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Calculating Characteristic Impedance Without Using Symmetricity of Rectangular Coaxial Line

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ABSTRACT

A transmission line is used for transmitting electrical power between a transmitter to a receiver, load, or various distribution sections. Its characteristic impedance is one of its key parameters as it will deduce whether the maximum power is transferred to its other end. In this paper, the characteristic impedance was calculated without the use of symmetricity. As this has consistently been the method being used in computing, this study focused on being able to achieve the same output but through a different procedure. The code for this paper was done in the software called MATLAB. The program then works by simply being executed and the processes involved in producing the desired output such as the predefined dimensions of the coaxial transmission line, the established dimensions of the inner and outer conductors as well as the assigned voltages for the outer boundaries of the system, the node voltages, and the inner voltage of the conductors. The finite difference scheme will then be applied in order to calculate the convergence of the solution. The potential difference of the coaxial transmission line is then calculated by calculating the charge enclosed by the areas of the inner and outer conductors before finally calculating the characteristic impedance of the system. The results obtained from the simulation were compared with the results from one of the literature used. The output had a considerable value of percentage error which is 28.93%. Nonetheless, the conceived output was very close to the accurate answer.

Key words: characteristic impedance, rectangular coaxial line, coaxial cable, symmetricity.

1. INTRODUCTION

The rectangular coaxial lines are known to be used in microwave technology [1]. These rectangular coaxial lines, which is sometimes abbreviated into RCL, are used in order to transmit energy [2,3]. To learn more about rectangular coaxial lines, it is important to determine its different characteristic parameters [4]. These parameters are known as the capacitance per unit length, the inductance per unit length, and the characteristic impedance [5,6]. In the early years, there has been previous interest centered around the topic of the theoretical approaches of one of the parameters of rectangular coaxial lines [7]. The parameter in focus is the characteristic impedance. One of the earliest analyses on the parameters of rectangular coaxial lines, including the characteristic impedance, was done in the 1960s [8]. The analysis done by Chen was the first significant study, using the Schwarz-Chrsitoffel transformation and approximate analytical expressions in order to obtain and present the capacitance per unit length, inductance per unit length, and the characteristic impedance. In 1972, it was described as creating an exact general analysis of a rectangular coaxial line as “extremely difficult” to implement. However, he states that there have been some studies conducted, citing Sato and Ikeda as his primary source and example, that derived exact formulas for the different line parameters [9]. Included in these is the exact formula used to determine the exact characteristic impedance of the rectangular coaxial lines, given that it has arbitrary cross-sectional dimensions. Some researchers have also utilized the “exact” approach based on the use of conformal transformations. One example from a study used the same approach in analyzing the rectangular coaxial lines [10] Despite this, their results may not be practical due to the fact that it is in terms of upper and lower bounds on the characteristic impedance. There was also another study which used an approach that is a combination of an analytic approach and it numerical approach [11]. The research arrived at a result of a series representation of the characteristic impedance that is significantly general. This means that the result obtained has completely arbitrary cross-sectional dimensions and the axis of the strip conductor does not need to coincide with the axis of the rectangular shield in rectangular coaxial lines.

2. BACKGROUND OF THE STUDY

In order to properly understand this topic, extensive knowledge on rectangular coaxial lines and its characteristic parameters, most especially the characteristic impedance, is needed. A transmission line is a two-conductor structure that supports a transmission electron microscopy wave or TEM wave [12,13,14]. It is used to guide electrical energy from one point to another [15,16]. The coaxial line is the most common type of transmission line..

