Sound Production

- Production of vibrations
- Modification of vibrations
- Coupling vibrations to the environment
- Sound production systems
  - Insects
  - Anurans
  - Mammals
  - Birds

Sound production is uncommon

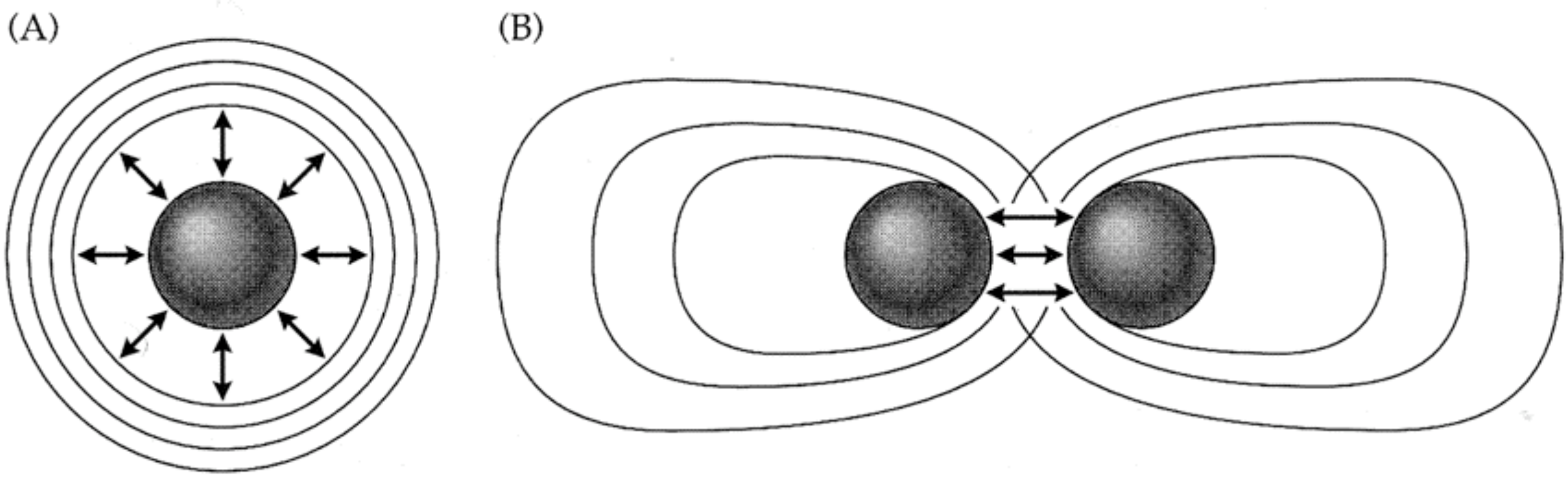
- Arthropods
  - Decapod crustaceans
    - Snapping shrimp
  - Insects
    - most orthopterans and cicadas
    - some bees, flies, beetles, aphids, bugs, moths and butterflies
  - Some spiders and millipedes
- Vertebrates
  - Some fish
  - Some reptiles (crocodiles, geckos, tortoises)
  - Anurans (frogs and toads)
  - Birds (dinosaurs?)
  - Mammals

Why is sound rare?

- Must produce vibrations with animal’s body
- Must modify sound to fit function
- Must couple modified sound to the environment and overcome impedance mismatch

- All three steps are physical challenges, especially for small animals, and solutions may involve tradeoffs between steps

