The Impact of Choice of Roofing Material on Navaids Wave Polarization

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Abstract
Buildings around aerodromes can influence, alter or distort navigation aid system (navaids) signals between the aircraft and ground equipment and therefore risking loss of intelligence in the transmissions. Such interference could have devastating effects on flight navigation especially during landing. Studies on various obstacles on microwave signal transmission have been conducted but very little to investigate and compare the effects of these obstacles on navaids wave polarization. This paper thus focuses on the choice of roofing materials and how they impact on navaids wave polarization. A transmitter, a receiver and a computer to measure signal level transmitted through roofing materials at a frequency of 9.4GHz were used. The study considered effects of decra, iron, steel, aluminum, plastic and clay materials on navaids wave polarization. From the results, roofing materials have no significant effect on wave polarization. This means that roofing materials have little effect on radiation patterns and therefore radiation patterns cannot be altered by the same in the propagation path. Signal strength depends on angle of incidence and wave polarization. Based on these findings, building industry and flight navigation authorities have been challenged to develop a compromise roofing material.

Keywords: Navaids, Roofing Materials, Transmission, Wave Polarization.

1. Introduction

The ability of the aircraft to navigate the air space expeditiously and safely by conforming to flight rules; and without fear of getting lost or endangering lives and property of those on board and on the ground is largely dependent on radio navigation systems.

Some radio navigation systems are airborne-based relying on the reception of signals from one or more beacons on the ground. Others may be ground-based systems which require transmissions from an aircraft. A third type of navaids is based on signals received from three or more satellites.

This paper considers ground based navaids whose signals are likely to interact with obstacles such as roofing materials on structures around aerodromes. To illustrate the effects of this interaction, the study chose to investigate operations of three main navaids namely; Distance Measuring Equipment (DME), Instrument Landing System (ILS) and Very High Frequency Omni-directional Range (VOR) equipment.

DME uses basic radio telemetry to provide information on the distance between the aircraft and the ground station. It manipulates both the radio signal received from an on-board interrogator and the reply transmitted from the ground transponder. The principle is based on distance = time x speed where speed is the velocity of electromagnetic wave.

When an aircraft is about to make an approach and landing on an airport runway during bad weather conditions, there is need to radiate navigational information to carter for lost visibility (ICAO Doc 8071, 2010). Instrument Landing System (ILS) is used for this purpose. ILS is a ground-based instrument approach system that provides precision guidance to an aircraft approaching and landing on a runway, using a combination of radio signals, visual and aural indications to enable a safe landing during bad weather.

The VOR operates on principle that the phase difference between two signals can be employed as a means of determining azimuth (direction and bearing) if one of the signals maintain a fixed phase through 360 degrees (so that it may be used as a reference) and the phase of the other is made to vary as a direct function of azimuth.

1.1 Polarization of radio antennas

The polarization of an antenna is the orientation of the electric field (E-plane) of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna, orientation and excitation fed to it. It has something in common with antenna directionality; horizontal, vertical, and circular. Thus, a simple straight wire antenna will have one polarization when mounted vertically, and a different polarization when mounted horizontally (Figure 1) Electromagnetic wave polarization filters are structures which can be employed to act directly on the electromagnetic wave to filter out wave energy of an undesired polarization and to pass wave energy of a desired polarization (Briendenbach & Kloza, 2007; Sandiku, 2001; Hayt, 2003). Navaids equipment such as Instrument Landing System (ILS) and Doppler VHF Omni-directional Range (DVOR) are installed with horizontally polarized orientation whereas Distance Measuring Equipment (DME) and Secondary Surveillance Radar (SSR) are vertically polarized.

