Sound-Off: Recorder Mikes: What Sounds Good, Is Good!

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Recorder Jody Call [1] (army marching cadence call)
Your recorder was great when you left, You're right,
Your timbre was hot when you left, You're right,
Your volume was high when you left, You're right,
Your whistle was wet when you left, You're right,
But now there's nothing left, You're right,
So Sound-Off, "One, two" ; Sound-Off, "Three, four"
"One-two— Three-four"

Have an itch to try a microphone with your recorder? Are you afraid of the electrons and the vocabulary? Worried about what your colleagues will think of you? Want some hints on how to begin? Well, listen in and Sound-Off.

Most players think only about the recorder, but in amplified playing the instrument is just the beginning. Down the marching line are the microphone, the amplifier, equalizers and mixers, speakers, the room, the audience's ears, and finally their minds. How you sound-off depends on what you want to do. Let's make the march step-by-step; when you've left, you'll be all right.

Where to Put the Mike

Recorder players have successfully placed microphones (Figure 1):

- behind them in the (1) *rear-field*; or
- in the *near-fields*— (2) near their own ear, (3) in the windway of the recorder, or (4) clipped to the outside of the instrument near the windway; or
- in (5) the *mid-field* about a meter or two in front of the instrument;
- or possibly (6) in the *far-field* toward front-stage.

Why so many choices? Sometimes the choice is forced on players by the venue, sometimes it is due to biased experiences, and often it is due a lack of appreciation of the complexity of the problems and available solutions.

If sound from a recorder was radiated uniformly in all directions, if microphone sensitivity in space and frequency was uniform in all directions, if the room was always a perfect acoustic enclosure, and if the musical pieces were all the same type— there would be no problem. A theoretician would start- *"Let us assume that recorders are spherical objects*". But reality has sharp edges!

The Shape of Sound

To many players, the sound from a perfect recorder is a spherical balloon that spreads in space from the instrument's window and falls gently on the listener's ear. Unfortunately that balloon must be burst. The sound waves from a recorder radiate from the window, open tone holes, and the foot. John Martin's superb experiments involved rotating a sounding recorder on a record turntable is shown in Figure 2. The microphone was placed 1.3 meters from the recorder center. The fundamental of the lowest note (alto F_4) does radiate somewhat spherically.[2] The second harmonic (first overtone) shows sharply reduced levels of sound at 90 and 270º (axis front/back), while the third harmonic shows dips in the sound at ~ 66, 112º; and 247, 292º, each pair centered around 90/270º. In a higher register, playing ~ one octave higher (G_5), the fundamental is largely omni-directional, but the higher harmonics become very directionally complex (Figure 3). At G_6, all of the harmonics show very marked directional patterns. This type of sound pattern is typical of a sound source that consists of a linear array of open note holes in addition to a window and foot. In general, woodwinds show relative omni-directionality at very low tones, distribution of sound in conical sections coaxial with the instrument at higher frequencies, and a more cylindrical radiation from the foot at very high frequencies (Figure 4)[3]. As the microphone is placed close to the instrument (~1-10 cm) directionality effects become very pronounced. The sound pressure levels from different open holes may be in-phase, and add together; or they may be out-of-phase and destructively interfere. The recorders sound distribution patterns look like a collection of inflated, knotted balloons in the hands of an adept magician—you, and your microphone.

The Shapes of Microphones

We often think that all microphones are also omni-directional, and pick up sound from all directions equally. However, many microphones are bi-directional, and pick-up sound most efficiently arriving from 0 and 180º directions (Figure 5). Off-axis, at 90 and 270º, they are deaf. A central bi-directional mike works well for sax groups, or a balanced SATB recorder consort. Sound engineers have developed combination microphones with both types of elements, leading to a sensitivity pattern that is somewhat heart-shaped, providing a more directional microphone. These are called cardiod microphones (Figure 5). Engineers have also combined omni-, bi-, and cardiod- microphones to produce very directional hypercardiod and supercardiod microphones. These can "spot" emphasize individual instruments. Each class of microphone has unique spatial characteristics, exhibit unique responses to various frequencies, and respond differently at various distances and directions from the sound source (Figure 5).[4] [5] In addition, all live performance venues have different reverberation characteristics, and random noise environments. Each class of microphone handles these sources differently, and requires proper distance placement to operate most effectively. The more directional a mike is, the further it can be removed from the instrument, or the closer competing instruments may be. Many classes of microphones are prone to boost bass note intensities at close-mike distances (bass-tip) (Figure 6). That's fine for "thumping" rock, or singers who want to sound a bit "richer". Couple this characteristic with the fact that the recorder openings radiate sound more favorably at higher frequencies (treble boost of about 6 db/octave) (Figure 6). The pure unprocessed sound someone hears a few meters from your instrument isn't what you hear, and it isn't what someone 15 meters away hears from a mike/pre-amp/amp/speaker combination. And, what our brains grasp is not exactly what our ears hear. The poets say it better:

> "… listen to the mystic sound
> That stole in fitful gasps around." (Shelley)
> "(and) hear the notes as when
> Once she sang to me." (Hardy)

The Mind Field[6 7 8]

“Miking” larger ensembles can involve intricate mixtures of stereo-mikes using crossed bi-directional microphone assemblies, and spot directional mikes for instruments with low dynamic ranges (recorders). The most common failures involve arrangements that are over-engineered and under-powered— too many mikes, poorly balanced, and inadequate speakers. Often the output of the main mike(s) are set incorrectly and overshadowed by the spot mike sounds. There is also a new performer in the mix- the sound engineer. When the team works in synergy the results are outstanding. But if the players and the engineer do not understand how electronics can maul and molest music, the results are cacophony.