Sources of sound vibrations

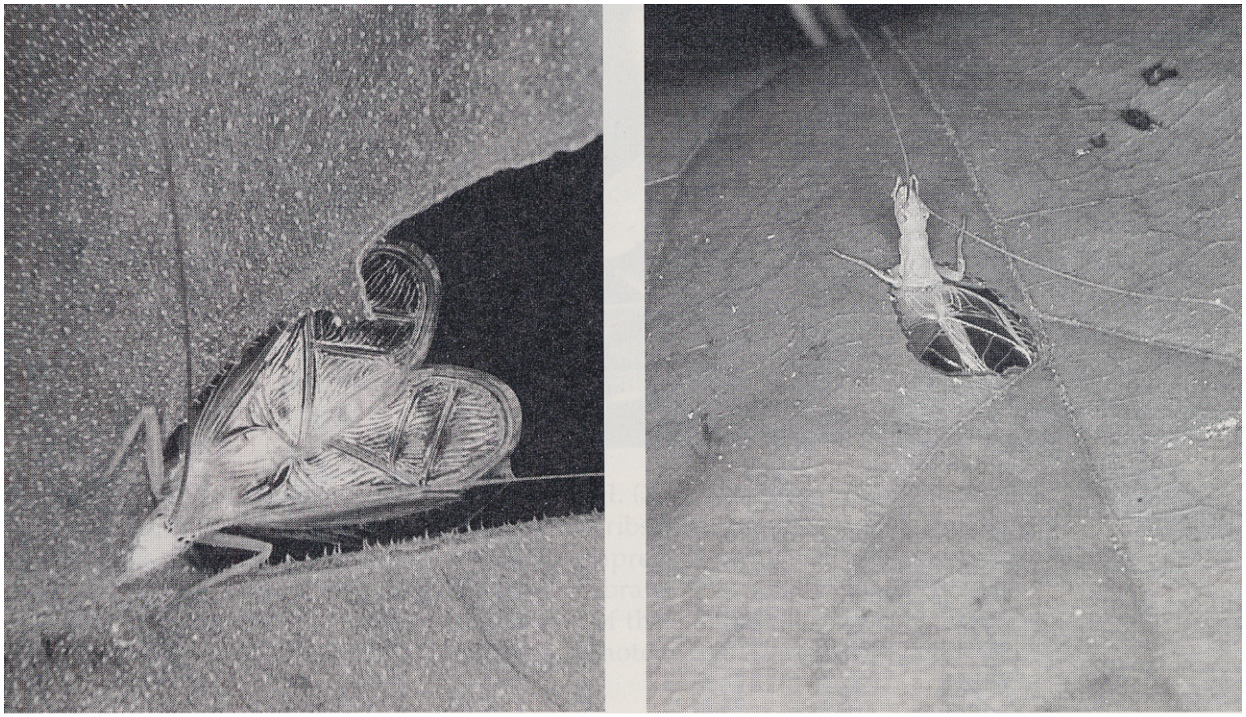


- Monopole: expands and contracts around a central point
  - fish swim bladder
- Dipole: move back and forth along a single axis
  - cricket file and plectum
- Tetrapole (and higher order): vibrates along 2 (or more) axes

Implications of monopole vs. dipole source

- Symmetry of sound field
- Sound pressure produced falls off rapidly as the ratio of wavelength to vibrator radius increases
  - Monopoles with square of radius
  - Dipoles with cube of radius

