CHAPTER V

Conclusion and Future Scope

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5.1 Conclusion

The current work on design of absorbers is focussed on development of suitable materials and structures which can provide consistent absorption over the X-band with reduced thickness, light weight, corrosion resistant and cost effective. The absorber is designed for X-band applications used for the terrestrial microwave radio communication, satellite links, weather monitoring, airborne radar systems etc. The design considerations such as the thickness of the absorber and the absorber impedance are based on the established transmission line model for designing electromagnetic shields.

For obtaining material properties for good absorption, initially absorbing materials are studied and developed. The materials with acceptable absorption properties are then used to fabricate 3 mm thick absorbers. M-type strontium ferrite nanoparticles are synthesized using co-precipitation technique. The particle size variation is achieved by controlling the annealing conditions. Formation of single phase M-type strontium ferrite is confirmed from XRD pattern. The average crystalline size of particles is found to be in the nanometre range. TEM analysis confirms the hexagonal shape of the synthesized ferrite particles. For the particles annealed at 850˚C with crystal lattice plane of anisotropy along c-axis and particle size of ~77 nm, elongated rod like shapes oriented in a particular direction is observed. Nanosized ferrites are reinforced in linear low density polyethylene (LLDPE) in different weight ratios (10 to 70 wt. %).

FTIR spectroscopy is carried out to obtain information on different bond structures of the ferrites and the composites confirming the Sr-O and Fe-O chemical bonds. Density measurement are carried out to ascertain the effect of increase in filler percentage on the density of the composite. Water absorbance studies show marginal increase in the weight of the composites from 0.01 to 0.03 %. TGA studies carried out show that the developed composites are thermally stable up to 400˚C, before they undergo thermal decomposition. Saturation magnetization and hysteresis measurements confirm the magnetic nature of the composites at room temperature. As expected, composites with high filler percentage leading to high saturation magnetization showed better absorption upto a certain filler percentage.

Microwave characterization of ferrite-LLDPE nanocomposites are carried out over the X-band. The complex permittivity and permeability are measured using Nicolson Ross method. $SrFe_{12}O_{19}$ particles annealed at 850˚C with 60 wt. % shows permittivity of ~ 6.1 and permeability of ~ 1.3 and dielectric and magnetic loss tangent of ~ 0.4 and ~ 0.12, respectively.

In a single layer absorber, the absorber thickness is dependent on the frequency of operation with maximal microwave absorption occurring at a thickness of $t_m = (2n+1)\,\lambda_g/4$. The absorption studies carried out for a single layer metal backed composite of ferrite nanoparticles in LLDPE matrix show that for a layer thickness of 3 mm, better absorption is obtained as compared to other prototype thicknesses for the compositions from 55 to 70 wt. %. The best reflection loss of -22.19 dB is obtained at 10.50 GHz with -10 dB absorption bandwidth of 3.36 GHz (8.53-11.89 GHz) for 60 wt. % of the $SrFe_{12}O_{19}$-LLDPE composite.

These initial performances of the strontium ferrite-LLDPE composites so obtained hold the basis of being a potential material and are therefore further studied with different modifications in the concentration and structure that may find application in certain systems where high bandwidth performance is required.

For achieving broadband absorption characteristics, doping elements are introduced in the M- type hexaferrite structure. Aluminium and cobalt are chosen as the two doping elements. The concentration of the aluminium dopant is varied as $x = 0.2$ to 0.8 initially, showing no effect on the absorption performances for the thickness of 3 mm and then varied from 1.0 to 3.0 showing a maximum reflection loss of -26.21 dB at 9.12 GHz with absorption bandwidth of 2.86 GHz (8.78-11.64 GHz) for $x = 2$. Strontium ferrite when doped with cobalt ions ($x = 0.2$ to 1.2) exhibited two resonant peaks evolving one in the lower frequency part and other in the higher frequency part of the X-band. For $x = 0.8$, the composite shows a -10 dB absorption bandwidth of 3.56 GHz (8.84-12.4 GHz) with two distinct absorption peaks better than -20 dB with a maximum reflection loss of -23.2 dB at 9.3 GHz and -22.11 dB at 11.7 GHz Doping with either aluminium or cobalt shifts the resonant frequency towards the lower end of the X-band. Although doping with aluminium has increased the reflection loss, there is a degradation in the absorption bandwidth performance, which may be due to the reduced field anisotropy. On the other hand, when cobalt is used as the doping element; not only the reflection loss increases when compared to $SrFe_{12}O_{19}$-LLDPE nano-composite but also the absorption bandwidth is enhanced.

