Life in between phase: understanding and manipulating microphone relationships with visual tools

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Daniel Pratt & Andrew Bourbon: Life In Between Phase: Understanding and Manipulating Microphone Relationships With Visualisation Tools

Abstract

Phase relationships are a complex and mystifying phenomenon for early stage recording engineers and university students. In this paper, we take the analytical capabilities of time shifting plugin Auto-Align and use it to develop new methods of understanding phase interaction. We utilise the visualisations and time shifting features to assist in recording a multi-miked drum kit and in the post-production soundstage for a thirty-two piece big band. We explore new methodologies for phase interaction and microphone manipulation by running these two experiments and documenting the process using a combination of text, audio, and video.

Introduction

In this paper, we examine the phase interaction of multi-microphone recording and mixing with the intent to develop an in depth understanding of relationships 'in between phase' to produce better recordings and mixes. In our curriculum design in both The Queensland University of Technology (QUT) and The University of West London (UWL) we discuss phase in technical descriptions relating to the acoustic and electronic summation of multiple sources. Phase relationships are also explained in practical recording workshops as well as theoretical lectures. One of the conceptual challenges that our students face is hearing phase variance and implementing the appropriate action to remedy what they hear. For educators, explaining phase becomes problematic when that variance represents a shift that cannot be solved via a simple binary polarity reversal.

We explore the use of metering and phase manipulation in the recording and mixing of audio. On the recording side, we investigate this phenomena through the creation of an educational drum recording video. The video examines the capture of phase interaction information, the analysis, and correction of resulting issues. The data analysis of the phase relationships informs the physical movement of microphones. We demonstrate real time phase interaction measurement using the innovative metering in the Sound Radix Auto-Align plugin. This information aids us in demystifying phase interaction between microphones and enables us to develop new methods for both microphone placement and the teaching of multi-microphone recording.

We then manipulate the complex phase relationships in a Big Band recording featuring thirty two microphones across twenty sources using a range of mono and stereo techniques. We use metering and analysis techniques to inform our alignment and manipulation of this pre-recorded work. In both of these case studies the sonic impact of the phase analysis and manipulation are presented as video and audio examples. The data will be used as a pedagogical tool for the demystification of phase in the teaching environment. Throughout this process, we are guided by the following questions, how can we use a tool dedicated to alignment to improve the understanding of phenomena like phase relationships? Can educators use this tool as a teaching device to accelerate the education of young engineers in the understanding of complex phase issues that take years of practice to fully understand?

Simplifying Phase Interaction

Phase interplay is a phenomenon whereby frequencies of multiple waveforms combine with one another and either cancel or amplify the sound source. Explanations of phase interaction often arrive with complex equations and scientific terminology, this initial overview is a simplification of these explanations with practical uses applied to microphones and speakers. To better recognise how a phase relationship occurs we must first understand how microphones and speakers work. "When we record sound, the diaphragms in our microphones essentially replicate the action of our eardrums, vibrating in accordance with those [sound pressure] waves" (Keller, 2011). Consider that both microphones and speakers are transducers that perform mirror images of the same process. For example microphones transform acoustical energy to electrical energy and speakers transform electrical energy into acoustical energy (Sigismondi, et al, 2014). As a microphone diaphragm moves backwards and forwards it transforms acoustic energy into positive and negative electrical current over a period of time. A speaker conversely takes this positive and negative electrical energy and transforms it into forwards and backwards motion which creates the acoustic energy that we hear as sound. When we use more than one microphone, we introduce the possibility of interference. Corbett (2015) explains these two typologies of interference as constructive and destructive. Constructive interference occurs when two microphone diaphragms are moving in the same direction; destructive interference happens when the microphone diaphragms are in contrary motion (ibid). When a sound is captured through multiple microphones and converted into electrical energy, constructive interference encourages free speaker movement. Destructive interference restricts the movement of the speaker which cannot move forwards and backwards at the same time. This destructive interference is often referred to as phase cancellation. Cancellation becomes more problematic as you add more microphones to any single source such as a drum kit or guitar amplifier. This is why “The principle idea is to get all the microphones working together constructively” (Weiss, 2014, para, 4). Clinch (2011) states that "inexperienced engineers often complain about thin sounds when mixing multiple microphones together even though each individual microphone may sound great" (para, 2). Understanding the relationships between microphones is crucial because "In most recording sessions, we’re dealing with multiple instruments and multiple microphones" (Keller, 2011, para, 13). These cancellations are neither good nor bad but a choice. Senior (2008) argues for moving microphones not only to remove destructive phase issues but to use minor phase cancellation as a creative choice.