Round-and-Round the Music Goes

Electronic filters allow the user to selectively remove frequency components. Typical filters cut off some bass frequencies to remove random, extraneous room noise (ventilation and traffic rumble) and instrumental artifacts; or, they can cut-off high frequency hissing. Equalizers selectively boost or reduce certain frequency bands. Full featured parametric equalizers and simpler graphic equalizers are available, the latter covering 1/3 octave to one octave sections. These may be used to bass-cut a close-mike setup that has led to a strong bass-tip. They can also be used to correct for the non-uniform frequency response of directional mikes, particularly when they receive sound off-axis (not perpendicular to the microphone face). Equalizers are especially useful in sessions where the reverberant field should predominate, and a high frequency boost may help (classic music). On the other hand, many performance spaces have a reverberant field that colors the sound captured by far-field miking with a heavy bass. Here, a bass-cut can help. Treble boosts can add sparkle to the music, while bass-boost can add weight. Examining the six scenarios described above will reveal where equalizers may be required.

Recall that John Martin observes “It is worth mentioning that the sound outside the recorder is different than inside”? Remember the bass-tip of a close-mike? Some mikes have bass equalization built-in, others do not. Imagine someone who tried to use a near-field technique, and chose the wrong microphone and position. Graphing (Figure 6) indicates that the timbre heard by the audience might have an objectionable bass boost, treble boost, mid-range gain discontinuity, and a burbly jet stream noise. A final diagram (Figure 5) indicates that off-axis pick-up can also dramatically change the timbre heard by listeners. Mikes become more directional at higher frequencies. Unless you pick a mike that moves with you and the instrument, the timbre will dance round and round.

If you want to get in-step, one way to start is to ask instrumental groups if you might “tootle” your recorder at the end of one of their gigs. Try out the various bits-and-pieces till you find a match. As an active Blues busker, I prefer a wireless near-field ear-mounted mike (e.g., DPA 406x series) with a Pig-Nose AC/DC amp and speaker set [9]. It’s street portable, fills the sound needs (>5 W), and permits quick instrument switches. But if you play with many other instruments, prefer a more classical sound, enjoy good acoustic venues, or other types of music, your needs may be different. Experiment. What you use depends on the music you play, and where you play it. The associated chart (Table I) will give you an idea of where to begin. ***Sound-Off***. You’ll have music to be proud of. (A more technical ***sidebar*** presents other considerations)

TABLE I

FIELD	#	easy swap	possible bass-tip	ext treble boost	jet noise	Spot use
Rear	1	X				X
Near	2	X	X			X
Near	3		X	?	X	X
Near	4		X		X	X
Mid	5	X				X
Far	6	X				

The *Kind* Field: A higher note sidebar

The sounds that recorders make, and the sounds microphones hear, have complex shapes. Mike selection and placement is thus a challenge, and prone to subjectivity. But many different kinds of mikes are also available. Recorder players use terms like trill, tremolo and turns. Using mikes correctly means adding a few new words to your vocabulary. Early mikes were resistor-based. They consisted of a metal diaphragm overlaying carbon granules. As sound pressure compressed the granules, their DC resistance (R) changed, as measured in ohms. As newer microphones were developed, the "resistance" a circuit offered to electrical flow began to be referred to as impedance (Z), since other factors (capacitance, inductance) are involved in processing AC signals. The new microphones were classed as low, medium and high impedance devices. Impedance is also measured in ohms. Learn more at:
http://www.shure.com/support/technotes/app-impedance.html

Most recorder players will encounter dynamic or condenser/electret mikes. Dynamic mikes involve diaphragm/coil units that sound pressures move in a magnetic field, thus creating a signal current. Condenser (capacitor) mikes involve two parallel films or plates. They have the ability to hold a charge. If the diaphragm/plates move to-and-fro with respect to one another, a sound pressure can cause a changing electrical signal. Condenser mikes need an external voltage to "charge" the capacitor and to power any internal preamplifier. These voltages may come from batteries, or more commonly via multi-pin/-conductor microphone cables providing phantom power (12-48 volts). Electret mikes have the charge permanently built into a special type of condenser. These do need a bias voltage supply (1.5-9 volts) to power the preamplifier, and the audio cable or a battery can provide it.
http://www.shure.com/support/technotes/app-phantom1.html

Dynamic mikes usually have heavier components that have a large inertia, and they may respond slowly to sharp attacks. They do give a mellow, round sound to audio signals. Condenser mikes tend to give crisp outputs. Dynamic mikes are rugged, and relatively insensitive to temperature and humidity. Condenser mikes are usually environmentally more sensitive, but can be made very small. Low impedance dynamic mikes (Lo-Z) can be used with very long cable runs. Without an amplifier, high impedance condenser/electret mikes (Hi-Z) can show high-frequency losses at cable runs as small as 20 feet.

