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COMPARISON OF THE EFFECTS OF VARIOUS ROOFING MATERIALS ON NAVAIDS TRANSMISSION DISTANCE

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ABSTRACT: *The occurrence of interference that causes partial loss of intelligence in air navigation signal is largely dependent on total environment around radio navigation aid systems (navaids). Directional antenna polar 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 and magnetic or H-plane for the vertical mode. This paper compares the effect that selected roofing materials have on Navaids transmission distance. To achieve this, a transmitter, a receiver and a computer to measure signal level transmitted through roofing materials at a frequency of 9.4GHz are used. The study considered effects of decra, iron, steel, aluminum, plastic and clay materials on navaids transmission distance. The study found that effects of roofing materials on transmission distance varied depending on the type of selected roofing material. Signals via plastic materials decreased with distance as those via aluminum increased with distance. However the overall effect of roofing materials on transmission distance was not significant since the received signal was within the recommended strength. Also the materials had path loss exponent factors of between 3.0 to 3.7 which meant that the rate at which the signal was propagated through these structures was significantly slower than in free space where exponent factor is 2. It is recommended that studies be directed in conducting experiments in open fields and factoring in sources of variability arising from the environment so as to relate to the actual scenario of flight navigation.*

KEYWORDS: Roofing Materials, Navaids, Transmission, Distance

INTRODUCTION

Air navigational aids (navaids) are radio communication systems used to provide navigation guidance to flights. The guidance includes direction, distance, lateral and inclination angles of the flight path. Navaids operate in Line of Sight (LOS) mode of propagation. LOS is the mode of propagation whereby the transmitter is able to 'see' the receiver in a straight line, in one direction and with no obstructions. The maximum radius for line of sight propagation is 100 km (Gupta, 2005). The LOS propagation caters for microwaves belonging to the radio band of VHF, UHF and SHF (300MHz to 30GHz) as defined in Table 1. The intelligence of navaids is contained in signal strength, phase angle, delay, depth of modulation and radiation pattern.

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Table 1. Frequency Bands, Wavelengths and Radio Band Designations

Frequency	Wavelength	Radio band	Use
30-300 Hz	10-1 Mm	ELF (Extreme Low Frequency)	
300-3000 Hz	1000-100k	ULF (Ultra Low Frequency)	
3-30 KHz	100-10 km	VLF (Very Low Frequency)	
30-300 KHz	10-1 km	LF (Low Frequency)	
300-3000 KHz	1000-100 m	MF (Medium Frequency)	
3-30 MHz	100-10 m	HF (High Frequency)	
30-300 MHz	10-1 m	VHF (Very High Frequency)	VOR, VHF Radio
300-3000 MHz	100-10 cm	UHF (Ultra High Frequency)	GP ILS, DME,
3-30 GHz	10-1 cm	SHF (Super High Frequency)	Radar, Cell-phones
30-300 GHz	10-1 mm	EHF (Extreme High Frequency)	

Adapted from Kenya Table of Frequency Allocations (CCK, 2008)

Communications Authority of Kenya (CAK) allocated frequency band K185 (9.3 – 9.5 GHz) to aeronautical radio navigation service for ground based surveillance systems. The authority recommends that for a frequency band in the region above 5.7 GHz with maximum Equivalent Isotropically Radiated Power (EIPR) of 200 mW, a Power Spectrum Density (PSD) of 10mW/MHz should be used (CAK, 2013). In the laboratory experiments; frequency applied was 9.4GHz, the power transmitted was 10mW, gain of transmit antenna was 63 (18dB), maximum distance between transmitter and receiver was 100cm and common resistance of antennas was 50 Ohms. From the Friis formula of free space loss, it was shown that propagation loss at 9.4Hz was 112dB per km. This study represented a field environment scaled down to a laboratory environment using Fraunhofer distance equation (Balanis, 2005; Volakis, 2007). Fraunhofer equation based on 9.4GHz and 16mm dipole antenna enabled a distance of 100cm to fulfill far-field conditions that are equivalent to open field environment. Attenuation increases with frequency, and quantity of power per unit frequency interval per unit distance in a specified sector is a specification from CAK and International Telecommunications Union (IEEE, 2000; Edler *et al.*, 2005; Sandiku, 2001; Hayt 2003). International Civil aviation Organization has standardized and recommended minimum received signal strength in navaids designated operation area as minus 28dBmV/M.

Near-field and Far-field Distances

The near-field and far-field are regions of electromagnetic field around an object such as transmitting antennas. The near-field strength decreases with distance, whereas far-field strength decreases with the inverse square of distance (Balanis, 2005).

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While far-field is the region in which the field acts as normal electromagnetic radiation where it is dominated by electric dipole type electric or magnetic fields, the near-field is governed by multi-pole type fields which can be considered as collections of dipoles with fixed phase relationship. The boundary between the two regions depends on the dominant wavelength emitted by the source (Volakis, 2007).