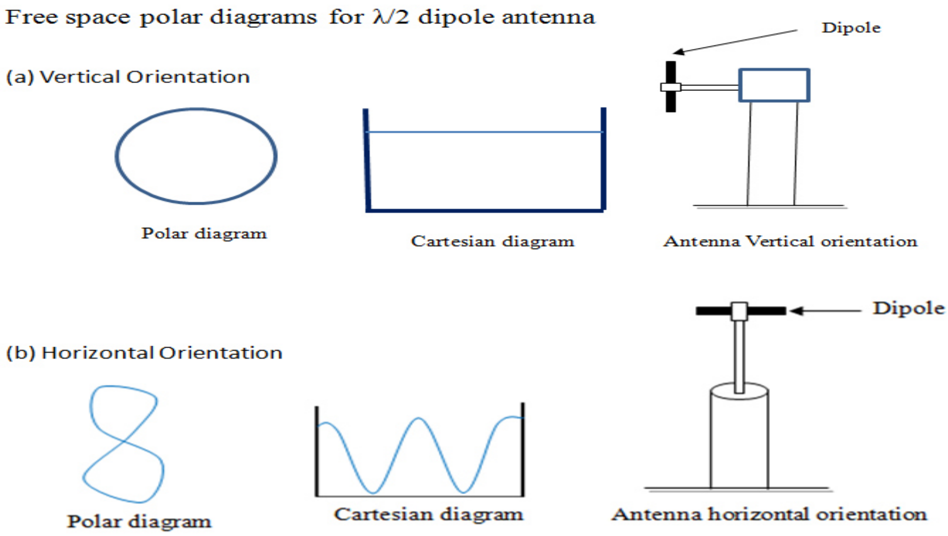

Figure1. Free space polar diagrams for λ/2 antenna

Directional diagrams can be measured in horizontal or vertical mode. Usually the horizontal mode means a rotation of the test antenna in the electric or E-Plane. The vertical mode means a rotation of the test antenna in the magnetic or H-plane.

1.2 Standards for navaids signals

International Civil Aviation Organization, ICAO, (Doc 8071 Rec. 2.3.5, 2010) notes that VOR polarization effect results from vertically polarized RF energy being radiated from the antenna system. It recommends that the presence of undesired vertical polarization should be checked.

The VOR antenna shall employ horizontal polarization with Omni-directional radiation pattern. Momentary deviations off the course due to roughness, scalloping or combinations thereof should not exceed 3 degrees from the average course. Designated operational coverage of en-route VOR should be 200NM (ICAO Doc 8071 Rec.2.3.13, 2010). The VOR minimum field strength to be protected throughout the designated operational coverage should be 39dBuV/M (90µV equivalent to -21dBmV/M) or power density of -107dBW/M^2 (ICAO Doc 8071 Rec. 3.2.2.2, 2010).

ILS localizer and glide path shall have signal input level from -104dBm to -18dBm. The minimum field strength to be protected throughout the ILS localizer front course is 32 dBµV/M (40 µV/M equivalent to -28dBmV/M) or power density of -114dBW/M^2. The ILS localizer signal shall be horizontally polarized. The localizer shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation within the localizer and glide path coverage sectors. The localizer coverage sector shall extend from the centre of the localizer antenna system to distances of 25 NM within ±10° from the front course line; 17 NM between 10° and 35° from the front course line; 10 NM outside of ±35° if coverage is provided. The GP radial coverage shall be at least 10NM. DME receiver sensitivity shall be -89dBm (ICAO Annex 10 Vol. 1, 2012).

2. Materials and Methods

East African School of Aviation laboratory for aeronautical telecommunications was the preferred site for this experiment. The main reason for using this laboratory was because it is strategically designed and equipped to serve as a research and development centre for aeronautical telecommunications and avionics.

The equipment and instruments for the study included the Gunn Oscillator whose purpose was to generate microwave frequency tuned at 9.4 GHz. This translates to a wavelength (λ) of 32 mm and further translates to dipole aerial physical lengths of 8 mm (λ/4) and 16 mm (λ/2). These physical lengths were easily handled in a laboratory environment. Thus a choice of 9.4 GHz was the strategy to comfortably manage the experiment in a laboratory. A PIN modulator was used to modulate 10mW microwave signal before transmission.