Dynamic mikes are very difficult to overload, while condenser mikes may be easily saturated. Some musical instruments have a very large dynamic-sound-range; the recorder has a low dynamic-sound-range. Combining such instruments requires different mike characteristics. Some mike setups carry the audio information on one wire, with a shield; these are unbalanced feeds. Other setups use two wires, where the audio signal on each wire is of opposite polarity

to its companion. These setups feed dual input amplifiers that reject any noise common to the two wires, but reinforce signals that are of opposite polarity. Thus, balanced lines can reject environmental electrical noise, improving the signal/noise ratio.
http://www.shure.com/pdf/booklets/music.pdf

Music players, and listeners, don't want random noise. The self-noise in modern mikes is lower than ever. But players may also dislike the pin-sharp pickup of small condenser mikes. Possibly most damning is the fact that condenser microphones tend to record sound as it really is. Players must be really good, as any imperfections may stand out. This has lead to the creation of large diaphragm condenser microphones, which use the same basic technology, but have special, larger high-quality diaphragms to produce a more flattering sound. What has happened? The momentum for digital sound has led to the development of new mikes that let you hear things you've never heard before, and may not want to hear. Flat response isn't necessarily great. Some sound engineers and savvy players use microphones as aural paintbrushes. Retro-mikes, built the old fashioned way, are coming out of Eastern Europe. *New isn't always better*!

In systems requiring wireless transmission, the audio signal from the mike is used to modulate an FM carrier frequency. This combined signal, produced in a body-pack unit, is transmitted via a small antenna to a receiver. Here, the audio signal is stripped out and fed into the amplifier/speaker system, just like any other mike output. Each instrument must have its own unique FM carrier frequency. If the environment is simple, a single receiver antenna can be used. If walls, metal structures, long distances, etc., are present a twin-diversity antennae system should be used to avoid receiver drop-out.

You now have the words, and can read specifications:
An example? "The Shure KSM44/SL is a multiple pattern (switch selectable cardioid, omnidirectional, bidirectional), externally biased, dual large diaphragm condenser microphone with extremely low self-noise."

To put everything together, impedances must be matched/bridged in the component/cable chain, phantom and/or bias supplies need to be provided, and the connecting plugs and sockets must mate. That's what sound engineers do. They have the mikes, required impedance matchers, transformers, plug-adapters, and much more. You tell them when the sound is just right. There is no one ideal mike to use for a specific instrument; no one ideal way to place a mike. You must experiment. Learn the terms <u>now</u> so you can jot down the best way for your instrument to sound-off!
http://shure.custhelp.com/cgi-bin/shure.cfg/php/enduser/home.php

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HEAR WHAT THEY DO: Comments from recorder players and makers[10]:

John Martin (player, physicist)[2] - I guess the answer to the question of the best mike to use depends on what you mean by "best". These days, drilling a hole in the headpiece and inserting a mike which then feeds an effects box seems popular, and I've heard some pretty impressive results, if you like that kind of thing. Of course the internal spectrum is quite different from the spectrum of the radiated sound. Similar effects can be obtained by putting a microphone right over the window, although the spectrum feeding the effects would start-out different. If you mean, "what is the best place to put a microphone so as to record the best sound from a recorder", well I think from experience that not too close, and in a good acoustic space is best. Put the microphone where a listener would sit to hear the best sound. Otherwise the radiation patterns from the various sound sources on the recorder (window, holes, end) can adversely affect the sound. Certainly don't put the mike near the end - too uncharacteristic and too variable from note to note. If the mike has to be close, then near the window is best. All this is very, very subjective.
john.martin@uq.net.au

Alec Nisbett (sound engineer, BBC)[11]**-** Flutes, and other air reed instruments, often benefit from placement of the mike behind the performer. Directional mikes pick-up the full sound of the instrument, and reduce pick-up of the annoying air turbulence associated with the air jet. [see Photo 1 for an example] The audiences view of the player is not obscured by a fixed mike stand or boom. Many players and technicians unfortunately never think about the possibility of a microphone to the rear of the performer. [Placement should avoid the sound shadow created by the head]

Robert Deck (theatre sound designer)- Voice and solo instrument capture on an active stage has always been a problem. New skin-tinted close-mike electret units that can be patched at the hair/scalp interface near the ear offer superb capture capabilities. These units are available with built-in filtering capabilities, and are directly compatible with wireless RF transmitters. They are almost invisible to the audience. Woodwind pick-up has been particularly successful, since gain control allows our sound engineers to "spot" a particular instrument and piece, and then easily return to the normal dynamic balance. The musicians appreciate the freedom of movement the units offer, and the negligible physical presence doesn't distract the audience from the desired mood. Acoustical equalization grids are available providing a soft boost from 8-20 kHz, or stronger boosts at 12 kHz. [See Photo 2 for an example] Information can be found at: http://www.dpamicrophones.com info@dpamicrophones.com