Far-field carries a relatively uniform wave pattern, the far-field energy escapes to infinite distance i.e. it radiates. Near-field refers to regions such as near conductors and inside polarized media where propagation of electromagnetic waves is interfered with. The interaction with the media can cause energy to deflect back to source, in case of reactive near-field. The interaction with the medium can alternatively fail to return energy back to the source but cause a distortion in the electromagnetic wave (Rappaport, 2010).

According to Woodhouse (2005) near-field is that part of the radiated field that is below distances shorter than the Fraunhofer distance as defined in Equation 2.3 and Fig. 1.

$$d \leq 2\frac{D^2}{\lambda} \qquad [2.3]$$

Where;
D = longitudinal antenna diameter of transmitting source.
λ = wavelength
d = Fraunhofer distance

In both indoor and outdoor experiments, the distance between the source antenna and the receiver antenna must fulfill the far-field condition. Consequently a far field distance must be maintained as defined in Equation 2.4.

$$r_o \geq \frac{2(d_Q + d_t)^2}{\lambda_o} \qquad [2.4]$$

Where;
r_o = distance between receiver and transmitter
λ_o = wavelength of the radiated wave
d_Q and d_t = largest dimensions (in transverse or longitudinal direction) of the antenna

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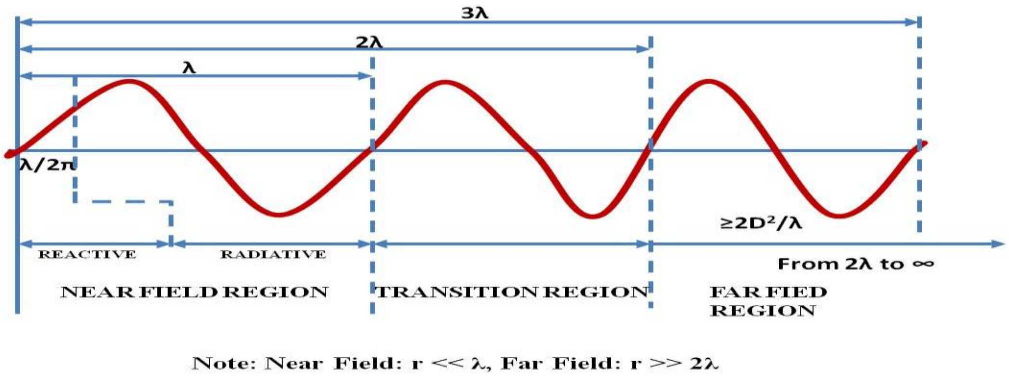

Figure 1. Near-field and far-field boundaries (Balanis, 2005)

The key consideration in designing a far-field range is to simulate the operating environment of the test antenna as closely as possible. Far-field measurements can be performed on indoor and outdoor ranges. The selection of an appropriate test range is dependent on many factors such as: Availability, access, and cost of real estate suitable for quality measurements, weather, budget, security considerations, test frequency and aperture size, antenna handling requirements, pattern and gain measurement accuracy requirements (Balanis, 2005).

Variation of Signal Strength with Distance

According to Fette (2007), the range of line-of-sight signals, when there are no reflections from the earth or ionosphere, is a function of the dispersion of the waves from the transmitter antenna.

In the free-space case the signal strength decreases in inverse proportion to the distance away from the transmitter antenna. When the radiated power is known, the field strength is given by Equation 2.5.

$$E = \frac{\sqrt{30 P_t} G_t}{d} \qquad [2.5]$$

where P_t is the transmitted power, G_t is the antenna gain, and d is the distance. When P_t is in watts and *d* is in meters, *E* is volts/meter.

To find the power at the receiver (P_r) when the power into the transmitter antenna is known, Friis formula is used as in Equation 2.6.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \qquad [2.6]$$

G_t and G_r are the transmitter and receiver antenna gains, and λ is the wavelength.

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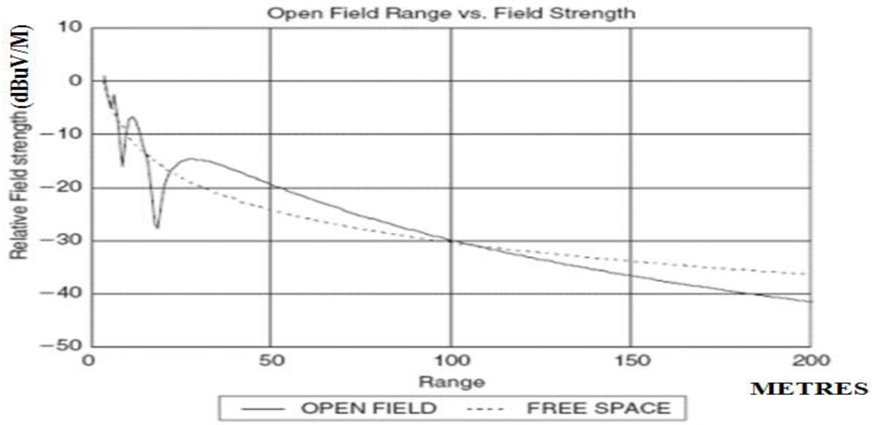

Figure 2. Field strength versus range at 300 MHz (Fette, 2007)

In both plots (Figure 2), signal strength is referenced to the free space field strength at a range of 3 meters. Up to a range of around 50 meters, there are several sharp depressions of field strength, but the signal strength is mostly higher than it would be in free space. Beyond 100 meters, signal strength decreases more rapidly than for the free space model. Whereas there is an inverse distance law for free space, in the open field beyond 100 meters the signal strength follows an inverse square law. Increasing the antenna heights extends the distance at which the inverse square law starts to take effect (Fette, 2007).

