Near-Direct and Far-Reverberant Field Response of Direct Radiator Loudspeakers

Aruna Godase, Farhat Surve

***Abstract:** Typical audience seating arrangements in rooms and auditoria warrant reinvestigation of the direct radiator speaker response in the near-direct and far-reverberant fields, as the response data provided by the manufacturer is always ideal and does not account for the effect of those fields. The speaker response characteristics of a variety of direct radiator loudspeakers ranging from the conventional squawker to the full range radiator have been investigated in these fields. The speaker response is investigated in the 50 -10 kHz frequency range, by measuring the A-weighted SPL (sound pressure level) in the near-direct and far-reverberant fields, using an acoustic analyzer. The field-specific characteristic for each of the radiators is determined by fitting the SPL data obtained to an appropriate polynomial. The coefficients obtained thereby, allow an objective field-specific study amongst radiators. When a set of direct radiator loudspeakers is available, it is necessary to configure their application, depending upon the optimum sound quality required for a given enclosure, in near-direct field and far-reverberant field. The outcome of this work assists one to configure the best radiator ensemble for a given enclosure, despite placement constraints.*

***Keywords:** Direct radiator loudspeaker, far-reverberant field, near-direct field, speaker response characteristics.*

I. INTRODUCTION

The major objective is to investigate the speaker response characteristics of direct radiator loudspeakers in the near-direct and far-reverberant fields within enclosures. Another objective is to study the speaker-response of a variety of direct radiator loudspeakers ranging from the conventional mid-range squawkers to the more recent full-range radiators and see how those would comply with specific enclosure requirements. The polynomial fits over SPL data obtained in the corresponding fields demonstrate possible interchangeability and combinations of radiators to be deployed depending upon field-response.

Selection of a specific direct radiator loudspeaker for an application generally depends upon its efficiency, response characteristic, resonance frequency and bandwidth -properties that designate the quality of sound radiated by the loudspeaker. However, none of them provide the study of radiators with regard to fields in an enclosure. A limited investigation implementing computational methods has been carried out by some researchers [1]. However, none of the works have experimentally investigated or studied the field-specific response viz. the response in the near, far and free fields. A special aspect of our work is that the measurements are made in a typical real-world environment rather than an anechoic chamber or in an ideal setup of any kind. Moreover, the variations in the response reported predict only on axis response [2] and concentrate on directivity [3, 4]. In an anechoic chamber, the placement or position of radiators is ideal, whereas in the real-world scenario, the placement of the radiator is critical, as it produces a variety of reflections depending on the enclosure. In most of the studies, the real-world scenario was implemented simply by mounting radiators in the centre of the room and at most by using two voice coils to get a uniform response and suppress distortion [5]. Some studies concentrate on reverberation time for an encloser with complex geometry and study the influence of how speech is perceived in different part of the enclosure [6] but in real-world scenario complex geometry enclosures are not frequent. Various researchers have investigated the design parameter of the electrodynamic loudspeaker by using Finite Element Method [7] whereas in rural and semirural areas with available set of loudspeakers, it is necessary to give most efficient work and quality of sound for different programmes. The comparison of loudspeaker sensitivity characteristics and the speaker response curves were carried out in different enclosures [8]. Some have developed stable control mechanism to obtain a uniform frequency response [9]. Some researchers have studied outdoor sound propagation of public address systems and used modeling techniques based on geometrical acoustics to increase speech intelligibility [10]. Some of the researchers have done the analysis of sound field in the closed spaces [11] for the low frequencies, where as there are some literatures works that are based on studying the acoustical characteristics of the multi-function halls [12]. There are few works which have done the simulations to get the equivalent sound sources in the closed spaces [13].

Revised Manuscript Received on October 15, 2019.

Aruna Godase, Electro-Acoustic Research Laboratory, Department of Physics, Nowrosjee Wadia College, SPPU, Pune-411001, Maharashtra, India. Email: arunaodase@gmail.com

Farhat Surve, Electro-Acoustic Research Laboratory, Department of Physics, Nowrosjee Wadia College, SPPU, Pune-411001, Maharashtra, India. Email: farhatsurve@hotmail.com

