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# Electromagnetic shielding effectiveness of woven fabrics having metal coated zari wrapped yarns

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Cotton and metal coated zari wrapped polyester filament yarns in different proportions have been used to produce woven fabrics for evaluating electromagnetic shielding effectiveness (EMSE). Coaxial transmission line measurement technique is used for the measurement of EMSE in the frequency range of 100-1500 MHz. The results show that the type of metal used, percentage of conductive yarns, type of weave and humidity have a significant effect on EMSE.

**Keywords**: Coaxial transmission line technique, Electrical properties, Electromagnetic shielding effectiveness, Woven fabrics, Zari yarn

## 1 Introduction

The sources of generation of electromagnetic waves are both natural and man-made. Sun is a natural source and cell phones, television, radars and other electrical and electronic items are man-made sources of electromagnetic radiations. These waves hamper the life of a person by creating unwanted electromagnetic interference (EMI) in electronic devices and the biological life of a person by having negative effects on people, animals and environment. In human beings, they obstruct generation of DNA and RNA and produce cells with abnormal chemical activities[1, 2].

Electromagnetic shielding is used to alienate external electromagnetic waves from the electromagnetic waves of internal sources and saves human body from such harmful radiations[3,4]. When an electromagnetic wave falls on a shield, its power gets attenuated by reflection, absorption and multiple reflections as shown in Fig. 1. Reflection is the surface phenomenon and blocks the electromagnetic waves because of having mismatch in the wave impedance and surface impedance.

There are publications in the literature on the EMSE of fabrics[2-19] and also on the theoretical calculation of EMSE on the basis of woven fabric parameters[20-24]. Wieckowski *et al.*[25] suggested MIL-STD-285, IEEE-STD-299 and ASTM D-4935 could be used in the frequency range 100 KHz-10 GHz, 9 KHz-18 GHz and 30 MHz-1.5 GHz respectively. Dyurechenskaya *et al.*[26] suggested the use of free space transmission technique with data processing in the frequency range 1-26.5 GHz and claimed more reasonable results than that of ASTM D 4935. Vasquiz *et al.*[27] presented a modified version of ASTM D-4935-99 and claimed it to be more precise than that of ASTM D-4935-99.

Endeavour of this study is to check the EMSE of the fabrics containing metal coated zari wrapped yarns and to study the effect of constructional parameters of the fabric on EMSE. For this purpose, ASTM D-4935 coaxial transmission line method is used to measure EMSE values in the low to medium frequency range (100-1500 MHz).

## 2 Materials and Methods

Zari, a conductive material, is a polyester slit of 0.280 mm width having conductive coating on it. Yarns of 100% cotton and metal coated zari wrapped multifilament polyester conductive yarns (Fig. 2) were used to produce fabrics for this study. The cotton yarn of 2/20 Ne count manufactured on ring frame and the silver/golden zari was wrapped on multifilament polyester yarn with 150 twists per meter. Details of yarns used to produce fabrics for this study are given in Table 1.

The conductive yarns are incorporated with 100% cotton in three different proportions 1:3, 1:5 and 1:7 in the samples. The samples with three different pick densities (1260, 1500 and 1690 per meter), five different weaves (plain, 2/1 twill, 2/2 twill, 5-end satin and honeycomb), same end density of 1575 per meter

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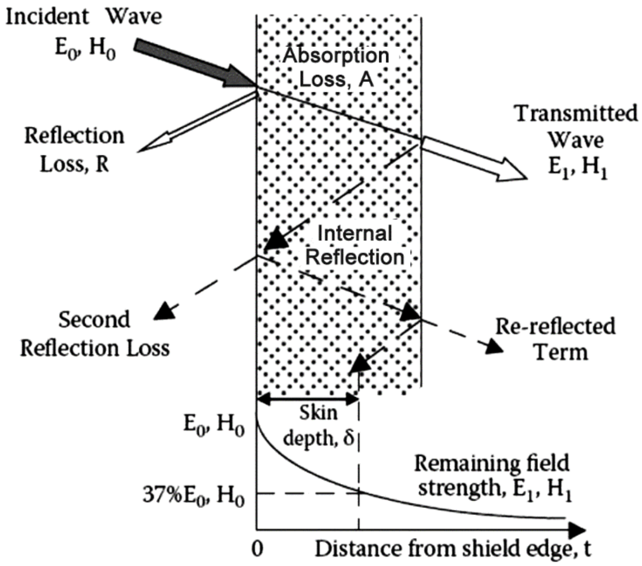