For propagation over the horizon and based on recommendation ITU-R P.528, curves for path loss are specified and established as follows;

Table 2. Frequency band and path loss per nautical mile

Frequency band (MHz)	Path loss (dB) per nautical mile (NM)
108 - 137	0.5
960 - 1215	1.6
5030 - 5091	2.7

(Adapted from ICAO doc 9718, 2012)

Distance Measuring Equipment (DME)

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. The distance is determined by measuring the propagation delay of a radio frequency (RF) pulse that is emitted by the aircraft transmitter and returned at a different frequency by the ground station (Andreassen, 2008).

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DME equipped (interrogator) aircraft transmit encoded RF pulse pairs to the ground beacon (transponder). The transponder replies with encoded pulse pairs to the interrogator. DME transponders transmit on a channel in the 962 to 1213 MHz range and receive on a corresponding channel between 1025 to 1150 MHz, where the two channels are 63 MHz apart. (ICAO Annex 10 Vol.II, 2010; ICAO Doc 8071, 2010).

This principle of measurement of distance is illustrated in Figure 3.

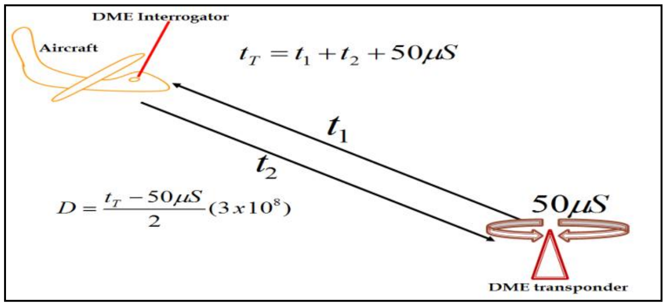

Figure 3 Basic Principle of DME

Errors in DME measurements

According to Andreassen (2008) measurement of distance based on radio frequency signals assumes free space propagation. However due to natural and artificial obstacles around airports, RF signals interact with this structures. This interaction is likely to result into attenuation and more particularly reflection. Figure 4 illustrates how reflection arising from the roof of a building can introduce errors in DME measurements.

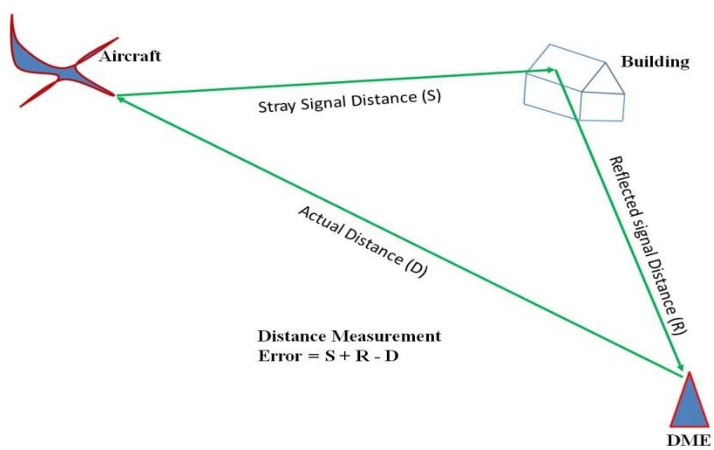

Figure 4. DME distance measurement errors due to reflection

Types of Roofing Materials

Clay roof tiles are designed mainly to keep out rain, and are traditionally made from locally available materials such as clay. There are flat, concave or convex curved, s-shaped, semi-cylindrical and interlocking types. They minimize heat from the sun passing through to the inside (California Energy Commission, 2013). They absorb and attenuate sun rays. Their ability to reflect radio signals is minimal however they tend to cause more diffraction because of their shape and layout.

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Corrugated galvanized iron commonly abbreviated CGI is a building material composed of sheets of hot-dip galvanized mild iron, cold-rolled to produce a linear corrugated pattern in them. Iron sheets are generally reflective to radio waves depending on the layout and pitch angle.

Decra panels are pressure formed aluminum/zinc alloy coated steel with an acrylic bonded stone chip finish. The aluminum/zinc alloy coated steel provides superior corrosion resistance. The stone chip finish, manufactured for roofing use, resists fading and UV-ray penetration. Their effect on propagation of radio waves has been the centre of this study.

