Techniques of Electromagnetic Cloaking

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***Abstract* -** Electromagnetic cloaking is a method that can cause objects, fighter planes or objects, to be partially or fully invisible to electromagnetic spectrum by guiding the incident waves around them without being affected by the object itself. However, over the whole spectrum, the cloaked device scatters more than electromagnetically cloaked device. In this paper, we discuss the various kinds of ways available hide an object electromagnetically.

INTRODUCTION

Radar (**RA**dio **D**etection **A**nd **R**anging) is an object detection devices that determines the angle, position and velocity of an object using radio waves. It can be used to detect aircraft, spaceships, missiles etc.

It was developed at the time of World War II. Radar has a transmitter that emits radio waves in predefined directions called radio waves. When these waves come into contact with an object with materials with electrical conductivity, seawater or wet grounds they reflect and scatter in many directions. These reflected waves are captured back receiving antenna which determines the position of the object. If the object is in motion then there is a slight change in frequency due to Doppler's effect. The received signal being very weak is passed through an amplifier.

The scattering of radio waves depends on the wavelength of the wave and the size of the target. If the wavelength is shorter than the target size, the wave will get reflected from the target. But if the wavelength is on shorter than the target size, the target may not be visible.

So Invisibility aims to cancel the scattering of the electromagnetic waves from the object by placing a cover (cloak) that makes is undetectable from electromagnetic sensors.

In this paper, we discuss different ways to electromagnetically hide objects, i.e. make it invisible from the radar. We tried to explain some the techniques mentioned below in further parts of the report:

1. Transformation-based cloaking
2. Transmission-line networks
3. Scattering cancellation approach
4. Parallel-plate cloaking
5. Active cloaking

ELECTROMAGNETIC CLOAKING TECHNIQUES

1. TRANSFORMATION-BASED CLOAKING

In this method we manipulate the electromagnetic energy flow using a transformation that alters the coordinate grid in space as referred Fig 1.

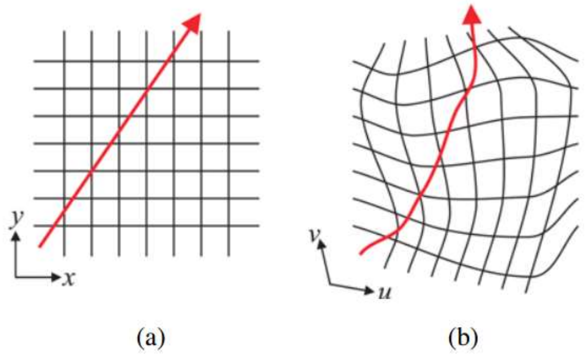
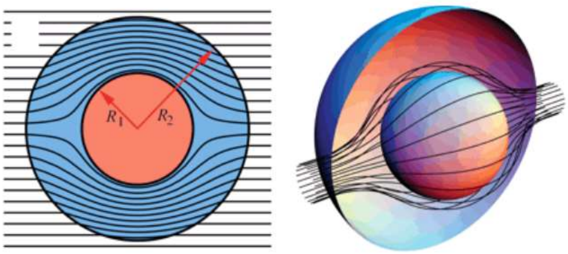


Figure 1. Illustration of the light manipulation possibilities offered by transformation optics. ©2006 AAAS. Reprinted with permission [57].

'a' part of the above figure represent a straight red arrow signifying the Poynting vector in homogeneous material. By the deformation caused in the Cartesian plane the bending of the ray of light can be controlled, as speculated in Fermet's principle. The electromagnetic propagation in deformed coordinate system can be re-interpreted as in the original system with varying distribution of permittivity and permeability because the Maxwell's equations are form-invariant under a coordinate transformation. In this in homogeneity and anisotropy helps in practically creating any coordinate transformation in space by giving the control of permittivity and permeability. Therefore it may lead to forcing the light to follow curved coordinates and making the object invisible.

