Chapter 6

Hard Ferrites for High Frequency Antenna Applications

Asha Kumari, Rahul Sharma*

Career Point University, Vill: Tikker-Kharwarian, Tehsil Bhoranj, Distt. Hamirpur, Himachal Pradesh, India 176041
*rsharma8886@gmail.com

Abstract

Advances in wireless communication place an increasing number of demands on antenna performance, necessitating the presence of various capabilities in a single device. Reconfigurable antennas are frequently utilized to meet these various application demands within a restricted area. The purpose of this book chapter is to summarize general introduction about hard ferrites, different synthesis methods of ferrite for antenna application and altering functioning of antenna by reconfiguring them by ferrites. Along with this we have also focused on miniaturization and reconfiguration of antennas which is becoming a very important aspect of wireless communication devices. Miniaturization and reconfiguration of antennas involves a deliberate alteration in the form and/or electrical behaviour of the antenna, leading in a change in the antenna's functioning.

Keywords

Miniaturization, Hard Ferrites, Reconfiguration, Electrical Behaviour, Hard Ferrites

Contents

Hard Ferrites for High Frequency Antenna Applications..............................152
1. Introduction.....................................................................................................153
   1.1 Ferrites for antenna application...............................................................154
2. Synthesis of hard ferries for antenna applications.................................159
   2.1 Various synthesis methods .................................................................159
   2.1.1 Ceramic powder milling method...................................................159

152
An Introduction to Hard Ferrites: From Fundamentals to Practical Applications

2.1.2 Reaction in solid state method ........................................................................................................160
2.1.3 Chemical coprecipitation method .....................................................................................................160
2.1.4 Sol gel synthesis method ..................................................................................................................161
2.1.5 Temperature specific combustion synthesis ......................................................................................161
2.1.6 Hydrothermal synthesis method .......................................................................................................162
2.1.7 Wet chemical method .......................................................................................................................162
2.1.8 Microemulsions method ...................................................................................................................163

3. Different compositions of hard ferrites for antenna applications ......................................................163

4. Factors affecting the performance of antenna ......................................................................................173
   4.1 Size ....................................................................................................................................................173
   4.2 Losses in dielectric material ...............................................................................................................173
   4.3 The loss in propagation .....................................................................................................................173
   4.4 Return loss .......................................................................................................................................174
   4.5 Radiation efficiency ...........................................................................................................................175

5. Artificial materials to improve efficiency ..............................................................................................175
   5.1 Use of substrate integrated waveguide (SIW) to reduce loss ............................................................176

6. Future prospects of antenna ..................................................................................................................177

Conclusion ..................................................................................................................................................177
References ..................................................................................................................................................178

1. Introduction

Antennas are anticipated to have varied performances and features depending on the application. One of the most essential characteristics to examine is efficiency, and efficiency is directly determined by losses. There are several elements that impact the performance of various types of antennas operating in various frequency bands. The mismatch loss and antenna size, for example, affect performance in the (High frequency) HF band (3 MHz-30 MHz). The dielectric loss of the substrate material is one of the most critical variables in the microwave frequency range, aside from mismatch loss. In the millimetre wave frequency spectrum, however, when all of the sub-antennas are perfectly matched, the loss in the feeding network is the component that limits antenna gain and efficiency.
Different strategies and methods are studied to increase the performances, taking into account diverse influencing variables. To begin, small and effective ferrites are chosen to increase the HF antennas' performance. To increase the performance of the HF antenna, effective ways of utilising ferrites are presented. The ferrites may be placed effectively and efficiently in locations with high current density by analysing the current in the ground plane of the antenna, reducing the effect of image current. Furthermore, by using ferrite loadings, the antenna's bandwidth is considerably enhanced while the antenna's size is reduced.

The frequently utilized high-loss material is the major factor influencing the antenna's efficiency for microstrip antennas that function in the microwave band. It's a commercial technique for putting planar periodic structures in the ground plane or on the patch. The antenna's used power is lowered, and the antenna's bandwidth is enhanced, thanks to periodic features in the ground plane. The periodic structures can operate in the same way as the patch when the planar structures are positioned regularly on it. From the slots in the patch, more energy may be emitted. The resonant frequencies can be found by examining the dispersion relationship. The antenna's bandwidth is substantially improved by using periodic features in the patch.

The loss in the millimetre wave antenna's feeding network results in a small number of antenna components in an array, limiting the array's gain. Instead of using a standard microstrip line, a low-loss transmission technique called substrate integrated waveguide is proposed for the feed network. Furthermore, the antenna array's shape is simplified. The antenna array's losses have been considerably reduced. As a result, the antenna array's gain is enhanced. Varied antenna optimization approaches are necessary due to the different frequency bands. The modelling findings are compared to the measurement data for the high-performance antennas. The antennas have great performance, efficiency, and are compact in size.

1.1 Ferrites for antenna application

Different types of antennas operating in various frequency bands have better performance. There have been a number of noteworthy contributions. Using commercial ferrite tiles substantially improves the performance of HF antennas. The mutual resistance of the antenna is studied using the image current theory. The ferrite is utilised successfully to decrease the influence of the picture current by evaluating the strength and dispersion of the image current. Commercial ferrite is also utilised to lower the antenna's height. The lower bound of bandwidth is increased by loading the ferrites, and HF antenna downsizing is achieved. The microwave antenna's performance is increased by etching periodic features.
The efficiency and bandwidth of the patch antenna are enhanced while the antenna size is reduced by etching the features in the ground plane. More energy may be emitted into free space and the bandwidth is improved by employing periodic structures as the patch. The size of the HF antenna is enormous due to the large wavelength of the HF band. As a result, it is preferable to minimise the HF antenna's size. However, by reducing the antenna's size, the antenna's efficiency is also diminished. The platform is positioned in relation to the lower bound of the HF band's wavelength. The effective size of the antenna is increased by activating partial or entire size of the platform, resulting in enhanced effectiveness at lower frequencies. However, the platform's geometry and size have a significant impact on the design's performance. This approach is not applicable to all antennas and platforms.

The antenna is based on a folded dipole that is electrically tiny. The antenna's efficiency is improved by connecting two dipoles with an 180° phase shifter. The balanced dipole antenna, like other horizontal polarised antennas, must be set high enough to function. To decrease mismatch loss and enhance efficiency at lower frequencies, commercial ferrites are utilised to cover the whole ground plane. The huge number of commercial ferrites, on the other hand, raises the total weight and price. The antenna's major source of energy is magnetic. By utilising ferrites to lower the amount of energy held in the antenna, more energy may be radiated out, increasing the antenna's overall efficiency.

