A Technical Assessment of Aperture-coupled Antenna Technology

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Abstract

Aperture coupling refers to a method of construction for patch antennas, which are specific types of microstrip antennas. These antennas are used in a variety of applications including cellular telephones, military radios, and other communications devices.

The purpose of this thesis is to assess the benefits and drawbacks of aperture-coupled antenna technology. To develop a successful analysis of the patch antenna construction technique known as aperture coupling, this assessment begins by examining basic antenna theory and patch antenna design. After uncovering some of the fundamental principles that govern aperture-coupled antenna technology, a hypothesis is created and assessed based on the positive and negative aspects of the technology. This thesis aims to analyze the positive and negative aspects of aperture coupling and conclusions will be drawn as to whether aperture-coupled antenna technology warrants further research and development within the field of electrical engineering.

A Technical Assessment of Aperture-coupled Antenna Technology

Introduction

Aperture-coupled antennas, a type of patch antennas, were developed in the mid-1980s in an attempt to reduce transmission line radiation and enhance the antenna's ability to radiate electromagnetic fields (HFSS, 2005). There are several applications for aperture coupling, particularly in the field of patch antenna technology, which will be examined in this paper. In order to conduct a thorough assessment of aperture-coupled antenna technology, a basic understanding must be developed pertaining to the underlying principles that aperture-coupled antennas are centered on. First, an understanding of basic antenna theory is required to provide a basis for further discussion on different varieties of antennas. Inside basic antenna theory lies a very important concept to the subject of aperture-coupled antennas, that being the antenna aperture itself. Thus, developing a familiarity with the concept of the antenna aperture is helpful before proceeding to assess this technology. In addition, developing a brief knowledge base of patch antennas is helpful because these antennas are closely related to aperture-coupled antennas. After developing a basis of understanding in antenna theory and the field of patch antennas it becomes plausible to examine aperture-coupled antenna technology. This paper will provide a foundation in antenna theory, examine the construction of patch antennas, and provide an assessment of aperture-coupled antenna technology. In this assessment, research of aperture-coupled antennas will be developed, and an assessment of benefits and drawbacks of the technology will be conducted.

Antenna Theory

Basic Antenna Model

In order to provide a thorough assessment of aperture-coupled antenna technology, a preliminary examination of the basic principles of antenna theory is necessary to develop a sufficient foundation for further analysis. Antennas are implemented in a variety of applications including cellular telephones, television broadcasting, satellite communications, and radio wave transmission. Understanding the basic concepts in antenna theory is essential due to the wide range of uses for electrical antennas in today's technology. There are two main types of antennas, receiving and transmitting. There are myriad transmitting and receiving antennas, however for the purpose of this assessment only three types will be discussed: wire antennas, patch antennas, and aperture-coupled antennas. Receiving antennas exist to transform electromagnetic waves into electric power; regardless of what application the antenna is being used. Alternatively, transmitting antennas convert electrical power into electromagnetic waves (Bakshi, 2009). A typical radio system consists of both a transmitting and receiving antenna. In radio applications the transmitting antenna is very large, and radiates electromagnetic waves over large distances. In these systems, radio waves may be received by numerous smaller antennas in vehicles or household radios. Figure 1, shown below, provides a good representation of how a radio transmitting antenna radiates electromagnetic waves and how a receiving antenna receives those waves.

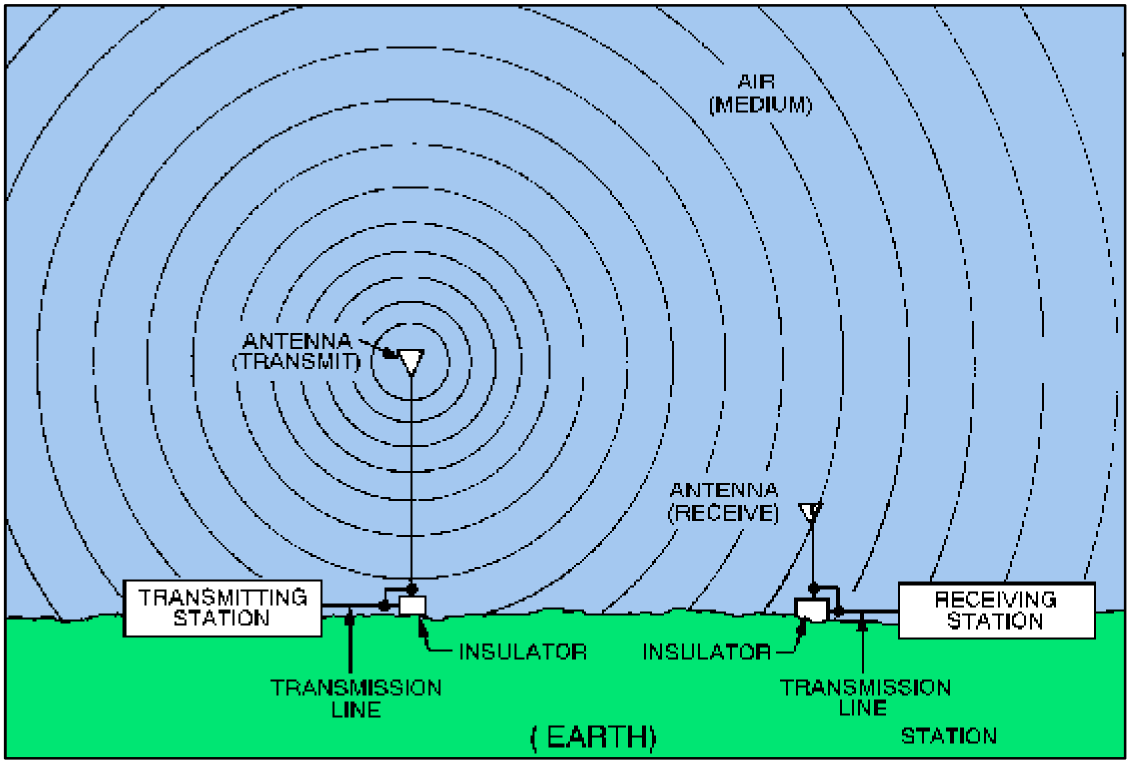

Figure 1: Transmitting and Receiving Radio Model (2011)
Source: http://diy.powet.eu/2011/01/10/2-the-expression-of-needs/?lang=en

Figure 1 provides a basic model for a standard radio system. The transmitting antenna shown in the diagram radiates electromagnetic waves outward from the peak of the antenna in a spherical pattern. The receiving antenna is well within the transmitting antenna range, therefore it is able to receive and convert the electromagnetic radiation into power. In this particular example the electromagnetic waves would be converted into electrical power, which would then be amplified and transformed into sound via a speaker. Figure 2, shown below, provides a more generic representation of antenna functions.