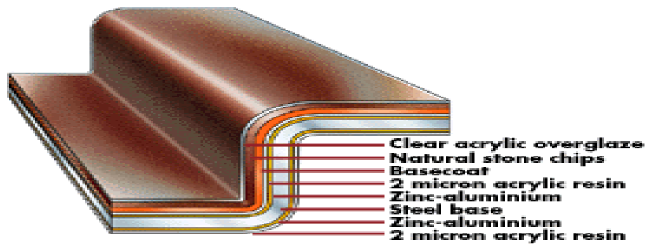

Figure 5. Composition of Decra roofing tiles (Decra Roofing Systems Inc, 2012)

Steel roofing sheets or tiles are corrugated and galvanized coated with zinc resin or just plain. They have high performance in terms of strength and durability. They tend to reflect radio waves.

Concrete roofing materials may be plain or reinforced with steel. They have high performance in terms of strength and durability. Concrete walls tend to attenuate microwave signal propagation due to absorption and reflection (Chomba *et al*., 2011a; Sandrolini *et al.,* 2007).

Aluminum roofs are attractive, durable, energy-efficient, and increasingly affordable. In the past, aluminum was not a popular roofing material for cost reasons and because of concerns about the structural limitations of aluminum. Recent innovations have resolved the structural problems and decreased the cost of aluminum. Aluminum reflects radio waves depending on layout pitch angle and is normally used in fabrication of radio aerials mainly as reflector elements (Sandiku, 2001; Hayt, 2003).

MATERIALS AND METHODS

East African School of Aviation laboratory for aeronautical telecommunications was the preferred site for this experiment because it is strategically designed and equipped to serve as a research and development centre for aeronautical telecommunications and avionics. The equipment and instruments used 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. Rotating antenna platform calibrated in polar deviations and designed for automatic rotation was used to enable a 360 degrees rotation of radiation pattern. Personal Computer (PC) with Windows XP was loaded with CASSY LAB software to record and store radiation patterns, angular positions and signal levels in millivolts. Sets of coaxial cables and microwave accessories were used to interconnect transmitter, receiver and PC.

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Empirical Bearing

Far-field and Near-field Condition Tests

The test antenna was a dipole of half-wave length (λ/2) which had a physical length of 16mm. The wavelength (λo) of the radiated wave was 32mm. The mean distance between the source antenna and the test antenna was set at various distances i.e. 100cm, 60cm and 30cm. Maximum transverse measurement (d_Q) of radiating horn antenna was 100mm. Therefore the far field condition was checked by determining the minimum distance (r_o) required to fulfill this condition given by Equation 3.1.

$$r_o \geq \frac{2(d_Q + d_t)^2}{\lambda_o} \qquad [3.1]$$

Hence $r_o \geq$ 841mm

It was therefore shown that far-field conditions were fulfilled for test distance of 100cm. However near-field conditions were tested for distances of 60cm and 30cm using the condition set by Equation 3.2

$$d \leq 2\frac{D^2}{\lambda} \qquad [3.2]$$

Where;

D = longitudinal antenna diameter of transmitting source = 100mm
λ = wavelength = 16mm

Hence $d \leq 625mm$

It was shown that 30cm distance fulfilled near-field conditions. However 60cm distance was found to be at the boundary between near-field and far-field.

Measuring transmission distance

The experiment was set up as in Figure 6 and Figure 7. Distance between the transmitter and the receiver was varied from 30 to 100 cm and the antenna orientation was maintained for horizontal polarization. The test materials were inserted one after the other at the centre between the receiver and the transmitter. The material variation began from None, Decra, Aluminum, Iron, Clay, Steel to Plastic.

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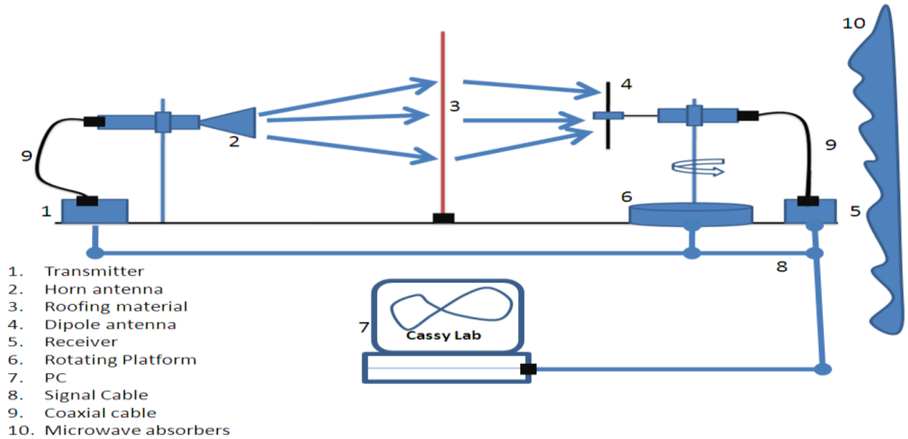

Figure 6. Equipment set up for Measuring Attenuation in Roofing Materials

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 receiving antenna and processed by the computer system and recorded in steps of 15 degrees from 0 to 180 degrees. The mean RSL was calculated for each material at three different distances and recorded as in Table 3 and plotted in Figure 8.

