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Correlation Between Radio Signal Strength and Attenuation as a Function of Linear Distance and Time

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Abstract: In this work, the Radio Signal Strength of FM Gotel, Yola (that transmits at 91.1 MHz) was measured as a function of linear distance and time of the day using a locally constructed Radio Signal Strength Meter and a Quantum Geographic Information System, (QGIS) version 2.8. Values of the radio signal strength against linear distance were also simulated using an empirical formula. Both the measured and the calculated statistical correlation results show a negative correlation of – 0.96 and – 0.50 respectively. This shows an inverse relationship between radio signal strength and linear distance. The respective radio signal attenuations were also calculated. The statistical correlation results show a positive correlation of 0.25 for the measured and 0.59 for the calculated between radio signal attenuation and the linear distance. This gives a linearly proportional relationship between radio signal attenuation and linear distance. Variations between radio signal strength and time of the day did not follow any pattern. The results conform to many researchers' studies on the effects of time of the day and linear distance on radio signal strength radio signal attenuation. This study will have applications in communications, such as in the procurement of transmitters for radio stations and in the installation of booster stations.

Key words: Signal Strength · Attenuation · Linear distance · Time · Correlation · QGIS version 2.8

INTRODUCTION

In wireless communication, radio signal propagation through atmosphere is a major concern. It is an established fact that electromagnetic signals propagated through the neutral atmosphere are affected by the constituent's gasses [1, 2]. Radio waves travel more slowly in the atmosphere due to interaction with air molecules, which consequently gives rise to refraction of the radio signal [3]. The influence of the atmosphere is strongly determined by its temporal and spatial variability, an indication that changing atmospheric conditions can lead to changes in radio wave propagation [4]. Radio waves are formed by energizing a "dipole" and are emitted by an oscillating dipole that escapes into electromagnetic space such as like music from a piano that moves the air near it. The radio receiver on the other hand detects the radio wave in a manner similar to the human ear detecting a note from a piano. Radio wave propagation is omnidirectional, which makes it to have vast applications in communication [5].

When a radio wave is radiated, it moves away from the source spreading out in the form of a sphere and the propagation is influenced by the properties of the earth and the atmosphere. The curvature of the earth and the conditions of the atmosphere can refract electromagnetic waves either up, away from, or down toward the earth's surface [6]. As it does so, the surface area of the sphere increases thereby decreasing the intensity of the signal, according to law of conservation of energy. Radio signal strength in communication decreases in a way that is inversely proportional to the square of the distance d from the source of the radio signal in free space as.

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$$Signal = \frac{1}{d^2} \quad (1)$$

This assumption holds only for a free space path loss model [7]. In recent times studies have shown that the transmitted radio signals may go through spatial and temporal changes due to variations in the atmospheric conditions as well as other environmental factors. These conditions vary with changes in height, geographical location and even with changes in time of the day as well as season of the year [8]. Virtually all weather factors that affect signal transmission take place in the atmosphere that extends from the surface of the earth to a height of about 6 km at the poles and 18 km at the equator. The temperature in this region decreases rapidly with altitude, clouds form and there may be much turbulence because of variations in temperature, density and pressure [8]. Temperature and humidity among others also lead to attenuation in the signal strength of radio waves [9-11]. FM Gotel radio station is not an exception to such effects arising as a result of these environmental and atmospheric factors.

The Study Area: This research was carried out on FM Gotel radio broadcasting station (an arm of Gotel communications) that broadcasts at a frequency 91.1 MHz, which is in the region of Very High Frequency (VHF) of the electromagnetic spectrum. The radio station operates for up to eighteen hours in a day and hence it serves the scope of this research work. The GOTEL communication is situated in Yola (9° 13` N 12° 27` E), the Adamawa State capital of Nigeria. The operational parameters of FM Gotel are shown in Table 1.

