CHAPTER-3

OBJECTIVES OF THE PRESENT WORK

3.1 INTRODUCTION

In this chapter, main motivation behind the present research work and objectives focused are discussed. Importance of the targeted five ferrites, their electrical, magnetic properties and also behaviour at different frequencies are discussed and presented.

3.2 MOTIVATION BEHIND THIS RESEARCH

In recent years, great interest has been focused on ferrites because of their vast range of technological applications in Electronics and Communication Engineering. Ferrite as a semiconductor has attracted considerable attention in the field of technological application in a wide range of frequencies extending from microwave to radio frequency, and also they are preferred because of their high resistivity and low eddy current losses. The biggest advantage of ferrites is that, by the introduction of relatively small amount of foreign ions, important modification in structure and magnetic properties can be obtained.

With the development of radar, microwave communication technology, anti-electromagnetic interference coatings, and micro-wave darkrooms, the requirement of highly efficient microwave absorbing materials has increased dramatically. Magnetic materials have received considerable attention due to their potential applications in electronic devices for industry, commerce, and military affairs. Up to now, ferrites and magnetic metals like cobalt, iron, and
nickel are the commonly used magnetic microwave absorbing materials. Previous studies showed that microwave absorbing abilities would largely depend on the morphology and size of the electromagnetic materials. Therefore, synthesis of materials having microwave absorbing properties with specific morphologies and sizes such as nanoparticles, nanofibers, and nanospheres has attracted much attention in recent years [5].

At present, nanoparticles are designed keeping in mind their functionality only. But, much attention is not paid to the hazardous substances released by nanotechnology to the environment. In the light of all these factors, microwave assisted chemistry has emerged as a greener protocol which eliminates most of the problems of nano-related toxicity and hazardous solvents.

The green chemistry utilizes a set of principles that reduces or eliminates the use or generation of hazardous substances in the synthesis and applications of ferrite materials. Some of the key areas of green chemistry are the elimination of solvents in chemical processes or the replacement of hazardous solvents with relatively benign solvents. The major goals are to maximize the efficient use of safer raw materials and to reduce waste [118]. This can be achieved by using the microwave synthesis as reported earlier.

Looking into the difficulties encountered in the synthesis of metal oxide nanoparticles, use of single-pot synthesis/ single-type precursor synthesis is thought to be beneficial. Employing a similar procedure reduces the number of precursors to be chosen, which helps in better understanding of the synthetic procedure. When the synthetic procedures are chemically understood, their reproducibility is easily attained [135].

Also, once the synthetic route is understood, extending the procedure for synthesis of other metal oxide nanoparticles will be easier. Hence, a single
synthetic procedure will then be a model synthetic approach. Keeping these criteria in view, the present investigation to obtain different metal oxide particles (bulk/ nanoparticles) in a simple/ efficient route is undertaken and is being reported here. Present work reports the synthesis of ferrites and metal oxide nanoparticles using metal oxalate precursors employing microwave-assisted route [141]. Further, we will also investigate whether it is environment friendly protocol for the synthesis of ferrites [135].

3.3 OBJECTIVES FOCUSED IN THE PRESENT RESEARCH WORK

After a detailed exploration on study of ferrites and their application to Electronics and Communication Engineering, the following objectives have been focused in this research,

1. To synthesize ferrites/ nano ferrites using microwave synthesis and verify whether it is environment friendly protocol.
2. To characterize them as synthesized ferrites.
3. To carry out a systematic study of the change in resistivity and conductivity with temperature to optimize the highest resistive state and lowest conductive state.
4. To study the nature of MH hysteresis loops of the ferrite to ascertain whether the synthesized ferrite is a hard ferrite or soft ferrite.
5. To study the variation of dielectric constant and dielectric loss as a function of frequency at different temperatures.
6. To study the variation of real part of impedance and imaginary part of impedance as a function of frequency at different temperatures.
7. To study the variation of Q- factor as a function of frequency at different temperatures.
3.4 FERRITES CONSIDERED FOR THE PRESENT STUDY

Although many ferrites are available along with their specific applications, some commonly available spinel ferrites especially having applications in Electronics and Communication Engineering are considered here for investigation. These are Nickel ferrite, Cobalt ferrite and Nano-sized Magnesium ferrite, nano-sized Barium ferrite and nano-sized Gamma ferrite, as shown in Table 3.3. Generally, ferrites are available in two categories i.e. ferrites and nano-sized ferrites.

