Antenna Beamforming

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Abstract — *Beamforming is a versatile processing technique for transmitting or receiving of a desired signal on an array of antenna elements. This is an attempt to have a better result of antenna connection, then the latest version of beamforming. This performance beamforming is to simulate a large antenna that can be electrically steered using a set of smaller antennas. This is a better way of getting faster connection and sending more data faster. This project will include the observation angel, single isolated element, and hamming. With this project, the researcher will use MATLAB to show the results of implementing more sensors for beamforming and formulas to improve beamforming.*

Key Terms — *Array, Beamforming, Mathlab, and MIMO.*

INTRODUCTION

The focus of the project is to make the beamforming more efficient without downstream. When the beams of the subscriber and access point intersect, can hear the subscriber receiving its data. This means that signals, at the same frequency as the access point and subscribers that enter the access point antenna beam shape, can interfere with signals from subscribers causing data loss. To get done beamforming, the researcher needs to use sensors to activate the order. When the order is activated, the user will see a graph made clear below of how sensors will be viewed in program and in formulas.

Project Description

Antenna beamforming is a type of radio frequency (RF) management in which a wireless signal is directed toward a specific receiving device. This helps transfer information with reduced latency on the internet. With this project the researcher will use MATLAB program to learn how to use the beamforming and will add simulation with graphs to see the response.

Objective

The main objective of this project is to create an antenna with beamforming and choose the appropriate parameters to improve the signal between antennas, as well as to find better ways to increase the efficiency of antennas.

Project Assignment

Under the assumption that all element patterns are identical, the array radiation pattern in the far field can be found by using the pattern multiplication principle:

E(θ)=E_0 (θ)F_A (θ) (1)

where EO(θ) is an isolated element pattern that includes the directional response of single sensor element in isolation from the array, and the patterns are the same for all elements of the array; FÆ(θ) is an array factor that determines the directional array pattern, which is the sum over N omnidirectional elements, and it is given as:

$$\boldsymbol{F}_{A(\boldsymbol{\theta})=\sum_{n=1}^{N} V_n^{inc}(\delta) e^{jnkdsin\theta}} \quad (2)$$

where

$$\boldsymbol{V_n^{inc}(\delta) = a_n e^{-jnkdsin\theta_0}}$$

$$\boldsymbol{= a\_ne\text{^}\{-jn\backslash delta\}}$$

(3)

is an incident voltage associated with nth element; δ = $kd\ sin\theta$ is an inter-element phasing; k=2π/γ the free space propagation constant; θ is an array observation angle; -90^θ≥θ≥90^θ,θ_0 is a main lobe steering angle; and an is the distribution coefficients of element feeding voltages.

As follows from equation (2), for arbitrary array scanning angle θ_∪ ∈ θ, the array factor maximum, max 〖 F〗 _A (θ)=F_A (θ_0), can be achieved by forming appropriate V_N^inc (δ), n=1,2,...,N, -90^θ≥θ≥90^θ.

Via adjusting corresponding weighting coefficients as

$$\boldsymbol{w_n(\delta) = e^{-jnkd\,sin\theta_0}} \quad (4)$$

Substituting (3) to (2), and denoting u = sinθ and u_o=sinθ_0 we get the resulting array factor with the maximum in direction θ_0

$$\boldsymbol{F_A(\theta) = \sum_{n=1}^{N} a_n e^{jnkd(u-u_0)}} \quad (5)$$

Combining (1), and (2), the resulting array pattern.

$$\boldsymbol{E(\theta) = E_0(\theta) \sum_{n=1}^{N} V_v^{inc}(\delta) e^{jnkdu}} \quad (6)$$

As follows from equation (5), when an is uniformly distributed, e.g., an = 1, n = 1, 2, …, N, then the magnitude of the antenna factor is

$$|F_A(\theta)| = N \frac{sinc(\frac{Nkd(u-u_0)}{2}}{sinc(\frac{kdu}{2})}$$

$$\cong N\,x\,sinc(\frac{NKd(u-u_0)}{2}) \quad (7)$$

Where $sinc\ x = \frac{sinx}{x}$ and the approximation is true only for small value of δ. Therefore, substituting (7) and (1) and squaring the magnitudes of both sides yields the array power pattern

$$|E(\theta)|^2 = E_0(\theta) x N^2 \frac{sinc^2(\frac{Nkd(u-u_0)}{2})}{sinc^2(\frac{kdu}{2})} \quad (8)$$