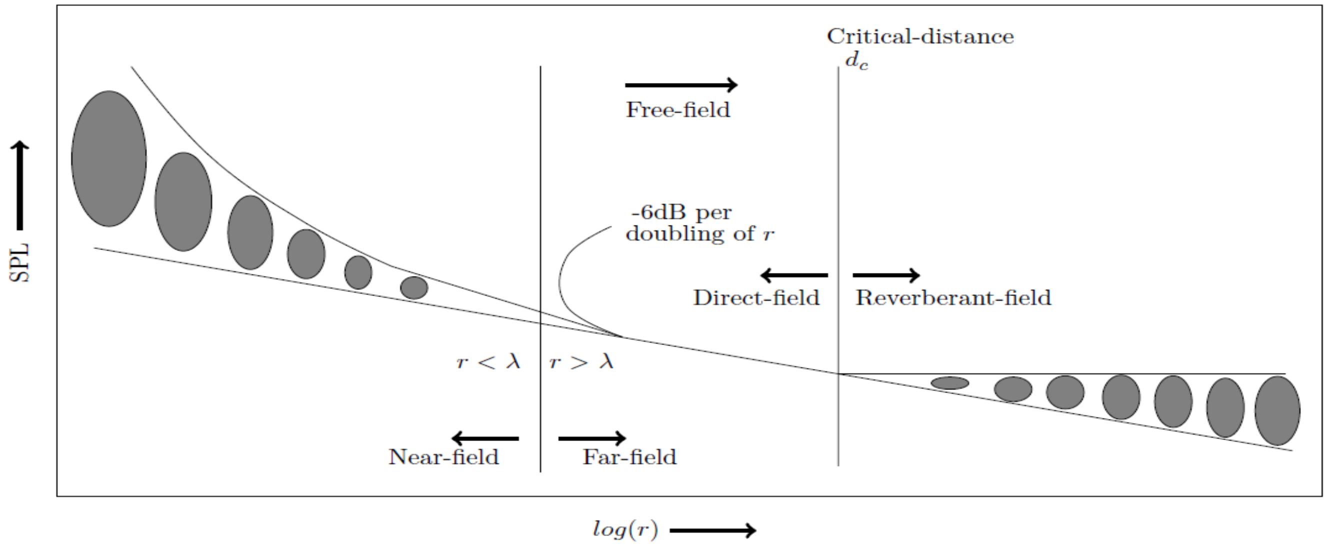

Fig. 1. Near-direct and far-reverberant fields.

In our work, we have examined the radiators in conditions that are close to those occurring normally, with a focus on field specific response of loudspeakers, wherein the objective is to achieve either an appropriate placement combination of radiators or to seek an equivalent replacement of an existing configuration. We have studied a variety of radiators in the near-direct and far-reverberant fields: Their SPL response has been studied over a range of frequencies and then fitted to appropriate polynomial functions. The coefficients that manifest over the polynomial fits are compared to find similarities in the characteristic response. The rate of rise and fall in response is also examined so as to study the radiators in order to facilitate a precise selection.

The measurements are made as follows:

1. Near-direct field measurement: The SPL measurements Fig. 1. Near-direct and far-reverberant fields are made in the near-direct field by placing the analyzer at a distance that is less than or equal to the wavelength.
2. Measurement in the near-direct field implies that the SPL measurement is made for sound waves arriving directly onto the analyzer.

3. Far-reverberant field measurement: The second set of observations is made in the far-reverberant field viz. the SPL measurements are made at a distance beyond the critical distance ($d > 2 * \lambda$)

4. The far-reverberant field implies the region wherein you have a mix of the direct and the reflected sound waves.

II. EXPERIMNETAL SETUP AND PROCEDURE

A wall mounted testing and calibration suite is used for a series of observations carried out to study the response characteristics of radiators (Fig. 2). The apparatus allows movement along three axes: The Y and Z axes are laid along the wall i.e. the YOZ plane is parallel to the wall and allows movement of the radiator in both the Y and Z direction. The X axis accommodates a pair of arms (transducer brackets) normal to the wall which are used to mount the radiator and the analyzer. The primary arm is used to hold the radiator whereas the secondary arm is used to mount the analyzer