Theoretical Overview of Radio Signal Strength and Signal Attenuation: A radio wave propagating through the earth atmosphere will experience path bending due to inhomogeneous spatial distribution of the refractive index of air, which causes adverse effects such as multipath, fading and interference [12]. In Telecommunication particularly in Radio Frequency Propagation, Signal Strength (also Referred to Field Strength) refers to the transmitter power output as received by a reference point antenna at a distance from the transmitting antenna. The signal strength can be determined empirically using the relationship given by [13] as in equation (2) be

$$s = \sqrt{\frac{\mu_o c P_{av}}{2\pi R^2}} \quad (2)$$

Table 1: Operational Parameters of FM Gotel

Station Parameters	Values
Antenna type	Unidirectional
Distance cover	250 km
Transmission frequency	91.1 MHz
Transmitting power	10 kW
Mast Height	150 m
Year of commissioning	2012

Source: Gotel's Coomunications, 2016

where μ□ is a constant given by $4\pi x10^{-7}$ H/m, c is the speed of light, P_{av} is the power of transmission and R is the distance from the transmitter. Equation (2) could be valid if environmental and atmospheric factors are neglected.

Signal attenuation is an important parameter in telecommunication applications, because of its importance in determining signal strength as a function of distance [2]. Radio signal strength can be attenuated with distance and could be define by equation (3)

$$\text{Attenuation} = \frac{\text{Signal Strength (dB)}}{\text{Distance (Km)}} \quad (3)$$

The signal attenuation in equation (3) is expressed in dB/m. Other Atmospheric factors that can lead to the degradation of radio signal strength are increase in atmospheric temperature [14] and Fog (Harmattan) [15, 16].

MATERIALS AND METHOD

Materials: The materials used in conducting this research work were; Constructed Radio Signal Strength meter, Q. GIS version 8 and automatic stop watch.

Materials for the Construction of the Radio Signal Strength Meter: The materials used to construct the radio signal strength meter were:

- Resistors – 2 x 2 KΩ, 220 KΩ, 2 x 100 KΩ, 47 KΩ, 10 KΩ and 33 KΩ
- Capacitors – 1 pF, 2 x 100 pF, 22 nF and 100 nF.
- Inductors – 15 turns and 13 turns
- Transistors – PN3563, BC547
- 10 cm folded dipole antenna, 2 1N4148 Diodes, Voltmeter (0 – 10 V), 6 V Battery, Enameled wire 1 – 25 cm, 1SPDT mini slide switch, jumper wires and Vero strip board of 5 x 5cm

Block Diagram and Circuit Description of the Constructed Signal Strength Meter: This section consists of the block diagram and the circuit description of the radio signal strength meter used in work.

