DISCRETE FREQUENCY NOISE REDUCTION OF 100 kVA DIESEL ENGINE COOLING FAN

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Abstract- This research work concentrates on measuring, analyzing and predicting the reduction of discrete frequency noise levels with focus on Perkins 100 kVA cooling fans. The measuring and fabricated materials used in carrying out the measurements were: digital sound level meter (SLM), frequency analyzer, AC electric motor, flange, basement and generating set cooling fan. The radiated sound levels were measured without contributions from other engine noise sources. These assisted in obtaining accurate sound pressure level (SPL) data on the fan noise. Discrete frequency tones of the cooling fans were measured within the audio and narrow band ranges using the calibrated TrueRTA spectrum analyzer. The sound power level (SWL) and sound intensity level (SIL) of the fans were calculated using values obtained from the measured SPL. Matrix Laboratory Application Software (MATLAB) was used for analysis of results. The background noise levels (BNL) were determined. It was observed that the un-banded fan used for 100 kVA generating set had SPL peak of 84 dB, at the fundamental blade passing frequency (BPF). In order to reduce the discrete tones at the blade passing frequency (BPF), the baseline fan were banded with a light flexible cylindrical plastic material. The band was found to effectively reduce the radiated sound levels (BPF tone) for the 100 kVA fan. Further observation showed that 10.89 dB SPL reduction was achieved by applying the flexible band on the fan used for the 100 kVA generating set. Almost all the blade rate tone levels were reduced which further increased the acoustical performance of the fan. However, a slight reduction in the aerodynamic performance of the system was observed. From the study, this effect can be mitigated by increasing the size of the radiator.

Keywords: Discrete Frequency Noise, Cooling Fan, Radiated Sound Level, Noise Reduction, Sound Level Meter, Sound Pressure Level.

1. INTRODUCTION

Generally, in industries, noise is referred to as an undesirable and unavoidable product of modern mechanized activities. To protect against the generation of these noise levels, noise limits have been recommended by control organizations and should be adhered to.

In developing countries, the main reason for high level of occupational noise is the absence of noise regulations [1].

In Nigeria for instance, frequent interruption of electricity supply have compelled many individuals, corporate bodies and industries to embark on massive purchase of large power generating plants for the generation of electricity. These generators in addition to generating electricity, generate noise.

Noise sources and vibration in most electrical machines are basically, aero-dynamic, electromagnetic and mechanical [2]. Hence the sources of noise from various components of these machines must be thoroughly investigated and properly understood.

Specifically, a good understanding of the dominant machine noise sources is very important and desirable, so that the required modifications can be carried-out. However, in machines that are complicated, it is sometimes difficult or cumbersome to acquire information; thereby making it hard to get relevant data on noise reduction [4]. In view of this hindrance, several attempts to reduce noise by researchers, innovators and industry regulators are often based on inadequate data. These in most cases, have led to very expensive, inefficient and uneconomical noise reduction procedures.

Noise sources identification methods depend on the specific problem, the duration, available resources, skilled personnel and required accuracy [4]. It is best practice to use more than one problem-solving methods in identifying issues relating to high noise levels.

2. LITERATURE REVIEW

The fundamental aerodynamic sound generation mechanisms of industrial fans are reviewed in this section. A great number of work has been done in the area of environmental acoustics. Most of the knowledge on fan noise reviewed was obtained for the high speed fans of aircraft engine, where contributions from monopole and quadrupole sources are significant.

It was however, shown by [5] that quadrupole radiation was very low for subsonic flow over thin blade sections. Monopole sources were generated by the volume displacements due to the finite thickness of the rotating fan blades. These volume displacements caused periodic changes in fluid mass and thus generated pressure fluctuations in the adjacent field. However, in the case of low to medium speed fans, the phase velocity of these pressure fluctuations was well below the speed of sound, this resulted to low acoustic radiation efficiency [6]. The primary mechanism for acoustic radiation from most subsonic industrial fans caused unsteady forces on the rotating blades due to blade interactions and unsteady incoming flow. The unsteady forces acting on the acoustic medium acted as dipole sources of sound.

The forces developed on the rotating fan blades can be either time periodic or random depending on the type of inflow that the blades encountered [7]. The periodic interaction generated discrete-frequency force spectrum on the blade. As the fan blades encountered these distortions, the generated unsteady force and radiated sound displayed broadband spectra [8].