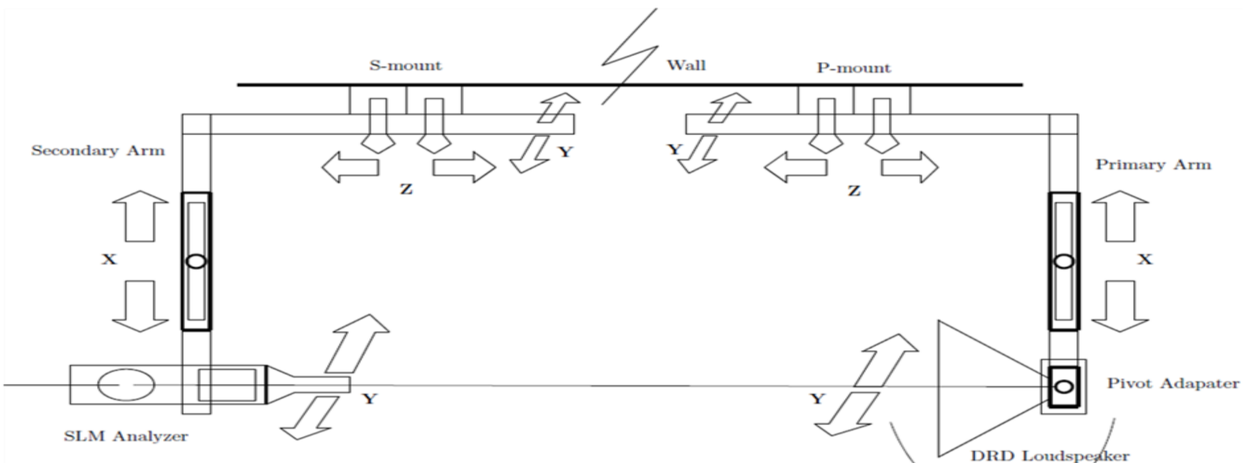

Fig. 2. Testing and calibration suite

Retrieval Number: A9791109119/2019©BEIESP
DOI: 10.35940/ijeat.A9791.109119

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

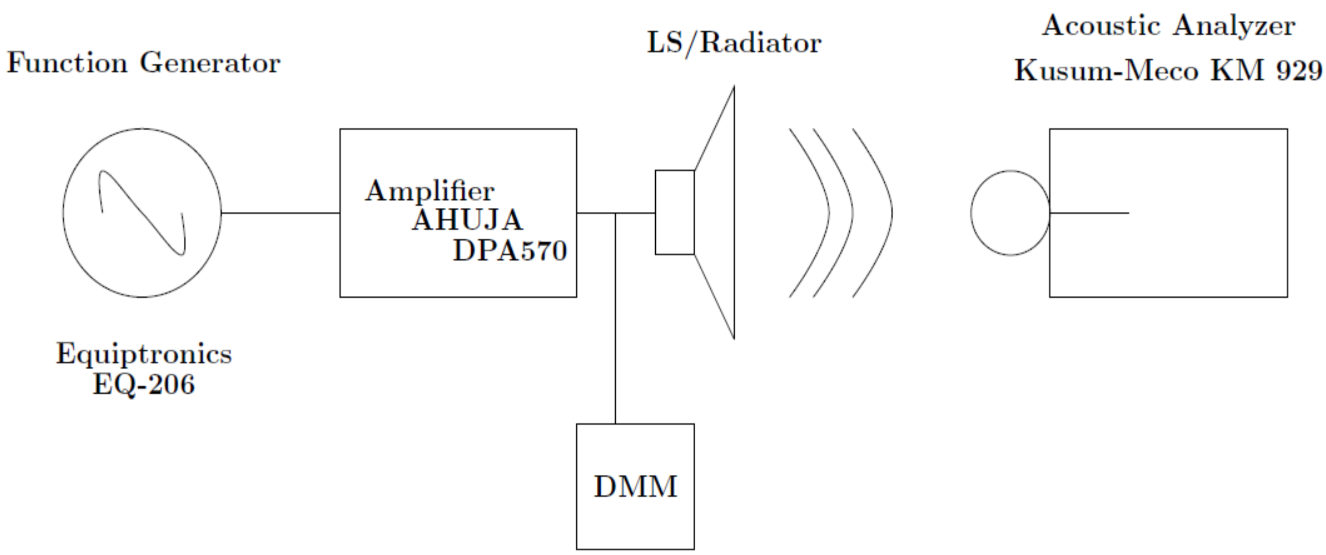

Fig. 3.Radiator driving circuit.

for the near-direct field measurement. The observations for the far-reverberant field are taken at a distance “d” where ($d > \lambda$), at times employing an angular rotation over the pivot on the primary bracket to direct the radiator towards the far-reverberant field.

Fig. 3 shows the radiator driving circuit. The radiator is driven by applying varying frequencies using the Equiptronics EQ 206 function generator through the AHUJA DPA-570 amplifier. The SPL (dBA) data is collected and analyzed using the acoustic analyzer (Kusum-Meco KM 929). The data for frequencies ranging from 50 Hz to 10000 Hz in a) The near-direct field ($d < \lambda$), and b) The far-reverberant field ($d < 2*\lambda$) is collected. The frequency response in the corresponding fields for the aforementioned direct radiator loudspeakers is studied by using curve fitting (polynomial fits of degree 3). The coefficients are then obtained using the trend-line equations in Excel.