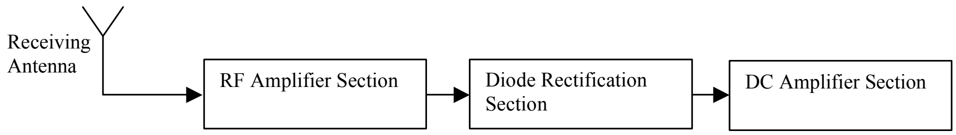

Fig. 1: Block diagram of Radio Signal Strength Meter

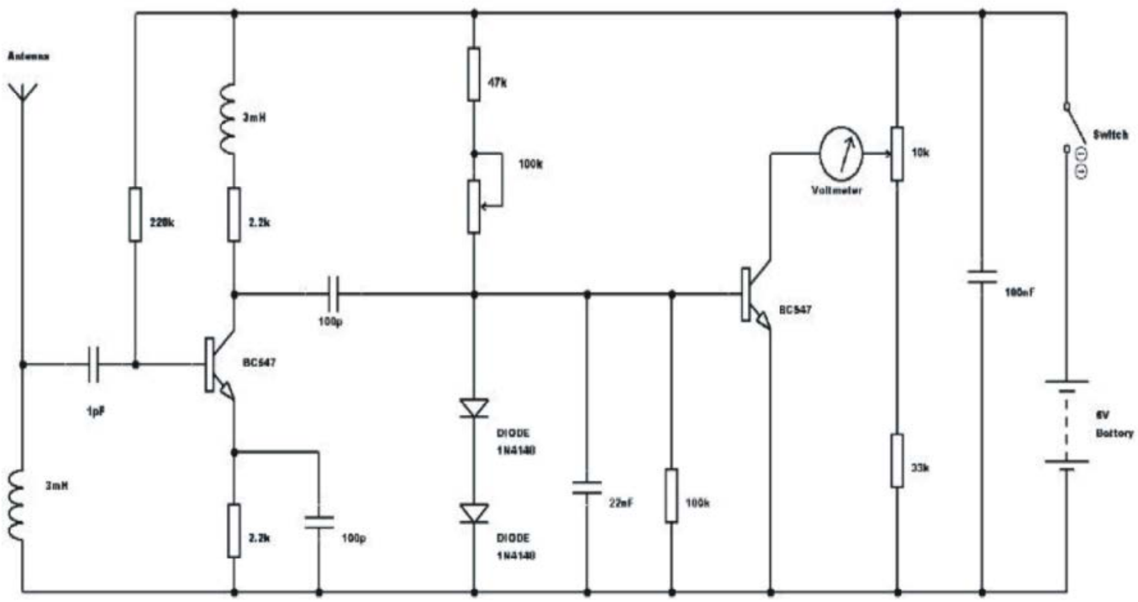

Fig. 2: Complete Circuit Diagram of a Radio Signal Strength Meter.

The Block Diagram of the Radio Signal Strength Meter: The block diagram of the constructed radio signal strength meter is shown in Fig. 1.

The functions of the various components of the block diagram are briefly described as follows:

- Radio Frequency Amplifier Section: This section receives and amplifies the Radio Frequency signal from the transmitting station (FM Gotel) through the receiving antenna and feeds it to the diode rectifier section.
- Diode Rectifier Section: This section rectifies the alternating Radio Frequency Signal to a signal which could be detected and measured by a DC Volt-meter.
- Direct Current Amplifier Section: It amplifies the DC Voltage fed into it by the diode rectifier section. It has a Voltmeter that measures the signal strength of the received Radio Frequency signal in mill volt per meter

Circuit Description of Signal Strength Meter: The circuit diagram of the signal strength meter consists of three sections as in Figure 2. The three sections are: the radio frequency amplifier section; the diode rectification section and a DC amplifier section.

The RF amplifier section has a 10 cm dipole antenna, a capacitor, an inductor of 15 turns and a transistor. It receives and amplifies the radio signal detected from FM Gotel by transistor PN3563. To effectively capture the 91.1 MHz carrier frequency of FM Gotel, we coiled a 15 turn copper wire to serve as the inductor and a 1 pF capacitor at the RF amplifier section.

The diode rectification section consists of two diodes that were used to provide a full wave rectification for the AC radio input signal to a DC signal. The diodes were partially forward biased via a 47 KΩ and 100 KΩ resistors controlled from the positive rail. The diodes were not switched on fully due to the fact that the base emitter junction of the DC amplifier transistor allows only 6 V to be transmitted across them.

The DC amplification section has transistor BC547 that was used to amplify the DC signal fed from the diode rectification section. This DC signal was detected and measured using a voltmeter. All other components were constructed as specified in the materials stated earlier.

Method: There are three ways of evaluating the performance of radio communication systems, namely mathematical analysis, computer simulations and by measurement [9]. In this study, we combined computer simulations and measurements to obtain our desire results. A radio signal strength meter was designed and constructed using locally active and passive devices. The received signal strengths of FM Gotel along a propagation linear distance of up to 95 Km at different distant points were measured. The different distance points were along Yola (in Adamawa State) – Gombe (in Gombe State) route, of North – Eastern Nigeria. Similarly, variations of the radio signal strength with time of the day (for two days in July, 2017) at MAUTECH, Yola (a linear distance of 5 Km from the radio station) were recorded and the readings were plotted.

A spatial analysis using QGIS version 2.8 with a map layer showing places and road networks as a guide was used on a scale of 1:43305 to determine the distances at which the various signal strengths were taken. The values of the radio signal strengths of FM Gotel were taken at different location points.

Theoretical values of the received signal strength were calculated by simulating the values of the different location points in equation (2). Signal attenuation for both measured and calculated were also determined.