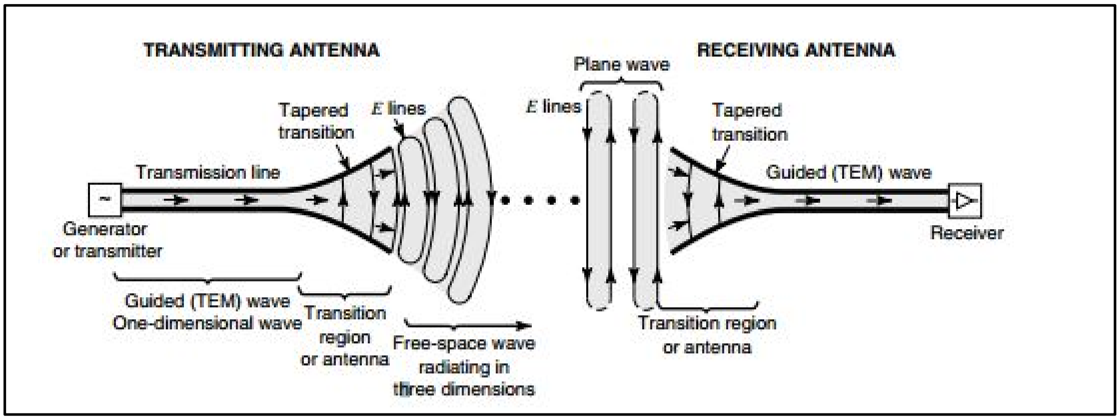

Figure 2: Transmitting and Receiving Antenna Model (2002)
Source: J. D. Kraus and R. J. Marhefka,"Antennas," McGraw-Hill

In Figure 2, the transmitting antenna is modeled as a generator connected to a transmission region via a transmission line. The generator in this diagram creates electrical power, which is then transmitted through a wave guide, modeled as a transmission line. The power stored in the transverse electromagnetic (TEM) waves propagates through the transmission line into the transmission region (Kishk, 2001). Once the waves are transmitted, they propagate through the air until they hit the receiving antenna. The receiving antenna gathers the electromagnetic waves that originated at the transmission antenna and guides them into a receiver via a transmission line. This model provides an excellent representation of the basic function of a generic antenna, however it should be noted that this is a very simple model. There are several different types of antennas, and each type must be modeled slightly differently based on its application and design characteristics. In any case, the transmitting and receiving antenna model offers a good representation of the basic functions of electrical antennas, and it can be examined to develop an understanding of how patch antennas function.

Antenna Aperture

In addition to understanding the basic operation of antennas, an introduction to the antenna aperture provides a foundation to conduct an assessment of aperture-coupled antenna technology. The aperture of an antenna refers to the area of the antenna that is oriented perpendicular to the incoming radio waves (Narayan, 2007). The antenna aperture is a means of determining how well the antenna is able to receive the power stored in radiating electromagnetic waves. Typically, a large antenna aperture is desirable because more power is collected from the incoming electromagnetic fields as the aperture size increases. The size of the effective area, or the antenna aperture, can be calculated from the following equation when the gain of the antenna is measured or known:

$$A_e = \frac{\lambda^2}{4\pi} G$$

Equation 1: Effective Aperture

This equation states that the wavelength of the transmitted radio waves, lambda, and the gain of the antenna, G, are directly related to the effective aperture of the antenna (Kishk, 2001). This equation is useful for calculating the size of the aperture when the antenna gain can be measured. In addition, the equation can be utilized to calculate the gain of the antenna when the effective area is known.

The antenna aperture describes the amount of power that is captured from a propagating electromagnetic wave. Thus, the effective aperture of an antenna can be used to relate the power propagating through electromagnetic waves to the power that is transmitted to the receiver. The following equation describes the relationship between the aperture, transmitted power, and the propagating power.

$$P_t = pA_e$$

Equation 2: Transmitted Power

In Equation 2, P_t refers to the power that is transmitted to the antenna (in Watts). The propagating power density, *p*, is measured in watts per meter squared, and the aperture is measured in meters squared (Kishk, 2001). The equation states that the propagating power times the size of the aperture is equal to the transmitted power. From this equation it can be seen that the larger the size of the effective aperture, the larger the amount of power that will be transferred to the antenna's receiver. This equation is useful because it shows that the size of the effective aperture of an antenna is one of the most important parts of the antenna's design. Understanding the concept of antenna aperture is necessary for beginning to assess aperture-coupled antenna technology. While this thesis does not attempt to discuss the design of antenna apertures, it is important to note that the aperture is one of the most important parts of antenna design.

Bandwidth and Impedance Matching

Another key topic to understand in antenna theory is the concept of bandwidth. Developing an understanding of the concept of bandwidth is fundamental for any type of antenna analysis because this parameter directly relates to how an antenna is designed and how the antenna can perform. The bandwidth of an antenna is defined as the range of frequencies over which the antenna can function as designed (Bevelacqua, 2010). Bandwidth is typically a key parameter in antenna design because the desired operating frequency for the antenna's application is usually known. For example, FM radio signals vary from 88 megahertz to 108 megahertz, thus an antenna designed to receive FM radio signals would need to be able operate within this bandwidth. The bandwidth of an antenna is related to the quality of the impedance match between the antenna, the source, and the transmission line. As the operating frequency moves outside of the antenna's bandwidth, the performance suffers because of an impedance mismatch (Bevelacqua, 2010). As the operating frequency changes, the imaginary component of the impedances will change as well. As the impedances change, they can become mismatched at certain frequencies and thus can affect the antenna's performance. For this reason, impedance matching must be considered so that the antenna can operate over the desired frequency range.

It is understood that the components of the antenna must be matched according to their impedances in order for the antenna to operate as designed. Because the quality of impedance matching affects the bandwidth of the antenna, the conditions of matching that allow the maximum amount of power to be transmitted from the voltage source to the antenna must be known. In order to describe the concept of impedance matching, the antenna model shown below in Figure 3 will be examined.