Acoustic short-circuiting

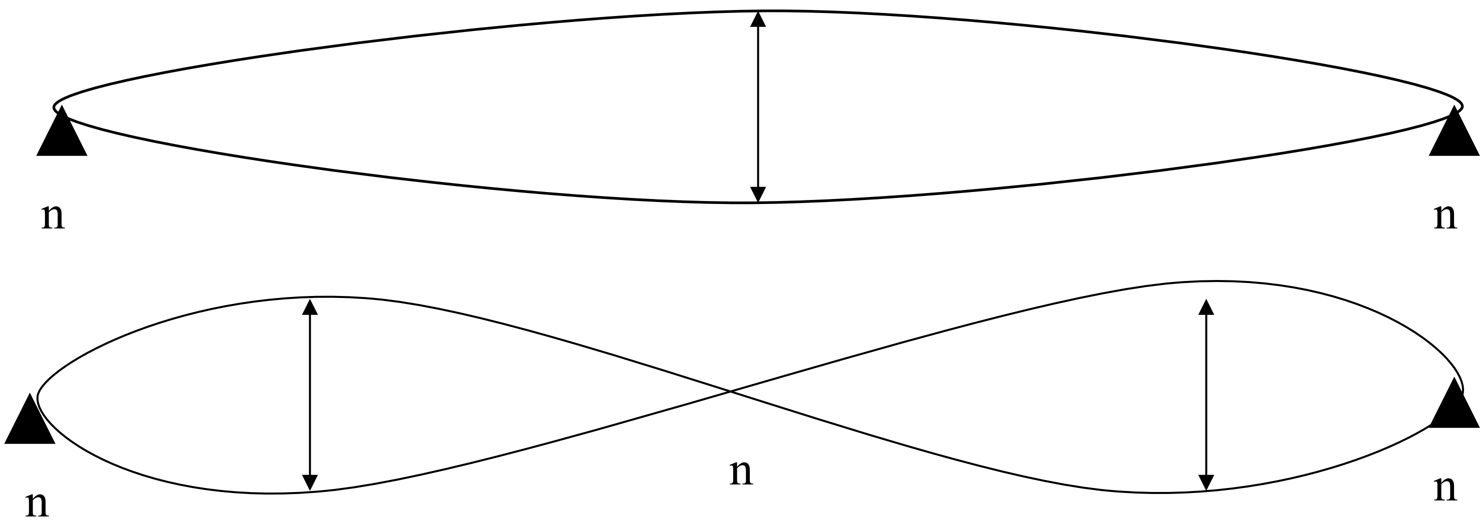


- Decrease in sound pressure caused by leaks of molecules from one condensation to opposite rarefaction
- Worse for smaller vibrators and longer wavelengths
- A 10 cm bird in air faces this problem with frequencies < 3.4 kHz
- A 10 cm shrimp in water has problems with frequencies < 15kHz

Sound production mechanisms

- Muscular vibration of a sac
  - fish
- Stridulation of one body part over another
  - crickets and grasshoppers
- Forced flow of medium through an orifice or past a thin membrane
  - frogs, birds, mammals
- Muscular vibration of an appendage
  - rattlesnakes
- Percussion on a substrate
  - spiders, kangaroo rats, woodpeckers

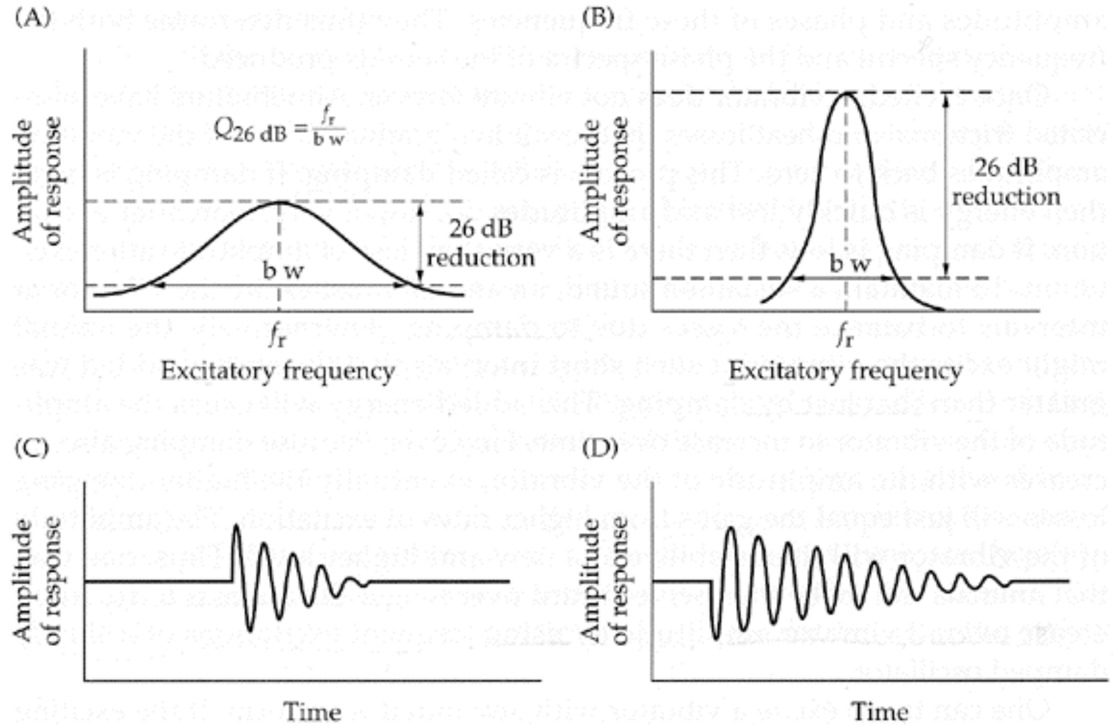
Standing waves and modes



- A plucked string creates a standing wave in which the reflected waves either cancel out at a node (n) or sum and oscillate maximally at antinodes
- Standing waves occur at natural modes, which create a harmonic series
- A string resonates when it vibrates at its natural modes

