A MODEL INSTRUMENTATION DESIGN TECHNIQUE AND CONSTRUCTION OF A 120W, 8Ω MB2X OUTPUT TRANSDUCER SYSTEM

D. I. Malgwi and I. Oluchukwu
Department of Physics, University of Maiduguri, Maiduguri, Nigeria.

(*Submitted: 19 January, 2006; Accepted: 15 March, 2006*)

Abstract

The Physics of electronic instrumentation and experimental techniques was studied and the design and construction of an output transducer (loudspeaker system) called MB2X rated 120W, 8Ω were conducted experimentally. The design incorporated a 12" woofer, 2 tweeters and a simple cross-over circuit using locally available and affordable materials and components.
Discrete components like, resistors, capacitors (10 mf) and an inductor were used in the construction of the cross-over circuit. Also used for the testing, reliability and specifications of the MB-2X output transducer system are a signal generator, multimeters and an oscilloscope.
Other materials like plywood, wood gum, nails, thick foam etc. were used for the speaker casing and cabinet. On testing and reliability, the MB2X has an operating bandwidth of 60Hz to 7.5KHz at ±2dB amplifier headroom with a minimum usable frequency of 53Hz.

Key words: *Instrumentation systems, output transducer, loudspeaker*

Introduction

An instrumentation system is made up of an input device, transducer, signal-processing unit and a display. Typical example of an instrumentation system is a public addressing system, which is an analog device. The three major components of public addressing system are the microphone (input-transducer), the amplifier (signal processor) and the loudspeaker (output transducer). The voice coil of a loudspeaker serves as an output transducer in a Hi-fi (high fidelity) or public address system, which converts electrical signal from an amplifier into a corresponding non-electrical signal known as sound (Malgwi, 2004).

A standard loudspeaker system must have the following features viz: i) the frequency section: which comprises the tweeter; ii) the low-frequency section: which is called the woofer; iii) the mid-frequency section: which projects sounds with frequency intermediate or between the low and high frequencies; iv) the cross-over section: serves as an internal proprietary circuit that splits the frequencies to the various sections; and, v) the cabinets (Malgwi, 2004; www.peaveay.com, 2005).

This paper intends to present the electronic instrumentation design and the construction of an output transducer (loudspeaker) system, which have all of the above-mentioned features with the exception of (iii) the mid-range section.

The proposed output transducer (loudspeaker) system will be named "M BLASTER 2X (MB 2X)". This high power handling two-way output transducer system will comprise a 12" woofer and two tweeters. It will have a trapezoidal shaped enclosure or cabinet, which allows rays to be constructed much more easily than it would be using a rectangular shaped box. This shape was chosen in order to attenuate or greatly reduce the build up of standing waves on the inside of the enclosure so as to ensure a minimum of mid-bass and mid-range coloration of the reproduced sound due to the cabinet (www.peaveay.com, 2005). The chosen dimensions are 525mm x 400mm x 345mm (H x W x D).

The MB2X output transducer (two-way loudspeaker) system will be designed and constructed using the principles of electronic instrumentation and experimental techniques in physics. Its architectural design and engineering specifications will have an operating bandwidth of 60Hz to 7.5KHz. The nominal output level will be 70dB when measured at a distance of 1m with an input power of 1W whereas the nominal impedance will be 8Ω. The continuous power handling will be 60W (rms) and 120W maximum power.

Theoretical Basis

Sound and hearing

The most general definition of sound is that it is a longitudinal wave in a medium usually described in terms of displacement of particles in the medium or in terms of pressure fluctuation (Nelkon and Phillip, 1995; Onuu, 2000). The simplest sound waves are sinusoidal waves, which have definite frequency, amplitude, and wavelength. Human ear is sensitive to waves in the frequency range from about 20 to 20,000Hz, called the audible range, but the term sound is also used for similar waves, with frequencies above (Ultrasonic) and below (Infrasonic) the range of human hearing (Stevens, 1956; Onuu, 1999).