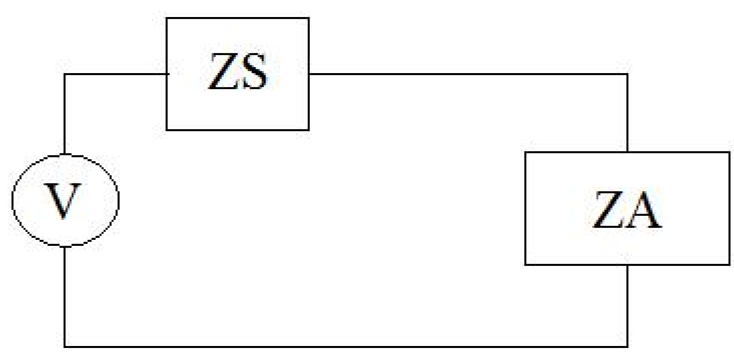

Figure 3: Impedance Model of an Antenna (2008)
Source: http://www.antenna-theory.com/basics/impedance.php

In Figure 3, a basic antenna is modeled as a combination of a voltage source, source impedance, and antenna impedance. In the diagram, V refers to the magnitude of the voltage source, ZS refers to the source impedance, and ZA refers to the antenna impedance. The power that is delivered to the antenna can be utilized to understand how the bandwidth affects the antenna's performance. Voltage division can be performed to derive an expression for the power delivered to the antenna. It is widely understood in electrical engineering that the following equation relates the power to the current and voltage of a system.

$$P = IV_A$$

Equation 3: Power Equation

The voltage parameter, V_A, is the voltage across the antenna element in the antenna model. This voltage can be derived using voltage division as follows:

$$V_A = V * \left(\frac{ZA}{ZA + ZS}\right)$$

Equation 4: Voltage Division

In addition, an expression can be derived for the current in the antenna from Ohm's Law, which relates the equivalent impedance and voltage with the current. This relationship is defined below.

$$I = \frac{V}{Z_{eq}}$$

Equation 5: Ohm's Law

Z_{eq} refers to the equivalent impedance, which can be found by simply adding the series connected impedances of the source and antenna. Thus, the following expression can be derived for the current in the antenna:

$$I = \frac{V}{ZA + ZS}$$

Equation 6: Antenna Current

Substituting Equation 4 and Equation 6 into Equation 3 yields an expression for the power delivered to the antenna, shown below.

$$P = V^2 * \frac{ZA}{(ZA + ZS)^2}$$

Equation 7: Power Delivered to the Antenna

A few observations can be gathered from Equation 7 regarding the characteristics of the antenna in the model. First, it can be seen that a very small antenna impedance, ZA, will result in a small amount of power being transferred to the antenna. In other words, as the impedance of the antenna approaches zero, the power delivered to the antenna also approaches zero. The same is true for the opposite scenario; if ZA is very large, very little power is delivered to the antenna. The nature of this equation proves that the impedance of the antenna and the source must be designed so that the maximum amount of power can be transferred to the antenna. It is widely known and accepted in the field of electrical engineering that the characteristic for maximum power transfer is as follows:

$$ZA = ZS^*$$

Equation 8: Maximum Power Transfer Condition

This condition states that the condition for maximum power transfer from the source to the load is dependent upon the imaginary components of the impedances being conjugate to one another. When ZA is conjugate to ZS, the reactances (the imaginary components of the impedances) are opposite in sign. The summed reactances in the denominator in Equation 7 result in the imaginary components cancelling each other, minimizing the value in the denominator. This condition results in maximum power transfer to the load antenna. Since maximum power transfer occurs when the equivalent impedance is a real value, the concept can be simplified to focus solely on real values for ZS and ZA.

An examination of an entirely real source impedance and an entirely real load impedance can be performed to demonstrate the characteristic for maximum power transfer. The following graph, produced using MATLAB, shows the transfer of power for different values of source and load resistance. In this model, the impedance of the voltage source is denoted as R_S and the source of the load is defined as R_L, which corresponds to the antenna impedance. In this simulation, the value for the source resistance was set at 50 ohms, a relatively standard value. An arbitrary value of 120 volts was assigned to the voltage source in order to illustrate the effect of impedance matching. In addition, the load resistance was evaluated in small increments from 0 ohms to 100 ohms to determine which value produced the highest transferred power. The transferred power shown on the graph was calculated using Equation 7.

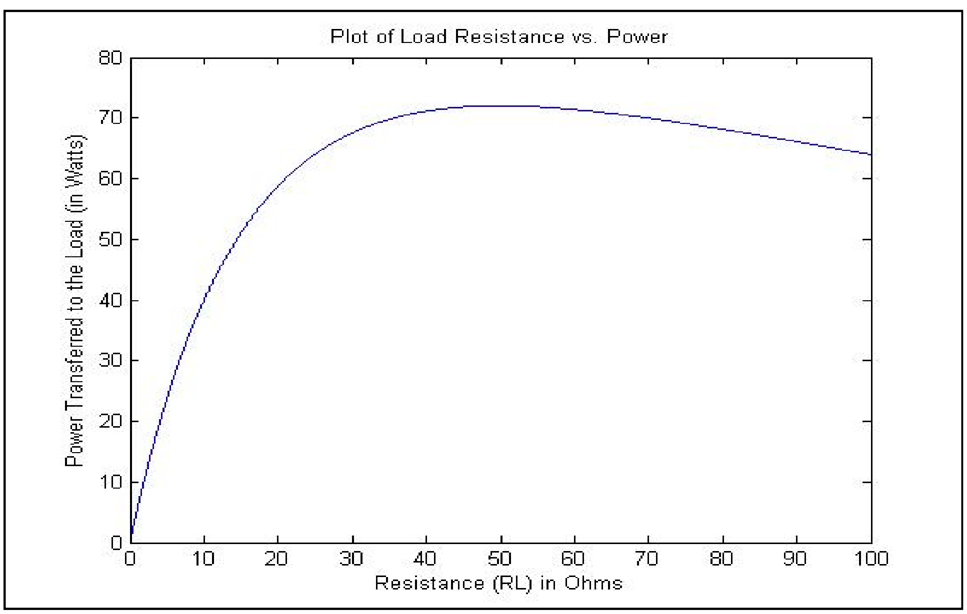

Figure 4: Plot of Load Resistance vs. Power (Graph Designed by the Author)

