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Microphone Placement for Tenor Pan Sound Recording: New Recommendations Based on Recent Research

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Abstract: *The placement of recording microphones used for live recording, studio recording or sound reinforcement of a tenor steelpan is revisited using new research findings on the soundfield of the instrument. The new results were obtained using a technique called Nearfield Acoustical Holography (NAH). An analysis of the existing microphone techniques and the recommendations for new positions based on the soundfield information is made.*

Keywords: *Acoustics, Nearfield Acoustical Holography, Sound Intensity*

1. Introduction

The placement of microphones for recording or reinforcing the sound of any musical instrument, has a significant effect on creating the overall tonal quality intended by the composer, performer, or recording engineer (Bartlett, 2010). The positioning of recording microphones has been largely a learnt art, requiring experimentation, trial and error, a keen ear and engineering know how. In the specific case of the tenor steelpan, the placement of microphones has been *ad hoc*, often dictated by stage clutter, convenience and logistics rather than being based on scientific evidence (Copeland, 2002).

A previous paper on the subject of microphone placement (Copeland, 2002) specifically advised where to **not** place the microphones based on the then available information. New research findings on the sound radiation characteristics of the tenor steel pan can provide much needed scientific guidance as to where microphones **can** be placed in order to better record or reinforce the full tonal range of this instrument. This paper will look at this new data, how it was obtained recommend microphone placement positions based on this new evidence.

2. Instrument Studied: The Kelman Low Tenor Steelpan

The Caribbean steelpan is a tuned idiophone whose sound is produced by the physical impact of playing sticks on the notes (Murr *et al.,* 2004). The steelpan instrument family has a note range of E_1 (41.2 Hz) to G_6 (1587.98 Hz) and if the contributions of partials are included, has a frequency range comparable to that of a grand piano (Copeland, 2005).

Individual instruments contain from three (3) notes, in the case of a single bass steelpan to thirty-two (32) notes arranged in three concentric rings in the case of a soprano tenor pan. The particular instrument being referred to in this paper is a twenty-nine (29) note, low C tenor designed, manufactured and tuned by Bertrand Kelman, an acknowledged maker and tuner in the steelpan fraternity. This instrument has a diameter of 0.585m, a skirt length of 0.18m and a bowl depth of 0.225m.

3. Measuring the Soundfield of the Kelman Tenor Steelpan

Scientifically supported placement of recording microphones requires knowledge of how the instrument behaves acoustically, specifically, from where does it generate its sound energy and in which directions does the sound energy propagate. Only when this information is known can the optimum location for the placement of microphones be decided. This acoustic behaviour is obtained by studying the sound (acoustic) intensity of the instrument.

The sound intensity, $\mathbf{I}(\mathbf{r})$, is a vector which is a measure of the magnitude and direction of the flow of sound energy. It is defined as the net flow of sound energy through a unit area in a direction perpendicular (normal) to the area (Fahy, 1997). At some field position $\mathbf{r}$, $\mathbf{I}(\mathbf{r})$ can be described in terms of the complex pressure $p(\mathbf{r})$ and particle velocity $\mathbf{u}(\mathbf{r})$ at that position as:

$$\mathbf{I}(\mathbf{r}) = \frac{1}{2} p(\mathbf{r})\mathbf{u}^*(\mathbf{r}) \tag{1}$$

The components of $\mathbf{u(r)}$ are themselves related to the pressure, p(**r**), according to Euler's equation 2:

$$\mathbf{u}(\mathbf{r}) = -\frac{j}{\omega\rho_0}\nabla p(\mathbf{r}) \tag{2}$$

where ω is the angular frequency of the source in *rad/s* and ρ_0 is the density of air in kg/m^3. Because of this relationship, it is possible to determine both components of **I**(**r**) using a pair of calibrated, precisely spaced microphones, to measure *p*(**r**), calculate ∇*p*(**r**) and then **u**(**r**). This technique has been extensively documented, for example by Fahy (1997) and has been used in the measurement of the soundfield of the steelpan by Copeland (2005).