The experiment was set up as in Figure 2 below. The distance between the transmitter and the receiver was fixed at 100 cm and the antenna orientation was varied from vertical, horizontal to circular polarization. The test materials were inserted one after the other at the centre between the receiver and the transmitter. The material variation ranged from None, Decra, Aluminum, Iron, Clay, steel to plastic. The angle of incidence was varied from -180 degrees to +180 degrees at intervals of 0.5 degrees. The propagated received signal level was captured by the computer system and recorded in steps of 15 degrees from 0 to 180 degrees as shown in Table 1.
The received signal level (RSL) was then converted to received signal ratio factors (RSR) and converted to dB by formula; RSR(dB) = 20Log(RSR). This is presented in table 4.

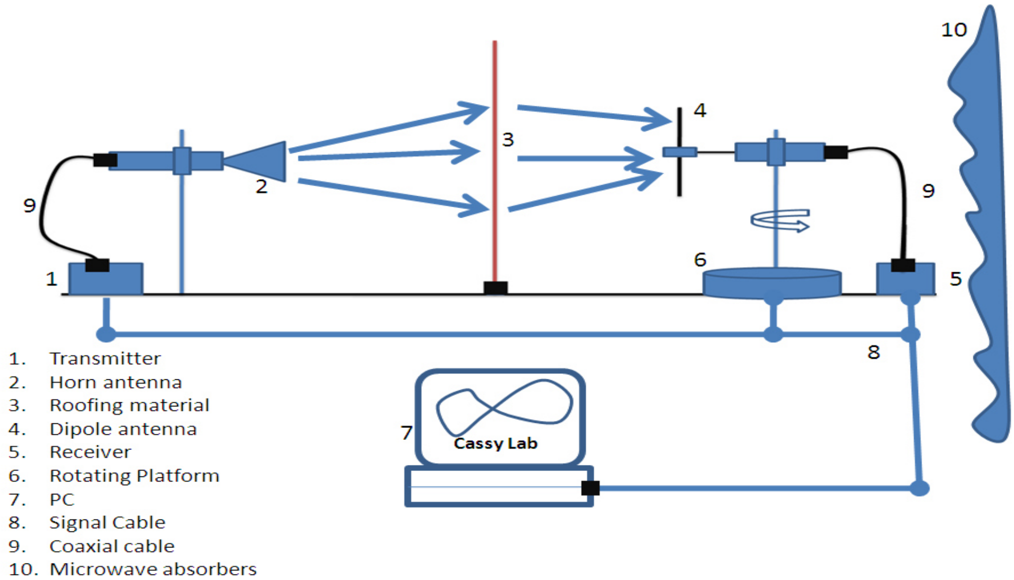

Figure 2. Equipment set up for Measuring Attenuation in Roofing Materials

3. Results and Discussion

The mean RSRs for each of the 6 materials and for each of the 3 given orientations was tabulated in Table 1 and the values converted to dB as in Table 2. This table assumes that the effect of angle of incidence is nil or constant.

Table 1. Effects of roofing materials on Navaids wave polarization (P-RSR)

	Mean Received Signal Ratios (P-RSR)			
	Distance = 100, assume effects of A = constant			
Polarization	Horizontal	Vertical	Circular	Mean
Materials				
Iron	0.93	0.23	0.18	0.45
Clay	0.84	0.66	0.27	0.59
Plastic	0.56	0.85	0.75	0.72
Aluminum	0.43	0.07	0.18	0.23
Steel	0.20	0.09	0.09	0.13
Decra	0.10	0.03	0.03	0.05
Mean	0.51	0.32	0.25	

Table 2. Effects of roofing materials on Navaids wave polarization (dB)

	Mean received signal ratios in dB Distance = 100, assume effects of A = constant			
Polarization	Horizontal	Vertical	Circular	Mean
Materials				
Iron	-0.63	-12.8	-14.9	-9.43
Clay	-1.51	-3.61	-11.4	-5.50
Plastic	-5.04	-1.41	-2.50	-2.98
Aluminum	-7.33	-23.1	-14.9	-15.1
Steel	-14.0	-20.9	-20.9	-18.6
Decra	-20.0	-30.5	-30.5	-27.0
Mean	-8.08	-15.38	-15.84	

Figure 3 was generated from Table 1 and indicates the variation of wave polarization with roofing materials. MS Excel data analysis tool kit was used to perform ANOVAs two-factor analysis to determine if roofing materials have any significant effect on wave polarization.