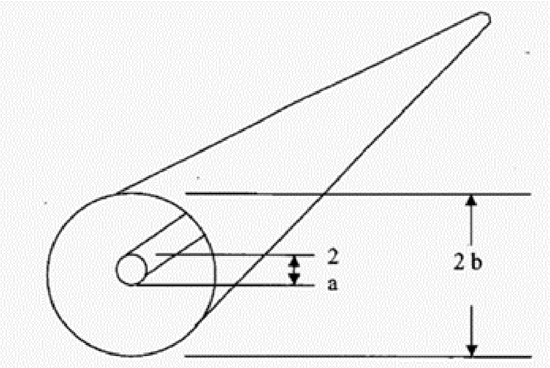


Figure 1: Coaxial line

In Figure 1 a coaxial line wherein a is considered as the radius of the inner conductor and b is the inner radius of the outer conductor. For this research, the main focus is the characteristic impedance of the rectangular coaxial lines. In transmission lines, the ratio of the voltage to the current at the input is known as the input impedance [17,18]. The input impedance is the impedance that is presented to the transmitter by means of the transmission line and the load. On the other hand, the ratio of voltage to the current at the output is known as the output impedance. This impedance is presented to the load using the transmission line and the source [19,20]. Suppose an infinitely long transmission line is used. The ratio of the voltage to the current at any given point in the said transmission line would result in a value of impedance. This is known as the characteristic impedance. When the source impedance matches with the load impedance, the maximum transfer of electrical energy occurs. This is also the most efficient way to transfer electrical energy. Having the characteristic impedance of the transmission line and the load impedance equal is important to the study. When these two impedances are equal, the energy found in the transmitter travels to the antenna by passing through the transmission line. In this situation, the energy experiences no power loss that is caused by reflection [21].

3. STATEMENT OF THE PROBLEM

Rectangular coaxial cable is a transmission line that is generally used for microwave technology to transmit radio frequency signals [22]. Therefore, it is important to know its characteristic parameters, wherein, its main parameters are: inductance per unit length, capacitance per unit length, and characteristic impedance. However, calculation using analytical methods has deemed to be difficult or impossible to find. Consequently, another way to solve the problem is with the help of technology by running an application through the computer which can efficiently use numerical computing methods we are able to approximate the values of the parameters. In fact, various numerical computing methods were used since the 1960s to solve the said parameters but, old methods are slower. Moreover, a method that is used to analyze electromagnetic fields and other potential fields which is finite difference method and was found successful in computing parameters for transmission line analysis than any other analytical or numerical method that is used [23].

4. SIGNIFICANCE OF THE STUDY

Coaxial cables are lines that are interconnected which transmits pulses to one point and to the next point, wherein the information in the signal is preserved. It consists of two conductors, which are cylindrical in shape and is concentric with each other, and also has a dielectric material to separate the two. As coaxial cables are tremendously helpful for audio and visual equipment, there has been continuous research involving improving the said transmission line and there are some that use coaxial cable as part of their study [24]. There had been numerous researches and papers that focused on demonstrating the differences and similarities on the properties of the transmission lines between expensive instruments and low-cost equipment. In these various studies, they focused on the topic of transit time in the transmission line. Their studies provided a guide for researchers and owners who produces these cables to know which areas need to be changed.

As there still exist areas where coaxial cables can be improved, the researchers of this paper believe that the calculations can be refined. As symmetricity is a method in computing for the characteristic impedance of a coaxial line, this paper will focus on proposing a new way of solving for it however in this case, without the use of symmetricity. The researchers believe that this can help with other studies in improving the features of coaxial cables and it may also help in this being more beneficial for electronics.

5. DESCRIPTION OF THE SYSTEM

The characteristic impedance of a rectangular coaxial line is a characteristic parameter for transmission lines. The program of the project is created with the use of the software MATLAB. For the program code, the coaxial cable is given dimensions, voltages, and other parameters. This is to be able to conduct and run the program with a set parameter. It may not run accordingly if there were no set values for the variables assumed.

6. METHODOLOGY

The algorithm of the program used in the study follows various short processes in order to achieve the goal which is to calculate the characteristic impedance and display the resulting graphs. The dimensions for the coaxial cable transmission line was already pre-defined. When the program is executed it first establishes the dimensions of the inner and outer conductor as well as its position. The voltages in the outer boundary of the transmission line are then assigned as well as the node voltages and the voltage at the inner conductor. With everything all set, the Laplace equation is then solved using the finite difference method or scheme in order to calculate for the convergence of the solution of the rectangular coaxial Tx line in which the results will then be plotted. The potential distribution of the transmission line will then be determined by calculating the charge enclosed by the areas of the inner and outer conductors which the results will also be plotted and displayed [25]. Lastly, the characteristic impedance will be calculated and displayed in the command window as well as with the characteristic impedance given by the reference paper. The two characteristic impedances will then be compared with each other and the percentage error between the two values will then be displayed.