Discrete-frequency noise radiation from a rotating steady force was first examined by [9]. His theory considered time-varying force-receiver positions that caused sound due to the Doppler Effect. Many authors including [10], [11], [12], [13] and [14], have derived expressions for the discrete-frequency sound radiation due to the fluctuating forces on rotor blades. Their derivations were based on the general solution of the inhomogeneous wave equation which was first formulated by [15]. Using Lighthill's inhomogeneous wave equation, [16], showed that stationary surfaces exposed to turbulent flow are equivalent to surface dipole distributions. [11], extended Curle's solution showing general features of noise radiation by arbitrary moving surface dipoles.

[17], identified the dominant noise sources of small subsonic electronic cooling fans and made modifications for discrete-frequency noise control. The influences of upstream obstructions to the tonal noise generation of a small cooling fan were also investigated experimentally by [18], [19].

[20], applied such discrete-frequency noise theory to the engine cooling fan noise problem. He measured the inlet flow field by a hot-wire probe fixed to the rotor and allowed it to rotate with the fan blades. The inlet velocity profile at only a single radial position was utilized though (a detailed flow measurement test set-up description was not published). [20], later investigated the influences of the radiator, cowl, and back-plate on automotive engine cooling fan noise.

Discrete-frequency fan noise can be reduced by either breaking up the periodic interactions of the fan blades with the incoming flow, or by adding a passive or active noise control device. An example is the skewed blade which is designed to mismatch the centers of lift of successive radial blade elements with the distorted incoming flow. It was noted that the skewed blade fan was advantageous to both the discrete-frequency noise and broadband noise. The skewed blade also reduced flow losses and dragged near the blade tip at transonic speed [21].

A fan with uneven blade spacing is another popular discrete-frequency fan noise control measure. The unevenly spaced blade fan disperses the harmonic tones of the blade-passing frequency (BPF). Therefore, it radiates less annoying noise than the regular evenly-spaced fan [22]; [23], although the sound power was not changed.

Passive noise control devices, such as resonators, can be used to reduce discrete-frequency tones, especially those generated by ducted fans. BPF tones that have frequencies below the first acoustic mode of the duct can be reduced by carefully tuned resonators. Successful applications of a quarter-wavelength tube to the reduction of the BPF noise of centrifugal blowers were reported by [24].

Active noise control techniques were also effective for the discrete-frequency fan noise reduction [25]; [26]. However, due to high cost, its application appears to be limited presently.

[27], investigated the noise sources of a half-stage automobile cooling fan. He showed that rotational and non-rotational noise sources dominate in high flow coefficient and low flow coefficient regions, respectively. [27] successfully reduced vortex shedding noise by the use of serrations located on the trailing edges of the blades. He also used rotating shrouds attached to the blade tips in order to prevent flow separation at the tips. Proper control and reduction of any recirculating flow was emphasized for successful noise control.

[28], reported an experimental investigation of the effects of clearance between the blade tips and a surrounding shroud on noise and aerodynamic performance of low pressure axial fans. They found that the broadband noise increased with increases in tip clearance. Likewise, the rotational tones increased with increases in fan eccentricity within the shroud.

[29], experimentally investigated the influence of tip vortices on the noise generation of turbo machines. Due mainly to the complicated nature of the vortex flow, no generalities regarding the tip noise mechanism was presented. However, most experimental works on tip clearance effects recommended that the tip clearance be kept as minimum as possible for very low noise generation and for better aerodynamic performance.

The fundamental theory of unsteady lift in noise level created on thin airfoils subjected to a transverse sinusoidal gust was investigated by [30]. This theory has subsequently been extended to include the influence of longitudinal gusts by [31], and angle of attack and camber effects by [32]. They derived closed-form solutions for a single airfoil exposed to two-dimensional flow. These theories have further been extended to include three-dimensional effects and the influence of adjacent blades and blade rows by other authors. However, the transverse velocity perturbations were the dominant sources of unsteady lift generation in many applications, particularly for low Mach number flow problems. Therefore, the Sears function was still the most widely used in practical applications.