Perspective of sound waves

The physical characteristics of sound waves are directly relative to the perception of that sound by the listener (Menkiti, 2001). For a given frequency, the greater the pressure amplitude of a sinusoidal sound wave, the greater the perceived loudness (Onuu, 1999). This phenomenon varies from one person to another because the human ear is not equally sensitive to all frequencies in the audible range (Asaquo et al., 2001; Malgwi, 2004). For instance, at 1000Hz frequency, the minimum pressure amplitude that can be perceived with normal hearing is about 3×10^{-5}Pa; to produce the same loudness at 200Hz or 12,000Hz requires about 3×10^{-4}Pa.

The frequency of a source wave is the primary factor in determining the pitch of a sound; the quality that allows us classifies the sound as "high" or "low" (Stevens, 1956). Pressure amplitude denoted by P_{max} of a sinusoidal sound wave is defined mathematically as:

$$P_{max} = BKA \qquad (1)$$

where k = 2/ = wave number; B is called the Bulk modulus; and, A is the displacement amplitude.

Sound intensity

Traveling sound waves, transfer energy from one region of space to another. We define the intensity, I, of sound waves as the average energy carried per unit time across a surface area perpendicular to the direction of propagation. In order words, intensity I is average power per unit area. Such that

$$I = \tfrac{1}{2} BWKA^2 \qquad (2)$$

Where I = intensity of a sinusoidal sound wave

Putting w = VK and $V^2 = B/P$, we obtain;

$$I = \tfrac{1}{2}(PB)^{1/2}W^2A^2 \qquad (3)$$

This equation shows why a low-frequency woofer has to vibrate with much larger amplitude than a high-frequency tweeter to produce the same sound intensity in a stereo system. However, it is more useful to express I in terms of the pressure amplitude P_{max}. Thus using the relation w = VK in: (2) we obtain

$$I = \frac{wP^3{}_{max}}{2BK} = \frac{VP^3{}_{max}}{2B} \qquad (4)$$

Alternatively, by using the wave speed relation $V^2 =$ B/, Equation (1) can also be written as:

$$I \frac{wP^2_{max}}{2\rho V} = \frac{VP^2_{max}}{2\sqrt{\rho\beta}} \qquad (5)$$

The total average power carried across a surface by a sound wave equals the product of the intensity at the surface area if the intensity over the surface is uniform. Similarly, the average total power of sound emitted by a person speaking in an ordinary conservational tone is about 10^{-5}W, while a loud shout corresponds to about 3×10^{-2}W (Young and Freedman, 1996).

Materials and Method

The materials employed in the actual construction of the sound box and speaker cabinets include; plywood, nails, thick foam materials, connecting speaker wires, Top bond wood gum. Plywood of thickness 1.2cm was used for each side of the box. The speaker enclosure was constructed into a trapezoidal shaped box with dimensions 525mm x 400mm x 345mm (H x W x D) for the front panel and 450mm x 345mm (H x W x D) for the backside. This material in collaboration with the trapezoidal shape of the sound box serve to reduce standing waves that would be built up inside the box. Also used for the testing, reliability and specifications of the MB-2X output transducer system are a signal generator, multimeters and an oscilloscope.

Selection of components

The circuit board used for the construction of the cross-over circuit is a Vero type. The following components were employed in the construction and design of the cross - over circuit viz:

(a) A 160-turn inductor, L, having a ratio of 0.01 and solenoid length of 0.06m was used. Hence, the self-inductance of the inductor is

$$L = \mu_0 N^2 r^2 l \qquad (6)$$

where μ_0 = (nil active permeability of free space) = 4x x 10^{-7}H/m

Such that

$$L = 4\pi^2 x^2 x (160)^2 x (0.01)^2 x 10^{-7} x 0.06 = 0.61H$$

(b) For low frequency section, choke resistors (10W 4.2Ω and 5W 4.7Ω) in series with the conductor were used. However, for the high frequency section, (5W, 6.8Ω) resistor was used.

(c) The value of the capacitor used in the high frequency section was a 10μF, 100V.

Other important equations (7-10) used in the subsequent instrumentation design of the output transducer include (with the usual notation):

(d) Capacitive reactance

$$X_c = \frac{1}{wC} = \frac{1}{2fC} \qquad (7)$$

(e) Inductive reactance

$$X_i = wl = 2\mu fl \qquad (8)$$

(f) Ohm's law V = IR (9)

(g) Power

$$P = IV = I^2R = \frac{V^2}{R} \qquad (10)$$

An example of how each component was obtained in the design is given below.

