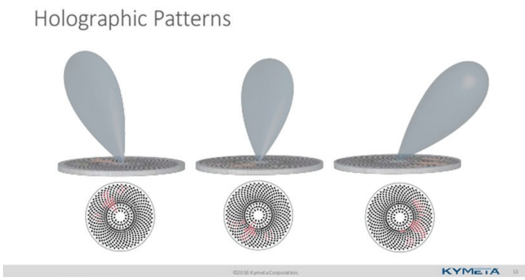


With Negative-Index Metamaterials (NIM), the ray, light or electromagnetic signal bends far differently than it would in common, natural materials such as water or glass. By controlling resistance or propagation of electromagnetic waves, the refractive index instead of being positive, as with conventional materials, may extend to a negative or zero refractive index. A NIM As a result the collective result of the metamaterial response to electromagnetic waves, is broader than normal. The real key is being able to manipulate the bending so as to direct the beam where it is wanted, and form it in the way that is wanted.

The Kymeta antenna permits more elements than typical phased array antennas, allowing for higher efficiency. The metamaterial in mTennaTM technology is a glass metasurface structure based on LCD (liquid crystal display). This is a kind of artificial sheet material with sub-wavelength thickness and electromagnetic properties generated on demand so as to modulate the behaviors of electromagnetic waves. Rather than reflecting satellite microwave beams like a standard parabolic dish antenna, or managing thousands of separate signals with a computer, as in an electronically steered phased array antenna, Kymetra creates a holographic beam using a thin structure with tunable metamaterial elements used to transmit and receive satellite signals.

VSAT antennas create beams with sidelobes, which are the lobes of the far field radiation pattern that are not the main lobe. The "main lobe" is the one directed to the satellite, while the side lobes are wasted energy, and may create ASI issues, as discussed above. Holographic beams are therefore more directed, and efficient. These elements (30,000 in an antenna) act together like "pixels" to create the holographic beam. Using software to change the pattern, the antenna can be pointed in the correct direction using no moving parts, internal or external. Kymeta's technology is protected by 200 international patents, so copycat products are unlikely to be available anytime soon.





Dynamic, electronic beam-steering performance similar to phased array antennas is now possible without expensive, power hungry phase shifters, amplifiers and other components. Because it has no phase shifters it is considered to be "passive." The liquid crystal and glass forming the surface has no active RF components, and because there are many more elements than a typical phased array antenna, it has greater ability to create the correct phase and amplitude distribution to form the most focused beam. Since there are no power amplifiers to create excess heat, there is no need for a cooling system, and thus less power is required – a few watts, compared with more than a thousand watts for typical phased array antennas. Where Phasor can create curved or conforming antennas, Kymeta's solution to scan and skew is to leverage its lower costs to deploy multiple antennas, all working together as one.

The Kymeta mTenna antenna weighs 9 kg (20 lbs.) and has a height of only 8 cm (3 in). It uses less than 1W of power for beam forming and 30W for the Antenna Subsystem Module (ASM) and features a single system with Transmit and Receive combined in one antenna. Each element is individually controlled by software, including the ability to switch polarization dynamically. It supports over-the-air (OTA) updates, and

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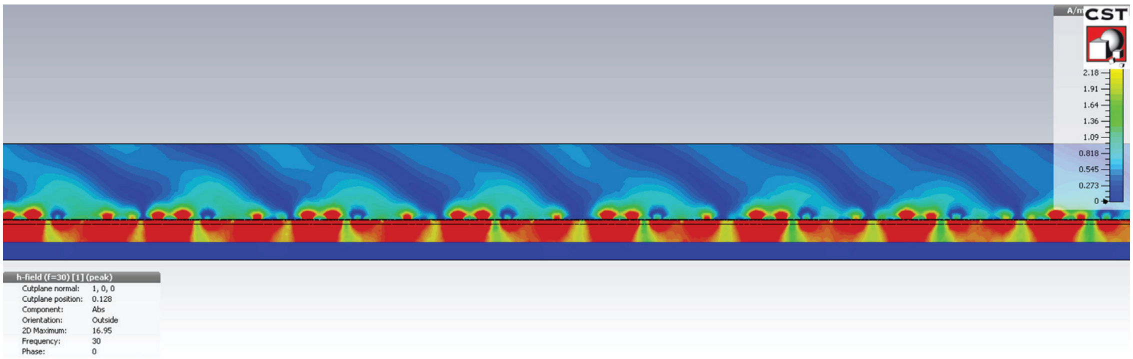

features high MTBR/MTBF numbers due to the lack of moving parts. The compact form factor provides auto acquisition, pointing and tracking, and self-provisioning. The terminal supports a standard rack mounted modem and power supply, and includes diplexer, BUC, LNB, modem, power supply, cables and housing.

Industry Direction with FPAs

So where are we going with FPAs? Northern Sky Research (NSR) asks whether flat panel antennas (FPA) are the High Throughput Satellite (HTS) white knight. NSR points out that the satellite industry is in a state of transformation, one in which the trend of dropping capacity prices signals a major technological shift. FPAs with low profiles and high bandwidth efficiencies are contributing to the technological and business changes in the satellite industry, helping to make new applications possible.

There have been new consumer-facing markets in the past that failed to get past the entry barrier for Satcom services. For example, the Iridium constellation launched in the 1990s met technical requirements but was a failure in the market due to insufficient demand based on the pricing at the time, and when revenues failed to pay for the deployment, the venture went bankrupt. Expensive ground terminals and/or poor quality of service have led to other past industry failures. The importance of FPAs and HTS are recognized by the industry, as illustrated in vendor booths at satellite shows in the last year, raising expectations that all the pieces will come together to support new markets and new applications. What has become clear is that there is no single FPA solution that is a best fit for all markets.

Integrators are looking to bandwidth efficiency, high pointing accuracy, superior beam steering and regulatory clearance as important criteria for FPA selection; and of course the price tag plays a key role, particularly for applications like the connected car. Where the ground segment has been a problem area in the past, this time around, operators, service providers, and the ground equipment manufacturers are forming relationships to achieve the right mix between performance and price. NSR predicts electronically steered antennas to take over the maritime and land-mobile market, but mechanically driven antennas such as ThinKom have a first to market advantage in the aeronautical industry with its rigorous antenna performance requirements, numerous regulations and barriers to entry. NSR suggests that the next generation of FPAs supporting multiple beam scanning, high bandwidth efficiencies, reliability and cost advantages, will provide the innovation the satellite industry needs right now. What seems clear is that there will soon be little distinction between fixed, inclined orbit, MEO or LEO satellites from the perspective of the antenna.