A spherical transformation cloak has been achieved by using a transformation that a spherical region of radius R2 and confides all the deformed electromagnetic waves between R1 and R2, making the spherical region of radius R1 isolated from external fields.
Therefore the propagation of electromagnetic waves near the object can be pictured as in distorted coordinate system i.e. having a curved space with a hole. Similarly, we could use these to realize a 3D cylindrical cloak in which the power flow is deviated and re-routed from around the object or any specific volume which needs to electromagnetically cloak from the rest of the world. One problem with using the transformation is that it’s singular, i.e. transforms a point to a finite area, therefore the central ray does not know where to go. The behavior of ray is undetermined. The only way to ensure the electromagnetic cloaking is to solve the Maxwell’s equations.



(a) (b)

Figure 2. Principle of operation of transformation-based spherical cloaks. ©2006 AAAS. Reprinted with permission [57].

2. TRANSMISSION-LINE NETWORKS

Another way to hide the object from electromagnetic waves is by transmission-line networks. This technique of cloaking is illustrated in **Figure below.**

The main objective is to make the incident waves pass through a transmission line network that is tailored to have very low scattering cross-section. Therefore, inside the fishnet formed by the network, there is no virtual field and this method can hide any object inside it. Because no power is required to go around the object, superluminal propagation is not in principle required. Thus, the method is inherently is suitable and used for cloaking from short signals

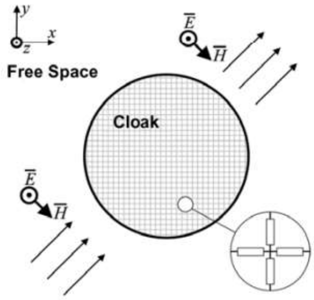


Figure Principle of cloaking using transmission-line networks. The incident wave is squeezed into a transmission line network that is specially designed to have very low scattering. Any object that fit in between the lines of the network is not traversed by the incident wave, and does not scatter. ©2008 IEEE. Reprinted with permission, from IEEE Transactions on Antennas and Propagation [166].

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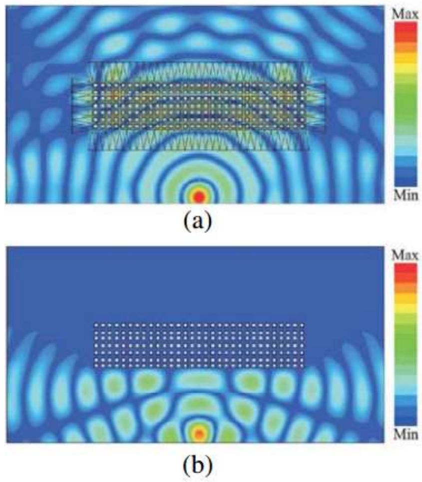


Figure (a) A transmission-line network cloak renders an array of rods invisible. (b) Without it, the object would be almost opaque. ©2008 IEEE. Reprinted with permission, from IEEE Transactions on Antennas and Propagation [165].

The main drawback of this technique is that the cloaked object is required to fit between the network lines, therefore only the objects which geometrically complement the network or our very small can be hidden electromagnetically. An example showing the operation of a transmission-line network cloak is given in **Figure above**.

3. SCATTERING CANCELLATION APPROACH

This technique cancels out only dominant scattering terms in the scattered field instead of totally cancelling the scattered fields from a

given space. The residual scattering is controlled as it relies on non-resonant approach for cancellation. The cloaks can be easily realised and experimentally verified more easily because of fewer constraints. The design is based on homogeneous and isotropic materials.
These cloaks can't be generalised and are made to hide a particular object. That is it may not work for all objects. This isn't major drawback; we only need to hide a reflecting object surface with a cloak of desired shape which protects its interiors to any electromagnetic wave. Flexibility in tailoring the clock is more desirable when it comes to tailoring the cloak as it leads to better robustness and broader bandwidths for penetrable objects. These cancellation techniques can't be used when the object's size are large when compared with the wavelength because of the increase in dominant scattering harmonics which leads to increasing the number of layers in cloak and complexity of the design.
Scattering cancellation technique can be implemented in Plasmonic cloaking which uses cloaks and shells made of homogenous and isotropic materials. The term came because of the below unity permittivity of materials with plasma like dispersion to cloak most objects. Natural plasmonic materials like metals are used to implement plasmonic cloaking. In the absence of natural plasmonic materials, it could be implemented using metamaterials. It is used in optical, infrared and microwave frequencies range.
Another technique which implements the scattering cancellation technique is the mantle cloaking technique. It has a different approach as compared to plasmonic cloaking by using ultrathin isotropic frequency selective surface instead of homogeneous isotropic layer. The dominant scattering from the object is cancelled by the surface impedance of the mantle cloak. This method leads to ultrathin, light weight and conformal designs, and it tends to provide broader bandwidths. The only difference that comes is this method while calculating the scattering coefficients is the boundary condition of the surface.