From Figure 4 it can be seen that the power delivered to the load reaches a maximum when RL is equal to 50 ohms. This confirms that the maximum power transfer occurs when the load resistance is equal to the source resistance. This concept extends to complex impedances that are conjugate to each other, confirming the condition stated in Equation 8. When the impedances are matched so that the maximum amount of power is transferred from the source to the antenna, the antenna performs at its highest potential. As the frequency shifts away from the designed operating frequency the impedance of the source and antenna shift as well, causing an impedance mismatch. As the impedances become less matched to each other, the power transferred to the antenna decreases, and thus the performance of the antenna drops. This principle states that there is a certain frequency range, known as the bandwidth, for which the antenna can perform adequately. The effect of an antenna's bandwidth can be illustrated by the following diagram:

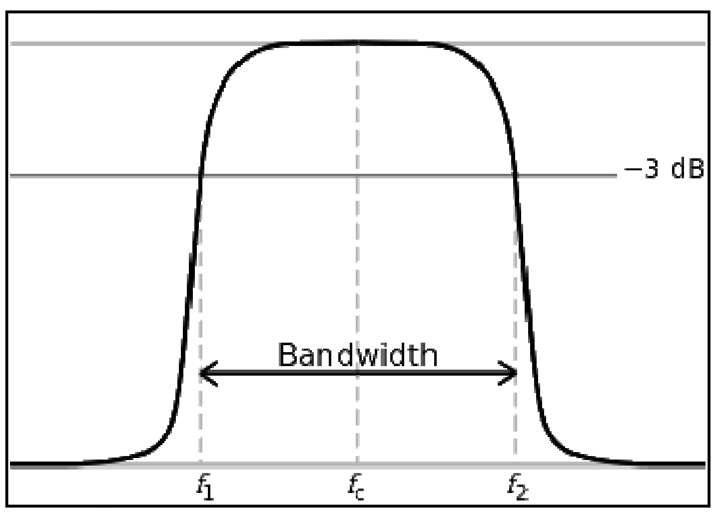

Figure 5: Bandwidth vs. Power (2007)
Source: http://commons.wikimedia.org/wiki/File:Bandwidth.svg

Figure 5 provides a visual representation of the relationship between operating frequency and delivered power. It can be seen in the figure that the bandwidth is from f_1 to f_2. The figure clearly shows that less power is transferred outside of the frequency range, and that the maximum power occurs at the center frequency, also known as the design frequency. These observations extend to the design of any antenna, as the design frequency will produce the highest level of performance. As the antenna begins to operate outside its bandwidth, the performance decreases dramatically. For these reasons consideration of desired antenna bandwidth as well as the quality of impedance matching is necessary when designing an antenna.

Patch Antenna Technology

Patch Antenna Fundamentals

Patch antennas are special types of radio antennas that feature a low-profile design that is ideal for implementation in mobile applications (Kuchar, 1996). These patch antennas are a special type of microstrip antenna, an antenna that is designed around printed circuit board technology. Microstrip refers to a special type of transmission line that can be printed using a circuit board printer. This technology is advantageous because it allows patch antennas to be manufactured very inexpensively. Patch antennas are typically mounted to flat surfaces, and feature a flat, rectangular shape (Kuchar, 1996). Patch antennas are useful because they are fairly simple to manufacture, they are relatively inexpensive to fabricate, and they are easy to modify after they are created. Figure 6, shown below, shows an assembled patch antenna.

Figure 6: Patch Antenna Example (2008)
Source:http://www.propagation.gatech.edu/ECE6390/project/Fall2008/Kuato/web/CommSys_RXAntenna.html

Patch antennas are constructed differently than a typical antenna due to their distinct applications. As mentioned above, patch antennas are typically rectangular in shape, and can vary in size based on the needs of the user or based on the application. These antennas are often implemented in mobile communications and cellular telephone applications (Civerolo, 2011). The patch antenna consists of a flat sheet of metal, known as the “patch”, and another large sheet of metal known as the “ground plane.” In the image above, the smaller rectangle is the patch and the large copper sheet serves as the ground plane. A typical patch antenna is constructed by placing a metal ground plate under a dielectric substrate, and then placing the micro-strip transmission line and patch antenna on top of that substrate (Civerolo, 2011). Figure 7, displayed on the following page, shows a side view of a standard patch antenna construction:

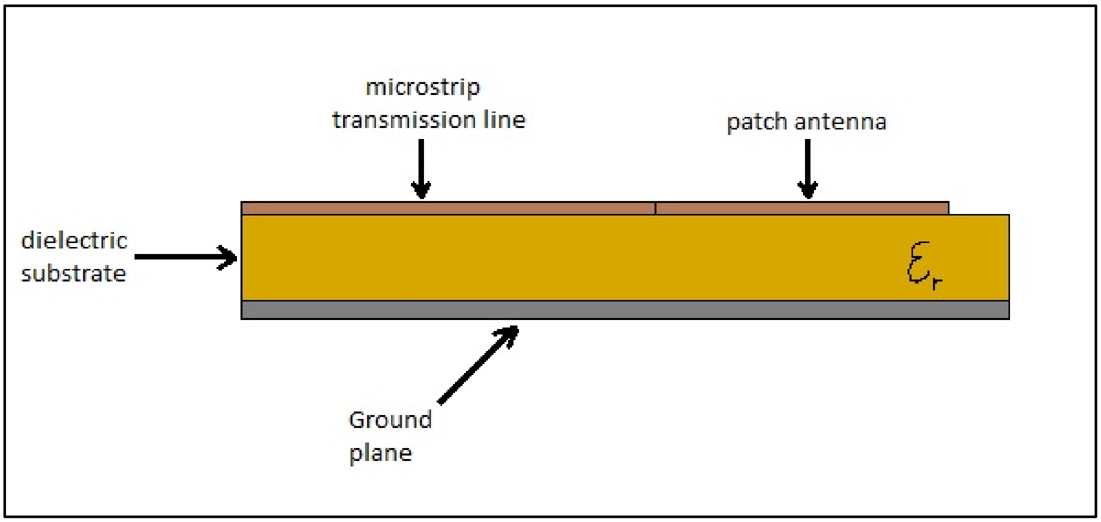

Figure 7: Typical Patch Antenna (Side View) (2014) Image adapted by the author from content at http://www.antenna-theory.com/antennas/patches/antenna.php

Figure 7 offers a representation of a very simply designed patch antenna. In this model a ground plane is separated from the patch antenna by a dielectric substrate. When a feed, or input voltage, is applied to the microstrip transmission line, electromagnetic fields propagate between the patch antenna and the ground plane within the dielectric substrate. These fields then radiate outward from the antenna to be picked up by a receiving antenna (Bevelacqua, 2010).