More gracefully (2) can be expressed in the matrix form when an observation angle, $-90^0 \geq \theta \geq 90^0$, is sampled with reasonably small scanning increment $\Delta\theta$,

$$F_A(\theta) = V^{inc}(\delta)V(\theta) \quad (9)$$

Where $F_A(\theta)$ is L -element row vector of the array factor,$V^{inc}(\delta) = [V_1^{inc}(\delta), V_2^{inc}(\delta), \dots, V_N^{inc}(\delta)$ is an N -dimensional row vector with elements values determined in (3), and $V(\theta) = \{V_{nl}(\theta_1)\}$ is an N x L observation matrix with $L = \frac{180}{\Delta\theta}$ + 1 and the elements values$V_{nl}(\theta_1) = e^{jnkd\,sin\theta_1}$ n= 1,2,…N, L=12,…,L.

Following the matrix notation, equation (6) can be expressed as

$$E(\theta) = E_0(\theta)\circ[V^{inc}(\delta)V(\theta)] \quad (10)$$

where $E_0(\theta)$ and E(θ) are L – elements row vectors, which are sampled version of the corresponding continuous patterns,$E_0(\theta)$ and $E(\theta)$ respectively, and ∘ is the Hadamard product operator (element by element multiplication).

Then, the array power pattern in the matrix form is

$$|E(\theta)|^2 = |E_0(\theta)\circ[V^{inc}(\delta)V(\theta)]|^2 \quad (11)$$

THEORY

Beamforming is a versatile processing technique for transmitting or receiving a desired signal on an array of antenna elements. This is an attempt to have a better result of antenna connection, then the latest version of beamforming. This performance beamforming is to simulate a large antenna that can be electrically steered using a set of smaller antennas. This is a better way of getting faster connection and sending more data in a faster speed. This project will include the observation angel, single isolated element, and hamming. With this report the researcher will use MATLAB to show the results.

Beamforming Description

Beamforming is a type of radio frequency management in which a wireless signal is directed towards a specific receiving device. Reference [1] says that phase array is a system to focus the wireless signal in a choose direction. This will give stronger beam towards the device that the researcher is trying to get more speed in the connection. Beamforming will also be a frequency filtering that can be grouped into two classes: data independent (so it will work with different devices) and data dependent (that will adapt weather it is in a nig area or small area). The user or researcher can also choose between optimal beamforming and adaptive beamforming.

Optimal beamforming is a versatile technique for signal transmission form an array of N antennas to one or multiple users and adaptive beamforming is a system that performs adaptive spatial signal processing with an array of transmitting or receiving. These are basic descriptions of what is beamforming and their application of antenna arrays.

How Beamforming Works

Beamforming works when an access point antenna transmits to a group of subscribers, generating a beam in a specific shape to cover those subscribers. The shape of the beam is determined by the amount of gain the access point antenna has in various directions. The higher the gain, the further the beam reaches in that direction. Signal energy is sent from the access point to antenna in this shape. Access point to antenna in this shape with all subscribers within the shape receiving signal energy from the access point antenna. The subscribers use narrower beam widths to transmit signals to the access point. When the access point antenna is receiving data from the subscribers, it is listening for signals within the same beam shape as when it is transmitting. When the beams of the subscriber and access point intersect, the access point can hear the subscriber receiving its data. This means that signals at the same frequency as the access point and subscribers that enter the access point antenna beam shape can interfere with signals from subscribers, causing data loss. This process of beamforming can be shown in Figure 1.