Table 3.1 Ferrites considered for the present study

<table>
<thead>
<tr>
<th>SNo</th>
<th>Ferrites</th>
<th>Nano-sized ferrites</th>
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<tbody>
<tr>
<td>1</td>
<td>Nickel ferrite</td>
<td>Magnesium ferrite</td>
</tr>
<tr>
<td>2</td>
<td>Cobalt ferrite</td>
<td>Barium ferrite</td>
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<tr>
<td>3</td>
<td></td>
<td>Gamma ferrite</td>
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3.4.1 Ferrites

In general, a bulk material is expected to have constant physical properties regardless of its size. It is well known that the physical properties of materials undergo changes from their ‘bulk’ values when the size of the particle is sufficiently reduced. The interparticle spacing and surface-to-volume ratio in particles play a predominant role in influencing the material properties.

The electrical and magnetic properties of bulk ferrites are found to be sensitive to a number of factors namely grain size, grain structure, porosity and distribution of the metal cat ions among the lattice sites in the spinel structure [132].
3.4.1.1 Nickel ferrite

Among the spinel type ferrites, nickel ferrite is a suitable material for microwave applications. It is noted for its high Curie temperature and good temperature stability of saturation magnetization. Nickel ferrite (NiFe$_2$O$_4$) is technologically an important ferrite for use in high frequency applications such as at microwave frequencies due to its high resistivity and low losses.

3.4.1.2 Cobalt ferrite

Cobalt ferrite is an important material not only for its magnetic properties but also for its catalytic properties which depends on the textural and morphological characteristics. This kind of ferrite is a spinel but it exhibits a large coercivity differently from the rest of the spinel ferrites [26].

Cobalt ferrite is a well-known hard magnetic material that has been studied in detail due to its high coercivity (5.40 kOe), moderate saturation magnetization (about 80 emu/g), and very high magnetocrystalline anisotropy and possesses remarkable chemical stability and mechanical hardness. Cobalt ferrite finds innumerable applications in stress sensors, as precursors for making ferrofluids and also magnetic refrigerants [33][40].

Cobalt ferrites are used in electrical equipment and electronic devices and are employed in high-frequency applications: telecommunications, quality filter circuits, high frequency transformers, wide band transformers, adjustable inductors, delay lines, and other high frequency electronic circuits, magnetic circuits for both low level and power applications. Some of the advantages of their utility are: low cost, shape versatility, high permeability, temperature and time stability, high electrical resistivity, resultant low eddy current losses over a wide frequency range (10 to 50 MHz) [69].
Recent developments in the field of electrochemical lithium driven reactions have opened a new field of research for the application of cobalt ferrite in the negative electrode of lithium ion batteries. Transition metal compounds can be electrochemically reduced to obtain the transition element in a metallic state and lithium oxide. The resulting nanometric metal particles are embedded in a \( \text{Li}_2\text{O} \) matrix. Although the energy for the subsequent oxidation is large; the close proximity of reagents favors the reversibility of the electrochemical reaction. In previous reports, cobalt containing compounds have demonstrated to deliver high capacity values for a long term cycling. The use of \( \text{CoFe}_2\text{O}_4 \) may provide some advantages as the introduction of a low-cost and environmentally friendly transition metal [22].