Jean-Luc Boudreau (artisan)- I'm presently developing a new model for the alto A442. We are still working on the design, but it will integrate a microphone. My past experience with microphones was quite deceptive. Many of them are not adequate for good tone capture. Then I found out about a suitable mike. … I'm using a device invented by a colleague who did some long research on it and registered a patent . This colleague (and friend) is Philippe Bolton. Basically the microphone is inserted in the head joint at the block line at 9:00 o'clock, with the mike itself in the bore. The amazing thing is that you can tap on the instrument with something hard and there is no response, but you just tap on a fingerhole and you get a "oumphhh" in the speaker, from the air

column. The only problem (is) it's impossible to switch instruments quickly during a performance, unless they are all equipped with (their own mike). Phillippe is trying to bring down the cost of the apparatus by bigger production volumes.
http://www.boudreau-flutes.ca/english/index.htm

Philippe Bolton (artisan)- I got the idea of amplifying a recorder during a concert where I was listening to the French jazz violinist Didier Lockwood playing on an electric violin, and I was amazed at all the sounds that it could produce, which blended perfectly with his music. It took me some time to get down to it, but I finally drilled a hole in one of my instruments where I thought it should be, and fitted the microphone there. I was able to test it on a friend's guitar amplifier. The (mike) is on the side of the head joint, at the top of the bore, just next to the labium. The exact place is not critical. I use a condenser (electret) microphone. The surface is flat inside the instrument. This does not seem to create any problem. There is no need to use any treble boost. However it is better to set the bass level low to filter out any low frequency wind noise. When not in use the microphone can be replaced by a plug. [see Photo 3 for example]
http://ourworld.compuserve.com/homepages/philippe_bolton
philippe_bolton@compuserve.com philippe_bolton@csi.com

Jerry Bellows (player)- I have been using a microphone and amplification system sold by Phillippe Bolton in France. Phillippe usually sells the system for use with the recorders that he makes himself. I chose to use his system with my von Huene alto recorder. Patrick von Huene drilled a hole in the side of the head of my von Huene grenadilla recorder. He then put threads into the wood, and Friedrich made a grenadilla threaded plug that can be turned into the hole when I'm using it for acoustic playing. The microphone sets into a small brass thumbscrew that goes into the hole when the plug is removed, and a wire connects to a small belt-pack that has the volume control. The belt-pack is wired to a pre-amp and then can be connected with regular amplification cables to any sound system. My need is for amplification for playing jazz on my alto recorder and I need to be able to "compete" with the sax, trumpet, trombone and electric instruments.
% Eric Haas eric@vonHuene.com

John Coltman (acoustician)- Members of the flute family are unique in having two sources of sound, approximately equal in intensity. The tube is open at both ends, and radiates from the mouth hole and from the first few open finger holes. Interference between these produces a radiation pattern with strong angular variation in intensity. In the first register, the sources are in phase. In the second register, the two sources are 180 degrees out of phase, and destructive interference gives a dipole-like pattern with a strong null in the plane perpendicular to the axis of the instrument.[12] You can see that mike placement is tricky, as the sound projects in different ways for different notes. Because the two strong sources are in phase on odd modes, and out of phase in even modes, a complex tone will have different radiation patterns for each of its harmonics. The timbre of the direct sound picked up by a microphone, as well as the strength, will then vary with the microphone position. The patterns described above are altered by reflections from the player's body and by room reflections, so that a distant listener is not so much

affected by this varying projection. This is one reason why a room with some reverberation is much preferred over a dead one for performance. In taking spectra of flute tones I can get good repeatability by using a very small tie-clip electret microphone (Radio Shack 33-3013). This is fastened to the flute, parallel to the axis with its face just 2 cm above the center of the mouth hole, the mike body being just above the flute lip plate. In my living room … reverberation is negligible compared to the direct sound picked up by the mike. There is a small interference from the other open-end source, but it is the same for different instruments, and independent of how the flute is pointing, since the mike is carried on the flute. I have never tried to use this with a PA system, and there might be some undesirable wind noises from the jet. For performances, extraneous sounds from room echoes and the other performers may be inconsequential, and one might place the microphone farther away from the mouth hole, avoiding wind noises, but still getting a more consistent pick-up than with mikes that are not fastened to the flute. Another technique I have used is a stiff ceramic piezo mike in place of the cork inside the headjoint. However, the tie-clip mike saturates at the high sound pressures there, and the ceramic plate I used had poor frequency response, so the external mike was preferred. The Radio Shack mike has excellent frequency characteristics - almost laboratory quality.
http://www.radioshack.com/
"John Coltman" ColtmanJW@worldnet.att.net

Warren Dion (player, electrical engineer)- I have been using a clip-on mike for several years. The clip (is made from a "T" cut from sheet aluminum alloy. The cross-bar arms are curved to fit the shaft of the recorder, and the "upright" portion bent to accept the mike. Heat-Shrink tubing is used to cover the arms and protect the recorder finish.) The mike is sheathed in foam sponge. Mounting is critical (to capture) the main sound sources, and avoid wind and breath noises. The sponge rubber sheath avoids vibration pick-up. I've also used polycarbonate thumb-rests as the basis for the clip-ons [http://www.susato.com/]. The Lexan™ can scratch soft recorder walls, so care is needed. [see Photo 4 for an example]