For a 50Hz main supply, the impedance of the 10μF capacitor using equation (7) is

$$X_C = \frac{1 x 10^6}{2\mu x 50 x 10} = 318.3\Omega$$

The capacitor is connected in series with 5W, 6.8Ω resistor in the high frequency section. Hence the effective impedance shall be

$$Z = (X_i^2 + R^2)^{1/2} = (318.3^2 + 6.8^2)^{1/2}\Omega = 318.4\Omega$$

This theoretical value may not be the same with the practical value of the component used in the final design in which case, the nearest available value with similar characteristics and tolerance is used.

Circuit Design and Analysis

The cross - over circuit is a typical example of an R-L-C circuit. It is an internal proprietary circuit that splits signal of various frequencies to the appropriate speakers. The architectural diagram of the circuit is shown in Fig 1.

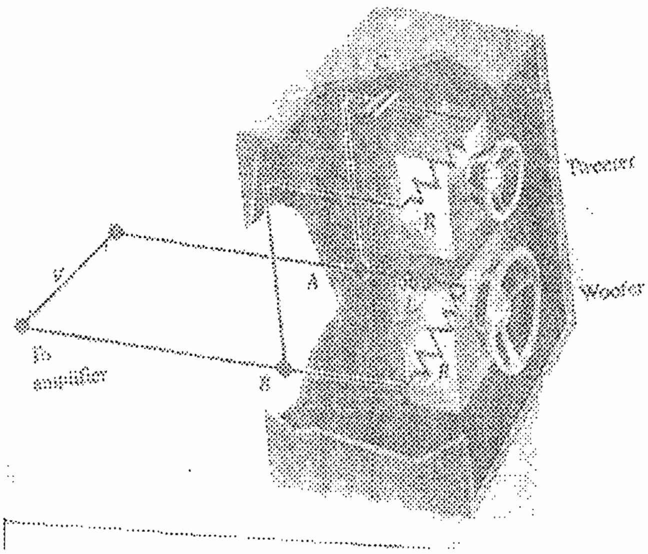

Fig 1: A cross over network in a loudspeaker system

In a loudspeaker system low frequency the woofer produces sounds, which is a speaker with large diameter. The tweeter is a speaker of smaller diameter, which produces high frequency sounds. In order to route signals of different frequency to the appropriate speaker, the cross - over circuit is very important. It provides a means of connecting the woofer and the tweeter in parallel to the amplifier output. The capacitor in the tweeter branch blocks the low-frequency components of sound but allows higher frequencies to pass. The inductor in the woofer branch does the opposite. Hence, the inductance feeds lower frequencies predominantly to the woofer while the capacitance feeds the higher frequencies to the tweeter (Young and Freedman, 1996).
Plotting the graphs of current amplitude in the tweeter and woofer as functions of frequency for a given amplifier voltage amplitude; we have

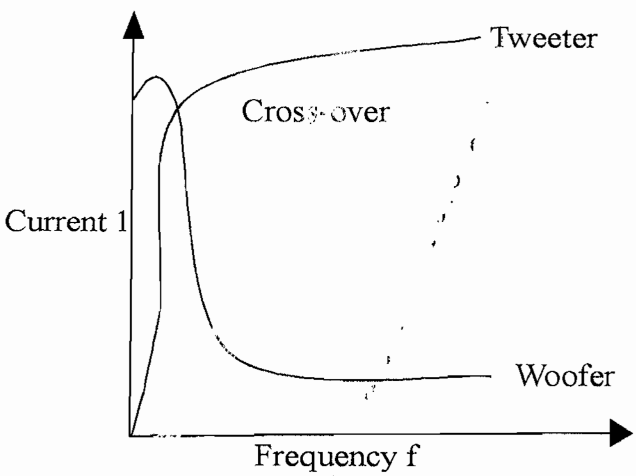

Fig. 2 A plot of current amplitude as a function of frequency in a loudspeaker

Low frequency components of sound but allows higher frequencies to pass. The inductor in the woofer branch does the opposite. Hence, the inductance feeds lower frequencies predominantly to the woofer while the capacitance feeds the higher frequencies to the tweeter (Young and Freedman, 1996).
Plotting the graphs of current amplitude in the tweeter and woofer as functions of frequency for a given amplifier voltage amplitude; we have
The circuit is as shown below in Fig. 3