3.4.2 Nano-sized ferrites

While nanotechnology has become the latest buzzword in science and technology, the effects of nanotechnology on environment and food chain has become a matter of great concern. Humans, the topmost consumers in the food chain, are likely to face a metal overload and resulting toxicity due to mushrooming of nanotechnology. As far as industrial products are concerned, it is important to control the random release of nanomaterials from manufacturing sites in to the surrounding environment and minimize manufacturing worker’s exposure. So, the need of the hour is to decide on the design criteria which would make engineered nanoparticles, environmentally compatible and also economically viable.

The present era belongs to science and technology of nano materials. It is difficult to single out any field wherein nano technology has not entered. Nano scale Iron oxides/hydroxides form one class of materials having diverse applications in almost all advanced fields including ferrites, piezoelectric, multiferroic materials, drug delivery, adsorbents and so on. The strength comes from the fact that these oxides/composites can be synthesized from
cheap and easily available source. As iron oxides are considered benign to human system, emphasis has been laid on their applications in the biomedical field. Nano composites having one of the components as iron or its oxide/hydroxides are also of importance in a variety of fields.

Nanoparticles often have different properties compared to the bulk material due to increased surface area which results in higher reactivity. A quantum effect which alters the electrical and visual properties due to confinement of electrons also changes the wavelengths. Size-dependent properties are observed such as quantum confinement in semiconductor particles and super paramagnetism in magnetic materials. The properties of materials change as their size approaches the nanoscale as the percentage of atoms at the surface of a material becomes significant.

The properties of nanoparticles are interesting due to the presence of very large and highly disordered grain boundaries. Because of the peculiarities of the grain boundaries, nano-particles exhibit unusual and/or enhanced dielectric properties [40].

3.4.2.1 Magnesium ferrite

Magnesium ferrite (MgFe$_2$O$_4$) is having a spinel structure, low loss characteristic and rectangular hysteresis loop making them highly suitable for use in the area of memory and switching circuits of digital computers and in low-loss microwave devices in microwave radar system. Routinely, these ferrites are synthesized by the chemical reaction between mixed oxides, hydroxides or carbonates [28].

3.4.2.2 Barium ferrite

Ba- ferrites have been used in various components for application at high frequency range due to their very low electrical conductivity, high magnetic anisotropy, high Curie temperature, mechanical hardness, excellent
chemical stability and corrosion resistivity. Recent studies have focused on the synthesis of nanocrystalline powders in order to improve magnetic properties with increase in the surface area of the nano powders to enable sintering of pressed articles at a lower temperatures and fabrication of dense ceramics achieving theoretical density. Barium ferrite also finds its application in the recording media with the emphasis on high-density perpendicular magnetic recording where nano crystalline magnetic thin-film media is required. Furthermore, the nano scale magnetic ferrites are of particular interest due to their chemical compatibility with biological tissues and their unique combination of electronic and magnetic properties [19].

Barium ferrite is one of the magnetic materials, which can be applied to the microwave band, because of its large magneto crystalline anisotropy. It is widely used as a microwave device and electromagnetic wave shielding coating. Substitution for the Fe\(^{3+}\) and Ba\(^{2+}\) is an effective method to vary the magnetic properties of barium ferrite. After the Fe or Ba-ions are substituted with Co–Ti, Zn–Ti, Zn–Sn, Co–Sn, Ni–Zr and Co–Mo the saturation magnetization, coercivity, anisotropy constant and ferromagnetic resonant frequency of barium ferrite are changed. One problem in the electromagnetic wave absorption field is that any material may absorb energy only in a narrow band. If several layers of barium ferrite with the different resonant frequencies are combined to a multilayer structure, it may absorb electromagnetic wave in a wide microwave band. However, the relationship between the ferromagnetic resonant frequency of the barium ferrite and the substitution elements needs to be investigated further. It is well known that some special phenomena possibly appear during ferromagnetic resonance at high frequency, such as multipeak. It is presumed that, this multipeak may increase the microwave absorption capability of barium ferrite [61].
3.4.2.3 Gamma ferrite

Gamma iron oxide (γ-Fe₂O₃) or Maghemite is a ferromagnetic material that is already widely used as magnetic storage media in audio and video recording, magneto-optical devices, magnetic refrigeration, bioprocess, gas sensor and controlled drug delivery [57].