[33], derived expressions for predicting the wideband noise of fans with axial-flow due to various mechanisms, and compared the predictions with empirical results. He observed a significant increase of the broadband noise when the blade encountered large-scale turbulence. He also noted that the noise spectra due to a stalled fan blade has a low-frequency hump centered roughly at a frequency associated with the frequency of vortex shedding from a bluff body in cross flow. Here, the size of the bluff body was analogous to the size of the stalled flow region.

[34], measured the spectrum of sound power radiated by a spoiler mounted inside a pipe at different angles of attack. He observed that the noise spectra due to the stalled spoiler agreed with the findings of Sharland.

Many efforts have been made by industries to utilize computational fluid dynamics (CFD) in fan noise analyses. [35], used a commercial CFD code to predict the discrete-frequency engine cooling fan noise of a passenger vehicle. The unsteady surface pressure statistics on the blade were calculated from the unsteady Reynolds Averaged Navier-Stokes Equations (RANS solutions), and the Hawkings and Ffowcs-Williams equation was utilized to predict sound pressure at field points. [36], utilized a boundary element solver to predict sound radiation by an HVAC radial blower. [37], utilized a three dimensional compressible unsteady CFD model to investigate the rotor-strut interaction of a computer cooling fan. [38], effectively utilized CFD, along with empirical equations, to predict the broadband noise of fans with axial-flow.

3.0 MATERIALS AND METHODS

This work was carried out using fabricated materials personally tailored and designed to suit the project. In addition, existing relevant tools necessary to aid measurements shall be used.

3.1 Materials

3.1.1 Measuring Tools

Measuring and analytical tools to be deployed in these investigations are listed below:

a. Digital Sound Level Meter

Mastech Precision Sound Level Meter was used to carry-out sound level measurements.

b. Frequency Analyzer

A spectrum analyzer was used for the measurement of the magnitude of the signal input against frequency taken within the maximum frequency range of the analyzer. This analyzer allows for the accurate measurement of the SPL against frequency, spurious phase noise and modulation analysis of communication signals without sacrificing dynamic range and speed.

c. Electric Motor (AC)

An electric motor was used to carry out this investigation. The motor used was a 1hp AC motor with frequency of 50/60 Hz and a voltage of 220/230V.

d. Computer Application Software (MATLAB)

A computer system with matrix laboratory (MATLAB) application software installed was used for statistical analysis.

1.1.2 Fabricated Tools

Fabricated tools to be deployed in these investigations are listed below:

a. Diesel Engine Cooling Fan

Diesel engine generator cooling fan used for 100 kVA generating set was fabricated and used to carry-out this research.

b. Flange

Flange was fabricated and was fitted properly to the Centre of the hub of each of the prototype fan. The flange was fasten suitably to the hub of the fan using metal springs. This was done to ensure proper alignment of the fan to the AC Electric motor's shaft as well as prevent wobbling of the fan.

3.2 Method

3.2.1 Meter Calibration

The meter was calibrated using an intelligent piston phone placed directly over the microphone. This was done to monitor the meter's performance.

3.2.2 Meter Response

The slow response characteristic was used in all measurements taken in this work, because the slow meter response helped average out the fluctuations of the meter.

3.2.3 Meter Positioning

The Sound Level Meter was held at 1m away from the source of noise and 1.2 m above the floor. To carry out these measurements, the microphone was placed away from interfering objects and surfaces in order to avoid unwanted influence on the measured sound levels.

3.2.4 Background Noise

The background noise level was determined by simply taking two readings of the levels of noise. The first reading was taken when the source of noise is turned "on" and the other reading was taken when the source of noise is turned "off". This method helped determine the extent to which the background noise is either affecting or not affecting the total noise level measured when the source of noise is "on".

3.2.5 Frequency Analyzer

The horizontal and vertical axes of the analyzer was calibrated in frequency and SPL respectively. The higher frequency was placed horizontally at the right hand side of the display while the SPL was placed vertically. Both logarithmic and linear scales was used in accordance with the range of frequency. For measurements taken within the audio range, the logarithmic scale was employed in order to allow a wide range of signal on the display, while for measurements taken within the narrowband range, the linear scale was used..