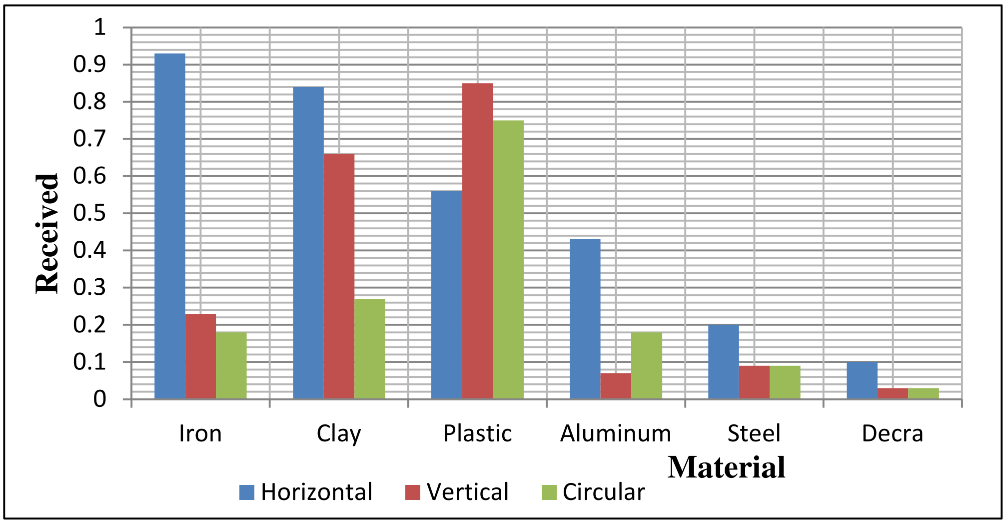

Figure 3. Effects of materials on Navaids wave polarization at constant angle

Figure 3 shows that iron and clay have the highest horizontal polarization response. It means that horizontally polarized Navaids signals are better propagated via iron and clay than other roofing materials. The figure further shows that vertically polarized signals are better propagated in plastic and clay than in any other material. It also shows that circularly polarized signals are best propagated in plastic roofing materials than all the rest. However the result does not provide evidence about significant differences between these materials. When assuming that the effect of angle of incidence is constant, the ANOVAs 2-factor analysis results showed that Fcrit > F-value and the range of P-value is $0.05<P<0.95$ for a 2-tailed test when polarization columns were considered. This implies that there is sufficient evidence to state that the three polarization methods do not have a significant difference. However there is evidence to show that at least one pair of the material types differ; which particular pairs differ remains the same as deduced by the effect these materials have on the navaids signal strength. See table 4a-g for statistical analysis.

Table 3. Effects of angle of incidence on navaids wave polarization

	Mean received signal ratios in P-RSR												
Angle	0	15	30	45	60	75	90	105	120	135	150	165	180
Polarization													
Horizontal	0.37	0.38	0.39	0.56	0.57	0.6	1.85	0.43	0.3	0.23	0.26	0.3	0.32
Vertical	0.18	0.17	0.25	0.4	0.45	0.33	0.29	0.21	0.33	0.37	0.38	0.37	0.42
Circular	0.18	0.26	0.13	0.18	0.21	0.2	0.19	0.34	0.25	0.24	0.39	0.33	0.34