III. RADIATORS AND MEASUREMENT ENCLOSURE

Five different Ahuja make loudspeakers were investigated.

1. SP-I-A-1-100
2. SP-II-CDH-200
3. SP-III-N-12-X-200
4. SP-IV-L-12 MB-300
5. SP-V- SK-15-FRX

The enclosure used was the Electro-Acoustic Research Laboratory (EARL) at the Nowrosjee Wadia College, Pune. The dimensions of the lab are 22x20x15 ft. i.e. a volume of 6600 ft^3. The reverberation time for the EARL ranges from 0.341 sec to 0.354 sec for frequencies ranging from 125 Hz to 4000 Hz respectively. The maximum reverberation time is 0.496 for the frequency 1000 Hz.

IV. RESULTS AND DISCUSSION

A. *Near-Direct field response*

Speaker response characteristics of five direct radiators [14] in the near-direct field are portrayed in Figs. 4 - 8. The data for each response is fitted to a polynomial of degree three [15] and the coefficient matrix is then analyzed.

Speaker response for SP-I: A-I-100 in the range 50 Hz to 8 kHz shows a maximum of 95.1 dB at 2.5 kHz (Fig. 4). Hence, resonance frequency for the A-I-100 is 2.5 kHz. We see a better response between 200 Hz and 8 kHz. The minimum SPL (63.8 dB) is seen at 50 Hz. The SPL varies from 63.8 dB to 95.1 dB over the range of frequencies. The bandwidth is 31.3 dB. The polynomial fit of degree 3 turns out to be:

$$y = 4*10^{-10}x^3 - 6*10^{-6}x^2 + 0.022x + 68.74 \quad (1)$$

All the other radiators SP-II to SP-V are investigated on similar lines and the corresponding frequency response is portrayed in Figs.5 – 8