There are numerous types of patch antennas that can vary based on application, bandwidth, gain, and range. The performance of the antenna can be adjusted with varying methods of construction. The material that is used in the construction of the antenna can directly affect the antenna's performance, which must be considered by the designer. In addition, the layers and dimensions of the patch antenna can be adjusted based on design needs. An alternative patch antenna design is shown in Figure 8 below:

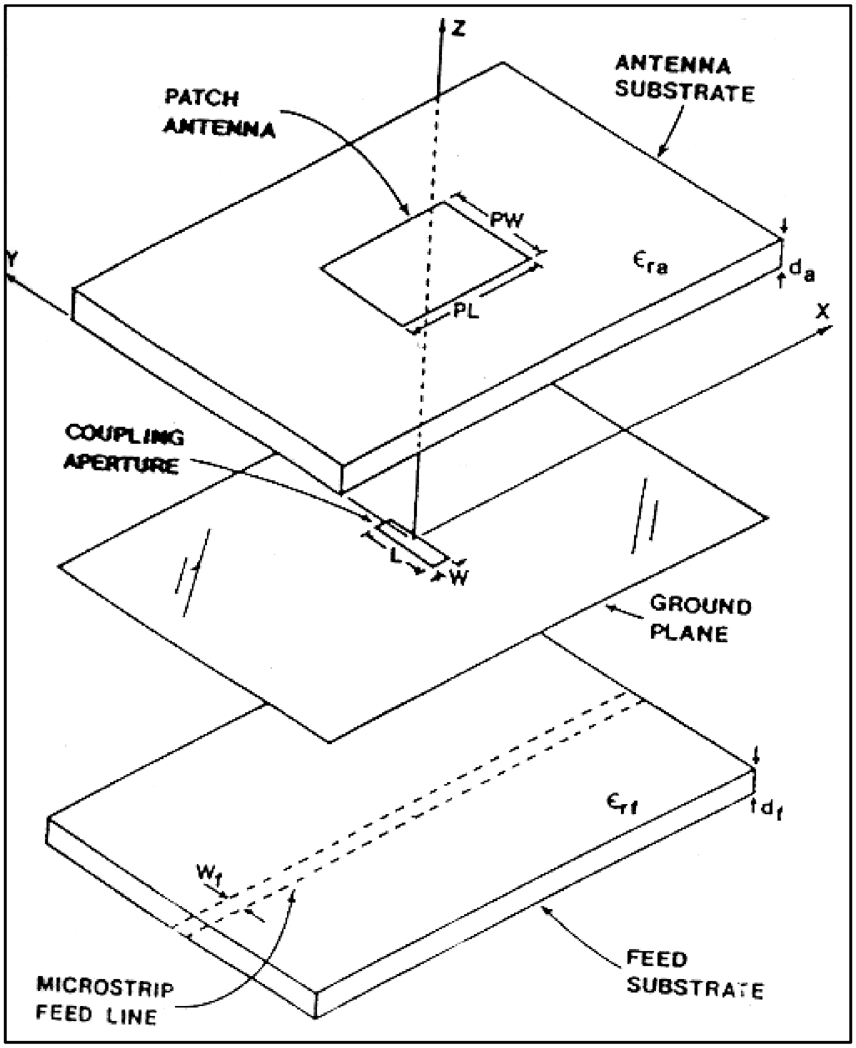

Figure 8: Alternative Patch Antenna Construction (Aperture-coupled) (n.d.) Source:http://eee.guc.edu.eg/Courses/Communications/COMM905%20Advanced%20Communication%20Lab/Sessions/Session%204.pdf

In Figure 8, the patch antenna is constructed similar to the one shown in Figure 7, with the exception that an additional layer of substrate is added on the bottom that contains the micro-strip feed line (Kuchar, 1996). This type of patch antenna is called an aperture-coupled antenna, which will be discussed in further detail in the following section. The center layer of the antenna shown in Figure 4 houses a coupling aperture, which will be also examined in the analysis of aperture-coupled antenna technology.

Each dimension of the patch antenna is related to a different parameter of the antenna's characteristics. The width of the patch antenna is directly related to the input impedance of the antenna. As the width increases, the input impedance decreases (Bevelacqua, 2010). Because the patch antenna dimensions relate to the way the antenna performs, several parameters must be considered in the beginning stages of antenna design due to their importance. For example, designing a patch antenna with a very low input impedance value usually results in a very wide antenna. This is often not a desirable trait because the antenna often times must be constrained to fit inside certain sized housings. Length also plays an important role in patch antenna design, as the antenna length directly relates to the frequency of operation (Bevelacqua, 2010). The equation that is shown below shows how the length of the antenna corresponds to the frequency in which the antenna can operate.

$$f_c \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0 \varepsilon_r \mu_0}}$$

Equation 9: Patch Antenna Frequency

An examination of this equation shows that the micro-strip antenna should be designed so that the length is equal to one half of the wavelength within the dielectric medium (Bevelacqua, 2010). The frequency of operation along with the required input impedance for the antenna must be considered because these parameters affect the overall size of the patch antenna.

Patch antennas are designed to function like any other antenna. They are able to receive and transmit electromagnetic energy through propagating waves. The method in which the power is transferred into electromagnetic wave radiation is slightly different in patch antennas than the typical ideal antenna model. In the ideal antenna model, energy is applied to the antenna and radiates from the top peak of the antenna. In the ideal model, the peak of the antenna is considered to be a point that allows for energy to radiate in every direction. The electromagnetic energy in the ideal antenna model radiates in an omnidirectional pattern. In patch antenna technology, electric and magnetic fields are created between the patch and the ground plane. The electric fields then combine with each other in phase to produce electromagnetic radiation from the micro-strip antenna (Bevelacqua, 2010). This results in a more directional pattern of electromagnetic radiation than the ideal model. The main difference between a standard wire antenna and a patch antenna is that patch antennas utilize voltage distribution to create electromagnetic radiation. In contrast, standard wire antennas radiate electromagnetic energy due to the summation of currents along the transmission line that composes the antenna. Figure 9, shown below, shows how electromagnetic fields gather between the patch and the ground plane on the antenna.