4.0 RESULT AND DISCUSSION

4.1 Results obtained for 100 kVA cooling fan

Radiated sound levels were measured for the 100 kVA cooling fan at a fixed speed of 1440 rpm and the results obtained are as shown in Tables 1, 2, 3 and 4 whereas the plots in FIGs. 1 and 2 display the comparison between the SPL of the un-banded and banded fan.

Broad band analysis was used to obtain noise spectra in the range 20 Hz – 20 kHz (known as audio band) while narrow band analysis was used to obtain noise spectra in the range 0 Hz - 2 kHz.

The audio spectrum for SPL of 100 kVA generator cooling fan un-banded and banded are tabulated in Tables 1 and 2. The ambient noise was also considered. In the same vein, Tables 3 and 4 depict data on SPL of 100 kVA un-banded and banded fan in the narrow band range. Considerations were also given that each noise level was taken at the various harmonic of the BPF.

FIG. 1 compare the noise levels (SPL) of the un-banded and banded fan used for the 100 kVA generating set in the audio range, while FIG. 2 present the noise levels in the narrow band range. The noise levels were plotted against the harmonics of the BPF.

The SWL and SIL displayed in Tables 1, 2, 3 and 4 were calculated using the equations below;

$$\text{SWL (dB)} = \text{SPL} + 20\log_{10}(r) + 11 \text{ dB} \qquad (1)$$

The term **r** refers to the distance usually in meters away from the source of sound (Cory, 2010).

The sound intensity level was also calculated using the formula;

$$SIL\ (dB) = 10 \times Log_{10}\ (I/I_o) \qquad (2)$$

Where I_o is the reference intensity given as $10^{-12} W/m^2$ and I, the intensity of sound given as $P^2/\rho c$, ρc is the characteristics impedance of sound in air given as 415 Rayls and P is the pressure of sound which can be obtained using the formula:

$$SPL\ (dB) = 20Log_{10}\ (\frac{P_{rms}}{P_{ref}}), \qquad (3)$$

where P_{rms} is the root mean square pressure and P_{ref} is the reference pressure.

TABLE 1

Result of sound level measurement obtained within the audio spectrum of an un-banded 100 kVA cooling fan

Un-banded Fan (100 kVA) Freq. (Hz)	Ambient Noise (dBA)	SPL (dBA)	SWL (dBA)	SIL (dBA)
15.6	31.79	52.24	63.24	32.08
31.2	34.67	60.77	71.77	40.59
62.5	38.55	74.53	85.53	54.35
125	32.90	83.64	94.64	63.46
250	26.98	80.11	91.11	59.93
500	23.23	78.82	89.82	58.64
1000	27.55	76.59	87.59	56.41
2000	12.16	72.51	83.51	52.33
4000	7.10	64.83	75.83	44.65
8000	4.48	52.16	63.16	31.98
16000	-11.66	21.68	32.68	1.52

TABLE 2

Result of sound level measurement obtained within the audio spectrum of a banded 100 kVA cooling fan

Banded Fan (100 kVA) Freq. (Hz)	Ambient Noise (dBA)	SPL (dBA)	SWL (dBA)	SIL (dBA)
15.6	31.79	49.64	60.64	29.46
31.2	34.67	60.81	71.81	40.63
62.5	38.55	68.62	77.62	48.44
125	32.90	72.81	83.81	52.63
250	26.98	70.82	81.82	50.64
500	23.23	68.09	79.09	47.91
1000	27.55	66.99	77.99	46.81
2000	12.16	61.41	72.41	41.23
4000	7.10	65.52	76.52	45.34
8000	4.48	56.66	64.66	36.48
16000	-11.66	21.42	32.42	1.24