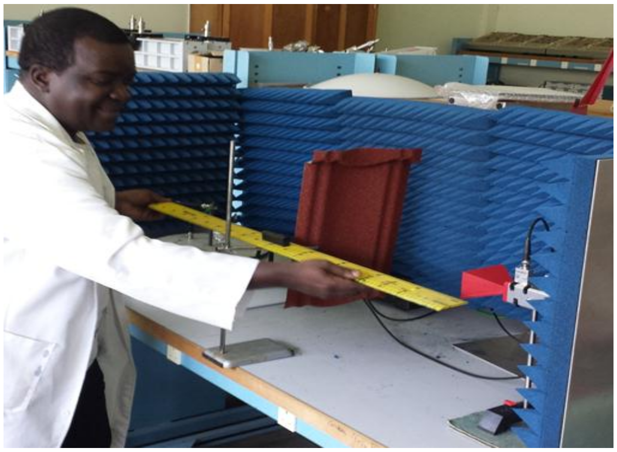

Figure 7. Measurement of transmission distance

RESULTS AND DISCUSSION

Microsoft excel correlation function was used to determine the relationship between distance and types of materials with reference to signal propagation (see table 3). The correlation table in appendix B was automatically generated to indicate the variation of distance with types of roofing materials.

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Table 3. Effects of roofing materials on transmission distance in mV

Mean Received Signal Level (RSL) mV Polarization (P) = Horizontal				
Distance(cm)	**30**	**60**	**100**	**Mean**
Materials				
Decra	0.05	0.04	0.08	**0.06**
Aluminum	0.13	0.23	0.94	**0.43**
Iron	0.25	0.08	1.93	**0.75**
Clay	23.2	2.87	1.75	**9.27**
Steel	1.33	1.65	0.59	**1.19**
Plastic	21.2	9.30	2.00	**10.8**
Mean	**7.69**	**2.36**	**1.22**	

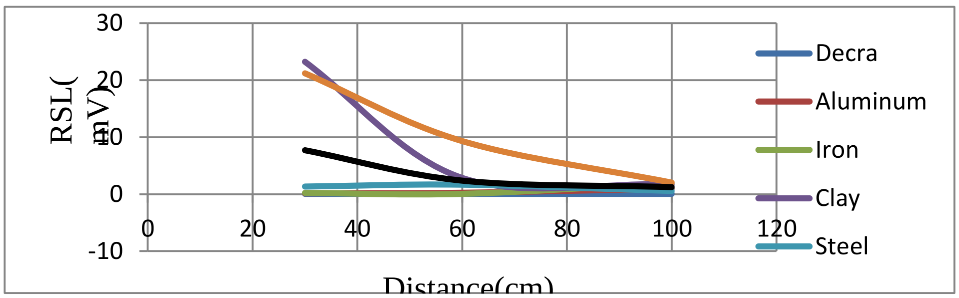

Figure 8. Received Signal Level (mV) Vs Transmission Distance (cm)

The RSL (mV) was converted into dBmV by the formula dBmV = 20log (RSL/1mV). The results of this conversion were recorded in Table 4 and plotted in Figure 9.

Table 4. Effects of roofing materials on transmission distance in dBmV

Mean Received Signal Level (RSL) in dBmV Polarization (P) = Horizontal (V)				
Distance(cm)	**30**	**60**	**100**	**Mean**
Materials				
Decra	-26.0	-28.0	-21.9	**-24.4**
Aluminum	-17.7	-12.8	-0.50	**-7.30**
Iron	-12.0	-21.9	5.70	**-2.50**
Clay	27.3	9.20	4.90	**19.3**
Steel	2.50	4.30	-4.60	**1.50**
Plastic	26.5	19.4	6.00	**20.7**
Mean	**17.7**	**7.50**	**1.70**	

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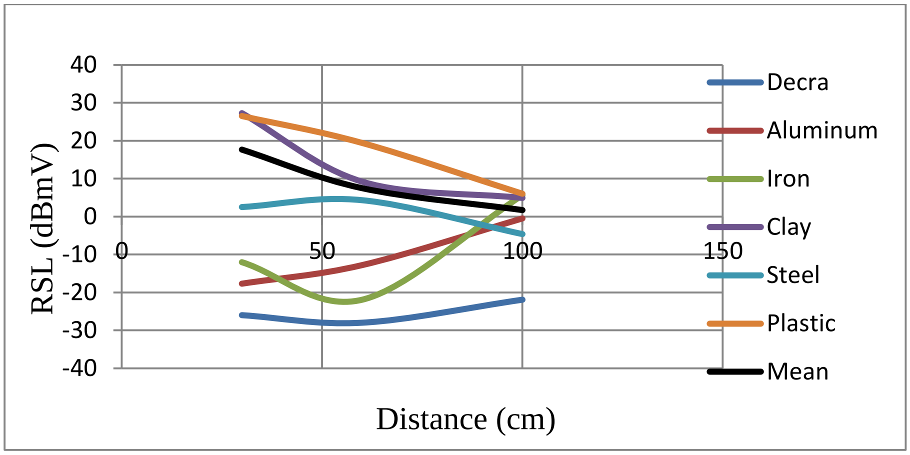