Fig. 1 — Mechanism of shielding[1]

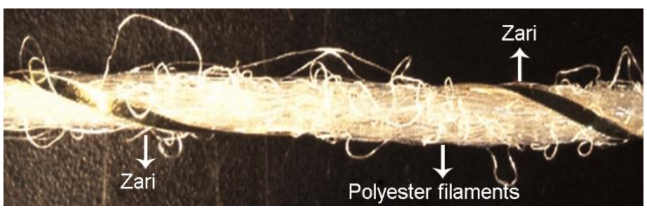


Fig. 2 — Structure of conductive yarn

Table 1 — Yarn characteristics

| Materials | Structure of yarns | Linear density tex |
|---|---|---|
| Cotton | 100% cotton produced on ring frame | 29.5/2 |
| PET and silver | Silver coated zari wrapped on multifilament polyester yarn | 50 |
| PET and gold | Gold coated zari wrapped on multifilament polyester yarn | 50 |

and the conductive yarns incorporated in either warp direction or in both warp and weft directions were produced. The thread density, air permeability and thickness were measured under standard testing conditions (65% RH and 27°C temperature). Details of the samples codes, fabric structure and test results are shown in Table 2.

### 2.1 EMSE Measurement by Coaxial Transmission Line Technique

EMSE measurement was done according to ASTM D 4935 in the frequency range 100-1500 MHz. The measurement system consisted of vector network analyzer, double shielded coaxial cables, N type connectors of 50 ohm impedance and 10 dB attenuators. The test, in this case, was done using a two port network that gives 4 S-parameters. A brief outline on the measurement of S-parameters is shown in Fig. 3. $S_{11}$ and $S_{21}$ were calculated as ratio of reflected to incident power and transmitted to incident power respectively by the instrument. For the sake of convenience, the instrument gives the values in a log-magnitude format (10 log$S_{21}$ and 10 log$S_{11}$). The negative of 10 log$S_{21}$ determines the total electromagnetic shielding effectiveness of the fabric. Average of five tests was used as EMSE for each sample.

### 2.2 Electrical Properties Measurement

Electric properties were measured at million mega-ohm meter (model MM-108 D) at the test voltage of 500 V. The instrument was used for measurement of electric resistance with ±1.5 % accuracy of full scale value of ± 9V. Surface resistivity ($\rho_s$) and volume resistivity ($\rho_v$) were calculated as follows[17]:

$$\rho_s = R_S \frac{2\pi}{In\left(\frac{R_2}{R_1}\right)}$$

$$\rho_v = R_V \frac{S}{t}$$

where $S$ is the surface area; $t$, the fabric thickness; $R_1$ and $R_2$, the inner radius of inner electrode and outer electrode; and $R_s$ and $R_v$, the surface resistance and volume resistance respectively.

## 3 Results and Discussion

Fabric samples are tested for electrical properties on million mega-ohm meter at standard testing conditions. The results for electric resistivity are shown in Figs 4 and 5. EMSE values at different frequencies are obtained by coaxial transmission line method (Fig. 6). It can be seen that the electric resistivity reduces with increase in content of conductive yarn and float of the yarn into the fabric, and EMSE values change depending on frequency of incident wave, fabric constructional parameters and content of conductive yarns.

### 3.1 Electrical Properties

The volume and surface resistivities of the samples containing different amount of conducting yarns are shown in Figs 4 and 5. Figures show that as content of conductive yarn increases, both volume and surface resistivities of the fabric decrease because an increase in content of conductive yarn in fabrics increases