An alternative method for obtaining the components of **I**(**r**), without the need for the specially spaced microphones, is through the use of Planar Nearfield Acoustical Holography or NAH. Planar NAH is another well documented method (Maynard *et al.*, 1985, Rowell and Oldham 1995), whereby the acoustic energy emitted by a source can be reconstructed in three dimensions from a single set of measurements of the complex pressure taken on a measurement surface close to the source. In Cartesian coordinates, for a source oriented in the *xy* plane for example, the measurement surface, called the hologram or measurement plane, is located at some distance $z = z_0$ from the source plane at $z = z_s$. The distance $z_s - z_0$ must lie within what is termed the acoustic nearfield of the source, which typically taken as being within one eighth of the wavelength of the acoustic signal being processed (Williams, 1999), in order to capture essential acoustic information which decays rapidly as the distance from the source increases. Note that the source plane may or may not coincide with the actual source surface and is entirely dependent on the geometry of the source. Figure 1 illustrates the geometry of Planar NAH.

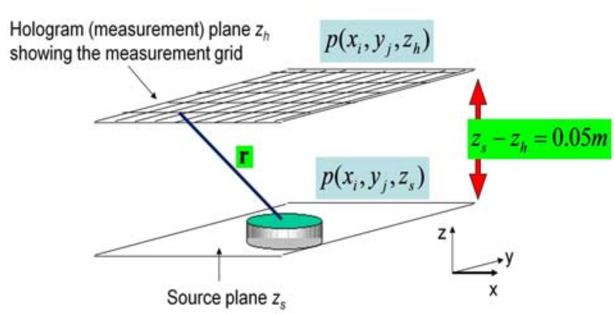


Figure 1. The geometry of Planar NAH

Planar NAH is described generally by a two dimensional convolution of the measured complex sound pressure $p(x,y,z_0)$ and the normal derivative of a function, *g*, as follows (Maynard *et al.*, 1985):

$$\Psi(x,y,z) = \iint_{\infty} p(x_0,y_0,z_0)\frac{\partial g}{\partial z}(x-x_0, y-y_0, z-z_0)dx_0dy_0 \tag{3}$$

In Eq.3, $\Psi(x, y, z)$ can refer to either the pressure *p* (*x, y, z*) or the particle velocity **u**(*x, y, z*). The variable *g*, is referred to as the free space Green's Function (Kinsler *et al.*, 2000) and is the impulse response of the sound propagating medium. For a field position **r**, *g*(**r**) and its normal derivative are given by:

$$g(\mathbf{r}) = \frac{e^{jk|\mathbf{r}|}}{4\pi|\mathbf{r}|} \tag{4}$$

$$\frac{\partial g}{\partial z} = -\frac{z(1-jk\mathbf{r})e^{jk\mathbf{r}}}{2\pi\mathbf{r}^3} \tag{5}$$

The practical implementation of planar NAH uses two (2) sampled, Fourier transformed versions of Eq.3, which facilitate (i) the evaluation of the convolution integral; and (ii) the calculation of both the pressure and particle velocity information. These versions are given in equations (6a) and (6b) respectively as:

$$p(x,y,z) = \mathcal{F}_x^{-1}\mathcal{F}_y^{-1}\left[\mathcal{F}_x\mathcal{F}_y\left[p(x,y,z_0)\right]\times G_p(k_x,k_y,z-z_0)\right] \tag{6a}$$

$$\mathbf{u}(x,y,z) = \mathcal{F}_x^{-1}\mathcal{F}_y^{-1}\left[\mathcal{F}_x\mathcal{F}_y\left[p(x,y,z_0)\right]\times G_v(k_x,k_y,z-z_0)\right] \tag{6b}$$

The following are the important features of Eq.6a and Eq.6b:

1) In both equations, $\mathcal{F}_x\mathcal{F}_y$ refers to a two dimensional *k*-space Fourier Transform defined as (Muddeen, 2012):

$$\mathcal{F}_x\mathcal{F}_y = \int_{\infty}^{\infty}\int_{\infty}^{\infty} f(x,y)e^{-i(k_x x)}e^{-i(k_y y)}dxdy \tag{7}$$

2) $G_p(k_x,k_y,z\text{-}z_0)$ and $G_y(k_x,k_y,z\text{-}z_0)$ the two-dimensional *k*-space Fourier transformed free-space Green's Function for pressure and particle velocity. In planar NAH, $G_p(k_x,k_y,z\text{-}z_0)$ is referred to as the *pressure* propagator function and $G_y(k_x,k_y,z\text{-}z_0)$ as the *velocity* propagator function (Williams, 1999). They are defined respectively as:

$$G_p(k_x,k_y,z-z_0) = e^{ik_z z} \tag{8}$$

$$G_v(k_x,k_y,z-z_0) = \frac{k_z}{\rho_0 ck}e^{ik_z z} \tag{9}$$

The derivation of (9) according to Williams (1999) incorporates Euler's Equation 2, so that both of the components that are required to calculate **I**(**r**) can be deduced from Equations 6a and 6b. The complete derivation of Eq.3 together with a discussion of the practical considerations, limitations and errors can be found in Muddeen (2012) and is based on the original derivation given in Maynard *et al.* (1985).

In summary, therefore, the usefulness and advantage of the NAH approach is that with a single set of complex pressure measurements, the velocity vector and hence the AI and RI vectors can be derived for the space above the source.

3.1 Sound Intensity Components

I(**r**) has two components – an *active* component which indicates how the acoustic energy propagates to the farfield and a *reactive* component which shows how the acoustic energy circulates around the source and also indicates the acoustic energy sources and sinks of the source. The direction of the active component vectors, called the *Active Intensity* (AI), is normal to surfaces of constant phase. The direction of the reactive component vectors, called the *Reactive Intensity* (RI), is normal to surfaces of constant pressure (that is, the soundfield wavefronts).

3.2 Complex pressure measurement

Planar NAH requires the use of complex pressure measurements, that is, pressure measurements whose magnitude and phase with respect to a reference source, are known. This information is obtained from the auto spectrum and the cross-spectrum of two sets of pressure data according to a method used by Blacodon *et al* (1987) as follows.

If the Fourier Transform of the reference pressure at spatial position $\mathbf{r}_0$, is denoted by $P_{ref}(\mathbf{r}_0)$, and the Fourier Transform of the measured pressure at spatial position $\mathbf{r}$ is denoted by $P(\mathbf{r})$, then the pressure magnitude $|P(\mathbf{r})|$ can be derived from:

$$|P(\mathbf{r})| = \sqrt{P(\mathbf{r}) \cdot P(\mathbf{r})^*} \tag{10}$$

The signal phase ϕ_{xy}, can be calculated from the angle of the cross spectrum according to the following equations:

$$S_{xy} = |P(\mathbf{r})||P_{ref}(\mathbf{r_0})^*| \angle \phi_{xy} \tag{11}$$

where

$$\phi_{xy} = \angle P(\mathbf{r}) - \angle P_{ref}(\mathbf{r_0}) \tag{12}$$

4. Experimental Setup

The experimental setup used is completely described in Muddeen (2012) and is summarised here. The complex sound pressure level (SPL) around the Kelman tenor pan was measured in six (6) planes completely enclosing it. The horizontal source planes were *x-y* planes in the global coordinates, with the top source plane taken as being that one through the rim of the instrument and the bottom source planes, the source plane as being that one through the lowest point of the bowl of the instrument. The horizontal measurement (hologram) planes were located 0.05m above and below these locations respectively The four (4) vertical source planes were *y-z* and *x-z* planes in the global coordinates in contact with the rim of the instrument as shown in Figure 1(a). The measurement planes were located 0.05 m away from these planes (Muddeen, 2012).