7. REVIEW OF RELATED LITERATURE

In a study conducted, it was proposed that an approach in solving the determining the characteristic impedance of rectangular coaxial lines is done. Given that rectangular coaxial lines are commonly used and holds an important role in microwave technology it is a must to know and be able to determine the characteristic parameters such as the capacitance per unit length, characteristic impedance and inductance per unit length, with the use of analytical and numerical methods to achieve the most accurate or nearest approximated result. The proposed approach by the authors of the study is the Equivalent Electrodes Method or EEM. The Equivalent Electrodes Method is a simple method which was originally used in the field of theoretical physics and in electromagnetic fields, there have also been studies in which the Equivalent Electrodes Method was also used in transmission line analysis which resulted in success. The results in the application of the Equivalent Electrode Method in transmission line analysis showed a great similarity percentage with the results from other analytical and numerical methods that are used in transmission line analysis [26]. This is the main reason why the authors of the paper chose to propose this specific type of method in calculating the characteristic impedance of Eccentric rectangular coaxial lines. The models used in the study of the researchers were done in conjunction with the software package COSMOL. The proposed method was used on rectangular coaxial lines both with eccentricity and without eccentricity, eccentricity in simple math terms means having a distinct, uniquely characterized shape. The results of the study showed great promise as the data gathered from the simulations were compared to the results that were found in the literature and have a very high percentage in similarity [27]. The results of the study also show that the characteristic impedance parameter changes and adjusts based on the parameters and dimensions of the cable which is due to the results that were acquired were from a wide variety of dimensions and shapes of lines. Additionally, based on the findings while comparing the results made with the Equivalent Electrode Method and the results from other analytical methods the authors of the study concluded that the Equivalent Electrode Method had clear advantages over the other methods with the Equivalent Electrode Method having a much more accurate result in combination with non-existent limitations with regards to the dimensions and shapes of the lines as well as being simple, straightforward and fast in terms of coding.

A study conducted proposes a different approach with a different and special kind of transmission line, the strip transmission line. The author of the paper mentioned that previous researchers of the said topic have approached this kind of scenario through the determination of the capacitance per unit length in order to solve the characteristic impedance of the lossless transmission line. The approach proposed by the authors of this paper goes by first determining the inductance per unit length in order to solve for the characteristic impedance of the lossless transmission line. After the simulation and gathering of data the three authors of the paper have come to a conclusion that if at frequencies in which the current distribution on the conductors of the transmission line are uniform that would mean that the inductance and resistance of the transmission line can be calculated and determined exactly, in turn, allowing the characteristic impedance of the transmission line to be solved with ease. On the other hand, if at frequencies in which the current distribution running through the conductors of the transmission line are non-uniform that would mean that the conductors must first be divided into different sections which would then allow the determination of only the approximate current distribution running through the conductors, from the approximate current distribution the approximate inductance per unit length, as well as the approximate resistance per unit length, can then be determined before being able to calculate for only the approximate characteristic impedance of the transmission line. The authors also added that the approach proposed in this study for obtaining the characteristic impedance of the strip transmission line can be applied to different types of transmission lines which have a more complex conic sections given the condition that the conductors of the transmission lines can be divided into sections which allow the mutual inductances as well as the d-c self to be calculated.

8. THEORETICAL CONSIDERATIONS

One must be wary of the predefined dimensions of the coaxial transmission line because if the program is executed with wrong dimensions the calculated voltage would give undesirable results. Should the users input wrong data to the Laplace equation, which is the most crucial step in the system, because it is where the outputs are transferred, to a finite difference algorithm? After, this then solves for the convergence of the solution of the user’s transmission. Finally, the said error would also result in failure to determine the potential distribution and characteristic impedance that is the main purpose of the system.