In most cases, Magnetite (Fe₃O₄) and Maghemite (γ-Fe₂O₃) have been employed for magnetic nanoparticles. These iron oxide particles can be formed at low temperatures under mild conditions, and display strong superparamagnetic behavior (thus having a reduced ability to aggregate due to mutual magnetic attraction, since they do not retain magnetization when not exposed to an external magnetic field)[141].

Iron is the fourth most abundant element of the earth’s crust (5.1% of mass). Iron oxides (including oxyhydroxides) should be a kind of natural minerals and geocatalysts. The iron oxides are found in soils and rocks, lakes and rivers, on the seafloor, in air and organism. Major iron oxides include Goethite (α-FeOOH), Hematite (α-Fe₂O₃), Maghemite (γ-Fe₂O₃), Lepidocrocite (γ-FeOOH) and Magnetite (Fe₃O₄). In natural conditions, Hematite usually exists together with Maghemite[62].

Iron (III) oxide in all its forms is one of the most commonly used metal oxides with various applications in many environmental and industrial fields. Iron oxides are components of several ores used for the production of iron and steel, geologically and archeologically important earth-samples, minerals as well as extraterrestrial materials. Due to their hardness, catalytic activity, surface resistivity and the other exceptional (magnetic, optical, electronic) properties, they are used as abrasives, polishing agents, catalysts, gas sensors, pigments, photo anodes for photo electrochemical cells or contrast agents in magnetic resonance imaging[63].
Colloids of Super Paramagnetic Iron Oxide Nanoparticles (SPIONs), Fe₃O₄ (Magnetite) and γ-Fe₂O₃ (Maghemite) with appropriate surface chemistry are considered as promising advanced materials for biomedical applications due to their chemical stability, low toxicity, and suitable magnetization[128].

Amongst iron oxide nanoparticles, Maghemite (γ-Fe₂O₃) is ferromagnetic and characterized by the super paramagnetic relaxation phenomenon, which is strongly affected by particle size, shape and various surface effects. The interesting magnetic properties of nano-structured maghemites are due to finite size effects and/or high surface/volume ratios, thus rendering the study of the interplay between its microstructure and magnetism immensely interesting. Iron oxide nanoparticles are rarely used as catalyst. However, iron oxides have been used as a matrix to prepare the nano-composites which catalyze a variety of heterogeneous catalytic reactions [66].

3.5 ELECTRICAL BEHAVIOUR OF FERRITES

Electrical behaviour of ferrites is explained on the basis of hopping mechanism. The electrical conductivity depends upon method of preparation, amount of impurities, stoichiometry and temperature and hence it is necessary to study this property. Ferrites possess very low conductivity and that is the reason for their considerations for microwave applications. Due to their poor electrical conductivity, they have revolutionized the field of high and ultrahigh frequency electronics with negligible eddy current losses [103].

It is known that, the transition metal monoxides such as MnO, CaO, NiO and ferrites such as cobalt ferrite, nickel ferrite, magnesium ferrite behave as semiconductors with low mobility of charge carriers and an exponential dependence of electrical conductivity on temperature. However, in the case of low mobility materials such as ferrites, the conventional band theory fails to predict the semiconducting properties of these materials. In such cases, the
conduction is explained on the basis of ‘hopping mechanism’. The low resistivities or high conductivities in ferrites are caused by the simultaneous presence of ferrous and ferric ions on equivalent lattice sites (octahedral sites) [18].