Vibration modification: resonators

Low Q

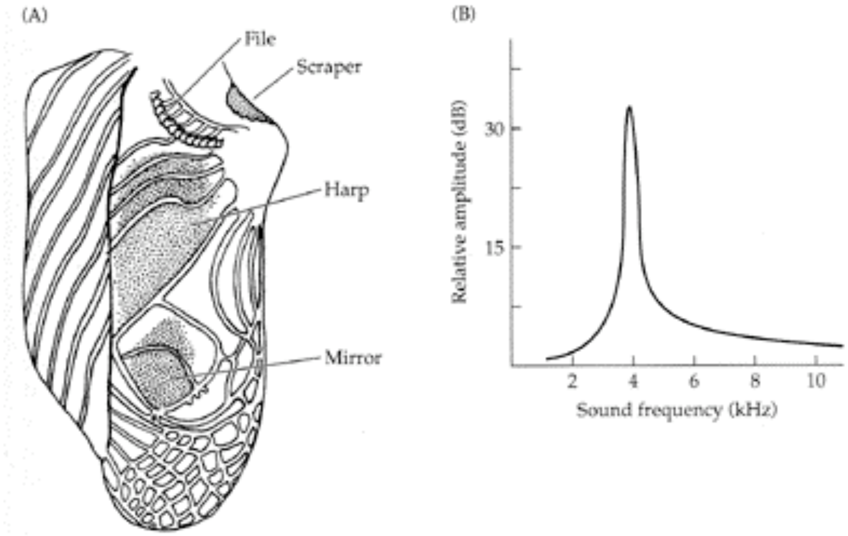


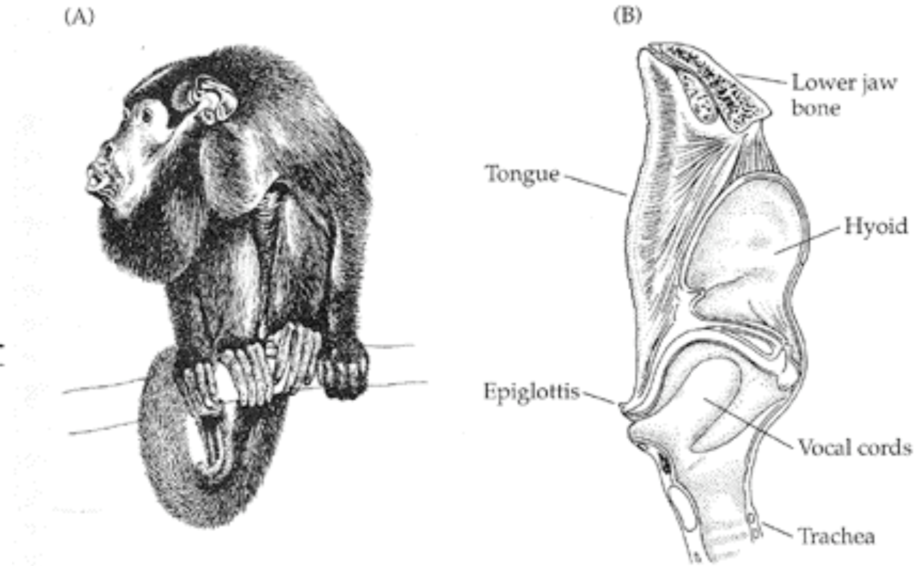
High Q

- A structure resonates when it vibrates at its natural modes
- Loss of standing waves is damping
- Resonators vary in bandwidth of response (low Q vs high Q)
- Inverse relationship between bandwidth and duration of response
- Thus, animals with high Q resonators can produce loud sounds, but only at a narrow range of frequencies.

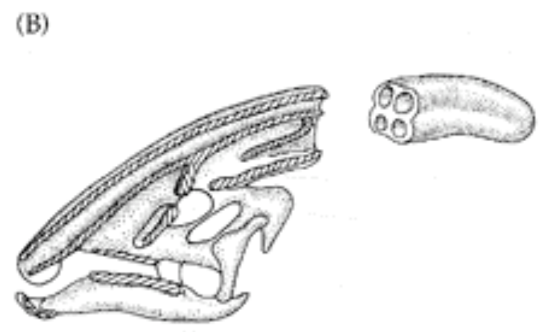
Impedance matching resonators

Animal examples of resonators





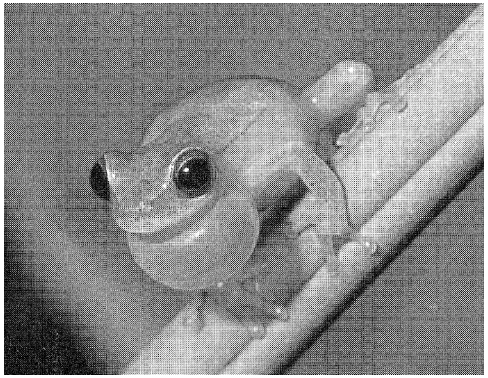
- Cricket wing harp and mirror
- Enlarged, hollow hyoid in howler monkey
- Hollow crests in Parasauralophus?
- Cartilaginous larynx in hammer-headed bats
- Cartilaginous chambers in ducks
- Elongated vocal tracts in cranes and grouse