The discovery of stones that would attract iron began the history of ferrite materials in different years before the advent of Christ. The minerals magnetite were called after the region of Magnesia in Asia Minor, where vast quantities of these stones were discovered (Fe₃O₄). The first usage of magnetite was in the form of "Loadstones," which were used by early navigators to determine magnetic north [1]. William Gilbert published the first scientific study on De magnete magnetism around 1600 [2]. Hans Christian Oersted proved in 1819 that an electric current in a wire influences the needle of a magnetic compass, a discovery that was later refined by other scientists and led to further discoveries in the subject of electromagnetism. Ferrite is derived from the Latin word ferrum, which means iron. Ferrites are now a homogenous ceramic substance made up of different oxides with iron oxide as the primary ingredient. Yogoro Kato and Takeshi Takei of Tokyo Institute of Technology published the first ferrite compound in 1930 [3].

Soft and hard ferrites are divided into two groups depending on their magnetic coercivity and resistance to demagnetization [4]. Soft ferrite, such as zinc, cobalt, nickel, manganese, and magnesium ferrites, do not keep their magnetic after being magnetised, but hard ferrites, also known as permanent magnets, may maintain their magnetism after being magnetised. However, in the majority of ferrites study, scientists categorise ferrites based on their crystal structure. Ferrites are divided into four categories: Spinal ferrites, garnet ferrites, hexa ferrites, and orthoferrites. Spinal ferrites, also known as FeO.Fe₂O₃, are a
kind of naturally occurring ferrite. Mineral spinal (MgAl$_2$O$_4$ or MgO.Al$_2$O$_3$) crystallises in the cubic system, resulting in the spinal structure [5]. Braggs [6] and Nishikawa [7] were the first to discover this crystal structure. MeO.Fe$_2$O$_3$ or MeFe$_2$O$_4$ is the general formula, where Me is a divalent metal ion.

Garnet ferrites are ferrites that can hold a big trivalent rare earth with a lot of magnetic moments. The structure of the silicate mineral garnet is shown through garnet ferrites. Similar to natural garnet, magnetic garnet crystallises in a dodecahedral or 12-sided shape. Me$_3$Fe$_5$O$_{12}$ is the general formula. Hexagonal ferrites class of magnetic oxide suggest magnetoplumbite structure which comes from the mineral of the same name. Hexagonal ferrites are defined by MeFe$_{12}$O$_{19}$ where Me is usually Ba,Sr or Pb Orthoferrites are also known as Perovskites. The formula if RFeO$_3$ where R is yttrium or rare earth ion [8]. These are also cubic ferrites with slightly distorted structure. Fig.1 describing classification of ferrites based on crystal structure and magnetic properties.

<table>
<thead>
<tr>
<th>Classification based on Crystal Structure</th>
<th>Classification Based on Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Spinal Ferrites</td>
<td>➢ Soft Ferrites</td>
</tr>
<tr>
<td>➢ Hexagonal Ferrites</td>
<td>➢ Hard Ferrites</td>
</tr>
<tr>
<td>➢ Garnet Ferrites</td>
<td></td>
</tr>
<tr>
<td>➢ Ortho ferrites</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 1. Classification of ferrites based on crystal structure and magnetic properties.*

With the fast growth of mobile communication networks, numerous services for mobile phone apps have become necessary and, as a result, realised. Antennas have been miniaturised as a result of miniaturisation and high-efficiency trends. With merely a circuit application, these antenna gains were restricted.

A variety of techniques have been used to miniaturise antennas, including meander lines or slots, dielectric loading, and so on [9]. The antenna's size is reduced, resulting in a reduction in bandwidth. The use of meander lines or slots to reduce antenna size reduces antenna performance such as bandwidth and efficiency. The dielectric loading approach
reduces antenna performance and hence restricts permittivity growth. To reduce antenna gain, a thick dielectric substrate either boosts surface wave energy or stores it within itself. Magneto-dielectric materials provide hope for overcoming the basic constraints of electrically tiny antennas. Relative permittivity (ε) and relative permeability (μ) are connected to the electrical wavelength, size, and bandwidth of an antenna [10]. An antenna's operational frequency and bandwidth are determined as follows by Eq. 1 and Eq. 2:

\[ f = \frac{c}{2L \sqrt{\varepsilon \mu}} \]  

\[ BW = \frac{96 \sqrt{\mu}}{\lambda_0 \sqrt{\varepsilon}} \frac{\mu}{\sqrt{2[4+17\mu\varepsilon]}} \]

Where, c is the velocity of light, L is the length of a patch, t is the thickness of the substrate and \( \lambda_0 \) is the wavelength in free space.

High permittivity or high permeability materials would be desirable for antenna size reduction based on the operating frequency and bandwidth equation, but they would also lower the bandwidth or raise the loss tangent, respectively. Materials with relatively high and comparable permittivity and permeability values, on the other hand, can shrink in size without reducing bandwidth. Because they may flip between functionalities inside a single structure without having to use numerous antennas, reconfigurable antennas have become a popular technique. Antenna reconfiguration entails an intentional modification in the antenna's shape and/or electrical behaviour, resulting in a change in the antenna's functionality [11]. Typically, such antennas have two or more states that may be switched discretely or continuously. These various states are usually achieved by modifying the antenna's current pathways, either by rearranging the antenna or by altering the antenna's surrounding medium. Many current radiofrequency (RF) systems, such as wireless and satellite communication, imaging, and sensing, employ reconfigurable antennas [12].

The issue has gotten a lot of interest since Schaubert [13] filed the first patent on reconfigurable antennas in 1983. Various designs have been presented in the literature to accomplish reconfigurability in terms of frequency, radiation pattern, polarisation, or a combination of two or three of the previously mentioned. Various reconfiguration strategies that may be integrated into an antenna design in order to redistribute its surface current through changes in the feeding network, the physical structure of the antenna, or the radiating edges can be used to achieve the necessary reconfigurability [14]. As illustrated in Fig. 2, reconfiguration approaches may be classified into various types. Electrical, optical, physical, and material reconfigurations are the four primary types of
reconfiguration procedures employed. To redirect surface currents, electrically reconfigurable antennas employ RF microelectromechanical systems (MEMS), PIN diodes, or varactors. Optically reconfigurable antennas are those that use photoconductive switching components. Mechanical deformation can be used to change the antenna shape in the physical reconfiguration approach.

Figure 2. Different strategies used to reconfigure Antennas.

Finally, the reconfiguration of an antenna may be accomplished using smart materials like ferrites, ferroelectrics, liquid metal, liquid crystal, and liquid dielectrics [15]. Hexagonal Ba-ferrites are frequently recommended as tiny antenna materials. M-type (BaFe_{12}O_{19}), W-type (BaM_{2}Fe_{16}O_{27}, M: Co, Zn, etc.), Y-type (Ba_{2}M_{2}Fe_{12}O_{22}), and Z-type (Ba_{3}M_{2}Fe_{24}O_{41}) are the different types of Ba-ferrites [16]. The Co_{2}Z ferrite (Ba_{3}Co_{2}Fe_{24}O_{41}) has a relatively high permeability and resonance frequency among these Ba ferrites. However, because of its complicated crystal structure, the single phase of Co_{2}Z ferrite is difficult to manufacture [17]. Kim et al. [18] investigated the structural and microwave characteristics of Mn added Co_{2}Z ferrite, Ba_{3}Co_{2-2x}Mn_{2x}Fe_{24}O_{41} (0.1 \times 0.5). The solid-state reaction technique was used to make all of the magnetic ceramics for small antenna applications. Their studies revealed that size of an antenna can be reduced by magneto dielectric materials.
2. Synthesis of hard ferrites for antenna applications

2.1 Various synthesis methods

Co-precipitation, salt-melt, ion exchange, sol-gel, citrate, hydrothermal, combustion, microemulsions, and other processes are used to make ferrites [19-23]. Other combination synthesis approaches, such as the sol gel-citrate method, the sol gel-hydrothermal technique, and others, exist in addition to these synthesis methods. Processing procedures have a major impact on the physical characteristics of ferrites, which also have a substantial impact on magnetic properties. Below are some of the chemical approaches that are addressed.