The measurements for this study were taken under controlled conditions in the anechoic chamber of the Physics Department at Northern Illinois University, DeKalb, Illinois. The test instrument was supported by a special frame which clamped the instrument under test by its rim and facilitated rotation of the steelpan in a vertical plane and locking at any desired inclination. The frame was designed by the author and fabricated by the workshop of the NIU Physics Department.

There are several accepted note excitation techniques available for the steelpan, which have been discussed in the literature, for example by Copeland (2005), Rossing and Hansen (2002, 2004) and Muddeen (2012). This experiment used an electromagnetic excitation system for exciting the notes for which a detailed description and photograph of the system used can be seen in Figure 3 in the paper by Copeland (2005). The pressure data was acquired using two calibrated sound level meters (SLMs) interfaced to a 12-bit ADC212 100 MHz PICO scope configured as a dual channel, computer controlled datalogger.

5. Observations on the Sound Radiation of the Tenor Pan

Figure 2 shows a typical result obtained for the AI of the tenor pan using planar NAH. This image was produced for a frequency of 286 Hz in the low frequency range of the instrument.

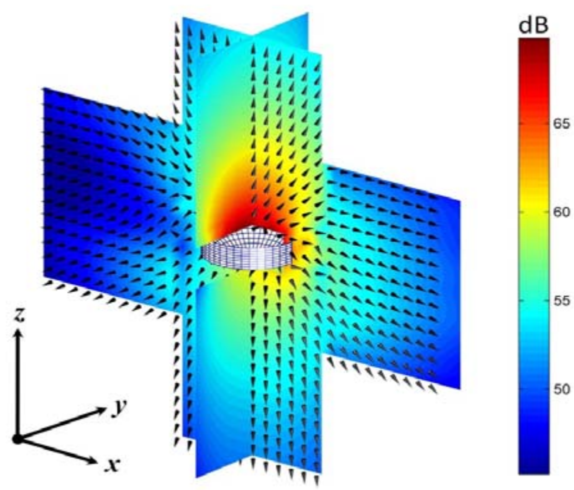


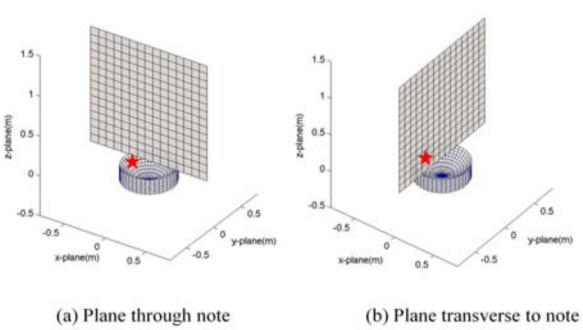
Figure 2. Typical low frequency active intensity behaviour of Kelman Tenor Pan

In this view, the AI vectors are depicted as cones in the *xz* plane and show the direction of the flow of acoustic energy, while the colour indicates the time averaged AI level in dB. A complete set of results showing the SPL, AI and RI behaviour of the tenor pan in detail, including some three dimensional isosurface plots, can be found in Muddeen (2011). In addition, more information on the sound radiation from caribbean steelpans and the use of sound intensity can be found in Copeland *et al.* (2005).

For the purpose of identifying locations for the placement of microphones, Figure 3 summarises the time averaged Active Intensity (AI) levels in two planes: one through the test note; and one transverse to the test note. This orientation is illustrated in Figure 2.