Table 2 — Technical specification of fabric samples

| Sample code | Combination (Warp/weft) | Content of conductive yarn % | Ends per meter /picks per meter | Weave | Air permeability $cm^3/cm^2/s$ | Thickness mm | Float |
|---|---|---|---|---|---|---|---|
| Normal | C/C | 0 | 1575/1500 | Plain | 51.2 | 0.52 | 1 |
| G-P-32-7*0 | (1G, 7C)/C | 6.25 | 1615/1260 | Plain | 64.5 | 0.56 | 1 |
| G-P-38-7*0 | (1G, 7C)/C | 6.25 | 1575/1500 | Plain | 53.4 | 0.58 | 1 |
| G-P-44-7*0 | (1G, 7C)/C | 6.25 | 1575/1690 | Plain | 60.6 | 0.58 | 1 |
| G-P-38-5*0 | (1G, 5C)/C | 8.33 | 1575/1420 | Plain | 55.3 | 0.58 | 1 |
| G-P-38-3*0 | (1G, 3C)/C | 12.5 | 1575/1420 | Plain | 44.7 | 0.67 | 1 |
| G-P-38-5*5 | (1G, 5C)/(1G, 5C) | 16.66 | 1575/1380 | Plain | 67.1 | 0.65 | 1 |
| G-P-38-3*3 | (1G, 3C)/(1G, 3C) | 25 | 1535/1380 | Plain | 66.8 | 0.71 | 1 |
| G-T21-38-3*0 | (1G, 3C)/C | 12.5 | 1575/1380 | 2/1 Twill | 67.5 | 0.75 | 1.5 |
| G-T21-38-7*7 | (1G, 7C)/(1G, 7C) | 12.5 | 1575/1380 | 2/1 Twill | 46.5 | 0.68 | 1.5 |
| G-T21-38-5*5 | (1G, 5C)/(1G, 5C) | 16.66 | 1575/1420 | 2/1 Twill | 45.4 | 0.69 | 1.5 |
| G-H-38-7*7 | (1G, 7C)/(1G, 7C) | 12.5 | 1535/1420 | Honeycomb | 62.4 | 0.85 | - |
| G-H-38-5*5 | (1G, 5C)/(1G, 5C) | 16.66 | 1615/1460 | Honeycomb | 58.6 | 0.86 | - |
| G-H-38-3*3 | (1G, 3C)/(1G, 3C) | 25 | 1575/1420 | Honeycomb | 68.3 | 0.94 | - |
| S-P-38-7*7 | (1S, 7C)/(1S, 7C) | 12.5 | 1535/1535 | Plain | 53.8 | 0.68 | 1 |
| S-P-38-5*5 | (1S, 5C)/(1S, 5C) | 16.66 | 1575/1420 | Plain | 45.6 | 0.71 | 1 |
| S-P-38-3*3 | (1S, 3C)/(1S, 3C) | 25 | 1575/1380 | Plain | 42.9 | 0.79 | 1 |
| S-T21-38-7*7 | (1S, 7C)/(1S, 7C) | 12.5 | 1575/1460 | 2/1 Twill | 56.5 | 0.69 | 1.5 |
| S-T21-38-5*5 | (1S, 5C)/(1S, 5C) | 16.66 | 1650/1500 | 2/1 Twill | 44.9 | 0.71 | 1.5 |
| S-T21-38-3*3 | (1S, 3C)/(1S, 3C) | 25 | 1650/1500 | 2/1 Twill | 44.5 | 0.81 | 1.5 |
| S-T22-38-5*5 | (1S, 5C)/(1S, 5C) | 16.66 | 1575/1535 | 2/2 Twill | 41.4 | 0.73 | 2 |
| S-S5-38-7*7 | (1S, 7C)/(1S, 7C) | 12.5 | 1660/1460 | 5 end satin | 32.6 | 0.95 | 2.5 |
| S-S5-38-5*5 | (1S, 5C)/(1S, 5C) | 16.66 | 1660/1460 | 5 end satin | 20.1 | 1 | 2.5 |
| S-S5-38-3*3 | (1S, 3C)/(1S, 3C) | 25 | 1575/1535 | 5 end satin | 28.6 | 1.2 | 2.5 |
| S-H-38-5*5 | (1S, 5C)/(1S, 5C) | 16.66 | 1660/1460 | Honeycomb | 54.8 | 1.4 | - |
| S-H-38-3*3 | (1S, 3C)/(1S, 3C) | 25 | 1615/1500 | Honeycomb | 52.3 | 2 | - |

G – Gold coated conductive yarn, S – Silver coated conductive yarn, C – Cotton yarn, P – Plain structure, T21 – 2/1 Twill structure, T22 – 2/2 Twill structure, S5 – 5 End satin structure, H – Honeycomb structure and 32, 38 & 44 – pick densities.