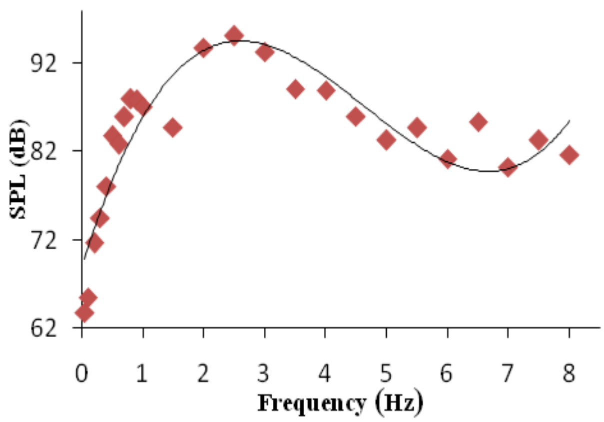

Fig. 4.Speaker-I; Near-direct field

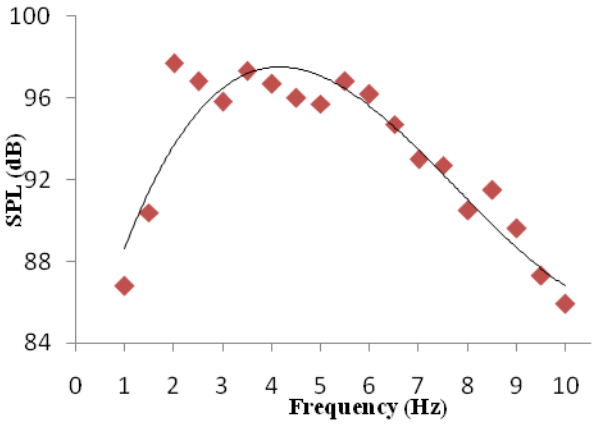

Fig. 5.Speaker-II; Near-direct field

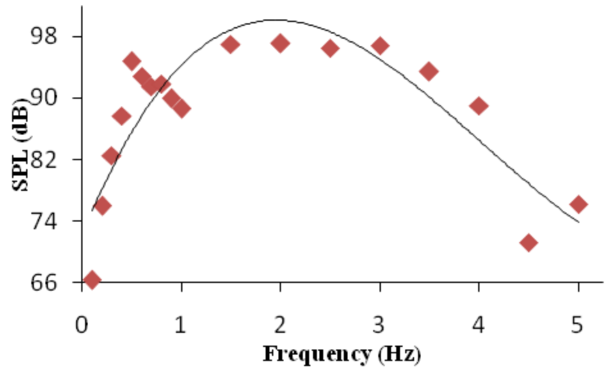

Fig. 7.**Speaker-*****IV; Near-direct field***

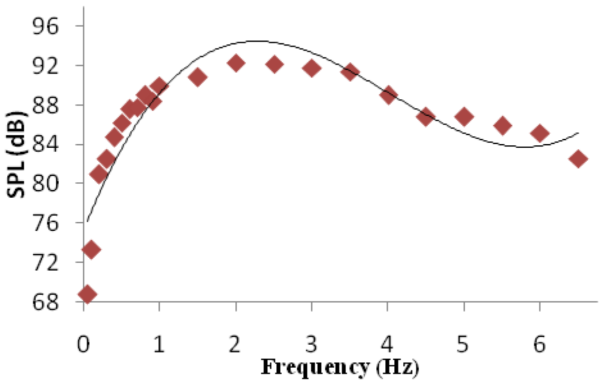

Fig. 6. Speaker-III; Near-direct field

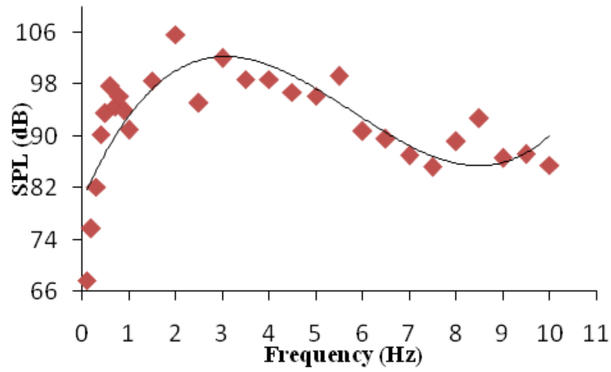

Fig. 8.Speaker-V; Near-direct field

B. *Far-Reverberant field response*

Speaker response characteristics of five direct radiators in the far-reverberant field are portrayed in Figs. 9 - 13. The data for each radiator response is fitted to a polynomial of degree three and the coefficient matrix then analyzed. Radiator response in the range 50 Hz to 8 kHz for SP-I (A-I-100) shows a maximum of 88 dB at 2.25 kHz (fig. 9). Hence, resonance frequency for the A-I-100 is 2.25 kHz. We see a better response from 300 Hz to 8 kHz. The minimum SPL (64.7 dB) appears at 50 Hz. The SPL varies from 64.7 dB to 88dB. The bandwidth is 23.3 dB. The polynomial fit of degree 3 turns out to be:

$$y = 3*10^{-3}x^3 - 5*10^{-6}x^2 + 0.016x + 67.41 \quad (2)$$

All the other radiators SP-II to SP-V are investigated on similar lines and the corresponding frequency response characteristics are portrayed in Figs. 10 – 13.

C. *Field dependent response*

SPL variations for various radiators is studied for frequencies ranging from 50 Hz to 10000 Hz. Table 1 summarizes the speaker response characteristics of the radiators in the near-direct field whereas Table 2 summarizes the speaker response characteristics in the far-reverberant field. Resonance frequency and the equation fits for the each of the radiators have been listed.

Figs. 14 – 15 show the rates of rise and fall in the SPL (dBA) for various radiators in the corresponding fields.

The rates at which the radiator response rises and falls are investigated using statistical methods. Table 3 and 4 elaborate the corresponding values for the near-direct and the far-reverberant fields respectively, whereas Fig. 14 and 15 show the graphical representation for the same.

Table-I: Near-Direct Field

Speaker	Reso. Freq. (kHz)	Equation fit
SP-I	2.5	$y=4*10^{-10}x^3-6*10^{-6}x^2+0.022x+68.74$
SP-II	4.0	$y= 6*10^{-11}x^3- 1*10^{-6}x^2+0.009x+81.03$
SP-III	2.5	$y=5*10^{-10} x^3- 6*10^{-6}x^2+0.019x+75.19$
SP-IV	2.0	$y=9*10^{-10}x^3-1*10^{-5}x^2+0.031x+72.24$
SP-V	3.0	$y= 2*10^{-10}x^3-4*10^{-6}x^2+0.016x+80.09$

Table-II: Far-reverberant Field

Speaker	Reso. Freq. (kHz)	Equation fit
SP-I	2.5	$y=4*10^{-10}x^3-6*10^{-6}x^2+0.022x+68.74$
SP-II	4.0	$y= 6*10^{-11}x^3- 1*10^{-6}x^2+0.009x+81.03$
SP-III	2.5	$y=5*10^{-10} x^3- 6*10^{-6}x^2+0.019x+75.19$
SP-IV	2.0	$y=9*10^{-10}x^3-1*10^{-5}x^2+0.031x+72.24$
SP-V	3.0	$y= 2*10^{-10}x^3-4*10^{-6}x^2+0.016x+80.09$