The following conclusions can be drawn from these figures:

1. The sound radiation patterns of the tenor pan vary considerably with frequency;
2. In general, the tenor steelpan projects its sound upwards and downwards, with a small forward directivity in a somewhat similar fashion to an unbaffled loudspeaker;
3. At low frequencies, the tenor pan radiates very uniformly in an omnidirectional pattern above the note playing surface of the instrument, as shown in Figure 4. In addition, the instrument radiates more sound energy above as compared to below;
4. As the frequency increases, very distinct regions of high sound intensity become apparent. At mid frequencies, shown in Figure 5, there are clearly two (2) zones of high AI level above the instrument and one below;
5. At high frequencies, shown in Figure 6, there are four (4) zones of high AI level above the instrument and two (2) zones below;
6. For both mid and high frequencies, in contrast to the low frequency behaviour, the instrument radiates more powerfully below than above the note playing surface; and
7. The instrument does not radiate efficiently or significantly in a horizontal direction in the region of the skirt.



Note: The location of the test note is shown by the red star.
(a) represents a plane through the test note and
(b) represents a plane transverse to the test note.

Figure 3. Orientation of the observation planes

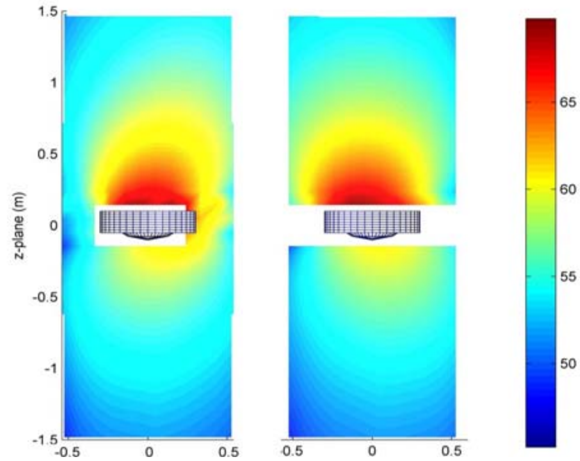


Figure 4. Frequency response at 287 Hz

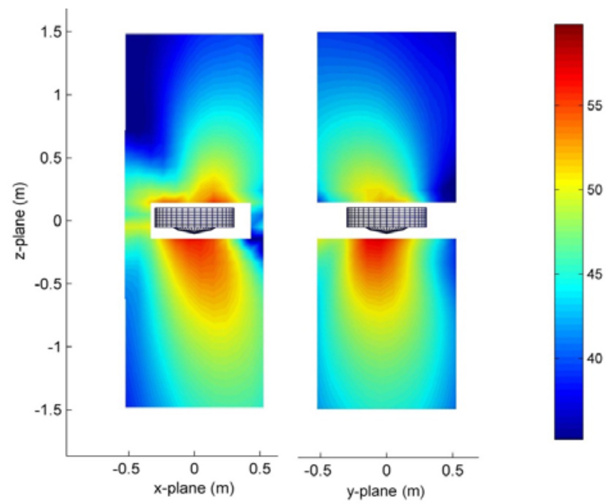


Figure 5. Frequency response at 585 Hz

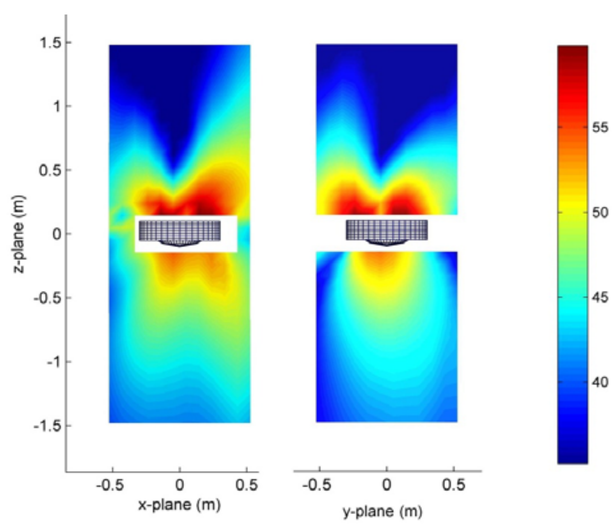


Figure 6. Frequency response at 885 Hz

6. Recommendations

The immediate conclusion with respect to microphone placement that can be drawn from these new results is that for proper recording of the tenor steelpan, a single microphone is not optimum, especially one located in front of the pan. Interestingly, Shure (2009) recommends a single microphone located 4" above the instrument, for the tenor pan. Shure (2009) does not specify where exactly above the pan, but are presumably referring to the centre of the bowl.