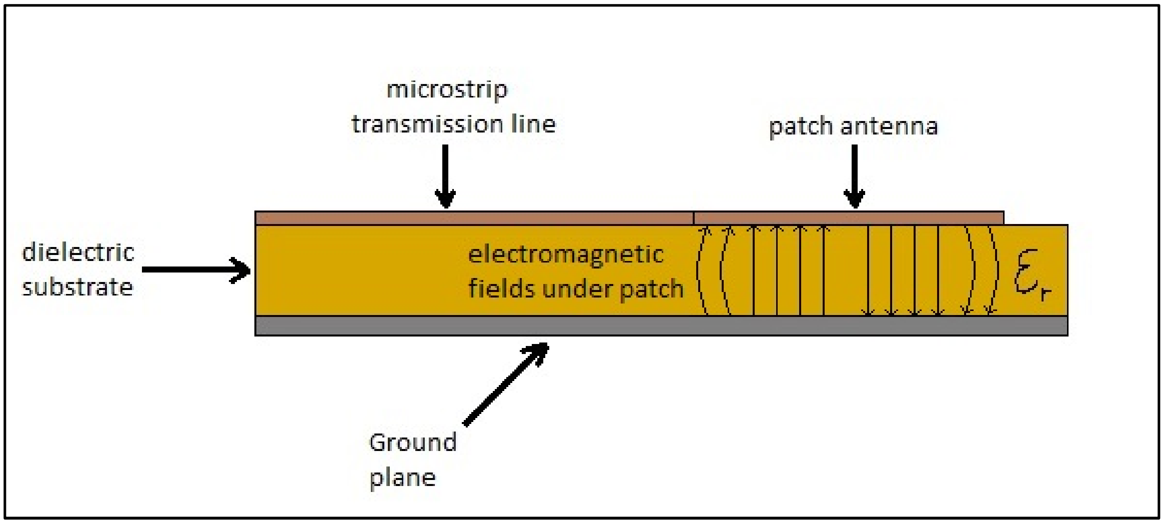

Figure 9: Fields inside a Patch Antenna (2014) Image adapted by the author from content at http://www.antenna-theory.com/antennas/patches/antenna.php

It is easy to see from the diagram that electromagnetic fields gather under the patch inside the dielectric. These fields combine to a point where they are able to radiate outward from the antenna, as they can no longer be contained within the dielectric. Depending on the design of the patch antenna, this radiation can be more direct than the spherical pattern produced in standard wire antenna applications (Bevelacqua, 2010).

Microstrip Patch Antenna Applications

Microstrip antennas have been implemented in several communications based industries because of their many benefits. The technology has been implemented in a variety of military, commercial, and private applications due to the ability to design and implement the antennas at low cost. One of the major reasons microstrip antennas are becoming more popular is their low-profile and compact design, which allows these antennas to be incorporated into a plethora of electronic devices. Microstrip antennas are utilized in several different industries because of the ability to design the antennas with different optimizations based on the desired application. To understand the many usages for microstrip antenna technology, three different industries will be examined in order to discover the potential for the technology. The military, commercial, and private applications of these antennas will be examined to provide a foundation for understanding the benefit of researching and developing microstrip antenna technology.

Microstrip patch antennas have been utilized in a variety of military applications. These antennas are often utilized in aircraft, radios, submarines, and land vehicles. Microstrip patch antennas are often incorporated into airplanes because of their slim and compact design. The small physical size of these antennas allows them to be implemented into the cockpit of an airplane without impeding other physical hardware. Microstrip patch antennas have more recently been utilized in unmanned aerial vehicles. In these applications the antenna allows the aircraft to receive signals from a user that is located on the ground many miles away. This application of patch antenna technology allows a user to control the aircraft without actually being on board. Unmanned aerial vehicles have become a key component in many branches of the military due to their ability to survey and attack enemy locations without the threat to human life. Microstrip antenna technology is a key component that makes it possible for the military to control these aircrafts from across vast distances.

In addition to their applications in unmanned aerial vehicle applications, patch antennas have often been incorporated inside military radios and submarines for communications purposes. Again, the small physical dimensions of these antennas allow them to be incorporated into communications devices without increasing the size of the equipment. The small physical size of microstrip antennas makes them ideal candidates for incorporation into submarines, radios, and other applications where space is limited. Microstrip antennas are implemented in military applications because they can be designed and sized based on the application while still providing adequate performance for the user.

In addition to their various usages in military applications, microstrip antennas are also widely used in the communications industry. As technology continues to become more sophisticated, electronic devices tend to get smaller in size. Thus, the desire is to design an antenna that requires less space and less power but still offers reliable performance. Microstrip antenna technology provides a bridge between performance and size for the communications industry. Cellular telephones, tablets, and laptop computers can incorporate microstrip patch antennas in their designs while still maintaining a slim profile. This is beneficial to electronics manufacturers because it allows for them to design products that perform well and are aesthetically appealing. The development of microstrip antenna technology has allowed the communications industry to grow rapidly because the antennas offer good performance, quality, and adaptability for the manufacturer.

As patch antennas have continued to make an impact in the military and communications industries, private applications for the technology have become prominent as well. Individuals with an interest in antenna theory and construction can design, build, and test their own microstrip patch antenna with supplies from an electronics store and a microstrip printer. The ability to design and create a patch antenna at home has allowed enthusiasts to incorporate the technology into private applications. The ability for an individual to be able to design, construct, and implement a patch antenna at a low cost is another reason that microstrip antennas continue to be a promising technology.

Microstrip antenna technology has seen a dramatic increase in sophistication due to its applications in the military, communications, and private industries. While the specific implementations of these antennas may differ in each application, the main benefits remain the same. The small size, ease of design and construction, low cost, and adaptability are clear benefits of the technology to be considered in evaluation.

Aperture-coupled Antenna Technology

Introduction to Aperture-coupled Antenna Technology

The assessment of aperture-coupled antenna technology is aided by establishing a background in antenna theory and patch antenna design and function. Once these two foundational principles are understood, a thorough assessment of the aperture-coupled antennas can be conducted. In this assessment of aperture-coupled antenna technology, basic functions, drawbacks, and benefits will be examined to draw conclusions as to whether or not the field of aperture-coupled antenna technology is worth pursuing. Since this technology is already over twenty five years old, it can be assumed from the start of this assessment that there is some merit in using this technology. As discussed above, there are apparent trade-offs that must take place when designing patch antennas. It is reasonable to hypothesize that similar trade-offs will be encountered when assessing the benefits and drawbacks of aperture-coupled antenna technology. The overall hypothesis that can be developed simply from the knowledge of antenna theory and patch antenna design is that aperture-coupled antenna technology is worth pursuing. Conclusions will be drawn in order to confirm or disprove this hypothesis through research and development the positive and negative aspects of aperture-coupled antennas.