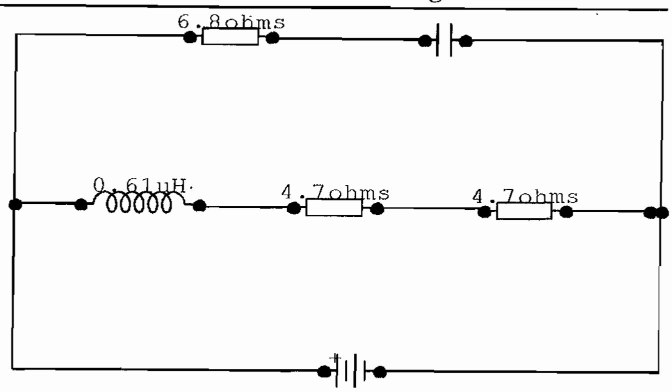

Fig. 3: The Cross-over circuit

Basic calculations

For the woofer section, two resistors each of 4.7Ω are connected in series with an inductor of L=0.6H. The inductor offers a negligible resistance. Hence, the total impedance across L-R combination of the woofer section is

$$Z_l = (4.7 + 4.7)\Omega \text{ (series connection)} \quad (11)$$

However, a 6.8Ω resistor is used in series with a 10μf capacitor in the tweeter branch.
The speaker system has an operating bandwidth of 60Hz to 7.5kHz, thus, the maximum reactance of the capacitor according to equation (8) will occur at 60Hz frequency. Such that

$$X_c = \frac{1 \times 10^6}{2 \times 3.14 \times 60 \times 10} = 265.3$$

$X_c = 265.3\Omega$
This capacitor in series with 6.8 resistors will yield an impedance of

$$Z_f = (R^2 + X_c^2)^{1/2} \quad (12)$$

$$Z_f = (6.5^2 + [265.3]^2)^{1/2}$$

$$Z_f = 265.4\,\Omega$$

Finally, the total impedance Z_f across the parallel combination of the two speakers will be

$$\frac{1}{Z_T} = \frac{1}{Z_L} + \frac{1}{Z_f} \quad (13)$$

$$Z_T = \frac{Z_L \times Z_f}{Z_L + Z_f} = \frac{9.4 \times 265.4}{9.4 + 265.4}$$

$Z_T = 9.1\Omega$
Self-inductance of the loudspeaker woofers

The woofer has 130 turns voice coil, each turn having a radius of 0.022m. The length of the solenoid is 0.03m. Hence the self-inductance of the woofer according to eqn. (8) is

$$L = 4x^2(130)^2 x (0.022)^2 x 10^{-7} x 0.03$$

$$L = 9.7 x 10^{-7} H$$

Testing, Reliability and Specifications

After construction of the voice coil and proper fitting of the rigid speaker cone, which is attached into the air-gap of a permanent magnet of the woofers in the MB-2X output transducer system, a laboratory test for reliability was conducted using a 250W amplifier.

Here, extreme care was taken in tuning the volume knob so as ensure minimum amplifiers' headroom that has the propensity of damaging the MB-2X speaker unit during short transients due to sudden surge of current or voltage above the steady state condition of the cross-over circuit. A maximum current (I = 3.9A) was delivered by the amplifier when a multimeter was connected in-between the amplifiers' output and the speakers input cable. The impedance of the MB-2X loudspeaker system was also found to be 8Ω , which implies a maximum power output of about 120 ± 1.4W.

The operating bandwidth of the MB-2X loudspeaker system using an oscilloscope and a signal generator was found to be 60Hz to 7.5KHz at ±2dB input. The usable low frequency of the cross-over circuit was measured to be 53Hz and the cross-over frequency was found to be 1500Hz.

This strenuous test assures the user that every portion of this system can withstand today's modern world high music technology. However, its use for sound production must ensure that the maximum power delivered to the speakers does not exceed its maximum power handling or ratings. These ratings are referred to as specifications.