For beamforming, the researcher used different formulas to get the result for overall array. Reference [2] shows that to achieve beamforming, the researcher used sensors to activate the array. First, use *d* = distance to get the area of the sensor. Then, implement *x(t)* impinge on the sensors to contain the elements in the Sin and get the signal source from direction in degree with respect of the array. This information will end up experiencing a delay with respect of the element sensor that the formula is $\tau = \frac{dsin\emptyset}{b}$. Later, will implement the array output signal to *y(t)* to give the sum of the sensor elements and this is the formula $y(t) = x(t) + x(t - \tau)$. Now, the researcher implemented the narrow band; this will help the frequency and the time delay that will phase shift to $2\pi(d/\gamma_0)\ \gamma_0$. The wavelength corresponds to the frequency and the formula used is $\gamma_0 = \frac{b}{f_0}$. Then, the researcher will phase some of the signal contribution from the array elements that are the sensors, and the formula is $y(t) = \sum_{i=1}^{2} x(t) e^{j(i-1)\varphi}$. This formula will convert to $\varphi = 2\pi(d/\gamma_0)sin\theta$. The next formula used is the direction pattern of the array that will help with the response of the signal for the specific frequency and the formula is $A(\theta) = \sum_{i=1}^{2} e^{j(i-1)\varphi}$. With this formula, normalize the direction pattern $G(\theta)(decibels) = 10log_{10}\left\{\frac{|A(\theta)|^2}{4}\right\}$. With this last formula, can plot the G(θ) for the sensor element to show the angel like the one shown in the Figure 1.

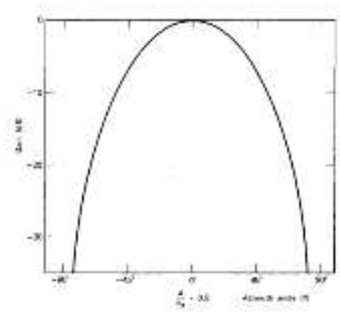

Figure 1
Sensor Element

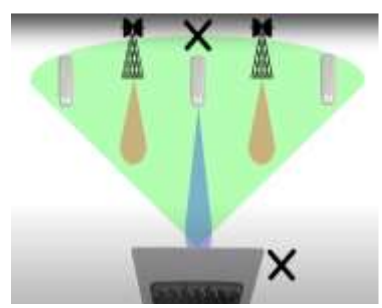

Figure 2
Beamforming drawing

As shown in Figure 2**,** can see that the top row has 2 antennas and 3 subscribers and below is the access point. This is what helps subscribers communicate in different devices. The focus of the project is to make the beamforming more efficient without downstream.

Massive MIMO (Multiple-Inputs Multiple-Output)

In Multiple-Inputs Multiple Output (MIMO) each spatial stream is transmitted from a different radio/antenna chain in the same frequency channel as the transmitter. Reference [3] shows that the receiver gets each stream on each of its identical radio/antenna chain. Since the receiver knows the phase offsets of its own antenna, it can reconstruct the original streams. In MIMO all the devices that are connected to won’t have to wait their turn because it allows communication to multiple devices, all at the same time. It breaks up the internet bandwidth and pushes it to the connected devices. So, with this technology subscribers will see a significant improvement in the speed of their internet, especially if they are doing things that require a lot of bandwidth like streaming, watching a series, or gaming. It reduces lag to the connected devices because the connection is never interrupted, which increases performance. So, this communication is like every device; will have its own Wi-Fi router, like shown in Figure 3.

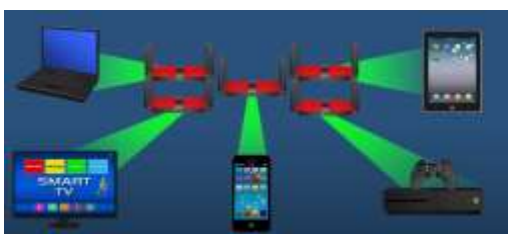

Figure 3
MIMO communication

Now, MIMO communication takes advantage of beamforming, but if the subscriber adds an old router that doesn’t have MIMO, it will not work as it supposed to because will have the old technology combined with new technology that does have MIMO.

Different types of MIMO

Reference [4] shows that MIMO comes with different variations. For example, they come in 2x2, 3x3, or 4x4 and these variations refer to the number of streams that are created. So, a 2x2 device means that it has 2 antennas that are used for 2 simultaneous streams. A 3x3 device means it has 3 antennas for 3 streams. And a 4x4 device will have 4 streams. To have the MIMO technology, it must support at least the 802.11ac wave 2 standard, which is known as Wi-Fi___33 5, because the previous versions, such as the 802.11a, b, g and n do not support it. These types of MIMO will make connection faster, depending on how many devices will be added in that MIMO connection.

METHODOLOGY: SIMULATION PROGRAM

Program

For this project, the researcher used MATLAB program to simulate the process of beamforming.