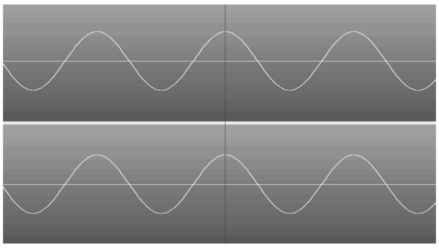

Figure 1. Constructive waveforms work together and allow the speaker to move

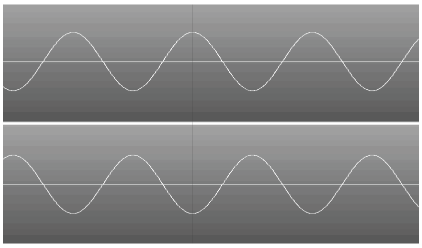

Figure 2. Destructive waveforms move in contrary motion, cancelling each other out and affecting speaker movement.

The Problem With a Binary Understanding of phase

One of the problems associated with explanations of phase interaction is the binary nature of the equipment, which offers only mirror images of phase relationships. A polarity button on a console provides the ability to reverse the phase relationship with an in or out push button. Coppinger (2012) refers to this as a polarity reversal. An experienced engineer is skilled at listening for the sonic change that occurs between multiple microphones when they invert the polarity of one microphone (Paterson, 2007). However, due to its on or off nature, the polarity button establishes a conversation that only offers a binary understanding of phase relationships. For example, a mirroring phase relationship of one hundred and eighty degrees does not account for a floor tom on a drum kit, which is often ninety degrees out of phase with the overhead microphones. In this case, a phase reversal will bring a floor tom to a two hundred and seventy degree relationship, which is the same level of audible phase cancellation. Corbett (2015) argues for an understanding of in-between phase relationships, which recognise phase as any relationship within three hundred and sixty degrees of a wave cycle. If we think of phase a merely binary of in or out, then we do not understand the nature of the relationship and we miss the full potential for the creative manipulation of microphone relationships. As a result, a phase relationship is neither constructive nor destructive; it is a tonal colour that encompasses three hundred and sixty degrees of frequency dependant manipulation. Microphone movement is the common methodology for manipulating tonal colour with more creative intent than just a binary response to phase relationships. However, a multi-microphone setup will inevitably have varying degrees of phase cancellation that Paterson (2007) suggests fill the role of creative tonal colours. Paterson (2007) states that "there is no known way of alleviating this, and indeed it has become an accepted part of the sound engineer's art to accept this and indeed harness it to creative effect" (para, 4).

Three Arguments for Pedagogical Approaches

There is an agreement in the literature that phase cancellation leads to an undesirable sound when using multiple microphones (Sigisomondi et al., 2014, Paterson, 2007, Senior, 2008, Corbett, 2015, Savage, 2011). However, at QUT for example, there are only twenty-four two-hour tutorials per week allocated for teaching students how to hear and understand all practical recording and mixing concepts for the entire year. The first year is concerned with establishing a baseline of rudimentary theoretical knowledge, the second and third year move into more advanced audio engineering. Hearing microphone relationships are only a small part of the full curriculum designed to develop well-rounded, production-capable music students. As a result we have limited time to embed "a relevant object of auditory knowledge [emerging] through interplay between a domain of targeted listening and a set of discursive practices played out in the context of specific sound-engineering activities" (Porcello, 2004, p.734). Condensing years tacit phase relationship understanding must address three main issues.

1. The explanations for detecting phase need to be less vague and binary in their delivery.
2. The assumption that early stage recording engineers can hear phase problems is flawed.
3. If the suggested correction is to move a microphone we must find a method of indicating which direction or how far.

Firstly, there are many variables that create destructive phase relationships such as microphone placement, room reflection, speaker placement, and equalisation. Without access to visualisations, it is difficult to explain what phase sounds like to an untrained student. Explanations from the literature include “typically a thin-sounding signal with little or no bass sound” (Keller, 2011), or “as a hollow sound in which certain frequencies, or tones, appear to be missing” (Lashua, Thompson, 2016, p.82). or "a hollow, filtered tone quality" Bartlett, 2017, p.15). Explanations like these make sense to experienced recording engineers but are not useful to an engineer that doesn't have the experience to understand what descriptors like hollow or thin mean in the context of a multi-microphone drum setup.

Secondly, the assumption that a student can hear phase relationship problems in a stereo setup is flawed. The understanding of relationships between phase and frequency in an audio recording environment is complex and time consuming (Paterson, 2007). Thirdly, moving a microphone is not a helpful suggestion to an inexperienced engineer, especially when there is no indication of which direction or how far. Weiss (2014) indicates that engineers are "simply going to have to move the microphone to different proximities and listen for what sounds best" (para, 8). Sigismondi et al. (2014) suggest that engineers "place the microphone at various distances and positions until you find a spot where you hear from the studio monitors the desired tonal balance and the desired amount of room acoustics" (p.5). Paterson (2007) suggests that microphone placement is “the art of the sound engineer, who will make minuscule adjustments to the positioning of microphones in a session, evaluating the monitor mix to choose final placements”. These suggestions are helpful, but ultimately take years of practice to hear and correct. Adding to this, different shaped rooms introduce different phase relationships so microphone placements do not translate between spaces. This potentially leads inexperienced engineers on a guessing game based on an assumption that they can hear the differences between various microphone movements. This confusion is compounded by the overwhelming amount of options when we move a microphone as stated by Senior.