The electrostatic interaction between conduction electron (or hole) and nearby ions may result in a displacement of the latter and hence in polarization of the surrounding region so that the carrier becomes situated at the centre of a polarization potential well. The carrier is trapped at a lattice site, if this potential well is deep enough. Its translation to a neighbouring site is determined by thermal activation and this is known as the hopping mechanism. For such a process—of jumping of electrons and holes—the mobilities are found to be proportional to exp (-Q/KT) where Q is an activation energy [18].

The electronic conduction in ferrites is mainly due to hopping of electrons between ions of the same element existing in more than one valence state and distributed randomly over crystallographically equivalent lattice sites. A number of such ions are formed during the sintering of ferrites. Fe$^{2+}$ ions concentration is a characteristic property of a ferrite material and depends upon several factors such as sintering temperature, time and the grain structure. This creation of Fe$^{2+}$ gives rise to electron hopping between Fe ions in 2+ and 3+ valence states. The electronic exchange between Fe$^{2+}$ and Fe$^{3+}$ results in local displacement of charges in the direction of applied electric field and is responsible for the polarization in ferrites. The magnitude of exchange depends on the concentration of Fe$^{2+}$/Fe$^{3+}$ ion pairs present in B-site. The dielectric constant decreases with increasing frequency and then reaches a constant value due to the fact that, beyond a certain frequency of external ac field, the electron exchange between Fe$^{2+}$ and Fe$^{3+}$ cannot follow the alternating field[121].
3.6 MAGNETIC BEHAVIOUR OF FERRITES

Ferrites are having useful electrical and magnetic properties. Ferrites may be considered as compounds containing oxides of iron or metals like cobalt, nickel, zinc and this leads to the formation of magnetic domains. Due to the presence of magnetic domains, ferrites are having special behavior in the presence of magnetic fields leading to a number of electronic applications.

The ferrite sintered at different temperatures will have different microstructure and different magnetic properties. With the rise in temperature, any residual magnetic field induced will become weak and at a predefined temperature residual magnetism disappears. However, the material returns to its usual behavior with a drop in temperature.

Iron, nickel, cobalt and some of the rare earths (gadolinium, dysprosium) exhibit a unique magnetic behavior which is called ferromagnetism. Ferromagnetism manifests itself in the fact that a small externally imposed magnetic field can cause the magnetic domains to line up with each other and the material is said to be magnetized. These magnetic ferrites are finding applications in the fabrication of modern electronic devices. Due to this use of magnetic material, there arises the need in industry to know magnetic materials in more minute details. An attempt to conduct a research in synthesis and characterization of some important ferromagnetic materials has been made. Here; ferrites like Nickel, Cobalt, Gamma ferrites and nano-sized barium ferrite along with nano-sized magnesium ferrite are investigated for their electromagnetic properties. The best method for determining the ferromagnetic nature of a material is to experimentally measure the magnetization-magnetic field (M-H) hysteresis curves. All of these listed properties are of utmost importance in designing and sizing any equipment that makes use of magnetic materials.
All magnetic materials display hysteresis, with hard magnetic materials showing the greatest hysteresis. A word of Greek derivation, hysteresis describes the observation that magnetic materials are highly nonlinear, meaning their response to a stimulus lags behind in a repeatable manner. The stimulus in this case is an applied magnetic field and the material’s response is the magnetization or induction [128]. Hysteresis loop is shown in Fig 3.1 which represents the magnetization 'M' v/s magnetic field strength 'H' for a ferromagnetic,

![Hysteresis Loop](image)

**Fig. 3.1** Magnetization ‘M’ vs magnetic field strength ‘H’ for ferromagnetic material

The different conditions of the hysteresis loop are shown in four quadrants in the Fig 3.1 as explained below,

Point-(a) starting at zero the material follows at first a non-linear magnetization curve and reaches the saturation level, when all the magnetic domains are aligned with the direction of a field; when afterwards driving magnetic field drops to zero, the ferromagnetic material retains a considerable degree of magnetization or "remember" the previous state of magnetization;
Point-(b) at this point, when \( H = 0 \), a ferromagnet is not fully demagnetized and only the partial domain reorientation persists.