Simulation

For MATLAB, the researcher simulated a beamforming program and watched the process of an observation angel and pattern forming. MATLAB is a program that uses mathematical equations and not with righting codes. Therefore, is simpler to simulate beamforming. Reference [5] shows examples of beamforming that help me guide to the program that was made.

MATLAB Program explanation

The first step of the beamformer code is to implement the parameters of the array. The parameters of the array are to pass an array of arguments to a procedure. They are the numbers of the calculation to make the array happened like they are supposed to. The first line of code is the number of antenna elements in a beamforming. Researchers can implement as much elements as needed. Then implemented the steering angle of each beamforming so it will have a range of angle for each place. As well, implemented the radius of steering angel to have a better angle. DL then is implemented; that is the beam forming is based on CSI and standardized precoding tables. Finally, executed the kd, that is the multiplication of 2*pi* the dl and finish with the Delta formula. This procedure will be shown in Figure 4.

```
% Beamformer
clear; close all; clc;
%Parameters of array
N =17; % Number of antenna elements
theta0deg=0; %steering angle (degree)
theta0= theta0deg*pi/180; %steering angle (radians)
dL =0.4;
kd=2*pi*dL;                 %k*d
delta=kd*sin(theta0);
delta1=kd*sind(theta0deg);
```

Figure 4
Parameters of Array

The observation angle is the target between a line to the observer and a line to the theta. Step is the quality of the picture. Then applied the thetadg, to increase the image quality and have a better view of the graph. This information of code will be shown in Figure 5.

```
%Observation angle
Step=0.1;
thetadg=[-90:Step:90];
theta =thetadg*pi/180;
```

Figure 5
Observation Angel

A single isolated element is the point in *x* which does not contain any other point in *S*. As you can see, the researcher has two types of isolated element: the isotropic and the dipole. The isotopic is an antenna element radiated equal power in all directions. And the dipole is a balanced antenna; it is the more fundamental form of antenna. For this MATLAB code, the researcher used these two formulas but one at the time to see the difference between both. Both formulas are shown in Figure 6.

```
%Single isolated element
Eisol=ones(1,length(theta)); %ISOTROPIC
%Eisol= sqrt(cos(theta).^3);    % Dipole
Eisol=Eisol/max(Eisol);
```

Figure 6
Single Isolated Element

In this part of the code, the researcher graphed the process of the beamforming. At the beginning of the code, a *N* value to de 40, so the graph will go to the N value to de 40 values. This graph will also plot the grid in the background. This code will be shown in Figure 7. The result of the figure will be in Figure 10 without the excitation coefficient but if implement the excitation coefficient, will see the result in Figure 11.

```
%a = ones(1,N); % exitation coefficients
%a = hamming(N)';
a=chebwin(N,40)';
a=triang(N)';

figure(1)
n=1:N;
plot(n,a); grid;
```

Figure 7
Plotting the figure of Excitation Coefficients

Next code part will be the VINC. VINC is the formula used to form a vector that will show the current graph of the beamforming from the value *N* to the value that the VINC gives. This will also depend on the number of elements that is used in beamforming. This will also help the sensor verify the setting of the formula. This MATLAB code is shown in Figure 8.

```
%Forming Vinc
n=1:N;
Vinc = a.*exp(-j*(n-1).*kd*sin(theta0));
Vinc=Vinc./(sum(abs(Vinc.^2)));
zoom on;  hold on; grid;
```

Figure 8
Forming VinC

Pattern forming is a pattern that will be formed in the graph so we can see the beamforming acting like it supposed to be. Power pattern represented the output voltage power of the element as a function of wave arrival direction. To make the pattern a matrix will be created. The first part of the code is to show the length of the theta. In the next code, matrix will be added to a zero metric; then create another loop to the matrix area. When the loop ends, the researcher will add to the code the pattern of the matrix. Lastly, create the figure to see the pattern of the loop of the matrix for beamforming. The Power Pattern title and labels were also created. This code will be shown in the Figure 9. The result in the simulation will be shown in Figure 12. The results with the cosine will be shown in Figure 13. It is interesting because in the cosine is almost close to the real solution, but it will never be exact.

```
%Pattern forming
lengththeta=length(theta);
Vtheta=zeros(N,lengththeta);
for u=1:lengththeta
    n=1:N;
    Vtheta(n,u)=exp(j*(n-1)*kd*sin(theta(u)));
end
Vtheta=Vtheta.*Eisol;

Pat=Vinc*Vtheta;
Pat_pow=abs(Pat).^2;
Pat_powdb=10*log10(Pat_pow);

figure(2)
plot(thetadg,Pat_powdb); grid; hold on
axis([min(thetadg) max(thetadg) -70 10]);
xlabel('\theta_0(deg)');
ylabel('Pdb(theta)')
title(['Power pattern, N=' num2str(N),',\theta_0(deg)=',num2str(theta0deg)
```