> Tweaking the distance between [microphones] subtly shifts the frequencies at which the comb-filtering occurs. Inverting the polarity of one of the mics yields another whole set of timbres, switching the frequencies at which the sine-wave components in the two mic signals cancel and reinforce, so the potential for tonal adjustment via multi-miking is enormous (Senior, 2008, Para, 21).

On top of this potentially overwhelming issue, there is also a personnel concern. Microphone movements for drum recording require a producer to listen, a drummer to hit drums, and an engineer to move microphones.

Finally, relying on microphone movement alone does not consider that there are other ways to manipulate phase relationships like equalisation. As stated by Savage.

> "applying EQ will alter the phase relationship of the sound that is being processed. This is because there is a certain amount of time required for the EQ to process the frequencies that it is acting on, and so those frequencies get shifted in their time relationships to other frequencies that make up the sound. This time shift creates changes in the phase relationship" (Savage, 2011 p.50).

Live Sound Design Approaches to Phase Relationships: Analyse First then Listen

One subject area outside the studio environment where an understanding of phase is essential is live sound system design. In live sound design, system alignment takes place through transfer function measurement, and is never trusted to the human ear alone. Though they are aligned using technical measuring tools, some aesthetic choices around the performance of the system are the result of either matching a target response curve or the choice of the experienced engineer. One of the key aims is to create a uniformity of performance throughout the space, with a minimised variance in frequency response and intensity through strategic placement and alignment of speakers. Destructive phase relationships cause ripples in the frequency response of the speakers so a system that is improperly aligned is challenging to manipulate by ear.

In the simplest of systems a single source is able to provide even coverage, however in practice the characteristics of a space normally make it impossible to achieve spatial uniformity without the addition of extra sources such as speakers for reinforcement of the system. Contemporary approaches to live sound design see line array speaker systems employed to increase the efficiency of sound distribution, utilising multiple aligned speakers to cover difficult to reach areas. Individual speakers in the main speaker array, and any auxiliary speaker arrays are designed to focus on isolated target zones. The focus of live sound system design is to avoid multiple sources hitting the same target zone. However, it is inevitable that there will be points in the space where there is interaction between sources leading to acoustic summing of signals much like overlapping regions in an audio crossover. It is these interaction zones where designers focus their attention in order to optimise the phase coherence of the summed response of two systems interacting at the same target zone. This means engineers must time and phase align speakers in the physical space which, as stated earlier, is achieved primarily through technical measurement and refined by ear. It is also important to clarify that the signals coming from the sources will be almost identical subject to speaker voicing, unlike sound received at microphones at different positions in a space as found in the recording examples.

A summation zone is any area where two independent speakers outputting the same signal are acoustically summed in physical space. This is the exact reverse of multiple microphone signals summing down into speakers. To create a phase coherent summation zone there are two key factors to take into account: relative level and phase (McCarthy, 2016). The impact of two sounds being acoustically summed is a resultant change in overall level, with potential summed output levels of between +6dB and -60dB, depending on the relative level and phase of the two sources. First consider the impact of relative level, with 2 sources arriving at a single receiver, but each at a different amplitude. If the level offset between the two sources at the point of reception is greater than 10dB, then the maximum ripple (change in frequency response) is limited to +-3dB. A ripple of +-3dB which is considered an acceptable result in PA system design for large venues. Designers strive to minimize the number of summation zones where multiple sources are within 10dB in level offset to maintain the best possible frequency domain behaviour.

The second point of consideration in exploring a summation zone is that of relative phase between sources. In a line source all the elements in the array are propagating with equal phase and amplitude, though in practice amplitude is manipulated to provide even coverage on complex audience planes where path length from source to the plane varies significantly. When a second source combines with the primary array, the relative phase has a significant impact on the summed level at the receiver. If the two sources are within 120 degrees of phase rotation, the maximum ripple at the receive is again +-3dB, with a potential ripple of +-30dB should the sources arrive with more than 120 degrees of phase difference. System designers are therefore looking to minimise the potential ripple by creating systems that interact within 120 degrees of phase rotation, and have a minimum offset in level of 10dB. It is important to note that, regardless of level, offset with less than 120 degrees of phase rotation, the impact on frequency response is less than +-3dB, but with a change in that response throughout the phase rotation range. This means that any variance in phase up to 120 degrees is challenging to hear.

In the recording environment, this study of live acoustic summation provides the student with an appreciation of the impact of relative amplitude and phase that does not occur in traditional studio-based music technology education. When placing a room mic and an overhead in the same room it is likely that the signals arriving into the recording device and then reproduced in the control room will be within 10dB in relative level. This level difference offers the potential for broad frequency response ripple. By moving the microphone, the level difference will not be significantly manipulated, leaving little change in frequency response due to amplitude.