Basic Design and Function of Aperture-coupled Antennas

Aperture-coupled antennas are a special type of patch antenna. They are constructed similarly to the standard patch antenna; however there is an electromagnetic coupling effect present due to a small aperture in the ground plane (Civerolo, 2011). The aperture-coupled antenna shown in Figure 10 (shown again below) consists of two dielectric substrates separated by a ground plane with a coupling aperture.

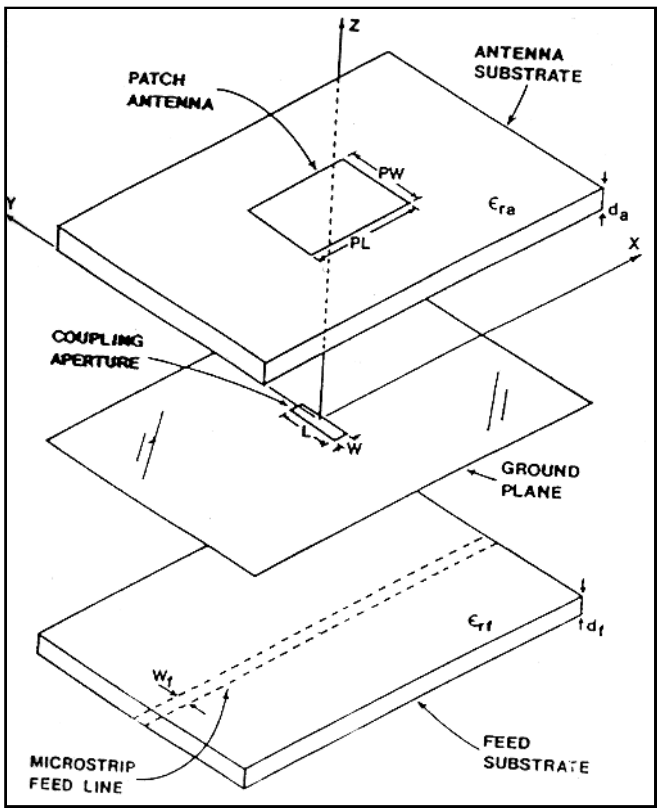

Figure 10: Alternative Patch Antenna Construction (Aperture-coupled) (n.d.) Source:http://eee.guc.edu.eg/Courses/Communications/COMM905%20Advanced%20Communication%20Lab/Sessions/Session%204.pdf

Figure 10 shows the typical aperture-coupled antenna model. In this model, the micro-strip feed line is in the bottom substrate and the antenna is in the top substrate. The separation of these two components in their own substrates allows the feed and antenna to be designed separately, and thus optimized based on application (Bhargava, 2010). These two substrates are separated by a metal ground plane that contains a coupling aperture. The incorporation of a coupling aperture brings about another set of design constraints, which will be discussed in the coming sections dealing with the analysis of benefits and drawbacks of aperture-coupled antenna technology.

There are several parameters that can affect the performance of an aperture-coupled antenna including the thickness of the substrates, the dielectric constant of each substrate, the patch length, the patch width, and the length and width of the aperture. In aperture-coupled antenna design, the coupling aperture is actually a “slot” that is designed based on the reaction of the antenna to the slot’s width and length. The overall size of the aperture affects the coupling level of the antenna (Bhargava, 2010). The basic function of the aperture, or slot, is to couple the energy from the micro-strip feed line to the patch.

Patch Antenna Aperture Feed Technique

Numerous feed methods have been developed to supply patch antennas with the power necessary to radiate electromagnetic energy. Some of these feed techniques include inset feeding, coaxial cable (probe) feeding, indirect (coupled) feeding, and aperture-coupled feeding. A brief examination of the aperture feeding technique is valuable in understanding some of the benefits and drawbacks of the use of aperture-coupled patch antennas. To begin the assessment of the aperture feeding technique an examination of how an aperture-fed antenna is constructed is considered. Figure 11 shown below offers a visual representation of an aperture-fed patch antenna.

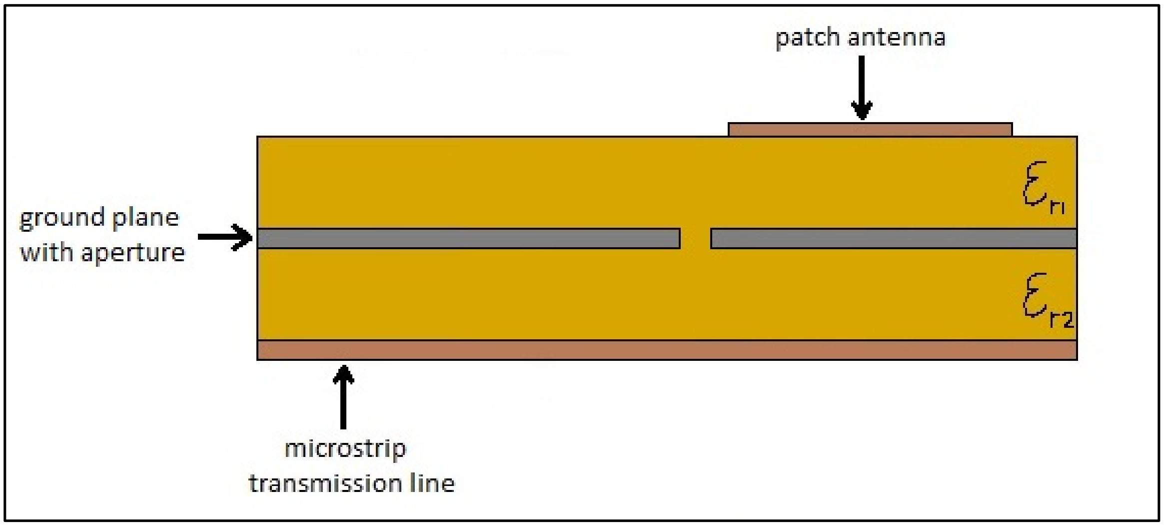

Figure 11: Aperture-fed Antenna Construction (Side View) (2014) Image adapted by the author from content at http://www.antenna-theory.com/antennas/patches/antenna.php