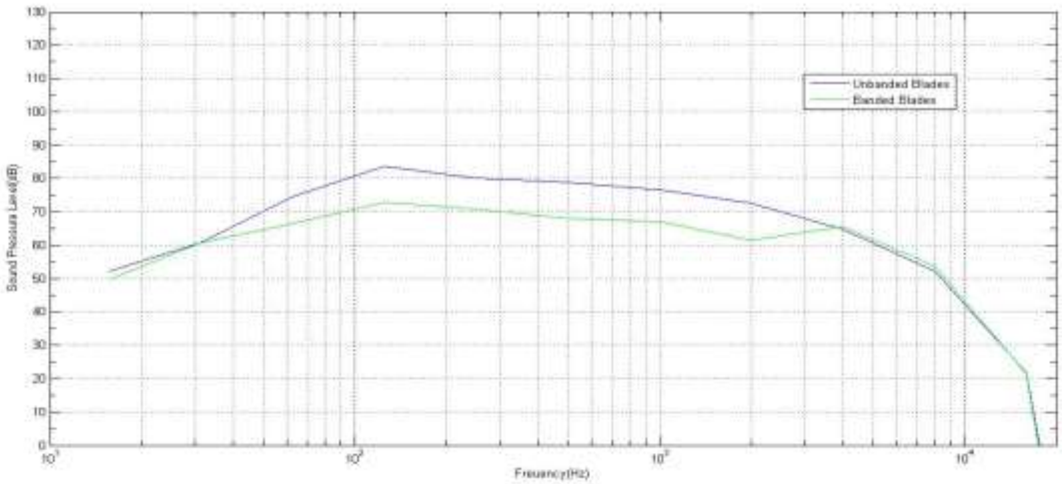

FIG 1: Comparison between SPL of un-banded and banded 100 kVA generator cooling fans within the audio spectrum.

TABLE 3

Result of sound level measurement obtained within the narrow band range of an un-banded 100 kVA cooling fan

F_p Un-banded Fan (100 kVA)	Ambient Noise (dBA)	SPL (dBA)	SWL (dBA)	SIL (dBA)
1 F_p	31.8	84	95	63.8
2 F_p	25.7	78	89	57.8
3 F_p	23.8	79	90	58.8
4 F_p	25.5	79	90	58.8
5 F_p	26.2	78	89	57.8
6 F_p	27.3	77	88	56.8
7 F_p	24.0	75	86	54.8
8 F_p	22.1	74	85	53.8
9 F_p	20.0	74	85	53.8
10 F_p	19.1	73	84	52.8

TABLE 4

Result of sound level measurement obtained within the narrow band range of a banded 100 kVA cooling fan

F_p Banded (100 kVA)	Ambient Noise (dBA)	SPL (dBA)	SWL (dBA)	SIL (dBA)
1 F_p	31.8	74.12	85.12	53.9
2 F_p	25.7	68.22	79.22	48.0
3 F_p	23.8	68.10	79.10	47.9
4 F_p	25.5	68.38	79.38	48.1
5 F_p	26.2	67.87	78.87	47.6
6 F_p	27.3	66.94	77.94	46.7
7 F_p	24.0	65.87	76.87	45.6
8 F_p	22.1	64.78	75.78	44.5
9 F_p	20.0	63.72	74.72	43.5
10 F_p	19.1	62.76	73.76	42.5

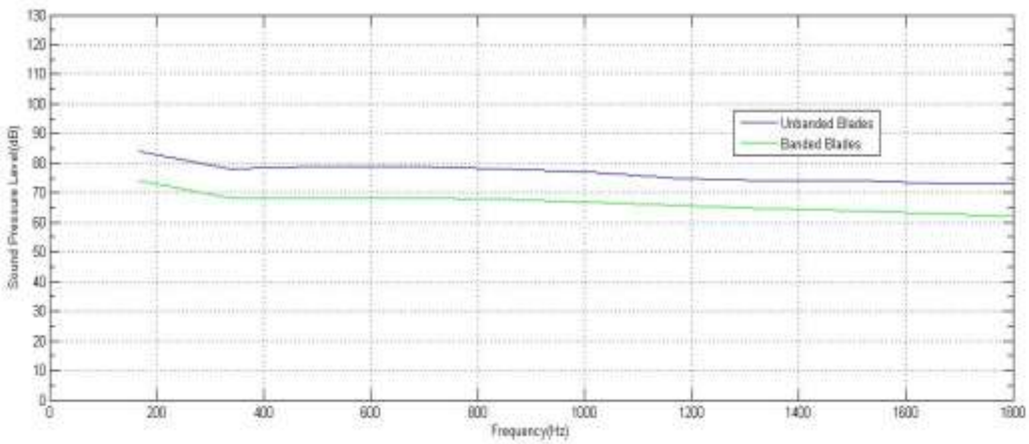

FIG. 2: Comparison between SPL of un-banded and banded 100 kVA generator cooling fans within the narrow band range.