To measure the degree of the correlation between radio signal strength (measured and calculated) with linear distance and radio signal attenuation (measured and calculated) with linear distance, we employed the Karl – Pearson correlation equation given in equation (5) below

$$r = \frac{N\Sigma XY - \Sigma X \Sigma Y}{\left\{\left(N\Sigma X^2 - (\Sigma X)^2\right)\left(N\Sigma Y^2 - (\Sigma Y)^2\right)\right\}^{\frac{1}{2}}} \tag{5}$$

where N is the number of value in each data set; ΣXY is the sum of products of paired scores; ΣX is the sum of X scores; ΣY is the sum of Y scores; ΣX^2 is the sum of squared X scores and ΣY^2 is the sum of squared Y scores.

RESULTS AND DISCUSSIONS

Results: The results of the measured and the calculated radio signal strength with linear distance at different location points are presented in Table 2. Using equation (7), there is a negative correlation of – 0.96 between the measured radio signal strength and linear distance and a negative correlation of – 0.50 between the calculated radio signal strength and linear distance.

The results for the measured and the calculated radio signal attenuation with linear distance at different location points are presented in Table 3. Hourly variation of radio signal strength is presented in Table 4.

Using equation (7), there is a positive correlation of 0.34 between the measured radio signal strength and linear distance and a positive correlation of 0.59 between the calculated radio signal strength and linear distance.

Table 4 represents the hourly variation of the radio signal strength for 6/03/2017 and 7/03/2017 respectively measured at Mautech, Yola, between 6:00 hrs and 24:00 hrs. Figures 3 and 4 represent the hourly variation of the radio signal strength for 6/03/2017 and 7/03/2017 respectively measured at Mautech, Yola, between 6:00 hrs and 24:00 hrs.

Table 2: Values of Radio Signal Strength at Different Locations and Distances in km

Location	Distance (km)	Signal Strength (mV/m) (Measured)	Signal Strength (mV/m)(Calculated)
Reference point	0.000	9.55	-
Yola Bridge	1.000	9.55	774.60
Mubi round about	5.212	9.44	148.62
Mai doki Round about	7.470	9.32	103.69
Welcome to Yola gate	13.137	9.29	58.96
Kwanan-waya Village	17.488	9.29	44.29
Ngurore Town	27.023	9.25	28.66
Afcot PLC	35.520	8.90	21.81
Demsa Town	39.952	8.86	19.56
Farai Village	42.865	8.86	18.07
Numan Town	51.464	8.85	15.05
Ngwalang Town	55.621	8.85	13.93
Savannah PLC	70.097	8.62	11.05
Lafia Town	82.190	8.56	9.42
Cham Town	95.063	8.53	8.15

Table 3: Values of Radio Signal Attenuations at Different Locations and Distances in km

Location	Distance (km)	Attenuation (dB/Km)(Measured)	Attenuation (dB/Km)(Calculated)
Yola Bridge	1.000	Reference Point	Reference Point
Mubi round about	5.212	- 0.0168	- 1.375
Mai doki Round about	7.470	- 0.0141	- 1.169
Welcome to Yola gate	13.137	- 0.0091	- 0.852
Kwanan-waya Village	17.488	- 0.0068	- 0.711
Ngurore Town	27.023	- 0.0051	- 0.530
Afcot PLC	35.520	- 0.0086	- 0.437
Demsa Town	39.952	- 0.0081	- 0.401
Farai Village	42.865	- 0.0076	- 0.382
Numan Town	51.464	- 0.0064	- 0.333
Ngwalang Town	55.621	- 0.0059	- 0.314
Savannah PLC	70.097	- 0.0063	- 0.264
Lafia Town	82.190	- 0.0058	- 0.234
Cham Town	95.063	- 0.0052	- 0.206

Table 4: Measured Hourly Values of Signal Strength of FM Gotel for Two Days (at Mautech)