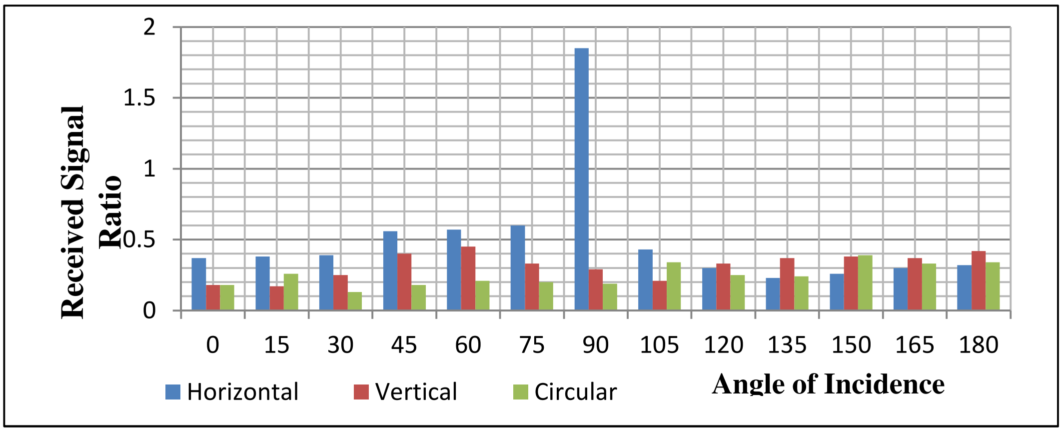

Figure 4. Effects of angle of incidence on wave polarization

By holding the type of material constant, the angle of incidence was manipulated with reference to mode of wave polarization. See Figure 4 which is derived from Table 3.

The maximum P-RSR for horizontally polarized wave was at 90 degrees however for vertical and circular polarizations the maximums were found to be at 60 and 150 degrees respectively. The combined effect type of roofing material and angle of incidence on wave polarization was not considered.

3.1 Tabulated Representation of Roofing Materials' Effect on Wave Polarization

Table 4a: Effects of Roofing Materials on Horizontally Polarized Wave - (RSL)

Received Signal Level in mV Distance (D) = 100 cm; Polarization = Horizontal														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	8.08	6.6	3.88	1.37	0.67	0.32	0.08	0.41	1.02	2.54	4.8	7.63	7.63	**3.5**
Iron	4.69	3.91	2.52	1.39	0.64	0.3	0.32	0.42	0.61	0.96	2.41	3.3	3.62	**1.9**
Clay	4.72	3.93	2.87	1.19	0.67	0.51	0.3	0.13	0.17	0.52	1.36	2.98	3.42	**1.8**
Plastic	4.91	3.7	1.55	0.25	0.04	0.02	0.09	0.37	0.78	1.67	3.07	4.74	4.85	**2**
Aluminı	2.39	2.5	1.94	1.3	0.59	0.2	0.11	0.03	0	0.08	0.45	1.1	1.54	**0.9**
Steel	1.21	0.88	0.16	0.4	0.24	0.06	0.02	0.09	0.22	0.53	0.98	1.55	1.32	**0.6**
Decra	0.1	0.09	0.12	0.12	0.09	0.07	0.05	0.03	0.06	0.01	0.12	0.11	0.06	**0.1**
Mean	**3.73**	**3.09**	**1.86**	**0.86**	**0.42**	**0.21**	**0.14**	**0.21**	**0.41**	**0.9**	**1.88**	**3.06**	**3.21**	

Table 4b: Effects of Roofing Materials on Horizontally Polarized Wave - (RSR)

Received Signal Ratio Distance (D) = 100 cm; Polarization = Horizontal														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	1	1	1	1	1	1	1	1	1	1	1	1	1	
Iron	0.58	0.592	0.649	1.015	0.955	0.938	4	1.024	0.598	0.378	0.502	0.433	0.474	**0.9**
Clay	0.584	0.595	0.74	0.869	1	1.594	3.75	0.317	0.167	0.205	0.283	0.391	0.448	**0.8**
Plastic	0.608	0.561	0.399	0.182	0.06	0.063	1.125	0.902	0.765	0.657	0.64	0.621	0.636	**0.6**
Aluminı	0.296	0.379	0.5	0.949	0.881	0.625	1.375	0.073	0	0.031	0.094	0.144	0.202	**0.4**
Steel	0.15	0.133	0.041	0.292	0.358	0.188	0.25	0.22	0.216	0.209	0.204	0.203	0.173	**0.2**
Decra	0.012	0.014	0.031	0.088	0.134	0.219	0.625	0.073	0.059	0.004	0.025	0.014	0.008	**0.1**
Mean	**0.37**	**0.38**	**0.39**	**0.56**	**0.57**	**0.6**	**1.85**	**0.43**	**0.3**	**0.23**	**0.26**	**0.3**	**0.32**	