4.2 Discussion of results

The results of measurement using fabricated 100 kVA fan blades are discussed here, after careful analysis of results obtained. These analysis were aided with the application software MATLAB.

4.2.1 100 kVA cooling fan evaluation

Results obtained showed that the ambient noise had no effect on the overall SPL. These results indicated that the fan blades were the major source of noise in the system.

Tables 1 and 3 show results obtained from sound level measurements taken within the audio spectrum and narrow band ranges respectively using an un-banded fan. From these results presented in Table 1, it was observed that SPL had a peak value of 83.64 dB at a frequency of 125 Hz, while from Table 3, SPL had a peak value of 84 dB at the fundamental BPF (168 Hz).

The SWL and SIL displayed in Tables 1 and 3 were calculated using Equations 1, 2 and 3. It was observed that the SWL and SIL taken within the audio and narrow band ranges also had their peaks at 125 Hz and fundamental BPF ($1F_p$) respectively.

From results tabulated in Tables 2 and 4, performed within the audio spectrum and narrow band range using a banded 100 kVA fan. It was observed that the SPL of the banded 100 kVA fan displayed in Table 2 had a maximum value of 72.81 dB at 125 Hz, while SWL had maximum value of 83.81 dB and SIL had maximum value of 52.63 dB at the same frequency. While for the banded 100 kVA fan in Table, a maximum SPL value of 74.13 dB was observed at the fundamental BPF ($1F_p$). It was further noted that this result influenced the SWL and SIL obtained.

From empirical results, it was also observed that the banded 100 kVA cooling fan reduced the radiated sound levels (BPF tones) by 10.89 dB. The maximum sound level reduction was observed at the third harmonic ($3F_p$) of the BPF, in line with several levels of reduction observed at other frequencies.

Investigations in this study, showed that the SWL of the system increased by 11 dB, while the SIL decreased by 20.2 dB, when viewed from the SPL. Based on this finding, the study generates a calibrated equation (Equation 23) in which the SIL can be obtained directly under similar conditions.

$$SIL\ (dB) = SPL + 20\log_{10}(r) - 20.2\ dB \tag{23}$$

This is a novel contribution to knowledge by this study.

5.0 CONCLUSION

The primary objective of this research was to measure, analyze and predict the reduction of discrete-frequency fan noise from a 100 kVA generator. This goal was achieved through comprehensive study and understanding of the characteristics of the fan noise and generator noise reduction methods. Key variables such as SPL, SWL and SIL spectra were measured and analyzed to determine the radiated sound levels. All sound measurements were taken in line with recommended measurement standards. From the study, the unsteady force and turbulence on the fan blades' tip were the dominant acoustic sources of the investigated fans.

The plastic fan blades designed with constant radii of curvature were examined. The feasibility of a banded fan was also examined. The banded fan was fabricated by mounting a cylindrical band to tips of the propeller fan. The analyses of this model successfully resulted in significant tonal noise reductions; though, careful observation noticed slight reduction in the aerodynamics performance of the fan.

Further empirical results, confirmed that banded 100 kVA cooling fan reduced the radiated sound levels (BPF tones) by 10.89 dB. The maximum reduction was observed at the third harmonic ($3F_p$) of the BPF, while several levels of reduction was also observed at other frequencies.

Investigations in this study, showed that the SWL of the system increased by 11 dB, while the SIL decreased by 20.2 dB, when viewed from the SPL. Based on this finding, the study generates a calibrated equation (Equation 23) in which the SIL can be obtained directly under similar conditions. This is a novel contribution to knowledge by this study.

These reductions are significant because they were achieved at minimal cost, using methods which could be adopted by any skilled maintenance trades person.

REFERENCES:

[1] Okon, B. E & Umunnah, R. A (2015). Identification of Threats to Communication Security, Effects and Ways of Mitigation the Threats. International Journal of Scientific and Engineering Research (IJSER), Vol.6, Issue 5 pp. 1219-1235.

[2] Umunnah, R. A & Okon, B. E. (2015). A Survey of the Noise Generated by Timber Market Machines and its Health Implications on the Workers and their Environment, in Calabar, Cross River State. International Journal of Scientific and Engineering Research (IJSER), Vol.6, Issue 5 pp.1713-1721.