4. PARALLEL-PLATE CLOAKING

Parallel-plate cloaking also aims to guide the electromagnetic energy around the object by the use of cloak made of parallel metallic fins with decreasing separation. It is similar to the transformation cloak but does not use coordinate transformation. The basic theme of this technique is that the parallel perfectly conduction sheet perpendicular to the electric field does not affect the propagation of electromagnetic waves regardless of the distance between sheets. We can prevent the electromagnetic energy from reaching the centre of the cloak by increasing the thickness of parallel plates until they are in contact. Therefore, in the centre, the object is hidden as the energy prefers to go around the concealed object. Fig. below, shows the electric field distribution around the cloak (a) as well as the Poynting vector (b).

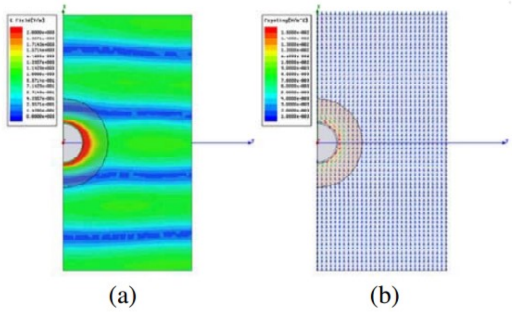
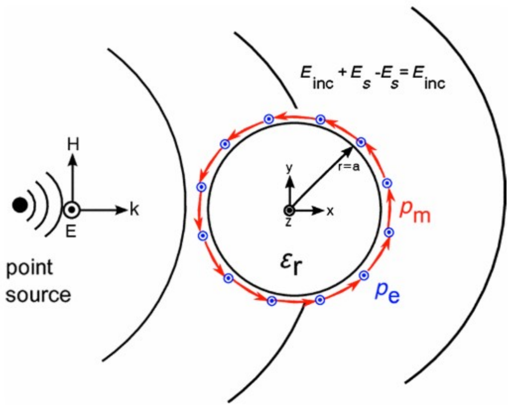


Figure Numerical simulations for a parallel plate cloak. (a) Electric field and (b) Poynting vector. ©2009 APS. Reprinted with permission [170].

5. ACTIVE CLOAKING

In above mentioned passive cloaking techniques there is always a trade-off between the bandwidth and total scattering reduction because of factors like linearity, causality, and passivity. There is always an increase in the scattering when integrated over the entire frequency spectrum accompanies the reduction at a particular frequency. But the limitations of active are less restricted when compared with the passive system with respect to bandwidth.
In Active cloaking sensors and sources are used to make any object invisible. An active interior cloak does this by placing the sources along the boundary of the object. The idea of this method is based on the concept leaving the interior fields unchanged and modifying the scattered fields. This was achieved by imposing appropriate orthogonal electric and magnetic currents around a scatterer (object).
These sources must radiate a field that cancels out the scattered field, leaving the incident field only.To determine the properties of these sources, their function can be interpreted as

imposing a discontinuity in the electromagnetic field at the boundary. By this, we mean that since the tangential incident and scattered electromagnetic fields outside the cylinder are continuous with the fields inside the cylinder across the boundary of the object, any other field existing either inside or outside the cylinder would create a discontinuity. This discontinuity must be supported by corresponding electric and magnetic currents. Thus, in the case of a cloak where one would like to cancel the scattered field outside the cylinder, these electric and magnetic currents are given by the negative of the tangential scattered field at the surface of the cylinder. Since, in all the calculations assume that we have prior information about the field that is going to incident on the object. However, this is not always the case. So, we can develop some approximation of the fields to set different parameters of the active cloak.



CONCLUSION

In this paper, we have studied and presented various methods to hide an object electromagnetically. There are various applications of hiding an object electromagnetically, eg. In Navy, Air force etc. Any method proposed here can be used depending on the purpose.

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