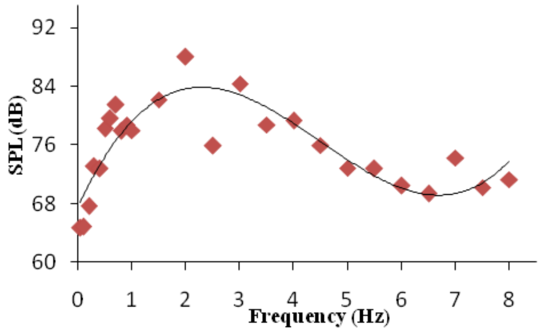

Fig. 9.Speaker-I, Far-reverberant field

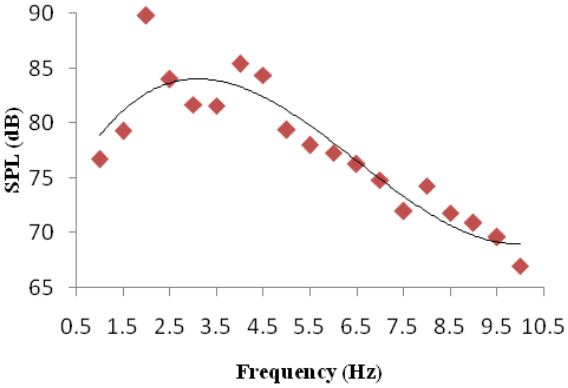

Fig. 10. Speaker-II, Far-reverberant field

Table-III : Rate of rise/fall of SPL in the near-direct field

Speaker		Rate of rise	Rate of fall
SP – I	A-1-100	0.011	0.006
SP – II	CDH-200	0.003	0.002
SP – III	N-12-X-200	0.008	0.005
SP – IV	L15-MB-300	0.020	0.006
SP – V	SK15-FRX	0.010	0.005

Table-IV: Rate of rise / fall in the far-reverberant field

Speaker		Rate of rise	Rate of fall
SP – I	A-1-100	0.012	0.005
SP – II	CDH-200	0.006	0.003
SP – III	N-12-X-200	0.010	0.005
SP – IV	L15-MB-300	0.016	0.009
SP – V	SK15-FRX	0.009	0.001