For example, a phase relationship change will only be significant when moving a room microphone to within 120 degrees of an overhead microphone. This movement will result in the combined microphones presenting a more balanced frequency response. It is important to note that unlike our theoretical approach to PA system design, the signal transduced by the microphones operates differently. The summation theory discussed here relies on the same signal being produced by both sources and being received at the point of summation. In the studio, indirect reflected sound is used creatively to give an impression of size and space and means that the single source becomes a multitude of sources as it is re-radiated through the boundaries in the recording room. Regardless of this difference, the phase response is manipulated through microphone movement, resulting in different frequency responses and therefore different musical impact subject to placement. Should there be negative tonal and spatial impact from using multiple microphones on a single source the engineer has two choices to improve or change the resultant response, the first being to manipulate the relative level of the microphones and the second to manipulate the relative phase. One of the challenges we face with pedagogical practice is assisting students in distinguishing the sonic impact of relative phase. With significant frequency response ripple and destructive changes in the summed level of the combined sounds, hearing the destructive impact of interactions beyond 120 degrees is unambiguous to the listener. However, Learning to hear the interactions in the first 120 degrees of rotation takes time and practice. We propose that visual aids assist students with the development of these skills by identifying phase relationships that they are not yet understanding and allowing students to practice listening to more subtle phase shift in recorded text.

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Understanding Auto-Align

In our pedagogical practice at QUT and UWL we regularly address student concerns based around phase. Our students often worry that they can't hear phase interactions that are obvious to the lecturers who have more experience in hearing these relationships. In order to develop a better understanding of phase for these students to improve their recordings we propose that we utilize tools that perform visual analysis to assist in their understanding of phase relationships in both the recording and mixing environment. Auto-Align is an automatic time aligning plugin developed for use in digital audio workstations. Its primary function is to detect and time align multiple waveforms to reduce phenomena like destructive phase cancellation and comb filtering while improving the dynamic intensity of multi-microphone recordings. Auto-Align is commonly used to correct microphone placement issues on drum overheads, multi-miked guitar amps, or to align a bass guitar recording that consists of a direct signal and a miked bass amp (SoundRadix, 2017).

Time aligning waveforms is a conventional technique that mix engineers use to correct problematic microphone placements. Savage (2011) recommends that mix engineers experiment with minuscule shifts in audio files known as nudging to create improved phase relationships between multiple microphones capturing the same source. Keller (2011) states that "You'd be amazed what a difference just moving a track by one or two milliseconds can make"(para, 20). Auto-Align is one of a few new audio plugins that take the guesswork out of shifting audio to improve phase relationships. It achieves this by employing a detection algorithm that listens to the audio between multiple microphone recordings and then offers the engineer several selections for phase coherent wave positioning. This type of detection allows mix engineers to select from a reduced choice of phase-coherent positions, changing the task of nudging audio and listening into an efficient automated process.

Auto-Align also has some additional features for the analysis and calculation of phase relationships and microphone placement. These analysis tools consist of a circular phase analyser, a delay relationship display, and a distance evaluation that offers estimated microphone distances in both centimetres and inches. It is this expansive suite of measurement tools that enables recording engineers to understand their microphone placement and phase relationships with an accuracy that redefines phase and microphone analysis. This new knowledge of phase relationships leaves us with a choice of continuing with established methods or using a new understanding to challenge established norms surrounding the recording process. A new measurement device calls traditional methods of recording into question and requires investigation to discover if these established practices can be redeveloped using newly refined methods (Bacon, 2012).

New Visualisations Paint a Detailed Picture

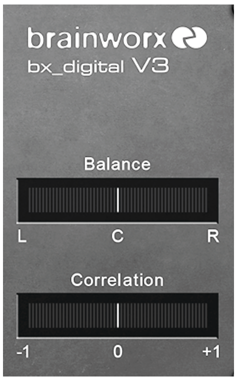

Figure 3. Bx_digital V3 equaliser comes equipped with a phase meter.

In the digital plugin market, there are several options for visualising phase interaction between microphones. Izotope Insight provides a detailed analysis of spaciality, phase interactions, and loudness information. There are also some stereo equalisation plugins that come with small phase scopes. By and large, they all use a similar two-dimensional approach to phase metering as the indicator moves to +1 the signal is more phase coherent.

Our investigation of Auto-Align reveals a paradigm shift in the visualisation of phase relationships, using a three hundred and sixty degree scope that establishes a detailed analysis of the relationships between microphones. Pointing north indicates the most constructive relationship, but the scope allows for detailed analysis of every single phase rotation. This level of choice means that an engineer can decide exactly how in or out of phase they want their microphones with high phase coherence offering clarity and punch and less phase coherence offering more depth and space. This new approach to phase metering also utilises colour information to indicate which frequencies ranges are causing constructive or destructive relationships. The more detailed approach to metering allows us to understand and manipulate microphone relationships to a far higher degree than previous analytical tools.