The following are the specifications of the designed MB-2X loudspeaker system, determined experimentally in the laboratory, using a signal generator, a multimeter and an oscilloscope:

Frequency Response

60Hz to 7.5KHz (±2dB)

Usable Low Frequency Limit:

53Hz

Power Handling:

(i) Low frequency Section

60W continuous

120W Maximum

(ii) High Frequency Section

5W Continuous

10W Maximum

Transducer Complement

(i) Low frequency Section

1 x 12in. Woofer, vented

(ii) High Frequency Section

2 x 3in tweeter

Impedance (Z)

(i) Low frequency

8.0 (nominal)

(ii) High frequency

16 x 2 (nominal)

Cost analysis of components used

One of the major aims of this paper is to show how a cross-over circuit of any loudspeaker system can be designed and constructed using locally available components at a cheaper rate compared to the current market price of imported ready made of the same ratings. A typical cross-over of 80W maximum output will cost about N4000 in the market depending on the product name for example Kenwood, Panasonic, Sharp, Technics, Akai, and so on. The following components were used in the construction.

Table 1 presents the cost analysis of components used in the construction of the MB-2X loudspeakers for comparison with current market prices of modern ready-made types.

Table 1: Cost analysis of components used

Components	Type	Value	Quantity	Amount (₦)
Resistors	Choke	10W 4.7Ω	1	
		5W 4.7Ω	1	
		5W 6.8Ω	1	200
Capacitor		10μf	1	
Inductor		0.61×10^{-7}H	1	
Mirror board			1	70
Ceiling wire	Copper of diameter (0.05mm)		2 dots	120

This study has revealed some important aspect of electronic instrumentation, design and construction of an output transducer (loudspeaker system) in the following respect:

(i) Coiling wires with greater thickness in terms of diameter can be used in preference to tiny ones in the construction of the voice coil as a means of regulating (attenuating) excess heat generation which usually results to its burning out;

(ii) Increments in the number of turns of a voice coil from its nominal value of 120 turns to 130 turns plays an important role in the output power characteristics of a speakers;

(iii) The improvised vent at the base of the flexible suspension ring serves as a cooling mechanism for the voice coil in order to ensure its durability;

(iv) The soft foams introduced in the casing of the MB-2X loudspeaker cabinet is an improvement to the currently adopted casing method of a speaker system in the sense that it helps to reduce shock and enhance its durability; and,

(v) With a frequency response of 60Hz to 7.5KHz and a minimum usable frequency of 53Hz at ±2dB input, the MB2X can withstand today's high musical instrumentation technology.

Discussion

A careful analyses has shown that thicker diameter of wires is required for power transmission in terms of high current. Since the power of a signal from an amplifier is a function of current amplitude, the MB-2X features a voice coil made of thick-coiled wire achieved by increasing the air gap and/or space between the magnetic poles of the permanent magnet so as to accommodate large current from the amplifier. This method was chosen in perfect synchronism with the principle of physics, which shows that the resistance of a wire varies inversely with its cross-sectional area. Hence, thicker wires have small resistance, and can conduct large current than thinner ones in an electronic circuit.

This study has also revealed that the output power characteristics of a loudspeaker depend on the strength of its permanent magnetic field as well as the self-inductance of its voice coil. The MB-2X instrumentation design has improved a means of boosting the power capability of any loudspeaker by increasing the number of turns from 120 turns to 130 turns. This method was adopted in conformity with Faraday's law of electromagnetic induction (Arthur, 1962; Grant and Phillips, 1990).

When the loudspeaker system is powered over prolonged period, some of the electrical energy supplied to this unit is irreversibly converted into heat (Noakes and Inst., 1968; Mettha and Mettha, 2003; www.peavey.com, 2005). As a cooling mechanism to this impediment, vent holes were created at the base of the loudspeaker box.

This unique and very vital idea possibly discovered by Peavey Electronics, U.S.A. was incorporated in the instrumentation design of MB-2X Output Transducer so as to ensure the durability of the voice coil.