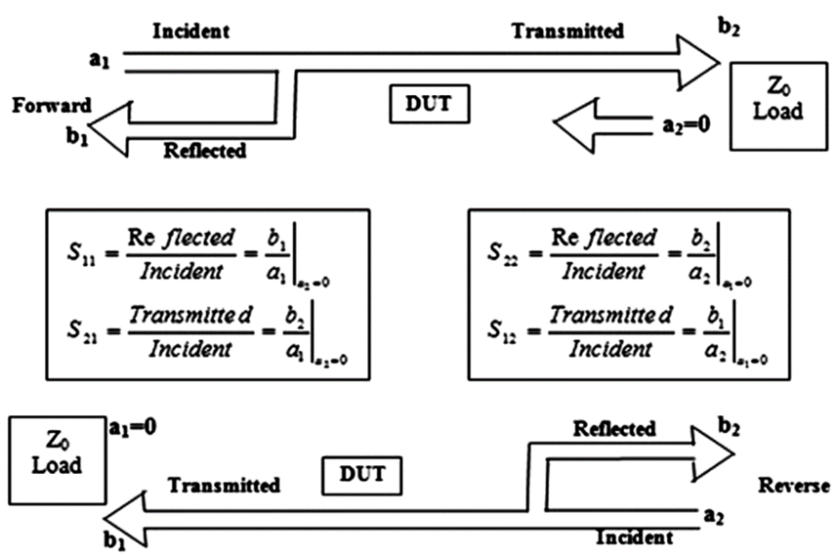


Fig. 3 — Measurement of S parameters using vector network analyzer

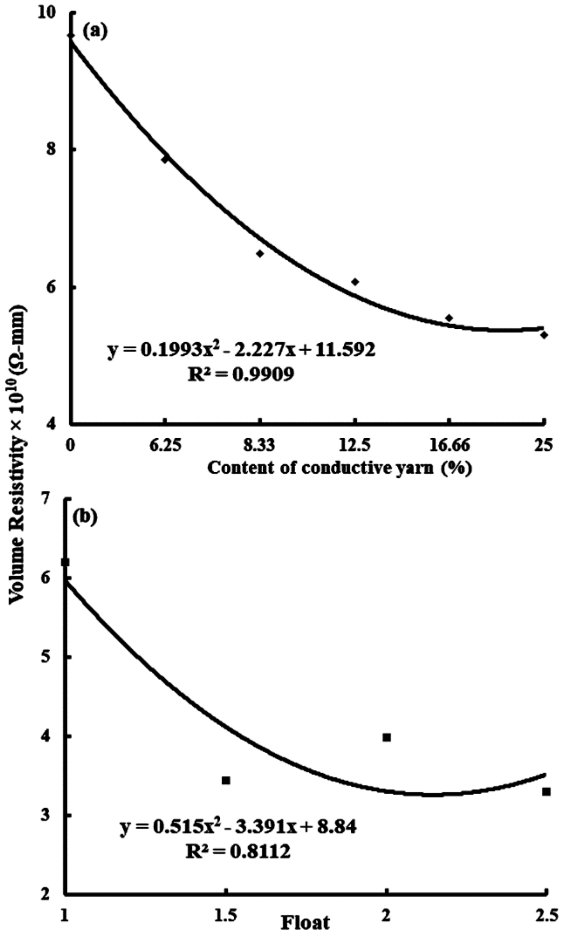


Fig. 4 — Effect of (a) content of silver conductive yarn on volume resistivity and (b) float of silver conductive yarn on volume resistivity