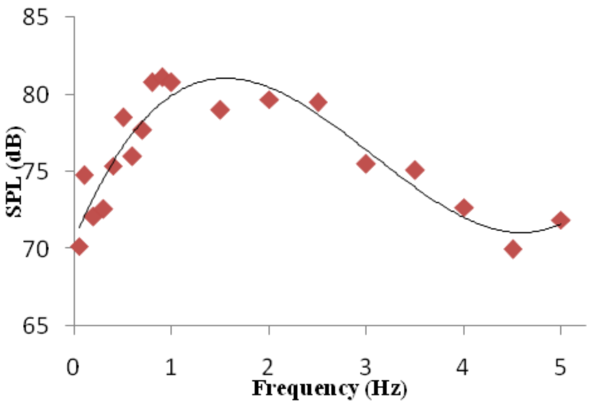

Fig. 11.Speaker-III; Far-reverberant field

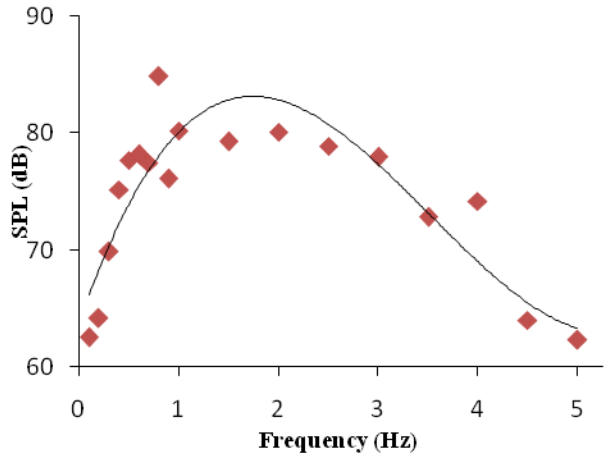

Fig. 12. Speaker-IV, Far-reverberant field

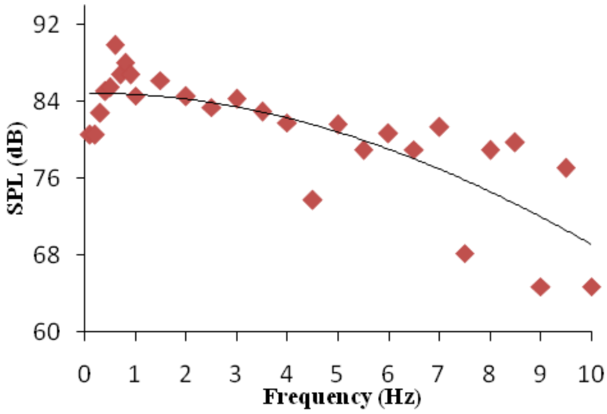

Fig. 13. Speaker-V, Far-reverberant field

V. CONCLUSION

1) The resonance frequencies, response ranges and equation fits for the radiators indicate possible interchangeability between SP-I and SP-III, as the coefficient a_2 is the same, and coefficients a_0, a_1 and a_3 are also close. For instance, one could choose SP-I over SP-III when there is a space constraint as it is portable – light-weight and smaller in size, for a near-direct field application.

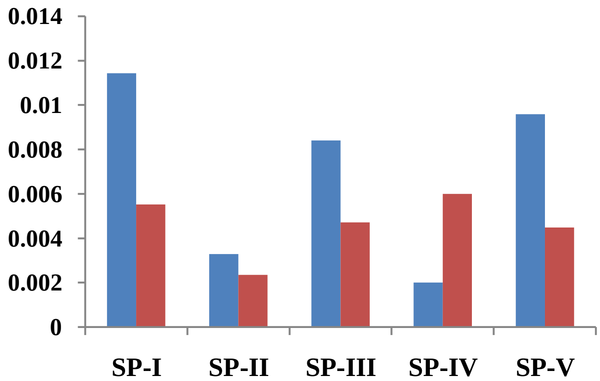

Fig. 14.Rate of rise and rate of fall for near-direct field

2) The resonance frequency, response range and the coefficients of the fit of SP-II, show maximum deviation from the coefficients for the other four speakers.

Hence, SP-II can't be substituted by those. Nonetheless, for the range 1 kHz to 10 kHz; we could use SP-II for near-direct and far-reverberant fields both.

3) Radiators SP-III and SP-V have the same uniform response range. Except for a_3, all other coefficients are close. The rate of rise and fall of speaker-response is also similar. Hence, SP-III and SP-V could be substitutes for one other. SP-III could be preferred over SP-V, being portable. Nonetheless, if a precise response is expected, one must prefer SP-V in far and near-direct field application.
4) Although SP-IV gives a uniform response in the range 200 Hz to 5 kHz in the near-direct field, the coefficients for SP-IV shows a large deviation from those of the other four speakers. Hence SP-IV can't be substituted for by the other speakers for a near-direct field application. But for the far-reverberant field the coefficients of SP-III and SP-IV are close. Hence, SP-III and SP-IV are interchangeable. As SP-III is portable, it could be preferred over SP-IV for a far-reverberant field application
5) The overall rate of rise in response with frequency is higher than the rate of fall across speakers: the response increases from 50 - 2.5 kHz, and thereafter it starts decreasing. The response increases up to 4 kHz in case of SP-II, whereas it rises up to 3.5 kHz for SP-V. However, the deviation from characteristic is significant in case of SP-IV. The difference between rates for SP-I and SP-V are similar.