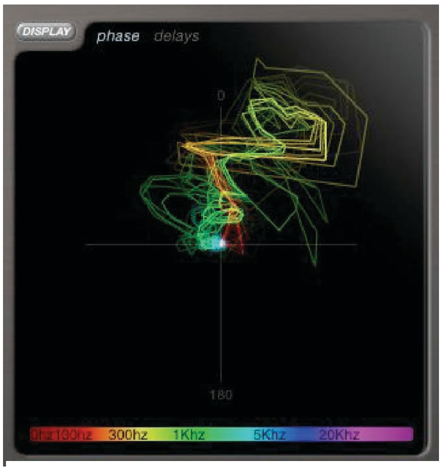

Figure 4. Auto-Align features a phase scope with detailed information on phase and frequency relationships.

In addition to the phase meter Auto-Align provides distance calculator that gives information on distances between microphones. Using a combination of both the phase and distance readings it is possible to virtually move microphones in the DAW to test phase relationships before venturing into the studio. Theoretically, this means we can know which direction and how far to move the microphone, removing the usual guesswork associated with the practice.

Figure 5. Auto-Align distance indicator allows us to estimate the distance in the computer and check for better phase relationships.

Finally, Auto-Align uses a detection algorithm that suggests multiple in phase measurements for microphone placements. These measurement points are displayed on a delay meter which gives users a choice of phase coherent microphone placements if they are inclined to experiment with different options and different levels of phase coherence to create colouration (Paterson, 2007). Having different choices offers engineers the ability to make informed choices on how much constructive or destructive interaction they want. The choice is an important factor depending on whether an engineer wants a sound that is "diffuse or blended, instead of sharply focused" (Bartlett, 2017, p.114). This ability to make informed choices between out of phase and in phase microphones allows the recording or mix engineer to design their desired spaciality around multi-microphone recordings by focussing on which instruments are more or less in phase.

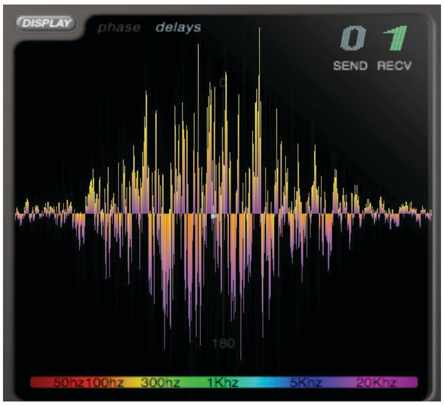

Figure 6. The delay meter offers multiple placement options, higher points means more in phase.

Such a detailed suite of analytical tools creates several options to enhance the creativity of the recording process without negatively affecting the phase relationships of the microphones. For example, an engineer can choose the best sounding spot for room microphones and not have to measure them and sacrifice the sound of one microphone to ensure that the measured relationship between a spaced pair of microphones is correct.

Methodology

Our methodological approach combines the use of nominalistic data generated by two experiments combined with participant observation conducted during the investigations. We use participant observation to bring our in-the-world experience to the research and present a humanistic dimension to the more nominalistic data that we generate (Atkinson & Hammersly, 1994). We triangulate this nominalistic and observational data with our tacit experience taken from our audio teaching practice. We aim to triangulate this multi-method approach to create a more in depth analysis of our test results (Flick, 2018). We present two systems for using visual tools, in this case Auto-Align, that involve more consideration than just loading the plugin and using auto detection algorithms. These two tests generate both audio and visual data for later analysis to triangulate with observations that the two participants collected while conducting the experiments. Firstly, we use the live sound system design approach of McCarthy (2016) to understand phase relationships in the post-production mixing of a big band. Secondly, we use the same procedure, using Auto-Align as a measurement tool to explore and manipulate phase issues while tracking a drum kit before the sound is committed to tape.

A better understanding of phase concepts aids educators to reinforce the importance of microphone placement. However, a written medium lacks the practical engagement that we see and hear when physically recording and mixing music. For a lasting pedagogical tool, we use a combination of visual aural and written mediums that offer students and educators a more in-depth understanding through repeated viewings. In the case of the drum recording, an edited video serves to demystify and highlight both microphone movements and relationships in a practical environment. In the big band mix, audio examples aid to highlight the changes in amplitude, spaciality, and punch that are problematic semiotic descriptors with vague meanings. In particular, the video offers the opportunity for outside engagement through impact with industry partners and educators around the world. Thus creating a more in-depth understanding and confidence that visual, aural, and written demonstrations give early stage recording engineers.