Reported works on multilayered absorbers in X-band are relatively few, possibly underlining the difficulty in achieving broad bandwidth with low thickness. Techniques to achieve broad bandwidth involve structural modifications (pyramidal, wedge-shaped) which involve a number of parameters e.g. height and width of the base layer as well as the top layer, orientation, shape etc. which makes it difficult to deploy at places where thickness is an issue. In contrast, stacking up of different layers together can provide desired characteristics with low overall thickness to suit the intended application.

Using a double layered absorber shows enhancement of bandwidth for again the same thickness of 3 mm. With proper adjustment of these two layers, viz., the $SrFe_{12}O_{19}$-LLDPE and $SrCo_{0.8}Fe_{11.2}O_{19}$-LLDPE layers, reflection loss of -22.10 dB at 9.1 GHz and -24.40 dB at 10.80 GHz with -10 dB absorption bandwidth of 3.69 GHz (8.45-12.14 GHz) is obtained. An increase in the absorption bandwidth is observed when compared to single layer absorbers using $SrFe_{12}O_{19}$-LLDPE and the doped nano-composites.

Triple layered structures of overall thickness of 3 mm are fabricated using a dielctric layer sandwiched between the two ferrite layers. LLDPE polymer is added as the sandwiched dielectric layer in one of the structures, which showed a maxmium reflection loss of -30 dB at 11.20 GHz with -10 dB absorption bandwidth of 3.70 GHz and -20 dB bandwidth of 0.34 GHz. Studies are also carried out by replacing the sandwiched layer by expanded graphite-LLDPE composite. When the LLDPE layer is replaced by EG-LLDPE layer, the resonant frequency shifts towards the lower range of the X-band. In 8 wt. % of EG-LLDPE composite, three resonant peaks of better than -15 dB are observed. Reflection loss of -15.5 dB at 8.45 GHz, -32.3 dB at 10.0 GHz and -16 dB at 11.6 GHz with -10 dB absorption bandwidth of 4.03 GHz, covering almost the entire X-band is obtained. The -20 dB bandwidth for the same structure is 0.67 GHz. When the performance of sandwiched structures is compared with the double layer structures, it is seen that reducing the thickness of the ferrite layers and by loading the gap with dielectric layers improves the absorption performance.

The results show that M-type strontium ferrite-LLDPE and aluminium and cobalt substituted M-type strontium ferrite-LLDPE nanocomposites can be used as an efficient broad band absorber in X-band with an absorber thickness of 3 mm. The absorbers are sufficiently resistant to change in environmental conditions like temperature and humidity. The constituent materials of the composites are of low cost. The synthesizing technique is simple and can be easily incorporated for mass scale production with some modifications.

Compared to the other reported works for achieving good absorption, the developed ferrite composites yield better absorption along with high -10 dB absorption bandwidth with 3 mm thickness profile by employing modifications. From the application point of view, the $SrFe_{12}O_{19}$-LLDPE absorber and its variations may find their use in radio, satellite and airborne systems. The aluminium and cobalt doped composite absorbers with absorption performance centered around 9.12 GHz (for aluminium) and 9.30 GHz (for cobalt) may find their application in systems like precision approach radar, surface movement radar, airborne weather radar etc. operating in the range of 9.0-9.5 GHz. Other configurations of the double layer structure with absorption performance centered around 9.1 GHz may also be suitable for these applications. The absorption performance of sandwiched structure centered around 10.1 GHz can be used for terrestrial communications and networking (10.00-10.70 GHz).