The trapezoidal shaped loudspeaker cabinet which is quite trendy in the latest musical instrumentation systems industry in terms of quality sound production coupled with the introduction of a thick but soft foam was chosen to respectively reduce mid-bass, mid-frequency coloration of the sound reproduced and the absorption of possible shock due to vibration of sound by the cabinet.

Advantages of MB2X

A careful study and analysis of similar works and products produced by several electronic industries such as Celestion Electronic Company in England, and Behringer Electronic Company in Germany amongst others in the year 2005 shows that the voice coil of every 12" woofer has 120 turns using wire of very small diameter (www.peaveay.com, 2005). These specifications can generate heat when large current is supplied to the speaker unit (Mettha and Mettha, 2003). As an improvement to this, the MB2X has 130 turns to reduce heat generation and to avoid its burning out when large current is supplied. This is achieved by increasing the air space in between the magnetic poles so as to accommodate a voice coil comprising of larger diameter of wire. More so, the increase in the number of turns from the nominal value to 130 turns, shows that the MB-2X is expected to have higher power output characteristics coupled with larger coil duration than the previous works and products already in the market.

Conclusion

A trapezoidal shaped, 8Ω impedance output transducer (loudspeaker) system with a maximum output of 120W has been designed using simple electronic instrumentation design and experimental techniques in physics. Locally and readily available components were used in the construction of the cross-over circuit of the loudspeaker system. The design ensures that the cross-over circuit delivers an output commensurate with the power handling of the loudspeaker system.

This study revealed how an output transducer with a long lasting voice coil can be achieved using a thick diameter coiling wire and by creating a vent at the base of the speaker box. Moreover, the speaker cabinets internally covered by thick foam are more durable than products lacking this unique feature.

The MB2X loudspeaker system can be improved with the availability of a more rigid and stronger speaker cone. This can be achieved by re-designing and re-calculating specifications of the components to be used coupled with computer-aided technology. MB2X is recommended for lecture halls, musical concerts, music studios, churches and mosques, disco halls and host of others.

Finally, with the use of the simplest and most economical method of electronic design, this model instrumentation technique implies social satisfaction derived from high quality sound production and, economic advantage, costing cheaper than a ready-made loudspeaker system of the same specifications in the modern market in Nigeria.

References

Arthur, F. K. (1962): Fundamentals of Electricity and Magnetism New York: McGraw Hill, Inc., 398-407.

Asaquo, U.E., Menkiti, A.I., Onuu, M.U., and Opaluwa, E.H.O. (2001): Environmental Noise Studies in some areas of Calabar and Uyo, Nigeria. GJPAS 7(2): 339-334.

Grant, I. S. and Philips, W.R. (1990):. Electromagnetism. Chichester: John, W. and sons Ltd., 150-257.

Malgwi, D. I. (2004): Instrumentation and Experimental Techniques in Physics (Unpublished Lecture Notes). University of Maiduguri, Nigeria.

Menkiti, A.I., (2001): Analysis of Noise bother by survey method. GJPAS 7(3): 545-552.

Mettha V. K. and Mettha, S. (2003): Principle of Electronics. New Delhi: S. Chand and Company Ltd.

Nelkon, M. and Philip, P. (1995): Advanced Level Physics. II, Daryagaj, New Delhi: S. K. Jain for CBS publishers, 571-578.

Noakes, G. R. and Inst. P. F. (1968): Electricity and Magnetism. London: Macmillan and Co. Ltd., 63.

Onuu, M. U. (1999): A New Set of Empirical Relationships between Sound Pressure Levels and Objectionable Qualities of Noise. Acoustic. Lett. 22: 208-212.

Onuu, M. U. (2000): Noise Pollution in the Urban Environment: Assessment of Objectionable Qualities of Road Traffic Noise. Nig. Journ. of Physics. 12: 68-71.

Stevens, S. S. (1956): Calculations of the Loudness of Complex Noise. J. Acoustic. Soc. Am.28: 807-833.

Young, H. D. and Freedman, R. A (1996): University Physics. New Delhi: Addison Wesley Company, Inc. 646 1004.e

www.beringu.com (2005). Peavey Speaker Catalogue. 711 A street

Meridian: Peavey Electronics Cooperation, 1- 3.