Figure 3. Different methods for synthesis of hard ferrites for antenna applications.

- Co-Precipitation
- Sol Gel
- Hydrothermal
- Solid State
- Auto combustion
- Wet Chemical
- Microemulsion
- Standard Ceramic

2.1.1 Ceramic powder milling method

The ferrites are synthesised by heating a combination of barium carbonate powders and oxides. After that, the ceramic powder is processed to obtain the finer material. After a lot of milling, we can get nanosize. This approach does not allow for the creation of single-phase ferrites. During the processing, impurities are picked up and material is lost. Due to the poor reactivity of the starting components, processing requires a high temperature and a lengthy time [24]. Which allows nanoparticles to engage in thermal motion and gives the potential of their self-assembly into superstructures by finally reaching the thermodynamic optimum [25] while converting ferrites into ultrafine nano agglomerates.
2.1.2 Reaction in solid state method

This approach entails combining hydroxide, oxide, carbonate, or sulphate raw materials that have been heated to around 1100 °C for an extended period of time, resulting in homogeneous microstructures, aberrant grain development, poor sintering behaviour, and uncontrolled cation stoichiometry [26]. A combination of barium carbonate and iron oxide is burned at extremely high temperatures (1150–1250 °C) in this process. The powder is then pulverised, which can result in impurities in the powder as well as stains in the crystal lattices, affecting the magnetic characteristics [27, 28]. Chemical decomposition processes, in which a mixture of solid reactants is heated to form a new solid composition and gases, are used in the solid-state reaction approach. Complex oxides are often made from simple oxides, carbonates, nitrates, hydroxides, oxalates, alkoxides, and other metal salts using this process. To enhance the homogeneity of the mixture and reduce the particle size of the powder, the technique usually comprises numerous annealing phases with several intermediate milling operations.

2.1.3 Chemical coprecipitation method

Coprecipitation is a crucial subject in chemical analysis, where it may be both unwanted and advantageous. Coprecipitation is a difficulty in gravimetric analysis, which involves precipitating the analyte and measuring its mass to determine its concentration or purity. Unwanted contaminants frequently coprecipitate with the analyte, resulting in excess mass. This difficulty is frequently alleviated by "digesting" (waiting for the precipitate to equilibrate and create larger, purer particles) or redissolving and precipitating the material again.

Salts are chemically co-precipitated using a base (NaOH). Since the early 1960s, this approach has been employed [28, 29]. The mixture is magnetically stirred and heated to around 70°C. The particles are then centrifuged and rinsed with deionized water. The granules are finally dried.

Inclusion, occlusion, and adsorption are the three primary processes of coprecipitation. An inclusion (incorporation in the crystal lattice) happens when an impurity occupies a lattice site in the carrier's crystal structure, resulting in a crystallographic defect; this can happen when the impurity's ionic radius and charge are comparable to the carrier's. An adsorbate is an impurity that is weakly or firmly attached to the precipitate's surface (adsorbed). When an adsorbed impurity becomes physically stuck inside the crystal as it develops, it is called an occlusion.
2.1.4 Sol gel synthesis method

A homogenous solution of metal salts is prepared and put into a solution of citric acid in sol-gel synthesis. Ethylene glycol, an organic coordinating agent, is added to the solution to make a sol that forms a gel structure after the water evaporates. Ammonia solution is used to maintain pH. At the nanoscale, this approach is employed to create more complicated hexaferrites [30]. The sol-gel process has a variety of benefits, including a low annealing temperature and superior microstructure control [31]. Chemical decomposition processes, which require heating a combination of solid reactants to form a new solid composition and gases, are used in the solid-state reaction method. Simple oxides, carbonates, nitrates, hydroxides, oxalates, alkoxides, and other metal salts are typically utilised in this process to produce complicated oxides. To enhance the homogeneity of the mixture and reduce the particle size of the powder, the technique typically comprises numerous annealing phases with multiple intermediate milling operations.

Extra milling makes the powder more active in the heat-treatment procedures that follow (i.e., more sinter active). The solid-state method is less costly and requires less complicated equipment. Furthermore, vast quantities of powder may be made in a very straightforward method. However, as compared to the wet powder production methods mentioned below, the resultant powder has a high degree of agglomeration, resulting in large particle size and restricted homogeneity.

2.1.5 Temperature specific combustion synthesis

Solution combustion synthesis (SCS) has become one of the most used processes for producing a wide range of oxide materials. The SCS method offers several advantages, including speed, ease of use, control over many elements of the products, production of high purity products, stabilisation of metastable phases, and the ability to create products of practically any size and shape. Environmental cleanup with SCS-derived powders is particularly successful. It has been established that a single-step combustion process may deposit nanocrystalline ionic catalysts on ceramic cordierite honeycombs.

On a heated plate, a solution of salts, ammonia, and citric acid is evaporated to a dry powder, with the pH adjusted to 7. Citric acid polymerizes, releasing carbon dioxide and entirely converting cations to iron oxide and barium carbonate. Because of the tiny grain size, the material formed has weak magnetic characteristics [32]. Aqueous combustion synthesis (ACS) or low temperature combustion synthesis (LCS) can be used to carry out this procedure [33]. After that, the mixture is auto-combusted in a microwave oven, yielding nano powder [34].
2.1.6 Hydrothermal synthesis method

One of the most frequent ways for preparing nanomaterials is hydrothermal synthesis. It's essentially a solution-reaction-based method. The creation of nanomaterials in hydrothermal synthesis may take place over a wide range of temperatures, from ambient temperature to extremely high temperatures. Depending on the vapour pressure of the primary component in the reaction, either low-pressure or high-pressure conditions can be utilised to regulate the morphology of the materials to be synthesised. This method has been used to successfully synthesis a wide range of nanomaterials.

Hydrothermal synthesis has a number of benefits over other methods. At high temperatures, hydrothermal synthesis can produce nanomaterials that are unstable. The hydrothermal process can generate nanomaterials with high vapour pressures with minimal material loss. In hydrothermal synthesis, the compositions of nanomaterials to be generated may be well controlled by liquid phase or multiphase chemical processes. This special issue provides as a venue for presenting the most recent research findings in hydrothermal nanomaterial production.