Source vs response driven systems

- Source-driven: source vibrates at frequencies independent of attached structures or surrounding medium
  - Guitar string
  - Human voice, stridulation devices
- Response-driven: vibration of source controlled by structures which it excites
  - Clarinet - reed and tube work together to produce sound
  - Bird song
- Test: alter the density of medium
  - If fundamental frequency changes with helium, then must be response driven

Coupling vibrations to the medium
Terrestrial animals



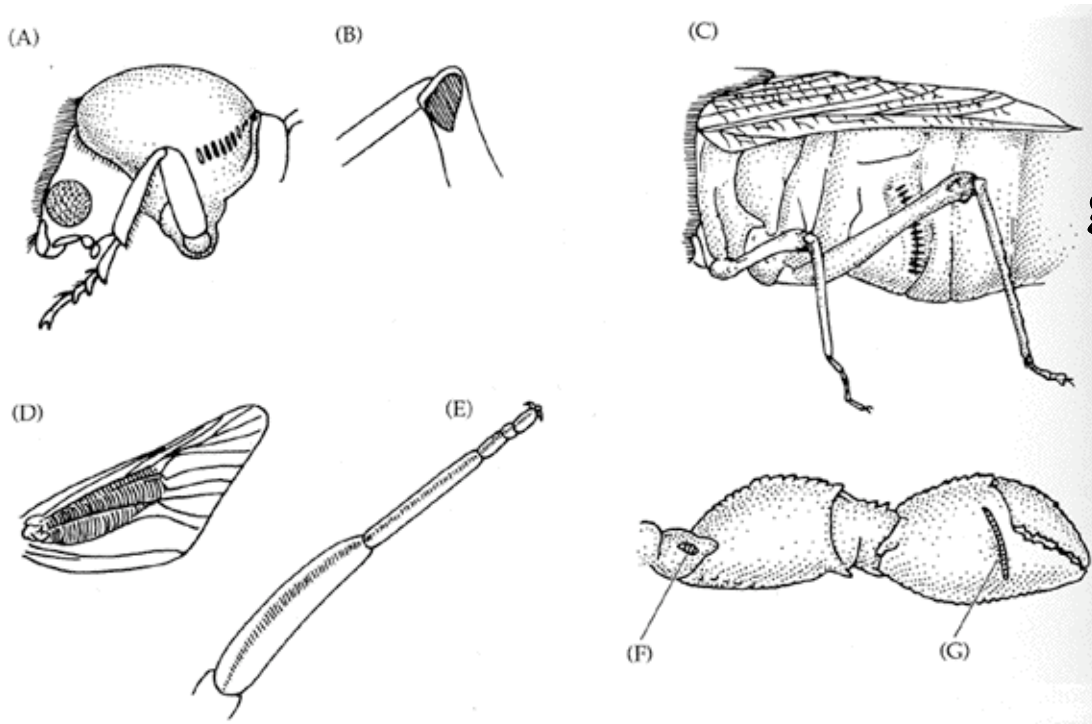
- Acoustic impedance mismatch between vibrating structure and outside medium
- Impedance matching devices
  - Resonators of intermediate impedance
  - Frog throat sac
- Flared horn
  - Gradual change in impedance lowers reflectance
  - Flared mouth cavities in birds and bats
- Couple vibrations to substrate
  - Spiders and webs or ground

Coupling vibrations to the medium
Aquatic animals

- Acoustic impedance mismatch not so much of a problem
  - Vibrating structures similar in impedance to water