Figure 9
Pattern Power

Simulation Results

This simulation is a perfect example of beamforming. In Figure 10 you can see the plot of G(θ) for this two elements. There is a two-element array beam pattern too in Figure 11 and Figure 12. This plot is made by adding this formula in MATLAB $G(\theta)(decibels) = 10log_{10}\{\frac{|A(\theta)|^2}{4}\}$. This formula normalized the direction of pattern in decibels for the two elements. As shown in all figures, there is a principal lobe having a beamwidth of 60 degrees off broadside. This occurs because at that sensor elements, the direction of arrival has a signal wavefront traveling exactly in $\frac{2}{\gamma 0}$ between all the sensors. Figures 13, 14, and 15 are all with Excitation Coefficients but they have different number of elements to see the reaction of beamforming on all of them. It is seen that as the number of elements increases, the main lobe beamwidth decreases and the number of sidelobes and pattern nulls increases. To illustrate how elements spacing affects the directional pattern for a seven-element linear array in an azimuth plane. Adding more elements reacts to the opposite, an interesting issue. The reason why this happens to antennas is because the beamwidth decreases and the signals that are sending will decrease and will not get far enough as it supposes to. That is why the researcher implemented more antennas in close range so the 5G connection will be better in every section of the location of the 5G antenna.

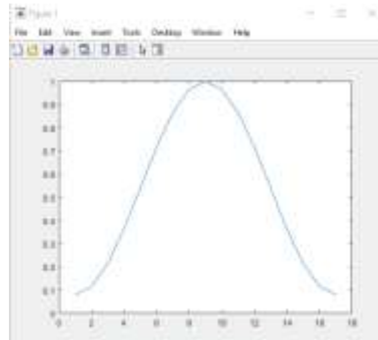

Figure 10
Excitation Coefficients graph

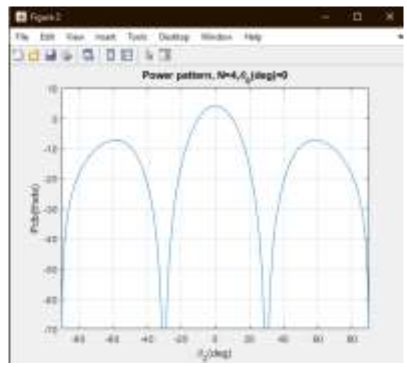

Figure 11
$\frac{d}{\gamma 0} = 1.5$ **N=4 and no Excitation Coefficients**

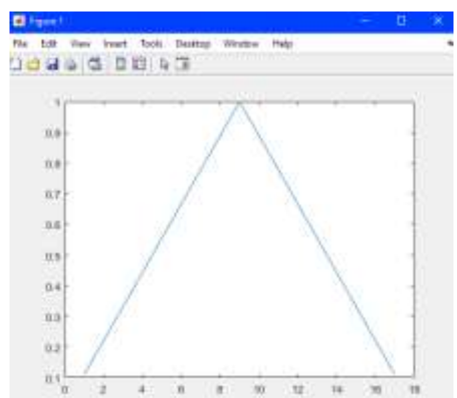

Figure 12
Graph without Excitation Coefficients

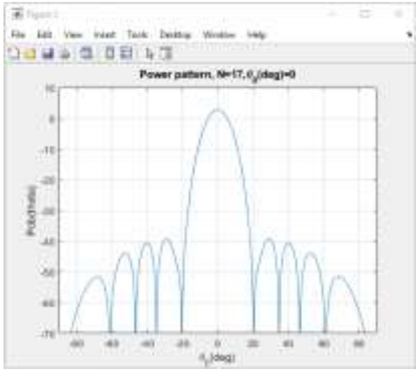

Figure 13
N=17 with Episole Power pattern with Excitation Coefficient

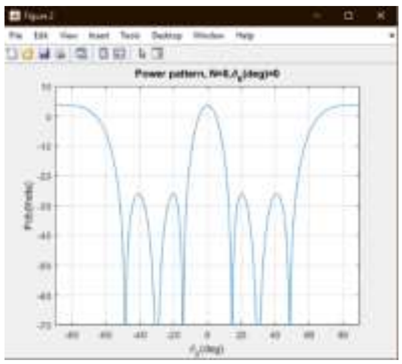

Figure 14
N=8 without Excitation Coefficients

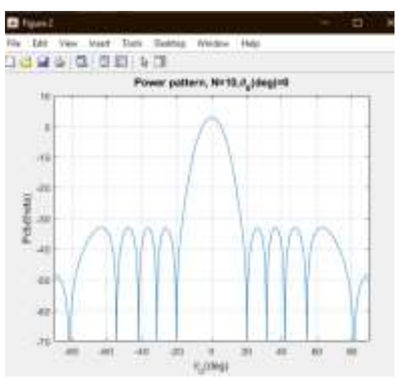

Figure 15
N=10 with Excitation Coefficients

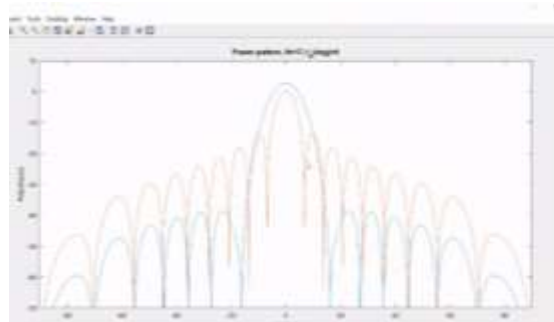

Figure 16
N=17 Power pattern with Excitation Coefficient and Beamwidths

CONCLUSIONS

With this project, the researcher could develop the beamforming and print out their results. Beamforming is not just a simple calculation. Beamforming converted the entire process into the antenna, if not, takes multiple steps to end up making the antenna array as strong as it is in today's day.