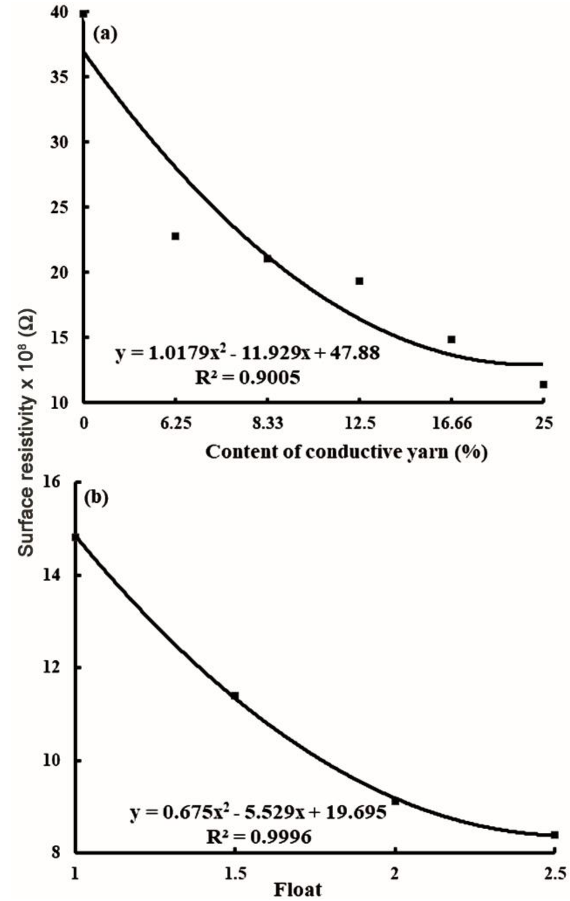


Fig. 5 — Effect of (a) content of gold conductive yarn on surface resistivity and (b) float of gold conductive yarn on surface resistivity

conductivity of fabrics. Table 3 shows that the content of conductive yarn in different fabric samples as G-P-38-7*0 (6.25%), G-P-38-5*0 (8.33%), G-P-38-3*0(12.5%), G-P-38-5*5(16.33%) and G-P-38-3*3 (25%) respectively and resistivities of the fabric samples decreases with an increase in content of conductive yarns. The same decreasing trends can be seen in fabric samples G-H-38-7*7 (12.5 %) to G-H-38-3*3 (25%), S-P-38-7*7 (12.5 %) to S-P-38-3*3 (25 %), S-S5-38-7*7 (12.5 %) to S-S5-38-3*3 (25%) and S-T21-38-7*7 (12.5) to S-T21-38-3*3 (25%). In the beginning the decrease in resistivity is steep, but afterwards it starts to become flat with an increase in content of conductive yarn.

Electric resistivity also changes with the float length of yarn in the fabric sample. More the float, the less is the resistivity (Figs 4 and 5) and this is due to lower crimp and lesser distance to be covered by electricity in structures with higher floats.

### 3.2 Electromagnetic Shielding Effectiveness

#### *3.2.1 Effect of Content of Conductive Yarn*

The shielding effectiveness for different fabric samples having different content of conductive yarns (6.25%, 8.33%, 12.5%, 16.66% and 25%) has been tested. The shielding effectiveness increases with an increase in content of conductive yarn because of increase in fabric conductivity of fabrics. Figure 6 shows that an increase in content of conductive yarn (Table 2) leads to an increase in EMSE values.

Figure 6 also shows that there is first decrease in EMSE values in the frequency range 100-400 MHz, followed by an increase up to 700 MHz of frequency and then again, a decrease up to 1100 MHz frequency. Finally there is again an increase in EMSE values with change in frequency. This trend may be due to change in the skin depth with change in frequency and is observed in all other samples as well. The difference of EMSE values between sample containing metallic

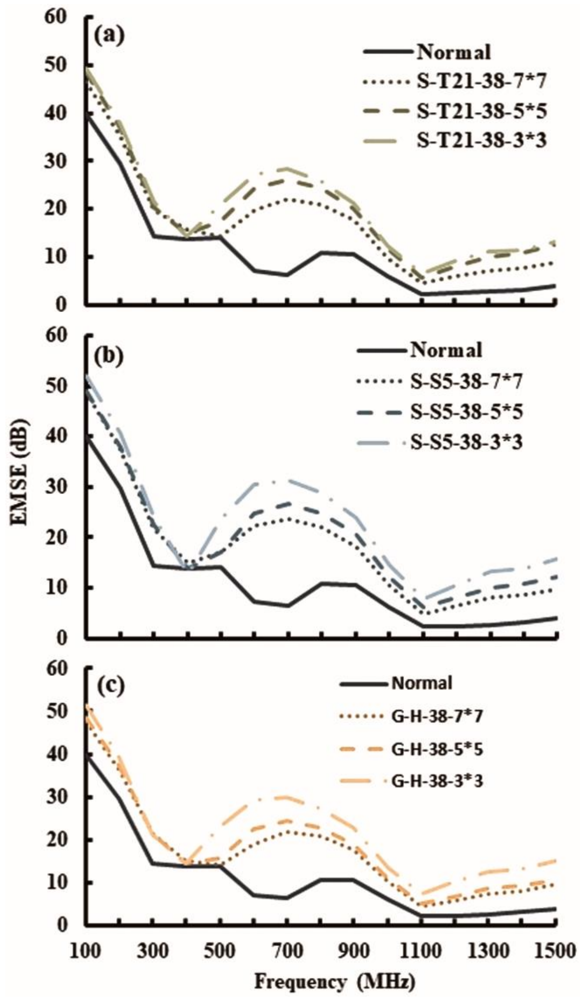


Fig. 6 — (a) EMSE values at different frequencies of twill fabrics with silver coated zari conductive yarns in different proportions, (b) satin fabrics with silver coated zari conductive yarns in different proportions, and (c) honeycomb fabrics with gold coated zari conductive yarns in different proportions