Point-(c) Saturation level in the opposite direction of applied field

Point-(d) In order to demagnetize a ferromagnetic material the strong magnetic field of the opposite direction called coercive field \( 'H_c' \) has to be applied [118].

The ever-escalating use of equipment’s working in the microwave (MW) frequency range such as radar, wireless and mobile communication systems and home appliances has resulted in an increase in Electro Magnetic Interference (EMI). This has resulted in an intensive research in the field of ‘MW absorbing materials’ for their use in minimizing the harmful effect of electromagnetic (EM) waves on biological tissues as well as in the form of EMI, along with their so-called use as Radar Absorbing Material (RAM).

Among various types of MW absorbing materials that have been investigated, the magnetic material has been proven to be most functional due to the simultaneous presence of dielectric and magnetic losses. Ferrite materials have been observed to exhibit substantial losses in the vicinity of ferromagnetic resonance (FMR) and dipole relaxation peak[46] [143].

Today magnetic materials are found in numerous products around us- home appliances, electronic products, automobiles, communication equipments and data processing devices and equipments. These materials have now become a vital part of everyday life in modern industries. The magnetic materials used in early applications were metallic magnetic materials. But for frequencies exceeding MHz, metals and alloys are generally not suitable as soft magnets, as the eddy current losses are very high. Ferrites are used today in radio and television, microwave and satellite communication, bubble devices, audio, video and digital recording and as permanent magnets [83].
Ferrite is such a material; its permeability is controlled by the exact composition of the different oxides that make it up (ferric, with typically nickel and zinc) and is heavily dependent on frequency. Also the permeability is complex and has both real and imaginary parts, which translate into both inductive and resistive components of the impedance "inserted" into the line passed through the ferrite. The ratio of these components varies with frequency - at the higher frequencies the resistive part dominates (the ferrite can be viewed as a frequency dependent resistor) and the assembly becomes lossy. So, the RF energy is dissipated in the bulk of the material and resonances with stray capacitances are avoided or damped [82].

The complex permeability is related to two different magnetizing mechanisms: the spin rotational magnetization and the domain wall motion. At low frequency magnetization is lead by magnetic wall displacement, while at high frequency rotation component becomes important. The domain wall motion is more sensitive to the microstructure and is controlled by the ferrite grain size [142]. High magnetic permeability is one important property of ferrites. The high permeability of the ferrites finds application in the cores of the inductors and transformers.

Recently, magnetic materials have been integrated for on chip inductor. For integration of the magnetic films into LSIs with GHz operation, not only high magnetic permeability but also high resistivity is needed to reduce eddy-current loss in the magnetic film [107].

Materials which can absorb microwaves can eliminate electromagnetic wave pollution. Wide spread applications of electromagnetic absorbers have inspired engineers to explore about optimal design with available algorithms. Ideally a thin, light weight and wideband absorber is an optimum one. Many types of the magnetic microwave devices have been devised with dielectric and magnetic substrates. The presences of magnetic material in the
propagating structure results in energy losses due to eddy currents which significantly dampen the electromagnetic waves, thus, the composite with high value of saturation magnetization of ferromagnetic material with extremely low electrical conductivity are used for microwave tuneable devices [74].

3.6.1 Role of ferrites as magnetic materials

The coercive force $H_c$ is the most important property of magnetic materials and it plays important role in the selection of these materials for practical applications. The magnetic materials may be classified into the following two types depending on the values of $M_r$ (Remanent magnetization) and $H_c$ (Coercive magnetic field). However, materials having properties between hard and soft materials are referred to as semi hard magnetic materials

1) Hard magnetic materials
2) Soft magnetic materials

1) Hard magnetic material

These are the materials, which are difficult to be magnetized or demagnetized. It has been observed that the magnetization remains even after the field is switched off. These materials are known as permanent magnets. For hard magnetic material, the area inside the hysteresis loop is expected to be large because it represents the amount of useful energy that can be made available to do work.