Drum Recording

For the first measurement experiment using Auto-Align, we chose a multi-miked drum kit using a combination of close and distant microphones to present a multitude of destructive phase relationships. We recorded the drums at QUT recording studios, Kelvin Grove in Australia to test our theories in a controlled and professional environment. According to Keller (2011) "It's hardly surprising that the more microphones used in a recording, the more potential for phase problems. In modern music recording, that usually points to the drum kit. (para, 17). We adopt a similar process to Weiss (2014), which begins with establishing a 'recorderman' overhead setup.

Tabel 1. List of microphones, microphone positions, and polar pattern

Microphone Position	Microphone Type	Polar Pattern
Overhead Left	SE Electronics RNR1	Figure 8
Overhead Right	SE Electronics RNR1	Figure 8
Room Left	Neumann U87 Ai	Omni
Room Right	Neumann U87 Ai	Omni
Kick In	Beyer M88	Cardioid
Kick Out	Bock 195 (fat switch on)	Cardioid
Snare Top	Shure SM 57	Cardioid
’Snare Bottom	Neumann KM184	Cardioid
Rack Tom	AKG C414B	Super Cardioid
Floor Tom	AKG C414B	Super Cardioid

The recorderman overhead microphones are set up with one microphone approximately 120 cm directly above the snare drum and the other placed over the right shoulder of the drummer measured equidistant from the snare and kick drum. We then close mic all the snare, rack tom, and floor tom on the kit with microphones approximately 8 cm above each drum. We double mic the kick drum with a dynamic microphone just inside the back hole of the drum and a large diaphragm condenser outside the kick drum approximately 15 cm. We also use two room microphones to capture the space so that we have multiple close and far microphones to measure. These rooms are set approximately 220 cm away from the drum kit and measured so that they are equidistant from the kick drum. The recording was conducted at QUT Skyline Studios Using the Neve Custom 73 Console. Tab.1 is a list of all the microphones used in the experiment.

Once the drums were set up Dan recorded a simple drum line using a metronome. This recording is the 'before correction' example of a multi-microphone drum setup. After the recording, We used Auto-Align to measure each microphones phase relationship to the primary overhead above the snare drum. Using the readings from Auto-Align, Dan re-recorded the drum groove for comparison with the earlier 'before correction' example. Each example used the same gain structure, so the only audible difference occurs from microphone movements. For a more detailed explanation of the experiment and to hear a comparison of both recordings, please watch the embedded video[1].

[1] Video Example - Drum Recording: The following video gives an overview of the drum recording experiment. It practically demonstrates the use of visual alignment analysis to inform microphone placement. The video contains examples of drum recordings before and after microphone movement: https://www.dropbox.com/s/16ofal0qkkbni4p/Drum Phase Inst Vid.mp4?dl=0

Discussion

It is important to note that neither drum recording is perfectly in phase but the second recording was adjusted for the maximum constructive phase interaction possible. On closer inspection, this experiment yielded some surprising results that challenge the orthodoxy of drum recording. From a logistical perspective, Dan was able to take a three-person job of moving listening and playing and reduce it to a one person method with a surprising efficiency. We propose that this method of phase measurement is of particular help to smaller studios or self produced songwriters without the resources to hire assistants. It also benefits producers that prefer to record in the room with a band as phase relationships are nearly impossible to hear when you are standing near a drum kit and attempting to evaluate microphones. Finally, this method benefits students of audio engineering by offering a comprehensive method for measuring and choosing phase relationships in multi-mic recordings. It also affords students the confidence to experiment with different microphone placements which opens up a new realm of creative manipulation in the recording environment. Having excellent recorded phase relationships also reduces the post-production work for any location recording where ideal listening environments do not exist such as mobile broadcast units.

Of particular surprise was the movement of the room microphones. It is common practice to measure room microphones so that they are equidistant from the source you want to emphasise. Up until this point, measuring from the kick drum has been the method of choice for our teaching practice. The aim is to create best phase relationship for room microphones and use those microphones to feature the kick drum in the room. In this case, Dan wanted the kick drum to feature in the room microphone recording, so he initially ensured that the room mics were equidistant from the kick drum. However, after measurement with a distance analytical tool, the right room microphone moved forward thirty centimetres, and the rear microphone moved back thirty centimetres. We posit that Auto-Align is also accounting for the shape of the room and measuring microphones considering the direct microphone relationship, the surrounding space as well as reflective wave information. This surprising development is of value to anyone who is recording in an unfamiliar drum room as phase measurement offers the opportunity to understand the relationships within any given space. This means that engineers don’t need to spend time accurately measuring rooms or guessing at microphone placements.

From a pedagogical perspective, the visualisation of phase relationships between the microphones on the plugin offers teachers a precise method for explaining what occurs to a recording when you move individual microphones within a network. This deeper understanding opens up possibilities for students to experiment with microphone placement and manipulate the tonal colour of their recordings without the possibility of accidentally creating destructive relationships. This assurance in microphone relationships shifts the teaching emphasis from mastering microphone placement to a more confident, discovery-based experimental approach to recording. A visual representation also affords the opportunity for students to familiarise themselves with out of phase placement. Using analysis tools, students can determine the level of phase colouration they intend to achieve. This information gives students the confidence of knowing the precise phase relationship that they have as well as the ability to creatively manipulate recordings.