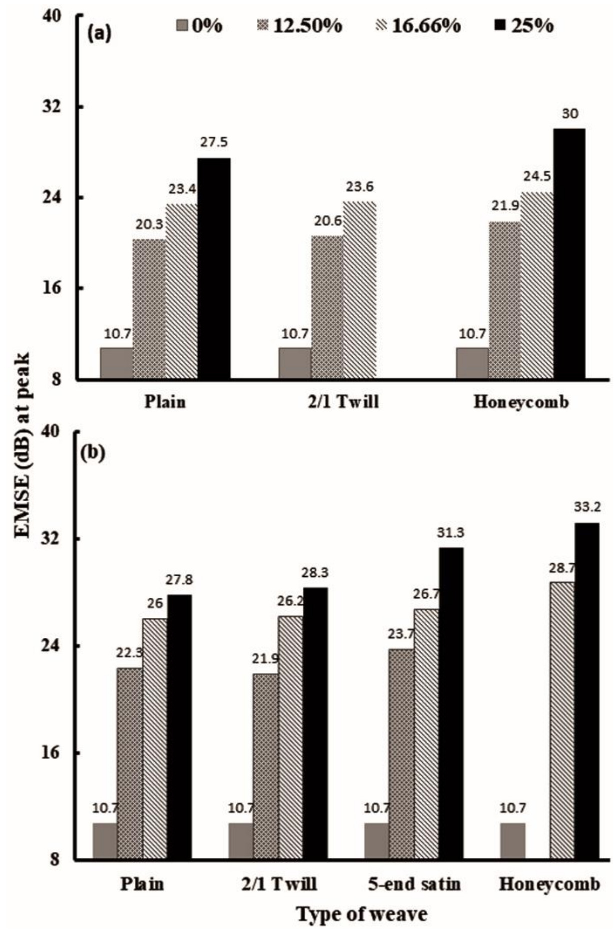


Fig. 7 — Effect of type of weaves and content of silver coated conductive yarn on EMSE values using (a) silver zari and (b) gold zari

yarn and samples made of 100% cotton is significant and can be as high as 22 decibels.

Figure 7(a) shows that as silver conducting yarn content increases, EMSE values increase for all four weaves namely plain, twill, satin and honeycomb. Comparing the effect of weave in Fig. 7 (a), it is observed that for the same conducting yarn content, honeycomb weave shows the highest EMSE value while plain weave shows the least EMSE value. Same trend is also observed in case of gold coated conductive yarn fabric samples [Fig. 7(b)]. The honeycomb weave has more EMSE because of higher thickness than that of other weaves and followed by satin, 2/2 twill, 2/1 twill and plain weaves respectively as shown in Table 2. The difference of EMSE between satin and plain and twill structures is also found significant at 25% conductive yarn content and this is due to more float of satin structures which result in grouping of yarns, leading to reduced porosity and higher thickness.

#### *3.2.2 Effect of Metal Coated Zari Type Used on EMSE Values*

Two types of metal coated zari have been used, namely silver and gold in production of fabric samples. Values for same weave and zari yarn content of silver and gold can be compared in Fig. 7. The effect of type of metal coated zari used on EMSE values shows that fabrics having silver coated conductive yarns have more EMSE values than that of fabrics having gold coated conductive yarns because of more electric conductivity of silver (1.05) than that of gold (0.7) relative to copper[28].