Table 4c: Effects of Roofing Materials on Vertically Polarized Wave - (RSL)

Received Signal Level in mV Distance (D) = 100 cm; Polarization = Vertical														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	10.22	8.5	13	14.71	10.13	12.86	6.13	14.28	9.96	7.98	6.19	8.11	12.52	**10**
Iron	1.17	1.08	0.58	1.35	2.1	3.48	2.71	3.11	1.85	1.57	1.87	3.38	4.05	**2.2**
Clay	0.97	1.31	7.55	16.89	16.38	14.34	2.73	4.1	4.94	4.58	3.2	4.28	12.91	**7.2**
Plastic	8.68	5.26	9.56	9.76	5.9	7.42	4.33	9.24	12.21	10.08	7.28	8.62	11.93	**8.5**
Alumini	0.12	0.17	1.74	4.87	1	0.12	0.38	0.34	0.13	0.27	0.47	0.46	0.96	**0.9**
Steel	0.31	0.51	0.17	2.15	2.05	0.3	0.3	0.72	0.27	0.5	0.89	1.24	1.89	**0.9**
Decra	0.04	0.16	0.13	0.36	0.1	0.17	0.23	0.4	0.28	0.77	0.52	0.32	0.13	**0.3**
Mean	**3.07**	**2.43**	**4.68**	**7.16**	**5.38**	**5.53**	**2.4**	**4.6**	**4.23**	**3.68**	**2.92**	**3.77**	**6.34**	

Table 4d: Effects of Roofing Materials on Vertically Polarized Wave - (RSR)

Received Signal Ratio Distance (D) = 100 cm; Polarization = vertical														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	1	1	1	1	1	1	1	1	1	1	1	1	1	
Iron	0.114	0.127	0.045	0.092	0.207	0.271	0.442	0.218	0.186	0.197	0.302	0.417	0.323	**0.2**
Clay	0.095	0.154	0.581	1.148	1.617	1.115	0.445	0.287	0.496	0.574	0.517	0.528	1.031	**0.7**
Plastic	0.849	0.619	0.735	0.663	0.582	0.577	0.706	0.647	1.226	1.263	1.176	1.063	0.953	**0.9**
Alumini	0.012	0.02	0.134	0.331	0.099	0.009	0.062	0.024	0.013	0.034	0.076	0.057	0.077	**0.1**
Steel	0.03	0.06	0.013	0.146	0.202	0.023	0.049	0.05	0.027	0.063	0.144	0.153	0.151	**0.1**
Decra	0.004	0.019	0.01	0.024	0.01	0.013	0.038	0.028	0.028	0.096	0.084	0.039	0.01	**0**
Mean	**0.18**	**0.17**	**0.25**	**0.4**	**0.45**	**0.33**	**0.29**	**0.21**	**0.33**	**0.37**	**0.38**	**0.37**	**0.42**	

Table 4e: Effects of Roofing Materials on Circularly Polarized Wave - (RSL)

Received Signal Level in mV Distance (D) = 100 cm; Polarization = Circular														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	0.51	0.09	0.29	0.64	0.7	1.47	1.98	2.35	1.19	8.4	5.62	23.92	21.2	**5.3**
Iron	0.07	0	0.02	0.06	0.06	0.14	0.33	0.28	0.61	1.52	2.73	5.39	4.54	**1.2**
Clay	0.11	0	0.04	0.13	0.13	0.33	0.33	0.77	0.07	1.93	2.37	14.29	15.78	**2.8**
Plastic	0.31	0.11	0.12	0.47	0.54	1.08	1.4	2.91	0.33	6.87	3.87	20.36	14.79	**4.1**
Aluminum	0.06	0.03	0.02	0	0.02	0.09	0.08	0.32	0.65	1.01	1.82	4.21	8.09	**1.3**
Steel	0.01	0	0.02	0.02	0.08	0.08	0.09	0.51	0.01	0.83	1.89	2.61	0.42	**0.5**
Decra	0	0	0	0	0.05	0.05	0.04	0.05	0.08	0.18	0.61	0.85	0.51	**0.2**
Mean	**0.15**	**0.033**	**0.07**	**0.19**	**0.23**	**0.46**	**0.61**	**1.03**	**0.42**	**2.96**	**2.7**	**10.2**	**9.33**	