2) Soft magnetic materials

These materials are magnetically soft having low $M_r$ and a low $H_c$ values. These materials are also known as soft magnets. These materials can be easily demagnetized. For soft magnetic material, the hysteresis loop area represents undesirable core loss.
Soft magnetic material is mostly used as various inductance components, such as magnetic cores of filters, transformers, deflection, antenna, video magnetic heads and magnetic heads of multiple path communication and so on. Furthermore, the material has also brought potential applications in magnetic liquid absorbing materials [80].

With the rapid development of electronic information industries such as communications and computer networks, the size of electronic apparatus and equipments is miniaturized. Demand for electronic components with high density, light weight, thin type and fine performance is greatly increasing, which accelerates the demand for soft magnetic ferrites with high performance and thus contributes to the development of soft magnetic ferrites in the direction of higher operating frequency and lower power consumption [80].

### 3.7 BEHAVIOR OF FERRITES AT DIFFERENT RANGE OF FREQUENCIES

Ferrites form a very good class of electrical materials because of their high resistivity and low loss behaviour, and hence have vast technological applications over a wide range of frequencies. Ferrites assume special significance in the field of electronics and telecommunication industry because of their novel electrical properties which makes them useful in radiofrequency circuits, high quality filters, rod antennas, transformer cores, read/write heads for high digital tapes and other devices. Hence it is important to study their dielectric behaviour at different frequencies. The dielectric properties of ferrites are dependent on several factors, such as method of preparation, heat treatment, sintering conditions, chemical composition, cation distribution and crystallite size [96]. Similarly, Manganese-zinc ferrites are used widely in telecommunications and related applications [55].

The charge carriers that are responsible for propagating current through a material have different behavior for different applied frequencies. For high
frequency applications, the behavior can be very different. At microwave frequencies (1GHz to 90GHz) the metallic magnetic materials cannot be used. At those frequencies the skin depth is of the order of a few microns and the field does not penetrate the material. The only alternative is to use insulating oxide magnetic materials. The magnetic microwave oxides of technical interest fall in to two groups i.e. spinel ferrites and garnets [18].

Nanocrystalline (10–50 nm) ferrite thin films with spinel cubic structure have been subject of extensive investigation because of their potential applications in high-density magneto-optic recording devices, colour imaging, bioprocessing, magnetic refrigeration and ferro-fluids. In particular, nanocrystalline nickel–zinc ferrite thin films are of great interest at microwave frequencies not only due to properties like high resistivity and lower losses but also because they can be easily prepared at lower annealing temperature. Nickel–zinc ferrite thin films can also be used as non-reciprocal ferrite components on a microwave monolithic integrated circuit (MMIC) based on GaAs and as back layers to improve recording performances at high frequencies [72][103].

All these factors indicated that, there is a wide scope for investigating the structural, magnetic, dielectric and electrical properties of ferrite particles and ferrite nanoparticles for the different applications. However, to our knowledge, few reports are available for these ferrites prepared by the microwave route particularly their electromagnetic properties. The increased concern about environmental protection led to the development of the microwave route and this synthesis method is used for the preparation of all the above mentioned ferrites.

The rare literature data on magnesium, barium and gamma nano ferrites (with respect to their electromagnetic parameters) influenced us to go for a detailed investigation of these ferrites also. All these factors motivated us to go for a
detailed investigation of ferrites, their synthesis, characterization and their possible applications to electronics and communication engineering.

We proceed to the next chapter to discuss experimental details i.e. microwave synthesis of targeted five ferrites and their characterization.

3.8 CONCLUSIONS

The main motivation behind the present investigation is presented here. Different objectives focused in the present research work are also presented. The significance of the five targeted ferrites along with their electrical, magnetic properties is discussed. The behavior of ferrites at different frequencies and having application in Electronics and Communication Engineering field are presented in brief.