The evaluations of the developed absorbers are summarized below:

I. Performance of the absorbers in X-band

1. Absorbers designed and fabricated using strontium ferrite and LLDPE shows absorption of -22.19 dB at 10.50 GHz with -10 dB absorption bandwidth of 3.36 GHz (8.53-11.89 GHz).
2. A maximum reflection loss of -26.21 dB at 9.12 GHz and absorption bandwidth of 2.86 GHz (8.78-11.64 GHz) is obtained with the doping of aluminium (x = 2).
3. Strontium ferrite when doped with cobalt ions (x = 0.8) shows an improved -10 dB absorption bandwidth of 3.56 GHz (8.84-12.4 GHz) with two distinct absorption peaks better than -20 dB with a maximum reflection loss of -23.2 dB at 9.3 GHz.

II. Thin, light weighed and environmentally inert absorber

1. With a low thickness of 3 mm, absorbers provide sufficiently good absorption as compared to the work referred in chapterII, ref [45] and chapter III, references [29-31].
2. The absorbers are lightweighed as compared to their bulk counter parts due to low density of 1.36g/cc.
3. The composite system is sufficiently resistant to change in environmental conditions like temperature and humidity (stable up to 400°C and water absorbance of 0.03%) when compared to ref [31] in Chapter III.

III. Ease of processing and cost

1. The synthesizing technique is simple and can be easily incorporated for mass scale production with some modifications as compared to the techniques used in ref [44] in Chapter II, ref [30] in Chapter III and ref [15] in Chapter IV.
2. The cost of development inclusive of the other expenses like electricity etc. for absorber of 15.2 cm x 15.2cm with thickness of 0.3 cm is about Rs. 1150/-. The cost doesn't include the cost of equipment.

IV. Repeatability Studies

The studies are repeated over different intervals of time and results tabulated below. A consistent absorption performance in X- band for the sample is observed.

Table 5.1: Repeatability studies for single-layer absorber ($SrFe_{12}O_{19}$-LLDPE)

Time duration	Results	
	Reflection Loss (GHz)	-10 dB bandwidth (GHz)
Day 1	-22.19	3.36
After one week	-22.19	3.36
After two weeks	-22.19	3.36
After one month	-22.19	3.36
After three months	-22.19	3.36
After six months	-22.18	3.36
After 12 months	-22.18	3.36

The performances of the prepared composites (highlighted in Table 5.2) compared with some of the earlier works are given in Table 5.2. It is observed that for a low thickness of 3 mm, the experimental absorption bandwidth is quite high compared to others.

Table 5.2: Comparison of microwave absorbing properties of recent reported absorbers with the present work (highlighted)