Figure 9. Received Signal Level (dBmV) Vs Transmission Distance (cm)

Table 5 was used to generate Figure 8 which showed the mean variation of RSL (dBm) with distance (cm). For an aerial characteristics impedance of 50 ohms the formula; dBm = dBmV – 47dB was used to convert dBmV to dBm and tabulated in Table 5 and Figure10 below

Table 5. Effects of roofing materials on transmission distance in dBm

Mean Received Signal Level (RSL) dBm Polarization (P) = Horizontal				
Distance (cm)	**30**	**60**	**100**	**Mean**
Materials				
Decra	-73.0	-75.0	-68.9	**-71.4**
Aluminum	-64.7	-59.8	-47.5	**-54.3**
Iron	-59.0	-68.9	-41.3	**-49.5**
Clay	-19.7	-37.8	-42.1	**-27.7**
Steel	-44.5	-42.7	-51.6	**-45.5**
Plastic	-20.5	-27.6	-41.0	**-26.3**
Mean	**-29.3**	**-39.5**	**-45.3**	

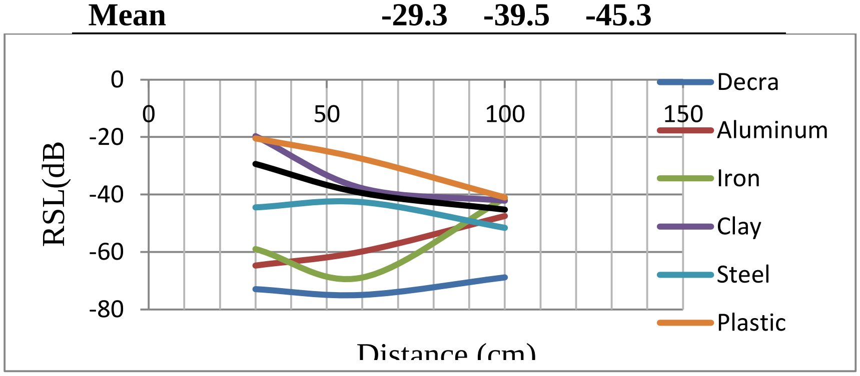

Figure 10. Mean variation of received signal level (RSL dBm) with distance (cm)

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The path loss exponent within roofing material was calculated using the formula;

Loss (dB) = 32.5 + 20Log f + 10nLog D

Where n = path loss exponent factor, F = frequency in MHz, D = distance in kilometers

At test frequency of 9.4GHz (9400MHz) and transmission distance of 0.001Km (100cm) the path loss exponent within material was determined and recorded as in Table 6

Table 6. Roofing Materials and Pathloss Exponents

Roofing Materials	ASR (factor)	PathLoss ASR(-dB)	Pathloss Exponent (n)
Iron	0.07	23.0	2.97
Clay	0.16	15.9	3.20
Plastic	0.44	7.13	3.50
Aluminum	0.57	4.88	3.57
Steel	0.80	1.94	3.67
Decra	0.90	0.92	3.70

Figure 10 above and the correlation table (see table 8) showed that different roofing materials interact differently with the signal at various distances. Decra, aluminum and iron provide positive correlation. The signal strength via these materials tends to increase with distance; however only aluminum (r = 0.988) shows significant direct proportional variation with distance. Clay, steel and plastic provide negative correlation whereby signal strength via these materials tends to decrease with distance; but this inverse proportionality is only significant with clay (r = -0.911) and plastic (r = -0.996).

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Tabulation on the Effects of Roofing Materials on Transmission Distance

Table 7. Raw Data Collection for Navaids Transmission Distance Measurements

	(a) Aluminum			
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	0.03	0.79	2.39	1.07
15	0.01	0.45	2.5	0.99
30	0.05	0.19	1.94	0.73
45	0.1	0.05	1.3	0.48
60	0.02	0.04	0.59	0.23
75	0.06	0.08	0.2	0.11
90	0.12	0.05	0.11	0.09
105	0.13	0.06	0.03	0.07
120	0.15	0.08	0	0.08
135	0.07	0.17	0.08	0.11
150	0.07	0.39	0.48	0.31
165	0.3	0.39	1.1	0.6
180	0.58	0.23	1.54	0.78
Mean	0.13	0.23	0.94	