Most any amp with a mike input would probably work, but I built my own using an Ampex PA26 power op-amp to drive a speaker from a car radio. A 5 v pre-amp and a commercial isolated regulated 24 v supply are used to drive an 8-ohm 8-inch speaker at 8 watts RMS. Those 8 watts have been able to fill any hall I have played in. The mike is a Radio Shack 33-3013 (*see Coltman above*). The level control is located between stages, and the input stage runs at full gain. The schematics are available.* The amp rolls off (filters) below 200 Hz to reduce hum and extraneous noise. A recorder can sound thin at times, so I often use a BOSS RV2 Digital Reverb unit. This adds dimension and richness.
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Terryville, CT 06786

Rich Carbone (player)- Coming out of a long time of playing pop and jazz, clarinet and sax, I gravitated toward picking out recorders that were louder and projected well to begin with (Nik von Huene says he can always recognize "a typical Carbone instrument-

-loud and clear"). I never attached any pick-ups to my recorders--I just stand near, for example, a Shure omni-directional mike--I only pay attention to the mike, or get close to it, if I want to play low/soft on a piece like "Send In The Clowns," or "You Needed Me." (http://www.shure.com/) I mention the Shure brand, but the modern mikes all seem so good--and do not distort the recorder sound. I couldn't say any one brand is head and shoulders above the rest. My point has always been that the recorder can contribute to any musical combination. When I first started using the recorders on my pop/jazz jobs, I'd hear some remarks from some of my colleagues like, "Here he comes with his toys," but after they saw the response I'd get from the audience, they became appreciative and supporting of the instrument.
Richsimcarbone@aol.com

David Griesinger (acoustician)- I would be strongly tempted to try some of the miniature Panasonic electret microphones. The usual disadvantage of small microphones (under 1/2" in diameter) is noise, which comes mostly from Brownian motion of the air on either side of the mike diaphragm. Human ears have the sound gathering power of the pinnae and concha, and do better than the diameter of the eardrum would suggest. However, with the limited dynamic range they ought to be OK.
http://www.panasonic.com/consumer_electronics/accessories/default.asp

Once you have the mike, you have to put it somewhere. I think either very near the windway or inside the bore would be best. If I wanted to sacrifice the instrument, I would drill a hole in the head plug, and flush mount the microphone in the end of the plug, just inside the instrument. As you point out, this would NOT give the sound of a recorder, so you would have to experiment with equalization to get the sound you want. I suspect this would be not too difficult. For example, you could play a particular piece of music while integrating the output of a near-field recording mike with a 1/3 octave analyzer such as JBL SMAART. Capture the curve and do the same thing with the internal mike. Subtract the two curves to get the needed equalization. An inexpensive 2/3 octave graphic or a 4 or 5 band parametric equalizer should do fine. You can always attempt to do the job by ear - but I don't recommend it. I rely increasingly on the power of modern instrumentation to get sounds I like - saves a lot of time, and does a better job too. Strikes me that the acoustics problem is a non-issue. You don't want the sound of a particular room in a recording anyway. You do want enough early (stereo) reflections to simulate some microphone distance - this can be done with a reverberation unit.
dgriesinger@lexicon.com

Figure 1. Six places you can put your microphone!