Type	**Material composition**	**Thickness (mm)**	**-10 dB bandwidth (GHz)**		**The reported results are compared with the present work in terms of experimental verification, thickness, -10dB absorption bandwidth and matrix cost**
			Theor.	**Exp.**	
Single layer	* SrF and $ZnFe_2O_4$ in paraffin wax, 2007 *(ref [44], Chapter II)*	2.2	2.21	-	• Reported work is theoretical. • Thickness is marginally less • Absorption bandwidth is less.
	* SrF & carbon black in nitrile rubber, 2013 *(ref [45], Chapter II)*	5.0	-	2.6	• Thickness is more • Absorption bandwidth is less • The cost of matrix is high.
	$SrFe_{12}O_{19}$-LLDPE	**3.0**	4.20	**3.36**	**Present Work**
Doped single layer	* $SrFe_{11.2}Zn_{0.8}O_{19}$ in epoxy resin, 2011 *(ref [29], Chapter III)*	2.5	2.77	-	• Reported work is theoretical. • Thickness is marginally less • Absorption bandwidth is less. • The cost of matrix is high.
	* $SrZn_{2x}Co_xFe_{16}O_{27}$ in epoxy resin, 2015 *(ref [31], Chapter III)*	4.5	2.10	-	• Reported work is theoretical. • Thickness is more. • Absorption bandwidth is less. • The cost of matrix is high.
	* $Sr_{1.96}Gd_{0.04}Co_2Fe_{27.80}Mn_{0.2}O_{46}$ in paraffin wax, 2016 *(ref [30], Chapter III)*	3.5	1.50	-	• Reported work is theoretical. • Thickness is marginally more • Absorption bandwidth is less.
	$SrCo_{0.8}Fe_{11.2}O_{19}$-LLDPE	**3.0**	4.20	**3.56**	**Present Work**
Double layer	* $BaCo_{0.8}Ti_{0.8}Mn_{0.1}Fe_{10.27}O_{19}$, $(Ba(MnTi)_{1.6}Fe_{8.8}O_{19}$ in epoxy resin, 2004 *(ref [14], Chapter IV)*	1.0	-	1.50	• Thickness is less • Absorption bandwidth is less. • The cost of matrix is high.
	* $BaCo_{0.4}Zn_{1.6}Fe_{16}O_{27}$ ferrite & carbonyl iron powder in epoxy resin, 2016 *(ref [15], Chapter IV)*	2.3	4.2	-	• Reported work is theoretical. • Thickness is marginally less • Theoretical absorption bandwidth is same as present work. • The cost of matrix is high.
	* $BaZn_{0.6}Zr_{0.3}Ti_{0.3}Fe_{10.8}O_{19}$, $BaZn_{0.6}Zr_{0.3}Ce_{0.3}Fe_{10.8}O_{19}$, $BaZn_{0.6}Zr_{0.3}Sn_{0.3}Fe_{10.8}O_{19}$ in rubber and epoxy resin, 2017 *(ref [16], Chapter IV)*	5.0	-	1.2	• Thickness is more. • Absorption bandwidth is less. • The cost of matrix is high.
	$SrFe_{12}O_{19}$-LLDPE and $SrCo_{0.8}Fe_{11.2}O_{19}$-LLDPE	**3.0**	4.2	**3.69**	**Present work**

**** Reported work and shaded rows are the present work***

Most of the ferrite based absorbers are thin, heavy showing high reflection loss but small absorption bandwidth. In this work the focus was to develop thin absorbers, light weight absorbers that showed broad absorption bandwidth. To enhance the absorption bandwidth, nanosized magnetic inclusions were considered. The nanosize inclusions increases the surface to volume ratio increasing the interaction with incident *em* waves, this also resulted in reduction in weight as compared to bulk ferrites. Strontium ferrite was chosen as the magnetic filler because of its high anisotropy which enhances the magnetic losses thus more effectively attenuating the wave. The LLDPE matrix used is light weight, resistant to moisture and chemicals and stable upto 100°C and hence the absorbers developed are durable. The fabrication process of absorbers involves thermal molding under controlled pressure conditions. The fabrication process is simple and component materials are of low cost which helps in keeping the costs down.

To sum up the absorbers developed using nanosized strontium ferrite and LLDPE are suitable for X-band applications with a -10 dB absorption bandwidth of ~4.02 GHz covering almost the X-band. The absorbers are thin (thickness of 3 mm) and light weight. The prototypes developed show good repeatability of performance.

5.2 Future scope

In order to find practical use on curved surfaces, absorbers with flexibility are desired without affecting the absorption performance. For conformal mounting, the absorber has to be more flexible and of higher tensile strength to be used as absorbing tapes. In future, absorption studies with flexible polymers on different curved surfaces may be carried out to obtain a detailed understanding of the effects of mounting surface curvatures on absorption performance; studies necessary to choose the appropriate absorber to suite specific application requirements. Moreover, the effects of structuring the absorber surface for ease of mounting can also be explored.

EMI shielding materials developed is confined to X-band only. Absorbers for C-band and Ku-band can be developed with enhanced bandwidth by altering the filler materials as these bands are being increasingly used for newer applications.