9. DATA AND RESULTS

9.1. Program code

```
%% Calculating characteristic impedance without using
symmetricity of the rectangular coax Tx line
%% Assuming Outer dimension is 3X3 and inner is
dimension 1X1,Voltage at outer conductor = 0V,Voltage at
inner conductor = 1V
```

```
clc
close all
clear all

% Outer dimension 3X3 and inner dimension 1X1
Vd = 1; % Voltage at inner conductor
Vc = 0; % Voltage at outer conductor

% along x - direction
a = 1;c = 1;
b = 1;


% along y - direction
d = 1;
e = 1;
f = 1;

h = 16;% number of steps between unit length
dx = 1/h;
dy = 1/h;

x = 0:dx:(a+b+c);
y = 0:dy:(d+e+f);

A = length(0:dx:a); % 1st end of inner conductor along x-
direction
B = length(0:dx:a+b); % 2nd end of inner conductor along
x- direction
C = length(0:dx:a+b+c); % Position of outer conductor
along x- direction
D = length(0:dy:d); % 1st end of inner conductor along y-
direction
E = length(0:dy:d+e); % 2nd end of inner conductor along
y- direction
F = length(0:dy:d+e+f); % Position of outer conductor
along y- direction

phi = zeros(F,C); % initialising variable

% Assigning voltage at outer boundary

phi(1,:) = Vc;
phi(F,:) = Vc;
phi(:,1) = Vc;
phi(:,C) = Vc;

% Assigning voltage at inner conductor and initializing all
free node to 0V

for l = 2:F-1
  for m = 2:C-1
    if (m>=A && m<=B) && (l>=D && l<=E)
      phi(l,m) = Vd;
    else
      phi(l,m) = 0;
    end
  end
end
% solving Laplace equation by Finite-Difference scheme
p = 1;
v(:,:,p) = phi;
phi_initial = phi;
error1 = v(:,:,p)-zeros(F,C);
error2 = rms(rms(error1)); % RMS error between two
iteration
RMS_err(p) = error2; % Storing RMS error between
iterations
while error2 > 1e-30   % Implementing iteration method
  p = p+1;


for l = 2:F-1

  for m = 2:C-1

    if (m>=A && m<=B) && (l>=D && l<=E)
      phi(l,m) = 1;
    else
        phi(l,m)=
(phi(l,m-1)+phi(l,m+1)+phi(l-1,m)+phi(l+1,m))/4;
    end

  end
end

v(:,:,p)= phi;
error1 = v(:,:,p)-v(:,:,p-1);
error2 = rms(rms(error1));
RMS_err(p) = error2; % Storing RMS error between
iterations
mesh(x,y,phi,'Linewidth',2)
pause(0.01)
end

mesh(x,y,phi,'Linewidth',2)
xlabel('x\rightarrow')
ylabel('\leftarrow y')
zlabel('Potential\rightarrow')
title('Potential distribution on an air filled coax rectangular
Tx line')
colorbar
set(get(gca,'xlabel'),'FontSize', 18, 'FontWeight', 'Bold');
set(get(gca,'ylabel'),'FontSize', 18, 'FontWeight', 'Bold');
set(get(gca,'zlabel'),'FontSize', 18, 'FontWeight', 'Bold');
set(get(gca,'title'),'FontSize', 18, 'FontWeight', 'Bold');
% box off; axis square;
set(gca,'LineWidth',2);
set(gca,'FontSize',14);
set(gca,'FontWeight','Bold');
set(gcf,'color','w');
set(gcf,'PaperUnits','inches');
set(gcf,'PaperSize', [12 12]);
set(gcf,'PaperPosition',[0.5 0.5 7 7]);
set(gcf,'PaperPositionMode','Manual');

% Plotting convergence of solution
figure
plot(RMS_err(1:250),'Linewidth',2)
```

```
axis([0 250 0 0.5])
xlabel('No of Iteration\rightarrow')
ylabel('RMS error between two iteration\rightarrow')

title('Convergence of solution of rectangular coax Tx line without using symmetricity by FD method')

set(get(gca,'xlabel'),'FontSize', 18, 'FontWeight', 'Bold');
set(get(gca,'ylabel'),'FontSize', 18, 'FontWeight', 'Bold');
set(get(gca,'title'),'FontSize', 18, 'FontWeight', 'Bold');
% box off; axis square;
set(gca,'LineWidth',2);
set(gca,'FontSize',14);
set(gca,'FontWeight','Bold');
set(gcf,'color','w');
set(gcf,'PaperUnits','inches');
set(gcf,'PaperSize', [12 12]);
set(gcf,'PaperPosition',[0.5 0.5 7 7]);
set(gcf,'PaperPositionMode','Manual');

%% Calculating charge enclosed by area just outside the inner conductor by
% Gauss's Law
K1 =sum((phi(D,A:B)- phi(D-1,A:B))) + sum ((phi(E,A:B)-phi(E+1,A:B))) + sum((phi(D:E,A)-phi(D:E,A-1))) + sum((phi(D:E,B)-phi(D:E,B+1)));

% Calculating charge enclosed by area just inside the outer conductor by
% Gauss's Law
K2 =sum((phi(2,2:C-1)- phi(1,2:C-1))) + sum((phi(F-1,2:C-1)- phi(F,2:C-1))) + sum((phi(2:F-1,2)-phi(2:F-1,1))) + sum((phi(2:F-1,C-1)- phi(2:F-1,C)));

epsilon = 8.854e-12; % Permittivity of air
Q = epsilon*K1; % Charge enclosed

V = Vd-Vc; % Voltage difference between inner and outer conductor
Cap = Q/V; % Capacitance per unit length

U0 = 3e8; % Speed of light
Z0 = 1/(Cap*U0); % Characteristics Impedance


cf1 = ( epsilon/pi)*(log((a^2+d^2)/4*d^2)+(2*d/a)*atan(a/d));
cf2 = (epsilon/pi)*(log((a^2+d^2)/4*a^2)+(2*a/d)*atan(d/a));

Z0d = 376.62/(2*((e/a)+(b/d))+(4/epsilon)*(cf1+cf2)) ;

%% Part(D) of Question : Calculating percentage error between simulated and referenced result

Error = abs((Z0d-Z0)/Z0d)*100;

disp('The characteristic impedance of air filled coax rectangular(3X3-outer conductor, 1X1-inner conductor) by FD scheme is')
disp(Z0)
disp('The characteristic impedance of air filled coax rectangular(3X3-outer conductor, 1X1-inner conductor) by reference paper is')
disp(Z0d)
disp('Percentage error between result of FD scheme and reference paper is')
disp(Error)
```