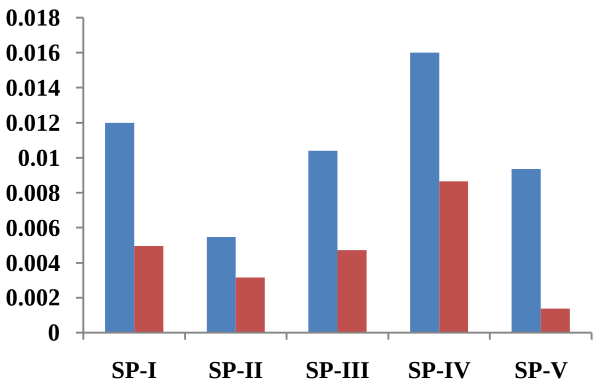

Fig. 15. Rate of rise and rate of fall for far-reverberant field

REFERENCES

1. Mathieu Lavandier, Philippe Herzog and Sabine Meunier, Comparative measurements of loudspeakers in a listening situation, *J. of Acoustical Society of America*, Vol.123 No.1, 2007
2. Jason D. Sagers, Timothy W. Leishman, Jonathan D. *Blotter*, Extended lumped-element model and parameter estimation technique to predict loudspeaker responses with possible surround-dip effect, *J. Acoustical Society of America*, Vol. 134, No.5, Nov. 2013, pp. 3580-3593
3. M. Poletti, F. M. Fazi and P. A. Nelson, Sound-field reproduction systems using fixed-directivity loudspeakers, *J. Acoustical Society of America*, Vol. 127, No. 6, 2010
4. Tobias Knuttel, Ingo B. Witew and Michael Vorlander, Influence of "Omni directional" loudspeaker directivity on measured room impulse responses, *J. Acoustical Society of America*, Vol. 134, No. 5, Nov. 2013, pp.3654-3662
5. Kenji Furihata, Atsushi Hayama, David K. Asano, and Takesaburo Yanagisawa, Acoustic characteristics of an electro-dynamic planar digital loudspeaker, *J. Acoustical Society of America*, Vol. 114, No. 1, 2003
6. Vlad Iordache, Tiberiu Catalina, Bogdanel Marius CUCU., Experimental Investigation of the Reverberation time Inside a Complex Geometry Indoor Space, *Romanian Journal of Acoustics and Vibration*, Vol. 10, No. 2, 2013, pp. 109-114
7. Rausch, M, Lerch, R, Kaltenbacher, M, Landes, H, Kreitmeier, L., Optimization of Electrodynamic loudspeaker-Design Parameters by using Numerical Calculation Scheme, *Acta Acustica united with Acustica*, Vol. 85, No. 3, May/June 1999, pp. 412-419 (8)
8. Bordone-Sacerdote, C., Comparative tests on loudspeakers, *Acta Acustica united with Acustica*, Vol. 11, No. 5, 1961, pp. 329-332(4)
9. Jen-Hsuan Ho, Arthur Berkhoff, A Low density, High stiffness flat Loudspeaker with improved sound frequency response *Proceeding of meetings on Acoustics (JASA)*, Vol. 19, 2013
10. Junichi Mori, Fumiaki Satoh, Sakae Yokoyama and Hideki Tachibana, Prediction of sound propagation by geometrical computer modeling. *Journal of Acoustical science and Technology*, Vol. 35, No. 1, 2014
11. Ioan Magheti et al, Analysis of the Sound Field in Enclosures, *Romanian Journal of Acoustics and Vibration*, Vol. VI No.1, 2009
12. Ovidiu Vasile et al, The Sound Distribution Uniformity Throughout the Multifunctional Hall EUTHERPE, *Romanian Journal of Acoustics and Vibration*, Vol. VI No.1, 2009
13. Constantin Onescu, Viorel Broasca, The Equivalent Source Method To Compute The Interior Sound Field, *Romanian Journal of Acoustics and Vibration*, Vol. III No.1, 2006
14. Lawrence E. Kinsler, Austin R. Fray, *Fundamentals of Acoustics*, Wiley Eastern Limited, 1962
15. Sandra Arlinghaus, *Practical Handbook of Curve Fitting*, CRC Press May 9, 1994

AUTHORS PROFILE

Aruna Godase is lecturer in the Department of Physics at Anantrao Thopte College, Bhor (Junior College (XI and XII)) and Research Scholar at EARL lab at N.Wadia College, Pune. She is NET qualified (August 2012). She is currently perusing her PhD in Acoustical Physics. She has completed her M.Sc. (1987) in Physics from University of Pune. Her research focuses on acoustical transducers. Her research work has been published in the form of research papers in FRSM-2016, Baripada and WESPAC-2018, New-Delhi. She is the recipient of the Indian Physics Association's Pune Chapter's M. R. Bhide Best Teacher Award (for Junior College Teacher). She has over 31 years of teaching experience

Dr Farhat Surve obtained his Master's degree in Physics jointly from TIFR and the University of Pune in 1987. He obtained his PhD (Physics) from the University of Pune in 2001. Dr Farhat Surve is a Fulbright Fellow and has over 30 years of teaching experience, including teaching at the State University of New York, Buffalo and the Pennsylvania State University. He is presently Associate Professor at the Nowrosjee Wadia College, S P Pune University. He is the recipient of the American Physical Society's Kilambi Ramavataram Fellowship wherein he worked on solitary wave dynamics at the State University of New York, Buffalo and on teaching-experiments at the Kansas State University. His research interests include rectification algorithms for flawed room acoustics, overtone dynamics, impedance characterization of acoustic materials, acoustic transducers, membrane percussion and bioacoustics. His work in physics education involves augmentation of open-ended extensions to the undergraduate laboratory, including structured pre and post-lab tutorials.Dr Farhat Surve is the recipient of the Pune University's Innovation in Teaching Award, the Indian Physics Association's Pune Chapter's Bhaskar Raye Best Teacher Award, and CDAC's Best Paper Award at the ICPCCS, 2012 amongst others.