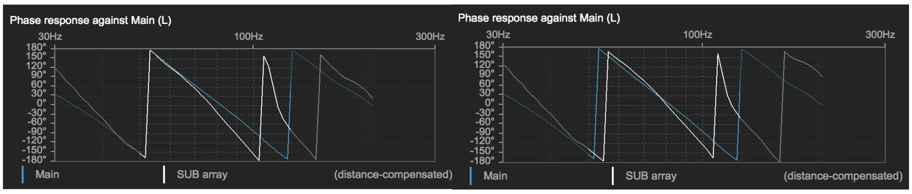

Figure 7. Wrapped phase response showing aligned and unaligned phase response at the crossover frequency

Big Band Mixing

Due to the thirty two microphones on the recording session, a recording of a big band provides a compelling opportunity to explore elaborate re-alignment in post-production. The methodology undertaken draws inspiration from live sound system design, with sectional mics aligned using an approach similar to that employed in McCarthy's (2016) ABC approach.

The initial processing involved alignment of bleed across all the microphones, with the drums providing the fundamental source for alignment. The alignment technique is the same as the one documented in the studio drum recording video presented earlier in this paper. Once the drum alignment was completed, Auto-Align was used to provide multiple in-phase suggestions as earlier demonstrated in the drum aligning video. These phase points are then auditioned and selected by ear. In this sense, we use the plugin to reduce the time shift selections to a manageable set of in-phase points. In live sound system design, the phase alignment in a single system takes place at the crossover point between speaker elements in a system.

This crossover point commonly occurs between a subwoofer and the principal part of a line array which is already phase aligned a part of the speaker design. The crossover point is the region in which there is maximum interaction between elements each generating the same frequency, and as such system designers strive to ensure that the majority of the target zone for the array are receiving both the subwoofers and tops 'in phase' (fig. 7). In the big band recording example, a similar approach is taken to alignment,

focussing on the target frequency range of the element being aligned to ensure optimised sonic performance in the alignment process.
In the case of the drum recording example, moving the room microphone 6 feet from the original position to ensure the desired response will not have a severe consequence in performance timing. As the microphone is in real physical space, it will provide significant tonal improvement when combining the room mic and close mics. These changes will occur as the relative intensity of the room mic increases and the balance of direct and reflected sound alters. In the case of the big band recording, however, virtually moving one microphone through multiple delay choices in post-production that forms part of a sax section will have negative consequences in the cohesion of the musical timing of each sections performance. To maintain the best possible timing in the performance across instrumental sections the choice of delay value is made based on two considerations. The first being the improvement in sonic performance, and the second is that the decision must minimise the virtual distance moved for each microphone as much as possible. Using a simple automatic alignment selection can see a delay suggested on a saxophone mic that effectively stages the saxophone behind the trumpet. This type of virtual movement is inappropriate for aligning big band microphones as it ignores the sound staging that audiences expect from big band recordings.

Once all the microphones have been aligned to the drum bleed, there is a change in the presentation of the drum sound in the recording. In this case, the impact of the room reflection is reduced resulting in a drier, closer sounding drum recording. The snare drum in particular comes across as being considerably less hollow with more sound of the body of the drum propagating into the recorded space. An example of the drums aligned and unaligned with all thirty two microphones open is provided in the example folder.[2]

In live sound design, the ABC approach sees the top section of a line array focussing on the furthest audio plane, this is labelled plane A. The next audience plane is targeted by the middle section of the array, this is labelled plane B. With the frequency response and amplitude at that plane a function of the combination of the top two sections of the array, rather than just the middle section. The lowest audience plane, C, is targeted by the lowest section of the array, but again is influenced by the previously focussed array sections. It is imperative that the individual sections are targeting their

[2] Audio Examples - Big Band: The following is an example of the big band before and after alignment. The drum only alignment featuring all 32 microphones is also provided for reference. Note that the only change in the audio files is the phase aligning of instruments. The recordings and volumes of the instruments are the same in both examples: https://www.dropbox.com/sh/4i9bd9entbx5hoq/AABQeGjpnkEZcQtyndD0Qr-ca?dl=0

allocated audience zones, but also that the array as a whole is working as a single unit to provide polar pattern control over the desired frequency range. The lowest controlled frequency is a function of the length of the array, meaning that the response at the listening plane is influenced by more than the section of array targeting that plane. Approaching the big band recording requires a similar methodology, with the need to target not just the bleed from the drums into the sectional mics (sectional mics become plane A) but also the local bleed from other players in the section. The saxophone section provides an example of this approach, with the Baritone saxophone providing the primary reference. The ABC approach is used to align the saxophone section as if it were a line array, bringing each element into the best possible alignment at the target frequency range. The tenor saxophone is added to the baritone, and other close measured in-phase points are auditioned, focussing on the tonal relationship between the two instruments at the recommended points. The points that are auditioned are not from an alignment measurement between the two saxophones, but still from the drum alignment (plane A), preserving the phase relationship with the bleed while optimising the relationship between sectional instruments. The process continues, adding each sectional mic (plane B and C) in turn and tuning in to the existing section using alignment options provided by the relationship with the drums (plane A).