From the acoustic information now available (shown in Figures 4, 5 and 6), this position is not adequate for three contradictory reasons:

1. The intensity of the sound radiation over the centre of the instrument (bowl) decreases rapidly as the frequency rises as can be seen in Figures 4 and 5. A microphone placed over the centre of the bowl would be picking up essentially the low frequency radiation of the pan;
2. The tenor pan is a percussion instrument played by striking the notes with a rubber wrapped, wooden or aluminium stick. Close microphone placement ('close miking'), would detect a substantial amount of the impact noise of the stick on the metal note surface which would severely colour the sound. The effect of close miking on tonal quality is discussed by Bartlett (2010), and his recommendations are made without the scientific support of the intensity measurements we now have available for the tenor pan; and
3. The steelpan is a loud instrument under most playing conditions. Sound measurements taken inside a playing orchestra have recorded SPL values of over 105dBA (Juman, 2004) in the centre of the front line pans, which comprise mostly tenor pans. This can create problems for close miking, for example amplitude clipped input signals and unwanted distortion unless the inputs are attenuated or a microphone selected especially to handle high SPLs is used.

Compensating for these scenarios electronically is not particularly easy since adjustment for one set of factors invariably makes another situation worse. For example in scenario (1) above, it is possible to boost the middle and high frequencies to compensate to some degree, but, based on the results obtained, significant gain would have to be used. However, this contradicts the requirement from scenario (3) that the inputs be attenuated to avoid clipping. In addition, the presence of impact noise from scenario (2) would reduce the SNR considerably if large gains are used, leading to the implementation of even more post recording signal conditioning and loss of tonal fidelity.

Observation (7) in Section 5 above has significant implications to the location of the audience in live performances. Because of the low sound radiation horizontally, an audience located at the same level as the performer or performers, will not hear the instrument as well as the listeners located in an elevated position. Ironically, for paid concerts, it is normal to have the highest priced seats located immediately in front of the performers, so that the costliest seats could actually experience the lowest audio quality.

Based on these recent sound field findings, the authors therefore make the following recommendations for the placement of microphones for the recording of the tenor pan for live or studio performances. The optimum recommendations use a combination of one dynamic microphone and one boundary (pressure zone) microphone and depend on whether or not the instrument is being played on an acoustically reflective (hard) surface or an acoustically absorptive (soft) surface.

6.1 Classification of acoustical reflectivity of surfaces

The acoustic reflection characteristics of a performing surface, for example a floor, can be ascertained by examining the sound absorption coefficient of the playing surface. The sound absorption coefficient, α, of a material can be calculated from:

$$\alpha = \frac{\mathbf{I}_{absorbed}}{\mathbf{I}_{incident}} \tag{13}$$

In Eq.13, $\mathbf{I}_{absorbed}$ is the intensity of sound absorbed by the material and $\mathbf{I}_{incident}$ is the incident intensity of sound on the particular material, both in units of Watts/m^2. The method for the determination of α has been standardised in International Standard, ISO 354 (2003) and tables of sound absorption coefficient data for various materials are available, for example in Crocker (2000), so that a scientific determination of the type of performing surface can be made. It is also important to note that sound absorption coefficient values are frequency dependent.

For example using standard values from Crocker (2000), a hard reflecting surface is one where the coefficient of absorption of sound is low, <0.02, at the frequencies of interest. Concrete floors, terrazzo, ceramic and porcelain tile fall into this category with coefficients of <=0.02 up to 4kHz. An acoustically absorbent surface is one where the coefficient of absorption of sound is high, >=0.5, at the frequencies of interest. Carpet, wood, artificial surfaces and grass as examples fall into this category with coefficients of >=0.5 up to 4kHz.