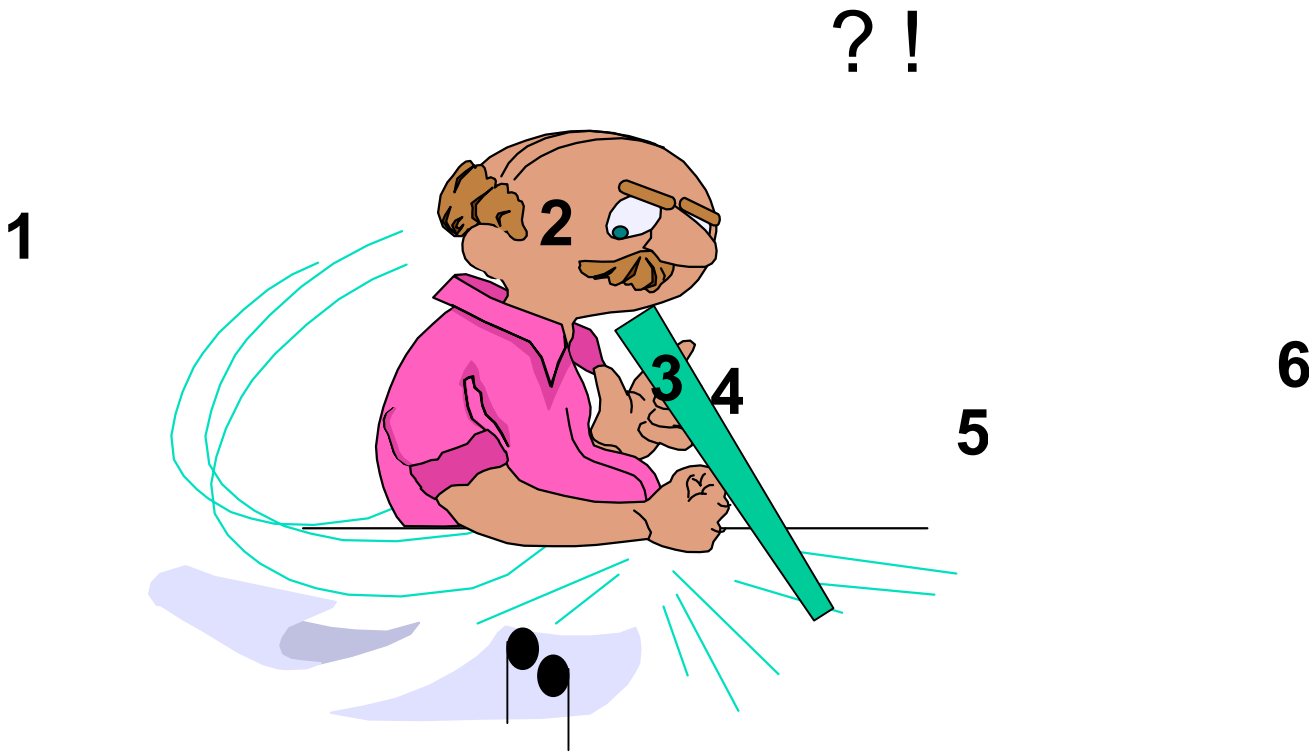


Figure 2. The Music Goes Round-and-Round …
Exploring a recorder's sound shapes:
The instrument, a turntable, a microphone.

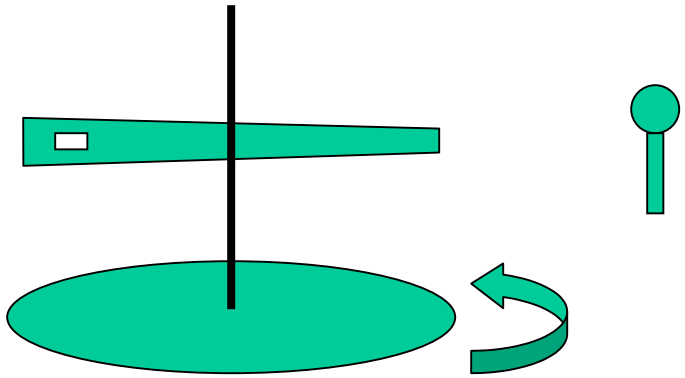


Figure 3. And it Comes Out Here?
Recorder sound level *vs* mike direction[2]

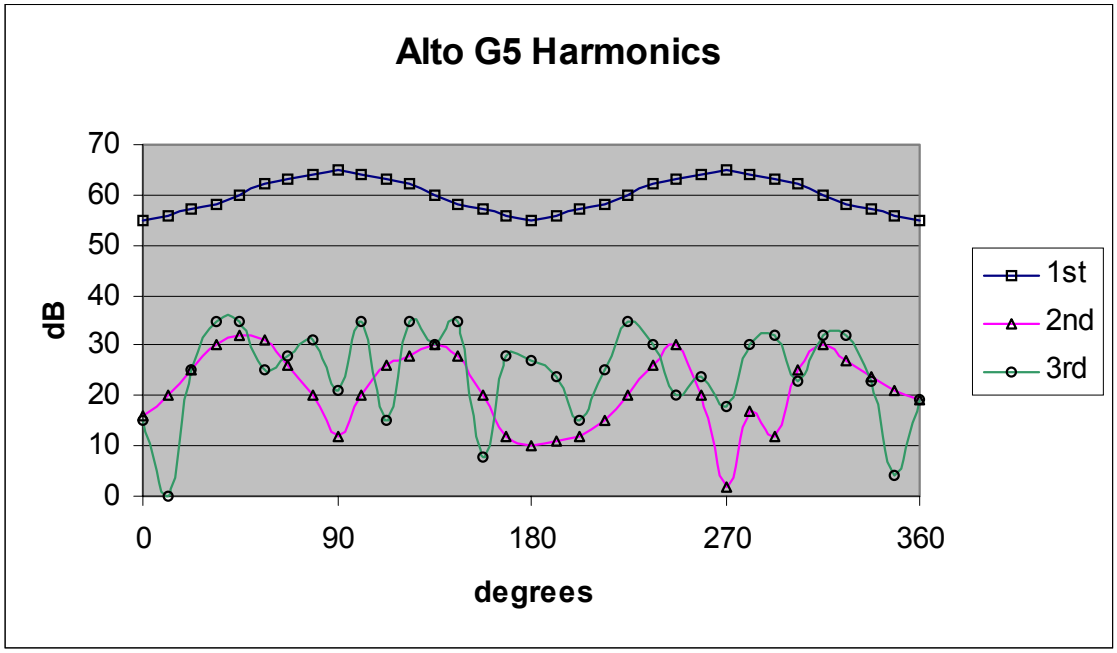


Figure 4. The shape of music[3] from tubular woodwinds

The music goes down and around
Whoa-ho-ho-ho-ho-ho,
And it comes out here.
I push the middle (finger) down,
The music goes down around below,
Below, below, deedle-dee-ho-ho-ho-
Tommy Dorsey