In hydrothermal synthesis a solution of metal salts and base are made under pressure to give the product. The unreactive precursors are washed away with dilute HCl. Ataie et al. studied the effects of many bases such as NaOH, KOH and NH4OH in the synthesis of hexaferrites [35].

2.1.7 Wet chemical method

It is feasible to generate specific surface structures, phases, forms, and sizes of metal oxide nanoparticles through wet chemical synthesis, resulting in a set of desired attributes. To get the required nanomaterials, wet chemical synthesis pathways allow careful control of the reaction conditions (temperature, substrate concentration, additives or surfactants, pH, etc.). Chemical reactions in the solution phase are dealt with employing precursors under controlled experimental settings in wet-chemical synthesis techniques. Each wet-chemical synthesis process is unique, hence there is no such thing as a universal norm for these types of synthesis methods. These synthesis procedures have been utilised to make 2D nanomaterials that are difficult to make using top-down methods. For 2D nanomaterial manufacturing, wet-chemical synthesis techniques offer a high degree of controllability and repeatability.

For the manufacture of hexaferrites, the wet chemical process is more effective than the ceramic method. The raw components are mixed together in a homogenous manner in this process. Processing requires a low temperature and sintering takes a lengthy time. During
the procedure, no material is lost. The good news is that there's a better chance of single-phase development [24].

2.1.8 Microemulsions method

Particles that can be controlled a precipitation in water-in-oil microemulsion technique was used to make starch nanoparticles of various sizes. Microemulsions have ultralow interfacial tension, a high interfacial area, and are thermodynamically stable, resulting in monodispersed nanoparticles. Because of their special features, including as ultralow interfacial tension, huge interfacial area, thermodynamic stability, and the ability to dissolve otherwise immiscible liquids, microemulsions have a wide range of functions and applications in the chemical and biological sciences. Nanoparticles have essential technical uses, such as catalysts, high-performance ceramic materials, microelectronic devices, high-density magnetic recording, and medication delivery, in addition to being of basic scientific interest.

Mixing two immiscible liquids and stabilising them with an artificial coating of surface-active substances yields nanoparticles. This approach [36] allows for morphological control. Separation, washing, and drying of the precipitates follow.

3. Different compositions of hard ferrites for antenna applications

Due to the huge size of the antenna, miniaturisation in electronics has virtually reached a limit, and decrease in the physical size of radio frequency (RF) systems is still a grey area [37]. By raising frequency, the size of the antenna may be decreased, but the cost of electronics rises, making it an unfeasible option in many sectors needing mass manufacturing. Small antennas are becoming increasingly important in communication, medical, space, and defence applications. Size and bandwidth are the primary constraints in missiles, satellites, military, and other space-based applications [38]. Microstrip antennas have grown in popularity in recent years due to its planar structure, conformal design, tiny size, low manufacturing cost, and simple fabrication procedure [39]. Table 1 elaborate the previously reported compositions of hard ferrites along with other parameter for antenna applications. Dielectric materials are used as the substrate in traditional microstrip antennas. Because of the low permittivity of the substrate materials, antennas must be big in order to fit into the given area. The use of a high-permittivity substrate can reduce the size of the device, but it reduces the gain, radiation pattern, and bandwidth. This is due to the field's confinement in a high-permittivity area, as well as an impedance mismatch with the surrounding medium [40].
Table 1: Previously reported compositions of hard ferrites along with other parameter for antenna applications.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition</th>
<th>Permittivity (ε)</th>
<th>Permeability (μ)</th>
<th>Size (nm)</th>
<th>Bandwidth</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cobalt ferrite LDPE</td>
<td>~1–2.905</td>
<td>~1.01–1.05</td>
<td>10 nm</td>
<td>9.5 GHz</td>
<td>44 (2012)</td>
</tr>
<tr>
<td>2</td>
<td>Ba₃Co₂₋₂ₓMn₂ₓFe₂₄O₄₁</td>
<td>19.774</td>
<td>15.183</td>
<td>--</td>
<td>510 MHz</td>
<td>18 (2014)</td>
</tr>
<tr>
<td>3</td>
<td>Ni₁₋ₓZnₓFe₂O₄ (NiZn), Ni₀.₈ₓZnₓCo₀.₂Fe₁.₉₈O₄₋₅ (NiZnCo)</td>
<td>--</td>
<td>~0.9–2.7</td>
<td>--</td>
<td>200 MHz-6 GHz</td>
<td>46 (2015)</td>
</tr>
<tr>
<td>4</td>
<td>Ni₀.₇Zn₀.₃Fe₂O₄ + x BaFe₁₂O₁₉ (x=30)</td>
<td>15</td>
<td>~15.5</td>
<td>--</td>
<td>75-570 MHz</td>
<td>45 (2014)</td>
</tr>
<tr>
<td>5</td>
<td>(Mn₀.₅Zn₀.₃₅Co₀.₁₅Fe₂O₄ + SrFe₁₂O₁₉)</td>
<td>4.1–0.1</td>
<td>3.72–0.28</td>
<td>--</td>
<td>1 GHz</td>
<td>47 (2016)</td>
</tr>
<tr>
<td>6</td>
<td>BaFe₁₂O₁₉</td>
<td>6.2-0.04</td>
<td>1.9 -0.18</td>
<td>70 nm</td>
<td>68-166 MHz</td>
<td>48 (2017)</td>
</tr>
<tr>
<td>7</td>
<td>(MnₓCo₁₋ₓFe₂O₄/PAA, 0-x-1)</td>
<td>--</td>
<td>--</td>
<td>6-12 nm</td>
<td>75 MHz</td>
<td>50 (2018)</td>
</tr>
<tr>
<td>8</td>
<td>BaFe₁₂O₁₉-CoFe₂O₄</td>
<td>15</td>
<td>13</td>
<td>--</td>
<td>500 MHz</td>
<td>49 (2020)</td>
</tr>
<tr>
<td>9</td>
<td>SrFe₁₂O₁₉−Li₂MoO₄</td>
<td>5-6.7</td>
<td>1.10-1.16</td>
<td>--</td>
<td>12.89 GHz</td>
<td>52 (2021)</td>
</tr>
<tr>
<td>10</td>
<td>Mg₀.₇Cd₀.₃Fe₁.₉₂Ga₀.₀₈O₄</td>
<td>21-30</td>
<td>15-19</td>
<td>0.42-1.18μm</td>
<td>1-200 MHz</td>
<td>51 (2021)</td>
</tr>
<tr>
<td>11</td>
<td>CoₓZn₀.₉₀₋ₓAl₀.₁₀Fe₂O₄</td>
<td>3.5-4.5</td>
<td>0.90-1.0</td>
<td>20-26 nm</td>
<td>2.5 to 5.5 GHz (S-band)</td>
<td>53 (2022)</td>
</tr>
</tbody>
</table>