6.2 Two Microphone Techniques

(a) Performance on a hard reflecting surface

For low frequencies, a cardioid, supercardioid or hypercardioid dynamic microphone mounted 0.5m over the centre of the instrument. There is some flexibility allowed in the lateral position because of the uniform low frequency radiation pattern of the tenor pan. For the middle and higher frequencies, a cardioid boundary (pressure zone) microphone located vertically below the front skirt. This configuration, shown in Figure 7, would be able to pick up a reasonably consistent level even when the pan moves during playing. Both top and bottom inputs would be equalised so as to create the desired tonal quality. Note that the boundary mike must not be used if the floor is being used for other performances for example dancing, accompanying the pan, since it would pick up the vibrations of the stage.

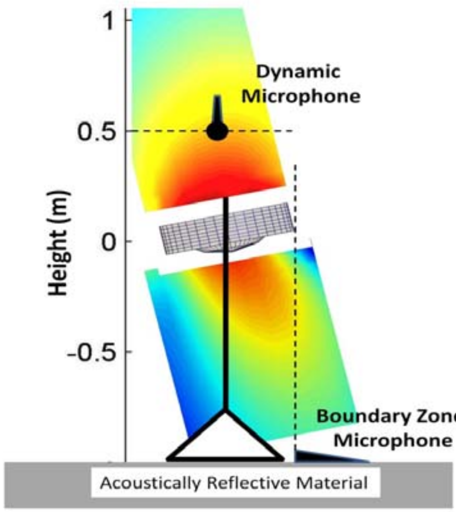


Figure 7. A cardioid boundary (pressure zone) microphone located vertically below the front skirt

(b) Performance on a soft reflecting surface

For low frequencies, a cardioid, supercardioid or hypercardioid dynamic microphone mounted 0.5m over the centre of the instrument as before. For the middle and higher frequencies, there are two possibilities listed in order of preference. The configuration shown in Figure 8(a) uses a cardioid, supercardioid or hypercardioid dynamic microphone located 0.5m vertically below the front skirt (Note that the lower microphone should be kept vertical to minimise reception of any residual floor reflections).

The second, less preferred configuration is shown in Figure 8(b) and uses a cardioid, supercardioid or hypercardioid dynamic microphone located 0.5m vertically above the front skirt. This configuration would require more equalisation than the first recommendation (see Figure 9(a)), because of the lower levels of mid and high frequency partials above the instrument. It will also be more susceptible to varying levels due to instrument movement.

6.3 Single Microphone Techniques

Situations will arise where, for a variety of reasons, two microphones cannot be used or are impractical. Under these circumstances, the following single microphone positions are recommended:

(a) Performance on a hard reflecting surface

Place a cardioid boundary (pressure zone) microphone vertically below the front skirt. This position, shown in Figure 9, would require boosting of the low frequencies since, according to the evidence presented, the tenor pan radiates its higher frequency partials more efficiently below the instrument. Again, this location would be able to pick up a reasonably consistent level even when the pan moves during playing.

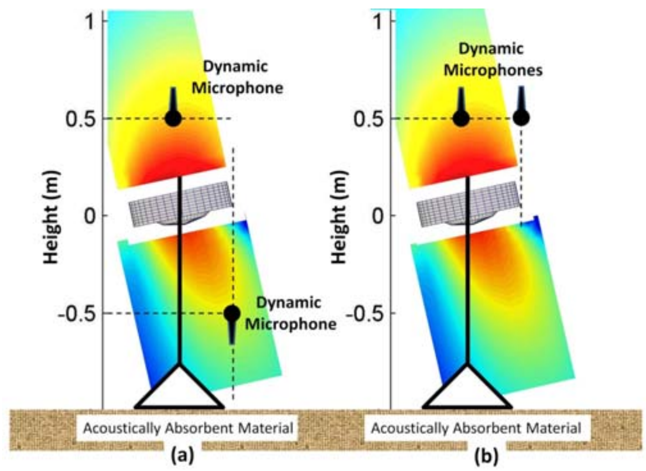


Figure 8. A cardioid, supercardioid or hypercardioid dynamic microphone located 0.5m vertically (a) below the front skirt and (b) above the front skirt