9.2. Program Output

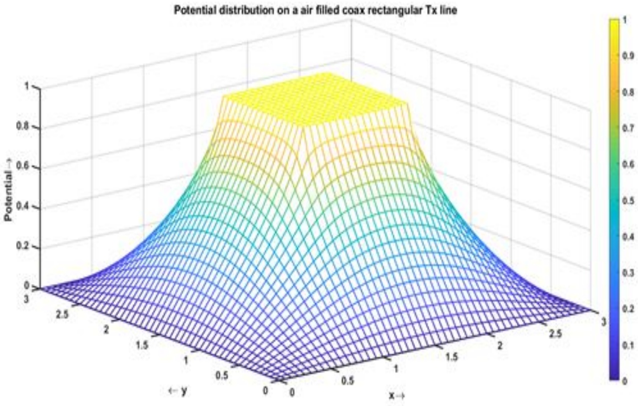


Figure 2: Potential Distribution on an air filled coaxial rectangular Tx line.

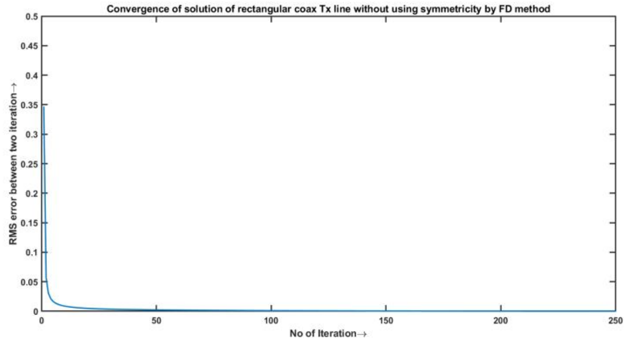
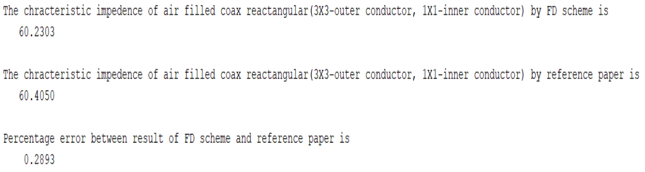


Figure 3: Convergence of solution of rectangular coaxial Tx Line without symmetricity by finite difference method



```
The chracteristic impedence of air filled coax reactangular(3X3-outer conductor, 1X1-inner conductor) by FD scheme is
   60.2303

The chracteristic impedence of air filled coax reactangular(3X3-outer conductor, 1X1-inner conductor) by reference paper is
   60.4050

Percentage error between result of FD scheme and reference paper is
    0.2893
```

Figure 4: Resulting characteristic impedance using finite difference method and the percentage difference with the result from the reference paper.