Using magneto-dielectric materials, these restrictions can be addressed [41]. Magneto-dielectric materials are non-natural materials that exhibit both dielectric and magnetic characteristics. Microwave specialists have been intrigued by these materials for two reasons: (i) They give two degrees of freedom in altering material characteristics, namely relative permittivity (εᵣ) and relative permeability (μᵣ), and therefore the flexibility to design the material that is best suited for a particular application. (ii) They have a high dielectric strength at high frequencies, which results in low eddy current losses, making them ideal for high-frequency applications. Ferrites are one example of this type of material. Proper raw material selection and synthesis methods can affect their structural and electromagnetic characteristics [42]. As a result, a moderate value of μᵣ and εᵣ can be used to miniaturise the antenna [43].
In 2012 Borah and Bhattacharyya carried out research to determine the complicated
permittivity and permeability of different volume fractions of magnetodielectric
composites containing cobalt ferrite nano inclusions, as well as magnetic characterisation
[44]. In deionized water, cobalt (II) nitrate hexahydrate (98 percent pure, Co (NO3)2.6H2O)
and iron (III) nitrate nonahydrate (P98 percent pure, Fe (NO 3)2.9H2O) were dissolved in
stochiometric proportions. Surfactant oleic acid (C17H33COOH) and 3M NaOH are added
and mixed up to precipitation after steady stirring for 2.5 hours at 80°C. The resulting
polycrystalline precipitate is annealed for three hours at 600 °C. Cobalt ferrite nanoparticles
had an average grain size of ~10 nanometers. With an increase in inclusion content from
1% VF to 5 percent VF, the actual part of permittivity and permeability of the samples
changes from ~1–2.905 to ~1.01–1.05. The imaginary portion of permeability and the tanδ
of permittivity are determined to be on the order of ~10⁻³ and ~10⁻¹, respectively.

Dielectric characteristics were evaluated using a contact superstrate method. The
complicated permeability of the materials is studied using the cavity perturbation
technique. Vibrating sample magnetometry is used to determine the 4πMs value and
coefficency. The size and homogenous distribution of nano inclusions are determined by
examining the structural and surface morphologies of composite materials. Cobalt ferrite
nanoparticles had an average grain size of ~10 nanometers. With an increase in inclusion
content from 1% VF to 5% VF, the actual portion of permittivity and permeability of the
samples changed from ~1–2.905 to ~1.01–1.05. The omnidirectional behaviour of the
antenna was revealed by the directivity values determined from the radiation
characteristics. Low side lobe will assist MIMO (Multiple-In Multiple-Out) applications
reduce interference in radiation patterns. The MPA’s (microstrip rectangular patch antenna)
radiation performance may be improved even further by using external magnetic bias.

For a tiny antenna application, the sintering behaviour and magneto-electric characteristics
of Ba3Co2−2xMn2xFe24O41 (0.1≤x≤0.5) ceramics were studied by Kim et al. 2014 [18]. All
Ba3Co2−2xMn2xFe24O41 ceramics were sintered at 1250°C using the solid state reaction
technique. Most sintered specimens, on the other hand, produced a single Z-type phase.
With increasing frequency, the real portion of permittivity dropped and the loss tangent of
permittivity grew. There was no discernible variation in component ratio. Over 500 MHz,
the actual component of permeability dropped significantly, with an inflection point about
800 MHz; it also dropped with Mn additions. The Ba3Co2−2xMn2xFe24O41 ceramics actual
portion of permeability was greater than that of the Ba3Co2Fe24O41 ceramics. The
permeability loss tangent increased with frequency but did not change significantly with
composition ratio. At 510 MHz, the Ba3Co0.2Mn0.8Fe24O41 ceramics sintered at 1250°C had
real part permittivity, loss tangent of permittivity, and real part permeability, loss tangent
of permeability of 19.774, 0.176 and 15.183, 0.073, respectively. The operating frequency
of the simulated PIFA using Ba$_3$Co$_{0.3}$Mn$_{0.8}$Fe$_{24}$O$_{41}$ ceramics was 541 MHz, while the
impedance bandwidth (Voltage Standing Wave Ratio, VSWR) was 39 MHz (7.2 percent).
In the operation band, the total efficiency of the suggested PIFA was around 25%. Based
on these findings, it appears that the size of an antenna may be decreased without
sacrificing bandwidth by utilising magneto-dielectric materials instead of FR4 (designation
FR-4 applies to glass-reinforced epoxy laminate materials).

Zheng et al. 2013 [45] used solid-state reaction technique to successfully manufacture a
variety of NiZn ferrite composites with different BaFe$_{12}$O$_{19}$ hexaferrite (BaM) additions
(x) for their prospective application as magneto-dielectric antenna substrate materials.
When a combination of NiZn ferrite and BaM was sintered at 1200°C, a W-type hexagonal
phase was produced, and a diphase composite ferrite consisting of NiZn spinel ferrite and
BaM hexaferrite was eventually created, according to XRD and energy-dispersive
spectrum studies. BaM considerably reduces the frequency dispersion of the permittivity
spectrum, resulting in a constant permittivity ε’ of about 15 for doped samples from 1MHz
to 1 GHz, which is confirmed to be closely connected to refined grains according to Koops'
hypothesis. Furthermore, the magnetic and dielectric losses in the doped samples were
shown to be lower than in the Undoped NiZn ferrite. In the sample with x = 30% wt percent,
nearly identical values of μ and ε were obtained. Authors suggested that a magneto-
dielectric composite with decreased physical dimensions and strong impedance matching
to free space might be a potential choice for antenna construction. This research might also
lead to a novel approach for fabricating magneto-dielectric materials with the requisite
electromagnetic properties.

Mattei et al. 2015 [46] studied the magnetocrystalline anisotropy constants (K1) and
saturation magnetostriction constants (S) of Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ (NiZn) and Ni$_{0.8-}
_x$Zn$_x$Co$_{0.2}$Fe$_{1.98}$O$_{4.8}$ (NiZnCo) ferrites suitable for antenna downsizing. The observed results
for NiZn ferrites were consistent with published data, indicating that both the experimental
procedure and the suggested modelling of stress-induced FMR (Ferrimagnetic Resonance)
changes were valid. The ability of Ni$_{0.6}$Zn$_{0.2}$Co$_{0.2}$Fe$_{1.98}$O$_4$ (which had the greatest natural
ferrimagnetic resonance and the highest λ$_S$ among the ferrites tested) to be utilised as a
substrate for antenna miniaturisation at frequencies up to 1 GHz has been proven.

Saini et al. 2016 [47] proposed the miniaturisation of a microstrip patch antenna utilising a
composite nanosized ferrite material. The effect of increasing the relative permeability of
the substrate material on the physical size and efficiency of a microstrip antenna was
studied using detailed simulations. On the basis of the comprehensive simulation, an
analytical formula for estimating the effective relative permeability was constructed. The
electromagnetic characteristics of a composite nano ferrite (Mn$_{0.5}$Zn$_{0.35}$Co$_{0.15}$Fe$_2$O$_4$ +
SrFe$_{12}$O$_{19}$) with an average crystallite size of 72 nm were investigated. Co-precipitation
was used to prepare the substrate material. The electromagnetic characterisation yielded matching values of complex permittivity ($\varepsilon^* = 4.1 - 0.1j$) and complex permeability ($\mu^* = 3.72 - 0.28j$) up to 1 GHz. In comparison to a pure dielectric FR4 substrate, simulation and test findings show that an antenna constructed using the following specifications may lower the patch size by almost 44% and enhance the reflection loss bandwidth by -10 dB. Authors suggested that composite nano ferrites of $\text{Mn}_{0.5}\text{Zn}_{0.35}\text{Co}_{0.15}\text{Fe}_2\text{O}_4 + \text{SrFe}_{12}\text{O}_{19}$ are strong contender for a high-bandwidth miniaturised antenna in the microwave frequency range.