#### *3.2.3 Effect of Humidity on EMSE Values*

The samples G-P-38-5*5 and S-H-38-3*3 are tested at three different humidity of 0% (fabrics kept in oven

Table 3 — Electrical resistivity of different fabrics

| Sample code | Weave | Content of conductive yarn % | Volume resistivity ×$10^{10}$ Ω-mm | Surface resistivity ×$10^{8}$ Ω |
|---|---|---|---|---|
| Normal | Plain | 0 | 9.66 | 39.9 |
| G-P-32-7*0 | Plain | 6.25 | 7.78 | 22.4 |
| G-P-38-7*0 | Plain | 6.25 | 7.85 | 22.8 |
| G-P-44-7*0 | Plain | 6.25 | 8 | 23.1 |
| G-P-38-5*0 | Plain | 8.33 | 6.49 | 21.09 |
| G-P-38-3*0 | Plain | 12.5 | 6.07 | 19.38 |
| G-P-38-5*5 | Plain | 16.66 | 5.55 | 14.82 |
| G-P-38-3*3 | Plain | 25 | 5.3 | 11.4 |
| G-T21-38-3*0 | 2/1 Twill | 12.5 | 6.32 | 22.23 |
| G-T21-38-7*7 | 2/1 Twill | 12.5 | 6.92 | 23.37 |
| G-T21-38-5*5 | 2/1 Twill | 16.66 | 5.46 | 17.1 |
| G-H-38-7*7 | Honeycomb | 12.5 | 7.2 | 18.24 |
| G-H-38-5*5 | Honeycomb | 16.66 | 5.47 | 15.39 |
| G-H-38-3*3 | Honeycomb | 25 | 4.17 | 11.4 |
| S-P-38-7*7 | Plain | 12.5 | 6.23 | 17.1 |
| S-P-38-5*5 | Plain | 16.66 | 6.19 | 14.82 |
| S-P-38-3*3 | Plain | 25 | 5.76 | 12.54 |
| S-T21-38-7*7 | 2/1 Twill | 12.5 | 4.55 | 15.96 |
| S-T21-38-5*5 | 2/1 Twill | 16.66 | 3.44 | 11.4 |
| S-T21-38-3*3 | 2/1 Twill | 25 | 3.29 | 10.26 |
| S-T22-38-5*5 | 2/2 Twill | 16.66 | 3.98 | 9.12 |
| S-S5-38-7*7 | 5 end satin | 12.5 | 3.3 | 10.96 |
| S-S5-38-5*5 | 5 end satin | 16.66 | 3.29 | 8.4 |
| S-S5-38-3*3 | 5 end satin | 25 | 3 | 8 |
| S-H-38-5*5 | Honeycomb | 16.66 | 4.03 | 12.54 |
| S-H-38-3*3 | Honeycomb | 25 | 3.45 | 11.4 |

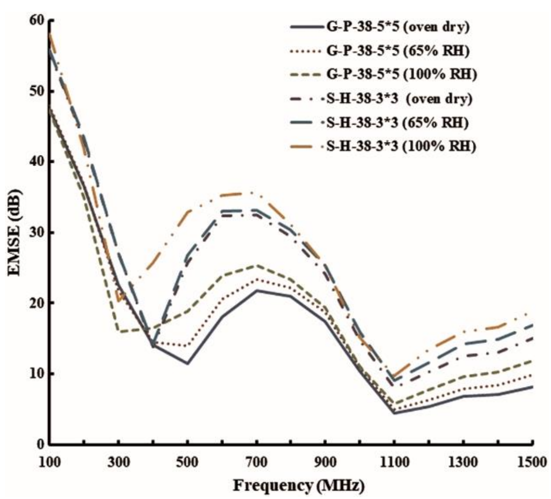


Fig. 8 — Effect of humidity on EMSE values of gold and silver coated conductive yarns at different frequencies

at 105°C for one hour), 65% (fabric at normal testing conditions) and 100% (fabrics kept in desiccators with water for 24 h) and their EMSE values are checked. Figure 8 shows that the fabric samples of 100% humidity have more EMSE values followed by 65% and 0% respectively, because an increase in humidity increases conductivity of the samples.

## 4 Conclusion

It has been observed that with an increase in content of conductive yarn, there is an increase in shielding effectiveness and this increase is significant at the medium frequency range 500-1200 MHz and peak is obtained at the frequency of 700 MHz. The difference of EMSE values between sample containing metallic yarn and samples made of 100% cotton is significant. Honeycomb structures show more shielding effectiveness and followed by satin, 2/2 twill, 2/1 twill and plain structure respectively. Shielding effectiveness of the fabrics with silver coated zari is more than that of fabrics with gold coated zari.

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