10. ANALYSIS OF DATA

The program used in the study shows the processes involved in obtaining characteristic impedance of the coaxial transmission line without symmetricity with the assumed dimensions of the coaxial line. The program used in the study includes the calculations and derivations required in order to achieve the goal that the program is made for [28]. When the program is executed it first establishes the voltage values present in the coaxial cable. Then the positions of the inner and outer dimensions of the conductors to be used in the simulated coaxial transmission line were gathered as well. For the next process, the code will go through is the establishing of voltages in the outer boundary of the transmission line as well as the node voltages present in the transmission line. The program then solves the laplace equation through the proposed method of the study which is the finite difference method or scheme. The results from the calculation are then displayed in a graph on the convergence of solution of rectangular coaxial Tx Line without symmetricity using the proposed method of the study which is the finite difference method or scheme [29]. The graph of the convergence shows very promising results. The program then calculates the charge in the inner and outer conductors using Gauss' Law which will be needed in showing the results of the potential Distribution on an air filled coaxial rectangular Tx line which also includes the permittivity of air. Lastly, the results of the calculated characteristic impedance of 60.2303 using the finite difference method or scheme are then displayed along with the given characteristic impedance of 60.4050 taken from the reference paper which shows that there is a 28.93% percentage error between the two values of characteristic impedances. The database configurations followed the studies of [30,31].

11. CONCLUSION

In this paper, the finite difference method for calculating the characteristic impedance of the transmission line was proposed using rectangular coaxial lines without the use of symmetricity in the transmission lines. The data and results gathered from the simulation of the code showed a simulated characteristic impedance value of 60.2303 with the use of the finite difference method while the resulting characteristic impedance based on the reference paper showed a value of 60.4050 and by comparing the results which shows a percentage error of 28.93% between the simulated and reference value. This result is very significant because characteristic impedance is a very important parameter in transmission lines. The characteristic impedance will be the one to determine whether all the power from the transmitter can be transferred onto the load without any form of power reflecting back. The ideal result is to have a matching characteristic impedance on the transmitter and receiver in order to achieve full power transfer without any power reflecting back onto the transmitter or almost perfect transfer of power with very minimal power reflecting back onto the transmitter due to a small difference in characteristic impedance between the transmitter and receiver. The rectangular coaxial line is generally used in microwave technology and it also plays a very important role in its functionality [32]. Which is why the parameters and characteristics of the type of transmission lines need to be well defined. Creating the correct program parameters are important in the system [33,34,35]. The program structures follows [36, 37, 38]. The rectangular coaxial line differs from the other types of transmission line especially in function since unlike the other types of transmission lines. The Coaxial transmission lines, in general, are very compact as well as sporting a low loss and low dispersion, which is due to the material that consists of the coaxial line which is mainly metal giving the coaxial line the capability to avoid dielectric and radiation losses. This, in turn, gives the coaxial cable a suitable structure for various applications for microwave technology such as in microwave filters or in millimeter-wave circuits.

12. RECOMMENDATIONS

The researchers recommend improving the algorithm done in this study. The simulation done showed a 28.93% percentage error between the value obtained from the simulation and the reference value. If the actual values are to be observed, it can be seen that the difference lies in the decimal values. Though the percentage error is lower than 50%, it is still a large error, and it is more advised to have it lower than 10% in order to have a more accurate answer or is closer to the reference value. With a lower percentage error, the algorithm would be more useful and when established well, it can be a great aid in calculating for it can save more time. Subsequently, this can also improve the functionality and applications of the coaxial cable. The important role that characteristic impedance plays is that when the transmitter transfers power to the receiver or a load it will determine whether all of what is sent will be received with minimal to no power reflecting back to the transmitter. The calculations are very crucial when using coaxial cables since the required output depends on this, hence makes characteristic impedance one of the most important parameters to consider all the time. It is also recommended to formulate an algorithm that can be easily customized for other researchers who plan to make use of the cable for a different application in a different manner. Improvements can be done not only on its calculations but also on its appearance. As the cables are big and bulky, it can be difficult to use and keep. Further testing can be done to make a smaller cable than the one sold nowadays but would still provide the maximum transfer of power and would function well when used in different equipment just like the one in a bigger size.

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