In the design of proximity fuzes, calculating the exact height of burst has always been a difficulty. Saini et al. 2017 [48] proposed miniaturisation of the patch antenna using barium hexaferrite ($\text{BaFe}_{12}\text{O}_{19}$) as the substrate material. Radio frequency-based sensors can be designed for this purpose, but the size and bandwidth of the antenna increases the design complexity; thus, this study proposed miniaturisation of the patch antenna using barium hexaferrite ($\text{BaFe}_{12}\text{O}_{19}$) as the substrate material. The structural and electromagnetic characteristics of the nanohexaferrite substrate material were determined using a wet chemical technique. X-ray diffraction revealed a crystallite size of 60 nm on average. The antenna construction built and simulated reveals that the size of the antenna may be decreased by up to 42.5% using the electromagnetic characteristics of synthesised magneto-dielectric material. It also boosts the bandwidth of the antenna on the (Flame retardant) FR4 substrate from 68 to 166 MHz. As a result, $\text{BaFe}_{12}\text{O}_{19}$ is offered as a potential choice for a downsized, high-bandwidth antenna for proximity fuzes.

For high-frequency antenna applications, Polley et al. created a $\text{BaFe}_{12}\text{O}_{19}$-$\text{CoFe}_2\text{O}_4$ ferrite composite [49]. Nanocomposites were synthesized by precipitation method. The existence of both BaM and CoF ferrite phases in composite ferrite was revealed by XRD analysis. The composites were sintered for 4 hours at 1100°C/4 h. In comparison to the other composites, the composite with $x = 0.25$ composition had the most compact microstructure and greater bulk density. Due to greater densification, the composite (with $x = 0.25$) also had the best permittivity (~15), permeability (~13), and antenna miniaturisation factor (~14) at 500 MHz. The permeability of the composite was nearly constant up to 500 MHz. The composite with $x = 0.25$ composition had the lowest coercivity, showing that the harsh magnetic behaviour of BaM ferrite changed to a soft magnetic character during composite production, possibly due to the development of larger BaM grains in the composite.

Alcala et al. 2017 [50] investigated the electrical response of toroidal coils containing mixed ferrites magnetic nanoparticles (MNPs) implanted in a polyacrylamide matrix ($\text{Mn}_x\text{Co}_{1-x}\text{Fe}_2\text{O}_4$/PAA, $0 \leq x \leq 1$). The MNPs were made by thermal breakdown of molecular precursors, and the $\text{Mn}_x\text{Co}_{1-x}\text{Fe}_2\text{O}_4$/PAA toroidal cores were made by copolymerization of MNPs with acrylamide and bis-acrylamide. The cubic spinel phase was represented by
MNP X-Ray Diffraction (XRD) patterns. The average size of MNPs measured by Transmission Electron Microscopy (TEM) and was in between 6 and 12 nm. To compare the results, authors measured the properties of a commercial toroidal coil and discovered that the impedance curves for each configuration (commercial and Laboratory-made coils) showed a resonance peak around 75 MHz; the signal intensity of the Laboratory-made coil increases by one order of magnitude over the commercial coil. Both magnetic and electrical measures were shown to be linked to manganese content. The benefit of the proposed MnxCo1-x Fe2O4/PAA toroidal coils system is that the flexible combinations of Mn2+ and Co2+ components allowed for easy tweaking of the electrical and magnetic characteristics in order to optimise the coils impedance.

Gan et al. 2021 [51] studied the impact of sintering temperature (900°C, 915°C, 930°C, 945°C, 960°C) on the magnetic and dielectric properties, as well as low-loss characteristics of Mg0.7Cd0.3Fe1.92Ga0.08O4 composites with 5 wt.% Bi2O3 addictive. The increase in permeability is due to an increase in magnetization (saturation magnetization Ms from 24.37 emu/g to 33.12 emu/g). The actual permeability (μ´) of Mg-Cd-Ga ferrites was shown to increase in a monotonic manner from 15 to 19 H/m. Increasing temperature also fine-tuned the actual portion of permittivity (ε´). As a consequence, at 920°C, and are almost equal in frequency ranges extending from 1 MHz to, and these properties may be exploited for antenna miniaturisation and excellent radiation behaviour. Furthermore, the extremely low magnetic (tanδμ~3*10^-2) and dielectric (tanδε~5*10^-3) tangents allow for high radiation efficiency during operation. These findings showed that the suggested materials have a promising future as high-frequency antenna substrate.

The broad-band electromagnetic characteristics of composites of (1-x)SrFe12O19-xLi2MoO4, x = 0.4, 0.5, 0.6, and 0.7 with density up to 91%, were synthesized using a cold-sintering technique by Rajan et al. 2021 [52]. In the composites, X-ray diffraction (XRD) examination as shown in Fig 4 indicated the coexistence of SrFe12O19 (SFO) and Li2MoO4 (LMO) phases, with no other phases.

With an increase in the LMO volume fraction, the evolution of microstructure allowing increased densification was seen. The dielectric loss (tanδε) dropped as the LMO volume percentage rose, but the real permittivity (ε’) increased. Furthermore, all of the composites have a real permeability (μ’) higher than unity, and the magnetic loss (tanδμ) is on the scale of 10^{-2}. A ferrite resonator antenna (FRA) integrated with the SFOLMO composite was developed, modelled, and built to show the magneto dielectric composite's application potential in microwave antenna applications. The manufactured FRA resonating at 12.89 GHz has a very high return loss of -40 dB and a 510 MHz broad impedance bandwidth Fig. 5.
Figure 4. Refined X-ray diffraction (XRD) patterns of \((1-x)\text{SrFe}_{12}\text{O}_{19}-x\text{Li}_2\text{MoO}_4\) cold-sintered composites with (a) \(x = 0.4\), (b) \(x = 0.5\), (c) \(x = 0.6\), and (d) \(x = 0.7\). Reprinted (adapted) with permission from ref [52] Copyright {2021} American Chemical Society.

Figure 5. Geometry of the (a) simulated FRA and (b) fabricated FRA. Reprinted (adapted) with permission from ref [52] Copyright {2021} American Chemical Society.
The constructed ferrite resonator antenna's exceptional characteristics imply that it might be a good option for Ku-band (microwave part of the electromagnetic spectrum with frequencies ranging from 12 to 18 gigahertz (GHz) applications.