Time (GMT)	Signal strength(mV/m) Day 1 (6/3/2017)	Signal strength(mV/m) Day 2 (7/3/2017)
6:00	5.50	4.92
7:00	4.16	4.69
8:00	4.38	4.59
9:00	4.50	4.63
10:00	5.83	4.99
11:00	6.12	4.58
12:00	6.75	6.52
13:00	7.77	7.00
14:00	7.62	7.10
15:00	9.30	9.23
16:00	9.31	9.30
17:00	8.15	8.16
18:00	8.25	8.21
19:00	8.64	8.00
20:00	7.15	7.00
21:00	8.33	8.54
22:00	8.07	8.00
23:00	7.25	7.11
24:00	7.00	7.20

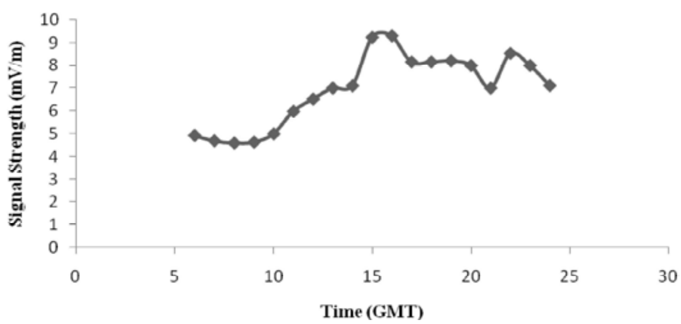

Fig. 3: Graph of Signal Strength against Time, on hourly bases for Day 1 (6/7/2017) (At Mautech)

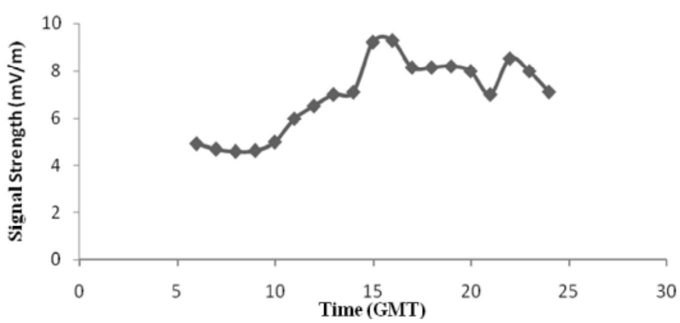

Fig. 4: Graph of Signal Strength against time, on hourly bases for Day 2 (7/7/2017) (At Mautech)

DISCUSSION

From Table 2, the values of both the measured and calculated radio signal strength decreases with increase in linear distance. These values are more pronounced in the calculated. The discrepancy could be as a result of the fact that the equation used in the computation ignores the effect of some atmospheric conditions such as temperature, humidity and atmospheric pressure on radio signal propagation. The values of the measured radio signal strength deceases steadily and gradual with increase in linear distance. This shows that the effects of atmospheric conditions on radio signal strength is gradual but significant. The strong negative or inverse correlation of – 0.96 between the measured radio signal strength and the linear distance shows that effects from atmospheric conditions play a significant role in radio signal propagation [17, 18]. This is a strong indication that the constructed signal strength meter used has some degree of accuracy.

In Table 3, the radio signal attenuation for both the measured and the calculated increases with increase in linear distance. There is further supported by a positive correlation of 0.34 between measured radio signal attenuation and linear distance, as against a positive correlation of 0.59 between the calculated radio signal attenuation and linear distance. The small proportional correlations could be as a result of the distance considered in the study.

The hourly variations of radio signal strength in Figures 3 and 4 did not follow any pattern. This shows that radio signal is independent of time of the day.

CONCLUSION

In this work, we have studied the correlation between radio signal strength and attenuation as a function of linear distance of FM Gotel, Yola. Statistical correlation shows an inverse relationship between radio signal strength and linear distance, i.e., as the distance increases the measured signal strength decreases and vice versa. There is also a proportional relationship between radio signal attenuation and linear distance, i.e. the larger the distance, the more the radio signal is attenuated. The relationship between the received signal strength and time of the day does not follow any pattern. These results agree with most of the research works conducted on radio wave propagation. Our findings could be useful in the procurement of radio communication transmitters and, installation of booster stations.