Discussion

The end result of this alignment process across all thirty two channels of the recording is a significant change in delivery. Before alignment there is a sense of a big band being in a space, with spatial cues arriving at the listener along with the direct sound, creating a sense of distance and a lack of intimacy and urgency. After alignment the staging of the band has changed, with a move from a band situated in a room to a sound that has clearer definition and a greater sense of immediacy, particularly in the brass stabs at the end of the short example provided. The sense of delivery and detail creates a greater sense of energy delivery, with the band now appearing to be located closer to the front of the soundstage rather than further into the room, with the splash of energy in the reverb now feeling like a result of the transient energy of the band, rather than a space that the transient is filtered through. Through a time and phase alignment process inspired by live sound system design approaches the balance of instruments can be manipulated without significant changes in frequency response, allowing considerable post production manipulation of sounds that sees significant changes in overall response without alignment.

From a pedagogical standpoint, the realigning of big band microphones using a considered methodology offers students the chance to understand how better microphone placement can affect the delivery of a recorded performance. The opportunity to visualise and understand such relationships without having to move microphones allows teachers to demonstrate extensive phase relationships in a less time-pressured environment. In this post-production example, the visual and automatic options provide the chance for students to hear multiple different placement suggestions from the algorithm. However, it also affords the opportunity for students and teachers to engage in critical discourse as to why certain positions work better than others. Finally, this experiment offers an insight into the choices that engineers need to make when visualising a complete recording as well as an opportunity to evaluate microphone placements that need correcting in future recordings.

Conclusions

In both of these phase experiments, we used comprehensive visualisations to inform our choices in pre- and post-production. In the experiments and our pedagogical practice, the value of visual tools to inform recording practice cannot be overstated. In our tests, the ability to utilise a precise visual analysis of microphone relationships removes the guesswork from creative microphone positioning. In our teaching environments in QUT and UWL, phase visualisation tools now play a significant role in presenting an explicit picture of microphone phase relationships to students. However, it is important to remember that there is no correct answer with phase choices. The notion of perfect phase relationships for a multi-microphone recording is an impossibility. Using a multiple microphone setup involves creative decisions between different microphone types and distances. The result of this distance mismatch creates a sense of space around the drum kit due to the natural phase cancellation. As stated by Paterson (2007), these unavoidable phase differences offer the chance to decide on the phase colouration. This colouration is a phenomenon that the listener is familiar with due to the ubiquitous nature of multi microphonic drum kit approaches in past recordings. This experiment improves the understanding of phase relationships to make deliberate choices as to the aesthetics of multi-microphone recordings. We intended to utilise these systems as teaching tools so that early stage recording engineers and students can understand and manipulate microphone choices with a deeper understanding of the consequences of their actions. Experienced recording engineers learn to hear and minimise the phase cancellation so that the microphone relationships allow the speaker to represent the recorded text with minimal nullification due to destructive relationships. In other words, the speaker can move with more freedom because it is not being asked to move backward and forwards at the same time due to ill-considered microphone placement. This listening method is a skill that takes years to acquire. The experienced engineer draws on years of tacit knowledge to quickly understand and correct phase issues. We assert that it is possible for the early career engineer using visual tools to produce their desired phase and frequency relationships in multi-miked drum recordings.

Further Study

Our use of optical phase analysis in post-production reveals a more considered approach to correcting phase issues. It is important to note that the tool we utilised is a post-production tool and is not designed for analysing microphone placement in recording scenarios. However, it was the only phase analysis tool that offered distance analysis as well as comprehensive frequency interaction, time delay, and phase analysis. As a result, it is the use of Auto-Align as an analytical tool that shows real promise for creative manipulation of phase in physical space. This experiment in phase analytics has opened up opportunities for experimentation using different microphone setups and relationships. As such, we intend to produce a series of videos that continue to explore the use of post-production analytical tools but with unconventional microphone placement in spaces that are less forgiving than QUT Skyline Studios. As stated in the literature review equalisation can drastically alter phase relationships between microphones. We intend to explore some aggressive equalisation and processing techniques with recordings to see if we radically shape drums using creative processing then reposition microphones for better phase coherence. We also intend to explore phase measurement in a variety of settings to test its validity for different applications such as guitar recording, orchestra recording, and various other acoustic sources. We feel that real-time phase measurement in the tracking environment offers the chance for us to develop a methodology of multi-microphone tracking that understands and creatively manipulates phase relationships to push analog recording into new frontiers of creativity.

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