Rahman et al. used the sol-gel process to make Co$_x$Zn$_{0.90-x}$Al$_{0.10}$Fe$_2$O$_4$ ferrites, which were used as flexible microwave substrates for microstrip patch antennas [53]. In addition, the suggested Co-Zn ferrites samples' dielectric and magnetic characteristics were tested for microwave application confirmation. The magnetic permeability $\varepsilon_r$ and magnetic loss tangent $(T_\delta)$ values are also calculated to generate the specified scattering parameters S11 and S21 derived from rectangular substrate pellets, with $\mu_r$ and $(T_\delta m)$ values ranging from 0.90 to 1.00 and 0.003 to 0.007, respectively. A modified diamond-shaped microstrip patch antenna is developed and produced on the suggested flexible substrates made from synthetic Co-Zn ferrites nanopowders mixed with PVA binder to demonstrate its use in the microwave regime's S-band.

In a research article Rajendran Lekshmi synthesized PMMA -NFO (NiFe$_2$O$_4$) nanoparticles composites with different volume fractions of NFO (0.05 V$_f$, 0.1 V$_f$, 0.15 V$_f$, 0.2 V$_f$) [54]. On the basis of result obtained, a remarkable miniaturization near about 95.46% was monitored for this Magneto Dielectric antenna as compared to normal dielectric substrates possess permittivity and permeability values equivalent to unity. Alteration in magnetocapacitance because of magnetic field is represented in Fig. 6(a). The fluctuation in magneto capacitance with increasing magnetic field is shown in this diagram. The magnetic and charge ordering in the magnetic phase of the composite will be reduced by a magnetic field, and the MC value will alter as a result [59]. As a result, at room temperature, an increase in the magnetic field will result in a higher negative magnetocapacitance value in the composite. However, no trace of an electromechanical resonance frequency can be found anywhere in the frequency range we looked at.

Because the MD characteristics show promise, they can be employed to benefit antenna shrinking in the future. Through a polymer hot pressing process, a functionally graded anisotropic substrate with attributes such as $\varepsilon_r$ and $\mu_r$ that change in the z plane (Fig. 6(b)).

A model assisted study on the fabrication of a microstrip patch antenna (MPA) is carried out to validate the applicability of the proposed laminar MD composites for size reduction in antennas. A comparison of the geometric parameters of the optimised designs of lossless dielectric substrate LD, ungraded magneto dielectric material UMD, and graded magneto dielectric material GMD substrate MPAs, as shown in Figures 7A and b, can be used to assess the efficiency of magnetodielectric loading in size reduction.
Figure 6. Variation in magneto capacitance with the application of different magnetic fields in the PMMA–NFO composites. (b) A schematic showing the developed functionally graded MD substrate and the enlarged single layer of the composite that contains magnetic filler in the PMMA matrix. Reprinted (adapted) from ref [54] Copyright {2022} Royal Society of Chemistry.

Figure 7. Schematic showing MPA employing the GMD substrate and the uniaxial variation in MD properties. (b) Return loss characteristics of MPAs with LD substrate, and GMD and UMD substrates. (b inset) Bandwidth comparison of MPAs with the LD substrate, and GMD and UMD substrate Reprinted (adapted) from ref [54] Copyright {2022} Royal Society of Chemistry.
ANSYS HFSS is used to simulate the spatial distribution of radio wave strength and antenna gain of modelled antennas, as shown in Fig. 8.

Figure 8. Radiation pattern of (a) LD substrate, and (b) GMD and UGD substrate; gain plots of (c) LD substrate, and (d) GMD and UMD substrate. Reprinted (adapted) from ref 54 Copyright ©2022 Royal Society of Chemistry.

The radiation pattern is the spatial distribution of the radiated waves. A functionally graded anisotropic composite was created, according to the findings by stacking the various filler-loaded samples in a methodical manner, with laminates with a higher level of solid loading on the top layer the suggested strategy. Patch antennas with functionally gradient and axially anisotropic substrates are appropriate for large-scale antennas.
4. Factors affecting the performance of antenna

4.1 Size

The HF antenna is quite large due to the enormous wavelength of the HF band. As a result, shrinking the HF antenna is a good idea. However, shrinking the antenna's size reduces its efficiency. Shih et al. proposed using a platform-mounted antenna to excite the platform's characteristic modes (CMs) in order to enhance overall efficiency and gain at lower frequencies [55]. The wavelength of the lower limit of the HF band is related to the platform. The effective size of the antenna is raised by stimulating a partial or entire size of the platform, which improves efficiency at lower frequencies. The platform's shape and size, however, have a significant impact on the design's performance. This technique is not applicable to all antennas and platforms. Microwave antennas are significantly smaller and need much less area than HF antennas. The antenna's size is no longer the most important issue. Other variables, such as dielectric material losses, become increasingly important.

4.2 Losses in dielectric material

Microstrip antennas are often made of low-cost, high-loss materials, resulting in low antenna efficiency. Chen et al. [56] proposed coupling arrangements to improve the efficiency of microstrip antennas. They created a non-resistive coupling structure antenna. The loss in the divider network is reduced without the resistors, and as a result, the efficiency is enhanced. The geometry of this type of antenna, on the other hand, is complicated and difficult to construct. Yang et al. proposed a planar-structured high-efficiency antenna [57]. The ground plane of the antenna is made of metasurface. Because the periodic structure has a low loss characteristic, the antenna's efficiency increases. Pan et al. [58] created an antenna with a metasurface as the patch. The frequency selective surface (FSS) was discovered to have filtering properties, and the metasurface inherited this characteristic. As a result of the metasurface patch's reduced insertion loss, the antenna's efficiency can be improved. The antenna's periodic structure can improve its efficiency [59].

4.3 The loss in propagation

The elements that influence the performance of millimetre wave antennas differ from those that influence the performance of HF and microwave antennas. The propagation loss in millimetre wave communication systems is substantial, for example, 15-30 dB/km at 60 GHz [60]. As a result, antenna arrays with excellent directivity and efficiency are required. The loss in the antenna array's feed network becomes the most important element impacting the array's overall efficiency, thus it's critical to maintain the loss in the feed network as
low as possible. Zarifi et al. proposed a slot antenna array with excellent efficiency [61]. The antenna is built using the waveguide gap method, which eliminates the requirement for electrical contact between the layers. This antenna, on the other hand, is complicated, with three layers. It is difficult to create. Wu et al. [62] developed a high-efficiency millimetre wave antenna that can be manufactured on a soft substrate. An array of patch antennas is proposed as the antenna. Slots feed the patches, avoiding the necessity of high-loss millimetre wave connections. Microstrip lines are utilised in the feed network. Because the width of the microstrip line and the thickness of the substrate are both quite big, there is a significant amount of loss in the feed network. The feed network was designed by Park et al using a substrate integrated waveguide (SIW) [63]. The design of SIW and gap coupling techniques are required approaches in order to build a high-efficiency and easy-to-fabricate millimetre wave antenna.