Table 4f: Effects of Roofing Materials on Circularly Polarized Wave - (RSR)

Received Signal Ratio Distance (D) = 100 cm; Polarization = Circular														
Angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	
Materials														**Mean**
None	1	1	1	1	1	1	1	1	1	1	1	1	1	
Iron	0.137	0	0.069	0.094	0.086	0.095	0.167	0.119	0.513	0.181	0.486	0.225	0.214	**0.2**
Clay	0.216	0	0.138	0.203	0.186	0.224	0.167	0.328	0.059	0.23	0.422	0.597	0.744	**0.3**
Plastic	0.608	1.222	0.414	0.734	0.771	0.735	0.707	1.238	0.277	0.818	0.689	0.851	0.698	**0.8**
Aluminum	0.118	0.333	0.069	0	0.029	0.061	0.04	0.136	0.546	0.12	0.324	0.176	0.382	**0.2**
Steel	0.02	0	0.069	0.031	0.114	0.054	0.045	0.217	0.008	0.099	0.336	0.109	0.02	**0.1**
Decra	0	0	0	0	0.071	0.034	0.02	0.021	0.067	0.021	0.109	0.036	0.024	**0**
Mean	**0.18**	**0.26**	**0.13**	**0.18**	**0.21**	**0.2**	**0.19**	**0.34**	**0.25**	**0.24**	**0.39**	**0.33**	**0.34**	

Table 4g: ANOVA Results for Interaction of Roofing Materials and Wave polarization

SUMMARY	Count	Sum	Average	Variance
Iron	3	1.34	0.45	0.175
Clay	3	1.77	0.59	0.085
Plastic	3	2.16	0.72	0.022
Aluminum	3	0.68	0.23	0.034
Steel	3	0.38	0.13	0.004
Decra	3	0.16	0.05	0.002
Horizontal	6	3.06	0.51	0.112
Vertical	6	1.93	0.32	0.121
Circular	6	1.5	0.25	0.067

ANOVA

Source of Variation						
Materials	1.069	5	0.213	4.99	0.015	3.326
Polarization	0.216	2	0.108	2.529	0.129	4.103
Error	0.428	10	0.043			
Total	1.713	17				

Since Fcrit > F and $0.05<p<0.95$ is true for polarization factor, therefore we state that there is no significant difference between the types of polarization.

4. Conclusion

The effects of roofing materials on wave polarization was determined by testing horizontally, vertically and circularly polarized waves via selected roofing materials inclined at specified angles of incidence. In horizontal polarization mode, Iron and clay provides higher propagation level than the rest whereas plastic has the highest propagation in vertical and circular polarization modes. Horizontal, vertical and circular polarization modes have different maximum propagation angles positioned at 90, 60 and 150 degrees respectively.

Despite the differences a statistical analysis revealed that roofing materials have little effect on wave polarization. It is evident that roofing materials have no significant effect on radiation patterns. Therefore a radiation pattern which is a prime variable in the operation of navaids systems cannot be altered by the presence of roofing materials in the propagation path.

5. Recommendation

The highest reflections were found to occur at angles of incidence of 90, 60, and 150 degrees for horizontal, vertical and circular polarization respectively. Roofed structures in the flight path should be designed to avoid these angles of incidence.

Whereas roofing materials had no significant effect on wave polarization, the author recommends a further study to determine the interaction effect of roofing material and angle of incidence on wave polarization.

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