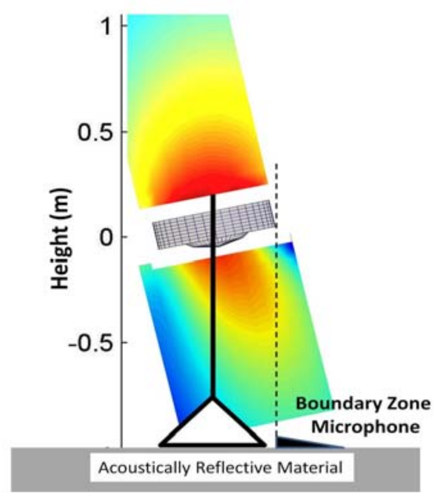


Figure 9. Placing a cardioid boundary (pressure zone) microphone vertically below the front skirt

(b) Performance on a soft reflecting surface

Two configurations are recommended in order of preference. The first, shown in Figure 10(a) uses a cardioid, supercardioid or hypercardioid dynamic microphone located 0.5m vertically below the front skirt. Note that the microphone should be kept vertical to minimise reception of any residual floor reflections. The second configuration, shown in Figure 10(b) uses a cardioid, supercardioid or hypercardioid dynamic microphone mounted located 0.5m vertically above the front skirt. This position would require boosting and equalisation of the mid frequencies since the tenor pan radiates at a significantly lower level in this location for partials in the 400 to 800 Hz range. The microphone should be aimed at the centre of the bowl to maximise the reception of all the frequencies.

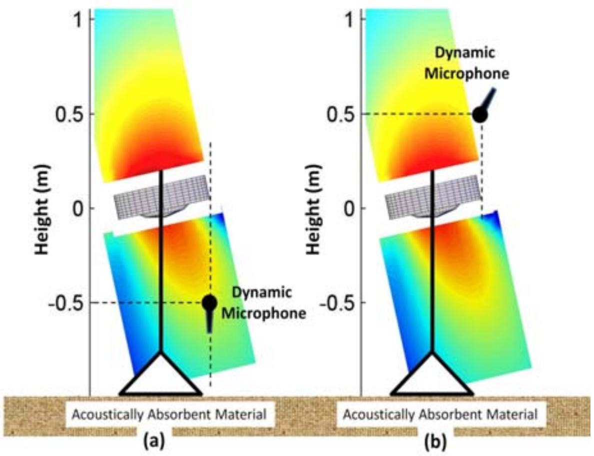


Figure 10. A cardioid, supercardioid or hypercardioid dynamic microphone located 0.5m vertically (a) below the front skirt and (b) above the front skirt

7. Conclusions

This paper has extended on the work done in Copeland (2002) on microphone placement for steelpan recording and live performances. Several options are presented based on the radiation patterns generated for a tenor steelpan, with the most significant being that at least two microphones are required for optimum recording of the instrument, preferably with one placed above and one below the instrument. It is also noteworthy that Copeland's (2002) results and observations for a Clifford Alexis double second steelpan, have also been shown to occur in the Kelman tenor pan tested for this paper, so that these new recommendations may be applicable to other steelpan instruments.

Until alternative techniques, for example those pickups based on strain gauges, piezo-electrics or magnetic proximity, as described in Copeland (1996), are refined or new ones discovered which have all of the advantages of microphones and none of the disadvantages, the information presented in this paper, should result in considerable improvement in the recorded sound obtained from the Caribbean steelpan.

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