[3] Bassey, D. E., Okoro, R. C., Okon, B. E., & Eyime, E. E. (2016). Broadband – Infrastructural Deficit and ICT Growth Potentials in Cross River State, Nigeria. International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE), Vol. 4, Issue 5, pp. 8465-8476.

[4] Bassey, D. E & Okon, B. E (2015). Comparative Studies between Reduction of Discrete Frequency Ranges and Radiated Sound Levels (A Case Study of 50 kVA Diesel Engine Cooling Fan). International Journal of Engineering Research and Technology (IJERT), Vol. 4, Issue 9, pp. 429-437.

[5] Bassey, D. E., Faith-Praise, F. O., Udoeno, E., & Eyime, E. E. (2016). Investigation of 2-Ghz Threshold Levels for Radio Waves in the Southern Region of Nigeria. International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE), Vol. 4, Issue 5, pp. 8477-8483.

[6] Bassey, D. E., Okon, B. E., Faith-Praise, F. O., & Eyime, E. E. (2016). Characterization of Traffic Flow Consumption Pattern and Subscribers' Behaviour. International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE), Vol. 4, Issue 5, pp. 8484-8493.

[7] Bassey, D. E., Okon, B. E. & Effiom, E. O. (2016). 'Broadband Network Penetration and Growth Pattern in North Eastern Part of Nigeria'. International Journal of Scientific & Engineering Research (IJSER), Vol. 7, Issue 3, pp. 1156-1170.

[8] Bassey, D. E., Okon, B. E. & Umunnah, R. (2016). 'The Security Implications of Virtual Local Area Network (VLAN), Niger Mills, Calabar, Nigeria'. International Journal of Scientific & Engineering Research (IJSER), Vol. 7, Issue 3, pp. 1187-1194.

[9] Gutin, L. (1936). *On the Sound Field of a Rotating Propeller*. NACA TM 1195, Heft 1 pp 67-71.

[10] Bassey, D. E., Okon, B. E. & FaithPraise, F. O. (2016). Design and Construction of a GSM-Based Multipurpose Measuring Device for UHF Signal Strength Levels. International Journal of Science, Engineering and Technology Research, Vol. 5, Issue 3, pp. 841-846.

[11] Ffowcs-Williams, J. E. & Hawkings, D. L. (1969). Theory Relating to the Noise of Rotating Machinery. *Journal of Sound and Vibration*, 10(1), 10-21.

[12] Bassey, D. E., Ogbulezie, J. C. & R. Umunnah (2016). Empirical Review of Basic Concepts of Teletraffic Postulates. International Journal of Scientific and Engineering Research, Vol. 7, Issue 3, pp.1171-1186.

[13] Goldstein, M. E. (1976). *Aeroacoustics.* New-York: McGraw-Hill., 233pp.

[14] Blake, W. K. (2012). *Mechanics of Flow-Induced Sound and Vibration*. New York: Academic Press, 1-151.

[15] Lighthill, M. J. (1952). On Sound Generated Aerodynamically. I. General Theory. *Proceedings of the Royal Society of London: Series A, Mathematical and Physical Science*, 211(1107), 564-587.

[16] Curle, N. (1955). The Influence of Solid Boundaries upon Aerodynamic Sound. *Proceedings of the Royal Society of London*: *Series A, Mathematical and Physical Sciences*, 231(1187), 505-514.

[17] Fitzgerald, J. M. & Lauchle, G. C. (1984). Reduction of Discrete Frequency Noise in Small, Subsonic Axial-flow Fans. *Journal of Acoustical Society of America*, 76(1), 158-166.

[18] Washburn, K. B. & Lauchle, G. C. (1988). Inlet Flow Conditions and Tonal Sound Radiation from a Subsonic Fan. *Noise Control Engineering Journal*, 31(2), 101-110.

[19] Chiu, W. S. & Lauchle, G. C. (1989). Subsonic Axial Flow Fan Noise and Unsteady Rotor Force. *Journal of Acoustical Society of America*, 85(2), 641-647.

[20] Bassey, D. E., Okon, B. E. & Effiom, E. O. (2016). Pilot Case Study of GSM - Network Load Measurement in Ikeja - Nigeria. International Journal of Science, Engineering and Technology Research, Vol. 5, Issue 3, pp. 824-829.