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REFERENCES

1. Oluwole, J.F. and O.M. Olayinka, 2013. A Test of the Relationship between Refractivity and Radio Signal Propagation for Dry Particulates. Research Desk, 2(4): 334-338.
2. Anthony, N.O. and O.O. Raphael, 2014. Characterization of Signal Attenuation Using Pathloss Exponent in South-South Nigeria. International Journal of Emerging Trends and Technology in Computer Science, 3(3): 100-104.
3. Mason, P.S., 2010. Atmospheric Effects on Radio Frequency (RF) wave Propagation in a Humid, Near-Surface Environment. M.Sc Thesis, Naval Postgraduate School Monterey, California, USA.
4. Olasoji, O.Y. and M.O. Kolawole, 2011. Seasonal Effect of Atmospheric Refractivity in Diverse Terrains. Journal of Environmental Science and Engineering, 5: 1537-1541.
5. Worlf, I.D., 2001. The ARRL Handbook for Radio Amateurs, 78^{th} Ed. ARRL Newington, USA.
6. Nor H.S, W.A. Atiq S.S. Shahirah and I.A. Zainol, 2015. The Effects of Solar Radiation on Radio Signal for Radio Astronomy Purposes. Malaysian Journal of Analytical Sciences, 19(6) 1394-2506.
7. Manisha, A.B., 2014. Signal Attenuation Measurement of Daily Variation in Fog at Bikaner Region. International Journal of Advanced Technology in Engineering and Science, 2(12): 2348-7550.
8. Abraham, U.U., U.O. Okpo and O.E. Elijah, 2015. Instantaneous GSM Signal Strength Variation with Weather and Environmental Factors. American Journal of Engineering Research. (AJER), 4(3): 104-115.
9. Dajab, D.D., 2006. Perspective on the Effects of Harmattan on Radio Frequency Waves. Journal of Applied Sciences Research, 2(11): 1014-1018.
10. Kennet, B., 2008.Wireless Sensor Networking for Hot Applications: Effects of Temperature on Signal Strength. Data collection and localization: Researchgate.net/publication/229039635.
11. Luomala, J. and I. Hakala, 2015. Effects of Temperature and Humidity on Radio Signal Strength in Outdoor Wireless Sensor Networks. Proceedings of Federal Conference on Computer Technology and Information System, 5: 1247-1255.
12. Bawa, M., B.G. Ayantunj, H. Mai-Unguwa, G.S.M. Galadanchi and M.I. Shamsudeen, 2015. Study of Average Hourly Variations of Radio Refractivity Variations across Some Selected Cities in Nigeria. IOSR Journal of Applied Physics, 7(6): 37-43.
13. Evwaraye, A.O. and N.E. Mgbenu, 1998. Electromagnetism and Modern Physics for Physical Sciences. Spectrum Books Limited, Ibadan Nigeria.
14. Joseph, A., 2015. A Mathematical Relationships between Radio Refractivity and its Meteorological Components with a New Linear Mathematical Equation to Determine Radio Refractivity. IJISET. 2(12): 953-957.

15. Sharma, M., A. Sharma, R.D. Godara and S. Rankawat, 2014. Signal Attenuation Measurement of Daily Variation in FOG at Bikaner Region. International Journal of Advanced Technology in Engineering and Science, 02(12): 144-150.
16. Eyo, O.E, I.A. Menkiti and S.O. Udo, 2003. Microwave Signal Attenuation in Harmattan Weather along Calabar-Akampkpa Line - of-Sight Link. Turk. J. Physics., pp: 153-160.
17. Nweke, F.U., 2015. Effect of Weather on Television Signal Transmission. World Applied Sciences Journal, 33(8): 1299-1304.
18. Sabri, H.N., W.A. Azlan, R. Umar, S.S. Sulan, A.Z. Ibrahim and W.A. Wan Mokhtar, 2015. The Effect of Solar Radiation on Radio Signal for Radio Astronomy Purposes. Malaysian Journal of Analytical Sciences, 19(6): 1374-1381.