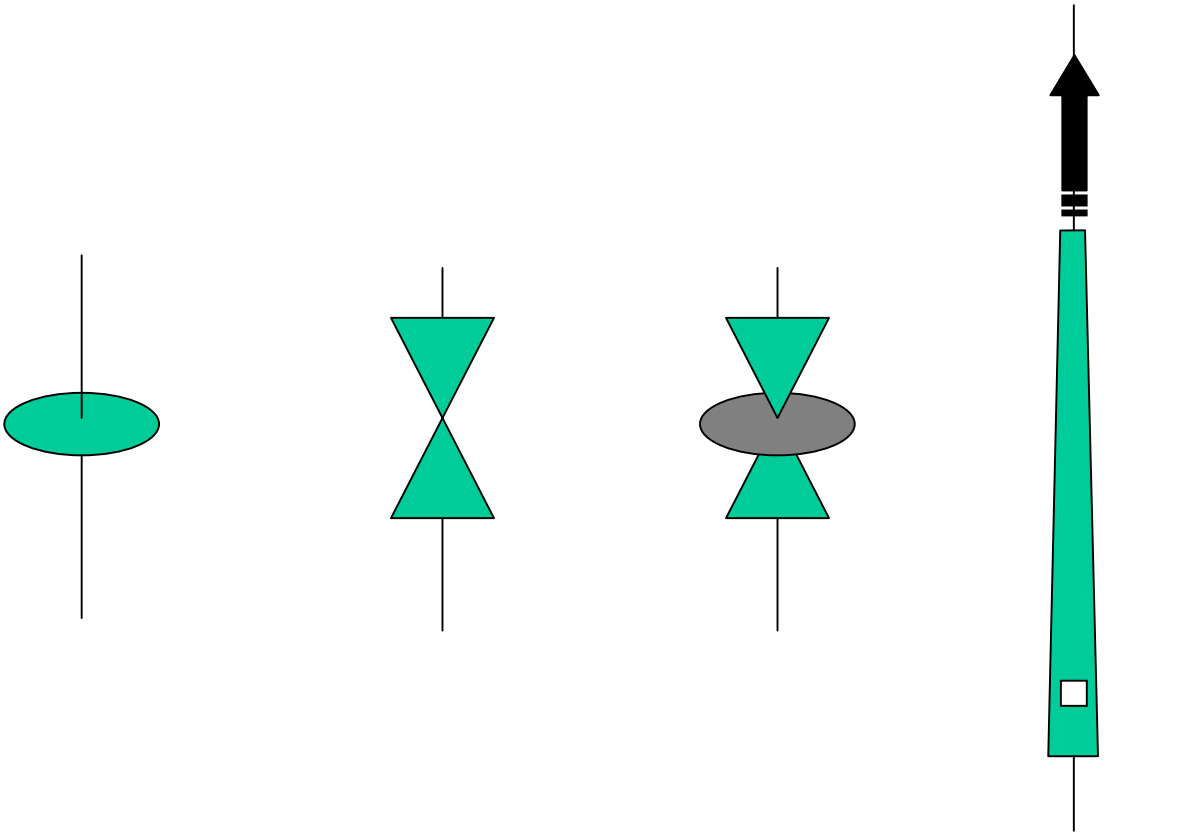
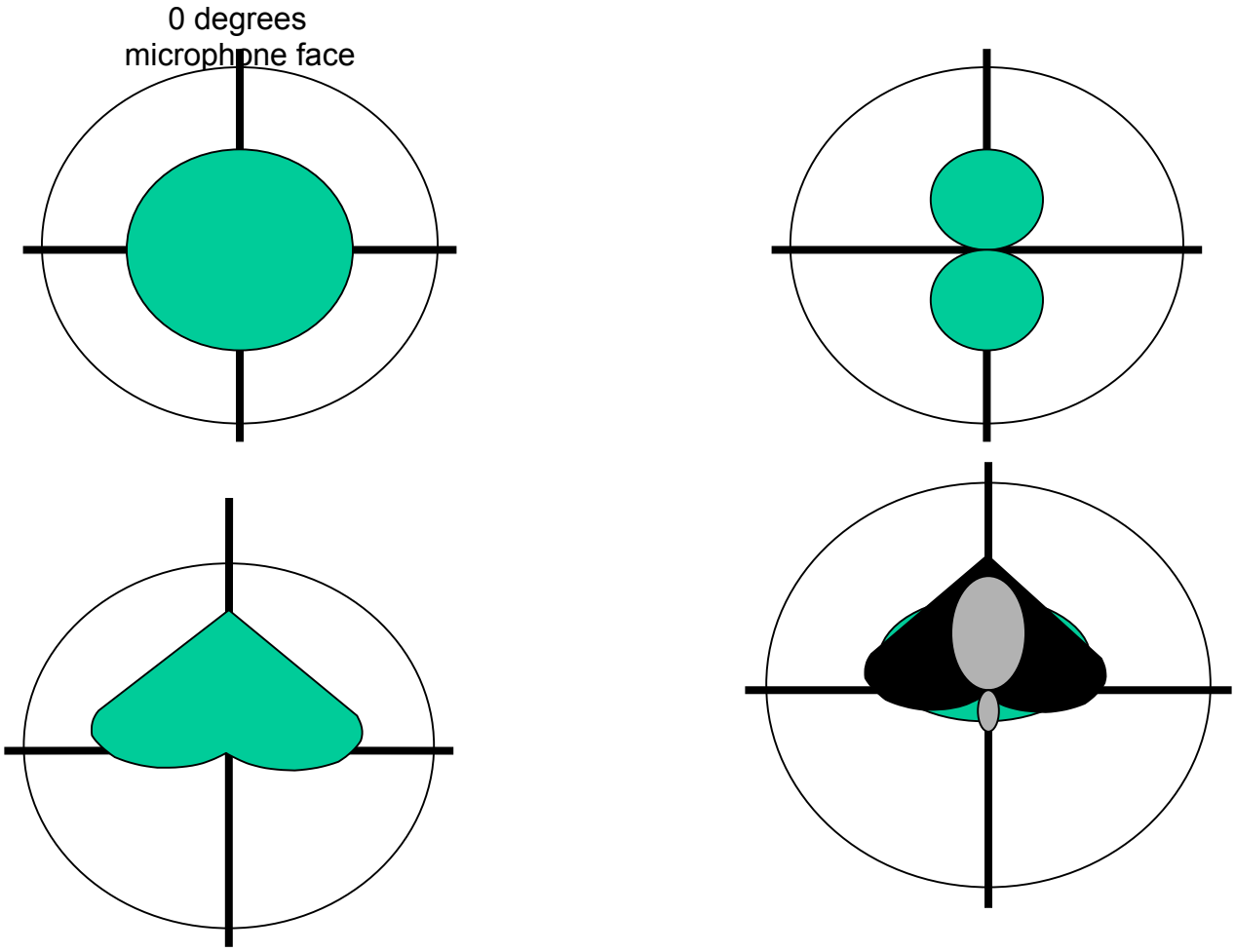