[21] Beiler, M. G. & Carolus, T. H. (1999). Computation and Measurement of the Flow in Axial Flow Fans with Skewed Blades. *Transactions of the American Society of Mechanical Engineering (ASME): Journal of Turbomachinery*, 121, 59-66.

[22] Boltezar, M. & Mesaric, M. (1998). The Influence of Uneven Blade Spacing on the SPL and Noise Spectra Radiated From Radial Fans. *Journal of Sound and Vibration*, 216(4), 697-711.

[23] Brungart, T. A. & Lauchle, G. C. (2001). Modification of a Handheld Vacuum Cleaner for Noise Control. *Noise Control Engineering Journal*, 49(2), 73-78.

[24] Bassey, D. E., Ogbulezie, J. C. & Okon, B. E. (2016). Modeling a Low Latency IP Network in Nigeria. International Journal of Science, Engineering and Technology Research, Vol. 5, Issue 3, pp. 830-834.

[25] Koopmann, G. H. & Fox, D. J. (1988). Active Source Cancellation of the Blade Tone Fundamental and Harmonics in Centrifugal Fans. *Journal of Sound and Vibration*, 126(2), 209-220.

[26] Lauchle, G. C. & MacGillivray, J. R. (1997). Active Control of Axial-Flow Fan Noise. *Journal of Acoustical Society of America*, 101(1), 341-349.

[27] Longhouse, R. E. (1977). Vortex Shedding Noise of Low Tip Speed, Axial Flow Fans. *Journal of Sound and Vibration*, 53(1), 25-46.

[28] Fukano, T. & Takamatsu, Y. (1986). The Effect of Tip Clearance on the Noise of Low Pressure Axial and Mixed Flow Fans. *Journal of Sound and Vibration*, 105(2), 291-308.

[29] Kameier, F. & Neise, W. (1997). Experimental Study of Tip Clearance Losses and Noise in Axial Turbomachines and Their Reduction. *Transaction of the American Society of Mechanical Engineering*, 119.

[30] Bassey, D. E., Akpan, Aniefiok. O. & Udoeno, E. (2016). UHF Wave Propagation Losses Beyond 40 Percent Fresnel Zone Radius in South-South Nigeria. International Journal of Science and Research, Vol. 5, Issue 2, pp. 740-745.

[31] Horlock, J. H. (1968). Fluctuating Lift Forces on Aerofoils Moving Through Transverse and Chord-wise Gusts. *Journal of Basic Engineering*, Series D, 90(4), 494-500.

[32] Naumann, H. & Yeh, H. (1973). Lift and Pressure Fluctuations of a Cambered Airfoil under Periodic Gusts and Applications in Turbomachinery. *Journal of Engineering for Power*, 5, 1-10.

[33] Sharland, I. J. (1964). Sources of Noise in Axial Flow Fans. *Journal of Sound and Vibration*, 1(3), 302-322.

[34] Gordon, C. G. (1969). Spoiler-Generated Flow noise: II. Results. *Journal of Acoustical Society of America*, 45(1), 214-223.

[35] Algermissen, G. & Siegert, R. (2001). Numerical Simulation of Aeroacoustic Sound Generalized by Fans under Installation Conditions. *7th AIAA/CEAS Aeroacoustics Conference, Maastricht, Netherlands, 1, 84.*

[36] Bassey, D. E., Okoro, R. C., Okon, B E. (2016). Modeling of Radio Waves Transmission of Building Located around Niger Delta Urban Microcell Environment Using "Ray Tracing Techniques". International Journal of Science and Research, *Vol.5, Issue 2,* pp. 337-346.

[37] Bassey, D. E., Okoro, R. C., Okon, B. E. (2016). Issues of Variance of Extreme Values in a Heterogenous Teletraffic Environment. International Journal of Science and Research, Vol. 5, Issue 2, pp. 164-169.

[38] Bassey, D. E., Okoro, R. C. & Okon, B. E. (2016). Issues Associated with Decimeter Waves Propagation at 0.6, 1.0 and 2.0 Peak Fresnel Zone Levels. International Journal of Science and Research, Vol. 5, Issue 2, pp. 159-163.