			(b) Iron	
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	0.44	0.03	4.69	1.72
15	0.57	0.03	3.91	1.5
30	0.41	0	2.52	0.98
45	0.35	0.01	1.39	0.58
60	0.39	0	0.64	0.34
75	0.2	0	0.3	0.17
90	0.08	0.04	0.32	0.15
105	0.05	0.05	0.42	0.17
120	0.03	0.19	0.61	0.28
135	0.02	0.12	0.96	0.37
150	0.15	0.16	2.41	0.91
165	0.29	0.21	3.3	1.27
180	0.22	0.22	3.62	1.35
Mean	0.25	0.08	1.93	

	(c) Steel			
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	3.05	4.08	1.21	2.78
15	2.97	4.17	0.88	2.67
30	2	3.13	0.16	1.76
45	1.19	1.55	0.4	1.05
60	0.7	0.83	0.24	0.59
75	0.29	0.34	0.06	0.23
90	0.17	0.04	0.02	0.08
105	0.13	0.01	0.09	0.08
120	0.26	0.15	0.22	0.21
135	0.61	0.51	0.53	0.55
150	1.31	1.27	0.98	1.19
165	2.16	2.34	1.55	2.02
180	2.4	2.97	1.32	2.23
Mean	1.33	1.65	0.59	

	(d) Clay			
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	44.08	8.66	4.73	19.16
15	43.83	8.49	3.93	18.75
30	41	5.1	2.87	16.32
45	28.26	2.72	1.19	10.72
60	13.66	1.04	0.67	5.12
75	5.19	0.59	0.51	2.1
90	1.42	0.31	0.3	0.68
105	1.17	0.15	0.13	0.48
120	3.73	0.02	0.17	1.31
135	10.66	0.16	0.52	3.78
150	25.27	1.44	1.36	9.36
165	40.59	3.52	2.98	15.7
180	42.78	5.14	3.42	17.11
Mean	23.2	2.87	1.75	

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	(e) Decra			
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	0.05	0.09	0.1	0.05
15	0.07	0.07	0.09	0.08
30	0.12	0.04	0.12	0.09
45	0.17	0.02	0.12	0.1
60	0.11	0.01	0.09	0.07
75	0.04	0.01	0.07	0.04
90	0.02	0.02	0.05	0.03
105	0.02	0.03	0.03	0.03
120	0.02	0.06	0.06	0.02
135	0.02	0.06	0.01	0.03
150	0.01	0.05	0.12	0.06
165	0.02	0.05	0.11	0.06
180	0.03	0.04	0.06	0.04
Mean	0.05	0.04	0.08	

	(f) Plastic			
	Received Signal Level (RSL) in mV			
	Polarization (P) = Horizontal			
Distance	30cm	60cm	100cm	Mean
Angle				
0	43.73	23.35	4.91	24
15	43.2	20.12	3.7	22.34
30	35.8	13.2	1.55	16.85
45	21.23	6.06	0.25	9.18
60	10.76	3.5	0.04	4.77
75	4.75	1.78	0.02	2.18
90	1.24	0.38	0.09	0.57
105	0.95	0.24	0.37	0.52
120	2.17	1	0.78	1.32
135	8.04	4.15	1.67	4.62
150	24.11	10.84	3.07	12.67
165	38.89	17.64	4.74	20.42
180	41.08	18.67	4.86	21.54
Mean	21.23	9.3	2	

Table 8. Correlation between Roofing Materials and Transmission Distance

	Correlation factors						
	Distance	**Decra**	**Aluminum**	**Iron**	**Clay**	**Steel**	**Plastic**
Distance	1						
Decra	0.723	1					
Aluminum	0.988	0.822	1				
Iron	0.695	0.999	0.799	1			
Clay	-0.911	-0.375	-0.835	-0.337	1		
Steel	-0.801	-0.993	-0.885	-0.987	0.484	1	
Plastic	-0.996	-0.783	-0.996	-0.757	0.870	0.852	1

	Distance	Mean
Distance	1	
Mean	-0.27978	1

Generally and assuming that effect of roofing materials is constant; the mean signal strength decreases slowly with increase in distance as indicated by a mean correlation factor (r = -0.2798). Table 6 showed that all the materials have path loss exponents (factor n) ranging from (3.0 to 3.7) which is higher than free space path loss of 2. It means that signal propagation via these materials is slower but how this slowness affects signal strength remains to be another study.

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CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The relationship between roofing materials and transmission distance was determined by the correlation factor 'r'. The correlation factors of plastic (r = -0.996), clay (r = -0.911) and steel (r = -0.801) were determined and found to be negative. Thus radio navigation signal via plastic, clay and steel roofing materials decreased with distance. However, the radio navigation signal via decra (r = +0.723), aluminum (r = +0.988) and iron (r = +0.695) increased with distance. The strength of a radio signal that interacts with plastic and clay structures decreases rapidly with distance. It therefore means that radio navigation systems positioned in such environments require extra power to attain a certain range. The signal via aluminum structures increase rapidly with distance in the near field. This rapid increase in signal strength with respect to distance is likely to create errors in systems like Instrument Landing System (ILS) whose intelligence is contained in the signal strength. However all navaids are positioned in far field regions and therefore such characteristics of aluminum will be less significant.