4.4 Return loss

A horizontally polarised dipole antenna must be positioned at a height of at least $\lambda/2$ to assure the antenna's impedance and radiation performance [64]. The influence of the image current cannot be ignored when the current flowing through the antenna is situated near the ground plane [65]. As illustrated in Fig. 9, the image current on the ground plane is in the opposite direction of the current in the antenna. The ground plane reflects the electromagnetic wave emitted by the antenna. The reflected wave shifts 180 degrees in phase. As a result, the wave from the image current cancels the reflected wave, resulting in the cancellation of radiated power by the image current.

Figure 9. Image current direction.
The authors used ferrite materials to construct a broadband (3 MHz - 6 MHz) bow-tie shaped HF antenna that is near the ground plane with a very low height and eliminates the destructive influence of the image current [66]. The influence of image current cannot be ignored when the antenna is close to a conductive ground plane. The authors utilised commercial ferrite tiles to cover the whole conductive ground to decrease the influence of image current and mutual resistance. It can be observed that a significant quantity of commercial ferrites may be utilised to enhance the voltage standing wave ratio of the near ground antenna. The overall efficiency, however, is not displayed. Even if the return loss is decreased, the antenna's efficiency is poor due to the lossy ferrite location.

4.5 Radiation efficiency

Zhao et al. suggested broadband monopoles for VHF-UHF band applications [67, 68]. However, the antenna's overall efficiency was still too low. At higher frequencies, the ferrite loading has no effect on the antenna's realised gain. At higher frequencies, the realised gain is even reduced significantly. The use of ferrite loading does not increase the total volume of the antenna, but it does substantially increase the weight of the antenna due to the high weight of the ferrite utilised. The arrangement of the commercial ferrite bars needs to be improved in order to reduce the antenna's weight. Moon et al. employed four distinct loading ferrite bars with varying heights and widths to reduce the antenna's weight while retaining its performance [69]. The authors recommended placing the ferrite in locations with large magnetic fields to reduce the required ferrite even further. The loading ferrite bars were kept to a bare minimum. The voltage standing wave ratio is considerably enhanced as compared to the antenna without ferrite loading. The loop antenna's major source of energy is magnetic.

The loading ferrite has a high permeability characteristic. As a result, the antenna's energy storage decreases, and the Q factor decreases [70]. The realised gain is improved at lower frequencies but lowered at higher frequencies when compared to the antenna without ferrite loading. The gain is nearly constant at lower frequencies and somewhat enhanced at higher frequencies as compared to the antenna with one full piece of ferrite. Because ferrite is used less at higher frequencies, the realised gain improves. The return loss is considerably decreased at lower frequencies. There will be less energy reflected. As a result, overall efficiency and realised gain both improve.

5. Artificial materials to improve efficiency

The ferrite is useful in improving the antenna's performance in the HF band. Due to its unique EM characteristics, the periodic structure is useful for improving antenna efficiency when the frequency rises to higher bands, such as the microwave band. Two of the most
essential characteristics are permittivity and permeability. The permittivity ($\varepsilon$) and permeability ($\mu$) can be used to characterise the EM characteristics of the substrate while designing a microstrip antenna. The most common substance in nature is a double positive medium, which has permittivity and permeability both greater than zero ($\varepsilon > 0$, and $\mu > 0$). Artificial materials arise in various applications because they require materials with non-naturally occurring or specialised characteristics [71]. By embedding different elements with unique shapes in some host medium, an artificial material based on periodic structure may be created. A vast number of independent parameters are provided by the periodic structure. Designers can obtain materials with specific permittivity and permeability because to the great degree of flexibility.

5.1 Use of substrate integrated waveguide (SIW) to reduce loss

Millimeter wave antennas are quickly evolving in tandem with the development of 5G communication methods. Because of the significant transmission loss in the air, a high realised gain is one of the most essential criteria. The antenna array is suggested in the millimetre wave communication system to obtain high gain. The feed network is widely recognised to be the primary source of loss in a big antenna array. As a result, in order to reduce losses in the antenna array's feed network, it is important to examine the performance of commonly used transmission techniques. The most common EM transmission techniques are rectangular waveguide, coaxial line, and microstrip line. Fig. 10 illustrates their geometries.

![Figure 10. Structure of rectangular waveguide, coaxial line, and microstrip line for transmission](image-url)
6. Future prospects of antenna

Self-adaptation and self-improvement are the future prospects of reconfigurable antennas, with the goal of achieving maximum energy efficiency with minimal losses and low power requirements, in order to maintain the communication link with the highest reliability in a dynamic and unpredictable environment. Future reconfigurable antennas should be capable of performing many roles at the same time with no noticeable hiccups. In order to perceive and adapt to dynamic RF changes, reconfiguration approaches should be increasingly oriented towards developing fields like software driven IoT gateways or machine learning models linked to ANN technology. New wireless technology developments, such as cognitive radio systems, developing cellular systems, and so on, should be used as a foundation for the development of reconfigurable antennas.

Conclusion

To begin with, the most important affecting elements were observed in various frequency bands. In the microwave band, the dielectric loss of the substrate is the most important element affecting the microstrip antenna's efficiency. The loss in the feed network is the major loss component that lowers the efficiency of a millimetre wave antenna array. Ferrites have been proposed in the HF band to decrease the impact of near-ground antenna image current. The HF antenna's mismatch loss and efficiency can be enhanced. Because the amount and strength of the image current is determined by the current density on the ground, the use of ferrites is more successful when the ferrites are positioned in a region with a high current density. The ferrites can also be utilised to enhance the bandwidth of the near ground HF antenna while reducing its size. The bottom bound of the bandwidth can be increased by adding ferrites. When the periodic structures are placed in the material, the characteristics of the original material will alter. The permittivity is lowered and the permeability is raised in a specific frequency range by etching periodic patterns in the ground plane. The radiator can also be made out of the periodic structure. With the periodic structures in the antenna patch, more energy can be radiated out, and the antenna's bandwidth may be substantially expanded, according to the studies of the transmission line model and the dispersion relation.

This book chapter concluded method used to reconfigure antenna with hard ferrites. Effect of increasing the relative permeability of the substrate material on the physical size and efficiency of a microstrip antenna. Although using a high-permittivity substrate helps minimise device size, it also reduces gain, radiation pattern, and bandwidth. Using magneto-dielectric materials, it appears that the size of an antenna may be reduced without compromising bandwidth. This happens due to the field's confinement in a high-
permittivity region and an impedance mismatch with the surrounding medium. It was also concluded that ferrite materials have a bright future as high-frequency antenna substrates.

References


[41] A. Saini, A. Thakur, P. Thakur, Matching permeability and permittivity of Ni0.5Zn0.3Co0.2In0.1Fe1.9O4 ferrite for substrate of large bandwidth miniaturized antenna, J. Mater. Sci.: Mater. Electron. 27 (2016) 2816-2823. https://doi.org/10.1007/s10854-015-4095-8


[54] D.R. Lekshmi, S.P. Adarsh, M. Bayal, S.S. Nair, K.P. Surendran, Functionally graded magnetodielectric composite substrates for massive miniaturization of