In Figure 11 the transmission line carrying the power for the antenna is separated from the patch antenna by two dielectric substrates and a conductive ground plane. The presence of a conductive ground plane between the feed and the patch antenna forces the electromagnetic radiation to travel through the dielectric substrate. This allows the energy from the transmission line to be “directed” to the patch antenna without physically connecting the two conductors to one another. The concept of transmitting energy from the transmission line to the patch antenna without a physical connection of the conductors is known as “coupling.” A hole exists in the ground plane to allow the electromagnetic energy to pass through the dielectric substrate into the antenna. Because there are two separate layers of dielectric substrate in this construction, each with a different permittivity value, the electromagnetic energy can be directed so that the radiation from the patch antenna is maximized. The lower level of substrate is typically constructed using a dielectric with a very high permittivity, which allows for the electromagnetic fields in the lower level to be tightly grouped together. When the fields are tightly grouped under the aperture, more electromagnetic energy is able to pass through the hole in the ground plane into the second layer of substrate. A high permittivity value in the lower substrate typically eliminates the potential losses due to the spread of electromagnetic energy into the ground plane. In contrast to the lower level, the upper level of dielectric substrate typically features a much lower permittivity value, allowing the electromagnetic fields to be loosely grouped inside the second layer of dielectric material. The loose grouping of the electromagnetic fields in the upper level of substrate promotes increased radiation from the patch antenna, which in turn increases the microstrip antenna's overall performance.

Developing and understanding of how aperture-fed antennas are constructed helps uncover some of the benefits of aperture-coupled antenna technology. The ability to independently design the feed and the patch antenna is a benefit that will be discussed further in the upcoming sections.

Analysis of Benefits and Drawbacks

The same design principles apply to aperture-coupled antennas that apply to all patch antennas. The width of the micro-strip antenna directly corresponds to the input impedance of the antenna. While it is often desirable to design antennas to small input impedances, such as 50 ohms, it is not always feasible based on size constraints. Thus, like patch antennas, aperture-coupled antennas must be carefully designed so that they meet the needs of the application. The addition of an aperture in patch antenna design creates added design constraints. One of the drawbacks of using aperture-coupled antenna technology is the existence of added constraints in the patch antenna design. Additional constraints and changing parameters are never ideal in design because they often generate tradeoffs between performance and utility (Bevelacqua, 2010). The presence of the additional substrate and the coupling aperture in aperture-coupled antennas requires the antenna to meet even more design criteria than a typical patch antenna. Instead of only having to design one type of dielectric the designer must design two layers consisting of different dielectric. This characteristic of aperture-coupled antennas results in a longer and more complicated design process than a standard patch antenna. This drawback, while not desirable, is not detrimental to the overall usefulness of the technology.

A second drawback in aperture-coupled antenna technology is the increased antenna size that results from the incorporation of another layer of substrate in the antenna construction. This property of aperture-coupled antennas can be both a drawback and a positive aspect of the technology. While the additional substrate allows the feed and the patch antenna to be designed and optimized separately, there is often an additional physical width present when incorporating two different dielectric substrates in the antenna's construction. The addition of another layer of substrate often results in a thicker antenna because more dielectric material is present when compared to a basic patch antenna. This is another example of tradeoff in design, as the designer must decide whether it is more important to optimize the antenna and feed parameters separately, or to design the patch antenna around size constraints. As stated previously, one of the overall benefits of patch antennas is their ability to be incorporated into small devices. Additional size is not usually desirable in today's technology, thus the presence of the additional substrate is often undesired as well.

In addition to the drawbacks of the aperture-coupled antenna, there are also several advantages to the technology that are not present in typical patch antenna designs.

As stated above, the use of aperture coupling and the presence of an additional substrate allow the antenna to be designed separately from the feed. This in turn implies that aperture-coupled antennas can be incorporated into a variety of applications when size is not an issue, because these antennas can conform to the voltage and power supplies in different devices without adjusting the antenna properties. This is a very useful application in the field of communications because aperture coupling can be utilized to adapt the same antenna to several different devices.

Another benefit of aperture coupling in patch antenna design is that the radiation pattern produced by the antenna is often more symmetric. This is an extremely beneficial characteristic of aperture-coupled antennas, as symmetrically radiating electromagnetic waves are much easier for receiving antennas to capture. The more symmetric the electromagnetic radiating waves, the better the pattern of radiation can be predicted and thus captured by a receiving antenna. This is an extremely important advantage of aperture coupling because it allows the antenna portion of the design to be extremely accurate and reliable. In addition to a more symmetric pattern of radiation, aperture-coupled antennas reduce the radiation from the transmission line feed, which maximizes the radiation from the antenna. This is important because it eliminates interference and conflicting radiation between the feed and antenna substrates.

Another more obvious benefit of aperture-coupled antennas is their ability to be mounted in low profile applications. The flat and rectangular nature of aperture-coupled antennas is ideal for incorporation into mobile devices, wireless routers, and other types of communications technology. Because the aperture-coupled patch antennas are small in nature, they are very low cost to produce. In today’s technology market cost is an obvious factor in every decision and design. Aperture-coupled antennas are inexpensive to produce, easy to modify, and can be incorporated into many different applications. These factors make aperture-coupled antennas suitable for use in many electrical devices.

Conclusion

While there are numerous drawbacks and benefits to using aperture-coupled antennas, it is clear that the benefits are far more significant than the drawbacks. The varieties of applications that exist for aperture-coupled antennas in conjunction with the adaptability of design make these antennas ideal for implementation in mobile communications applications. In addition to the various applications of aperture-coupled antennas, the antennas are also extremely cost effective. The low cost for the manufacturing of these aperture-coupled antennas is a large reason that implementing patch antennas is worthwhile. The ability to design aperture-coupled antennas to different applications, the low cost of manufacturing these antennas, and the small physical size of the antennas make them ideal for implementation in the field of communications. Thus, it can be concluded that the hypothesis outlined above is confirmed, aperture-coupled antenna technology is certainly worth pursuing.

In assessing the field of aperture-coupled antenna technology, it is helpful to develop an understanding of antenna theory and patch antenna design before determining the effectiveness of aperture coupling. Antenna theory provides a foundational understanding for why patch antennas and aperture coupling exist. The utilization of antennas to transmit and receive electromagnetic waves allows the devices to be implemented in a variety of industries, primarily in the field of communications. Patch antennas, a special type of antenna that features a low-profile rectangular design, are useful in mobile electronics because they are inexpensive to produce, easy to manufacture, and can fit inside small spaces based on the application. Aperture coupling is a technique used to create a more modular patch antenna because it allows the antenna and feed to be designed separately, thus increasing the antennas overall performance. The aperture-coupled antenna is a suitable technology to research and develop because of its vast amount of applications, low production cost, and modularity.

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