Figure 5. How Microphone's Listen, 360 Degrees Around
Cross sections of Omnidirectional, Bidirectional, and Cardiod shapes;at a given frequency. The last polar graph shows that as the frequency increases a given mike becomes more directional.[5]



C_3 pseudo-omni
C_6 cardiod
C_9 super-cardiod

Figure 6. What Microphones May Really Hear

Bass-tip-up and treble boost effects on an "ideal" flat response; "Pink-Noise" due to off-axis placement of mike.

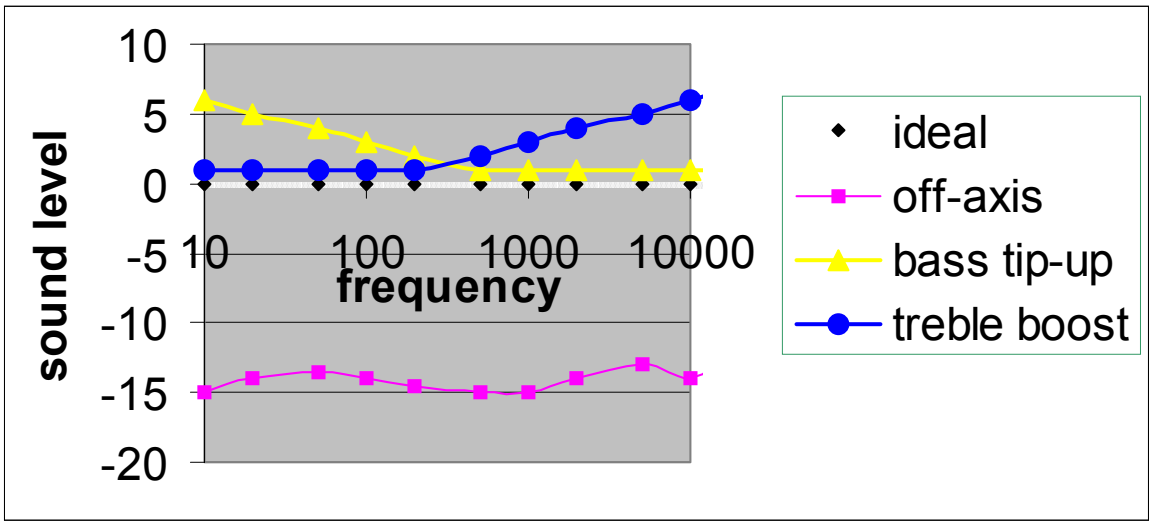


Photo 1. **Shure KSM44 Condenser Mike:**
Shell shows selectable omni-, cardiod-, bidirectional function switch;
X-Ray view shows diaphragm, and pre-amplifier circuit board.

Photo 2. **DPA Cheek Mike, Ear Clips**

Photo 3. **Phillipe Bolton's Bore Mike**

Photo 4. **Warren Dion's Window Electret Mike, Alto and 'nino:** Pre-amp, bias battery and on/off switch are in plastic case on audio cable

[1] http://users.erols.com/loriryan/history.html
http://www.uwlax.edu/rotc/Cadet-Resources/JodyCalls.htm
[2] *The Acoustics of the Recorder,* John Martin, Moeck, Celle, 1994
[3] *The Physics of Musical Instruments*, Fletcher and Rossing, Springer-Verlag, New York, 1991
[4] http://www.neumann.com/infopool/mics/
[5] for simplicity, some spatial diagrams are represented diagramatically
[6] *Microphones: Design and Application*, Lou Burroughs, Sagamore, Plainview NY, 1974
[7] *The Microphone Handbook*, John Eargle, Elar, Plainview NY, 1981
[8] *Microphone Engineering*, Michael Gayford, Focal Press, Oxford, 1994
[9] http://www.pignoseamps.com/
[10] Personal communications
[11] *The Use of Microphones*, Alec Nisbett, Focal & Butterworth-Heinemann, London, 1974-1994
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