Beamforming will be better in the future when the population will have better antennas and technology. Without beamforming, people may have the internet speed that is available nowadays. The researcher also noticed that with antennas array, between more sensors available in the antenna, the better the range of connection every device is going to have. Is impossible to have connected 40 sensors to an antenna for the reason that it will not work out as it is supposed to. This all depends on the location, because if you have multiple buildings between locations, can not just implement one antenna array and have it jumping from one side to another. This is why in the cities, companies installed multiple antennas around so that the connection will be the same in all places.

In conclusion, beamforming is bringing the future to a better place by implementing faster internet connection to the devices and getting everybody connected to each other. This will probably become better in the future; having a very fast connection to the internet anywhere.

Results confirmed researcher assumptions and with this simulation, can see better reaction between the power pattern and the Excitation Coefficients.

This is just the beginning of beamforming, and the researcher can't wait for what will be the future of beamforming.

REFERENCES

[1] K. M. Ahmed and R. J. Evans, "Broadband adaptive array processing," *IEE Proceedings F: Communications, Radar and Signal Processing*, vol. 130, no. 5, 433–440, August 1983.

[2] K. M. Ahmed and R. J. Evans, "An adaptive array processor with robustness and broadband capabilities," *IEE Proceedings F: Communications, Radar and Signal Processing*, vol. 130, no. 7, 460–48, 1984.

[3] A. Akansu and R. Haddad, *Multiresolution Signal Decomposition: Transforms, Subbands and Wavelets*, Boston, MA: Academic Press, 1992.

[4] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 8, 1451–1458, 1998. [Accessed: August 10, 2000].

[5] R. Kulke, S. Holzwarth, J. Kassner, A. Lauer, M. Rittweger, P. Uhlig and P. Weigand. "24 GHz Radar Sensor integrates Patch Antenna and Frontend Module in single Multilayer LTCC Substrate," *Mathworks*, April 15, 2005. https://www.mathworks.com/help/antenna/ug/fmcw-patch-antenna-array.html#atx_fmcw_patch_array-5 [Accessed: December 15, 2021].