The path loss exponent factor for all the six test materials was found to be well above the free space path loss exponent of factor 2. Decra and steel has the highest value at 3.7 whereas clay depicts the lowest value presented at 3.0. This means that the rate at which the signal propagated via these structures is significantly slower than propagation in free space.

Therefore, effects of roofing materials on transmission distance vary depending on the selected material. It also depends on whether the operation is in the near-field or far-field regions. The general trend is that signal strength decreases slowly with increase in transmission distance thus providing a low negative correlation factor (r = -0.280).

The analysis on comparison for the effects of selected roofing materials on radio signal propagation in open field environment has generally confirmed that transmission distance and signal level are inversely proportional and have mixed proportionality at very short distances. However the analysis goes further to show that the rate or the slope of proportionality will vary depending on the obstructions in the signal path.

International Civil Aviation Organization (ICAO Annex 10 Volume II, 2012) has specified that the minimum field strength for Very High Frequency (VHF) air-ground voice communication systems should be 75 μV/m throughout the designated operational coverage; the desired to undesired (D/U) ratio should be 20 dB (ICAO doc 9718, 2012).

RECOMMENDATION

It is recommended that studies be directed in conducting experiments in open fields and factoring in sources of variability arising from the environment so as to relate to the actual scenario of flight navigation

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REFERENCES

Andreassen, S. O. (2008). *Principles of enroute navigation systems*. Norwegian Telecommunication Administration, Oslo

Balanis, C. A. (2005). *Antenna theory: Analysis and Design*. Prentice Hall Inc. 3rd Ed. Ch 2, p34.

California Energy Commission (2013). *Choices for the home construction.* Retrieved from www.consumerenergycenter.org. Accessed on 14th July, 2013

CCK (Communication Commission of Kenya) (2008). Guidelines on the implementation of Wireless Local Area Networks (WLAN) on non-protected basis, Retrieved from www.cck.go.ke. Accessed on 18th September, 2011.

CAK (Communications Authority of Kenya) (2013). Guidelines on implementation of Fixed Wireless Links on non-protected basis, Retrieved from www.ca.go.ke. Accessed on 11th May 2015.

Chomba, B.K., Konditi, D.B.O., Nyaanga, D.M. & Githeko, J.M. (2011a). Effects of varying angle of incidence on wireless signal propagation, *International Journal of Pure and Applied Science and Technology, 7* (1), pp. 22 -29. www.ijopaasat.in

Decra Roofing Systems Inc, 2012. Composition of Decra roofing tiles. Retrieved from www.decra.com. Accessed on 11th May 2015.

Edler, J., Oskowsky, M. & Wang, W. (2005). *Wireless mesh network for building automation,* Technical article: Industrial Wireless book issue 10(2) Retrieved from www.wireless.industrialnetworking.com. Accessed 27th May, 2012.

Fette, A. B. (2007). *RF Basics: Radio propagation*. Retrieved from www.eetimes.com

Gupta, D. (2005). *WLAN signal characteristics in an indoor environment-an analytic model and experiments,* University of Maryland, College Park.

Hayt, W. H. & Buck, J. A. (2003). *Engineering Electromagnetics.* Atlanta US: McGraw Hill. Retrieved from www.mhhe.com. Accessed on 15th July 2011

International Civil Aviation Organization (ICAO) (2010). *Manual on testing of radio navigational aids;* Doc 8071, Vol.1-3. Montreal, ICAO

International Civil Aviation Organization (ICAO) (2012). Handout on radio frequency spectrum requirements for civil aviation; assignment planning criteria for radio communication and navigation systems Doc 9718 Vol.2, Montreal, ICAO

IEEE (Institute of Electrical and Electronics Engineers) (2000). *IEEE Std 100, The Authoritative Dictionary of IEEE Standards Terms*, 7th Edition, New York

Rappaport, T S. (2010). *Wireless communication principles and practice* 2nd Ed. Prentice Hall Inc. 19th Printing, p108.

Sandiku, M. N. O. (2001). *Elements of Electromagnetics.* Atlanta US: McGraw Hill. Retrieved from www.mhhe.com. Accessed on 15th July 2011

Sandrolini, L., Reggiani, U. & Ogunsola, A. (2007). Modeling the electrical properties of concrete for shielding effectiveness prediction. *Journal of Physics: Applied Physics, 40,* pp. 5360-5372.

Volakis, J.L. (2007). *Antenna engineering handbook*, 4th Ed. Mc Graw-Hill Retrieved from https://m.electronicdesign.com June 8, 2012.

Woodhouse, I. H. (2005). Introduction to microwave remote sensing: how to replicate FF conditions before launch to provide an accurate calibration of antenna that can replicate FF conditions. Retrieved from https://books.google.com

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