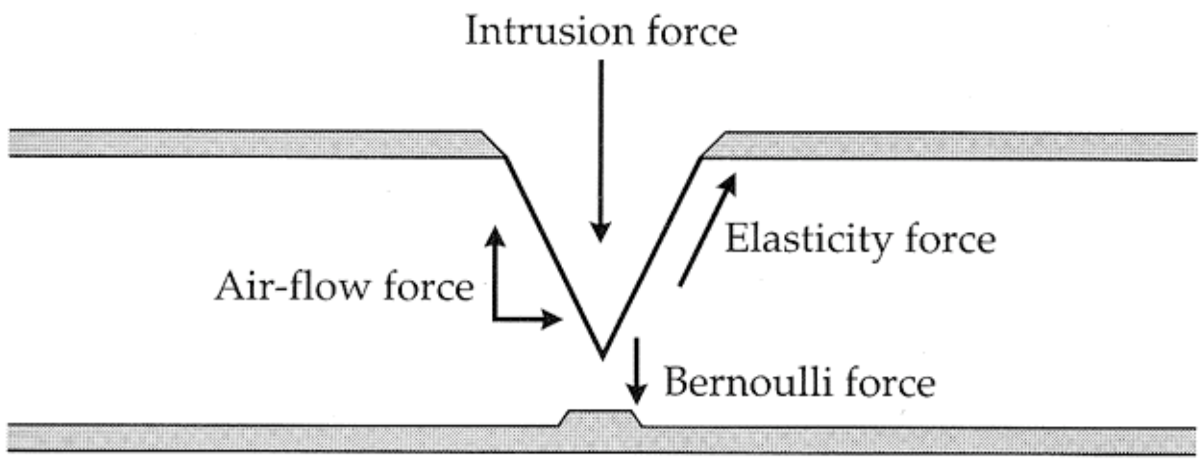
- Modification of sounds is difficult because energy is quickly lost to medium
  - Air-filled swim bladders act as resonant structures
  - Oil-filled acoustic lenses in cetaceans act to focus emitted sounds by refraction

Sound production in insects



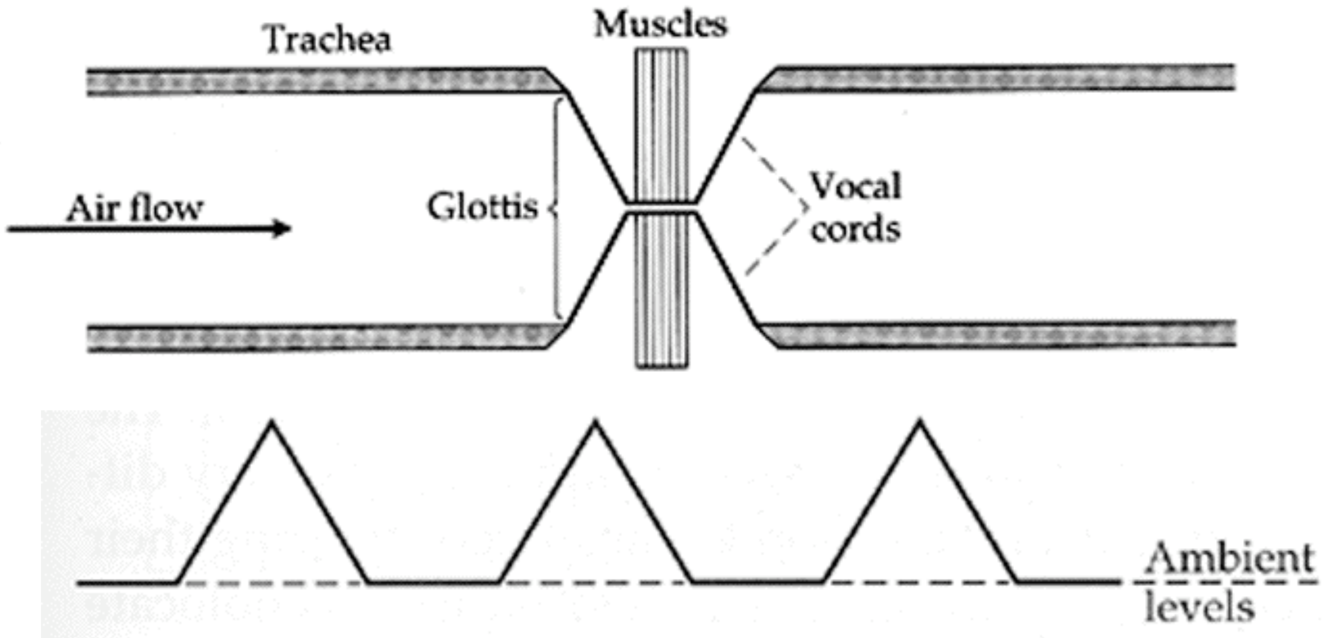
- Stridulation: scraping a file over a plectum
- Maximm muscle contraction rate is 100/s. Consequently, use frequency multipliers (e.g. teeth in comb) to attain higher frequencies
- Fundamental frequency equals click rate, not muscle contraction rate
- Wide array of stridulatory organs

Sound production in vertebrates



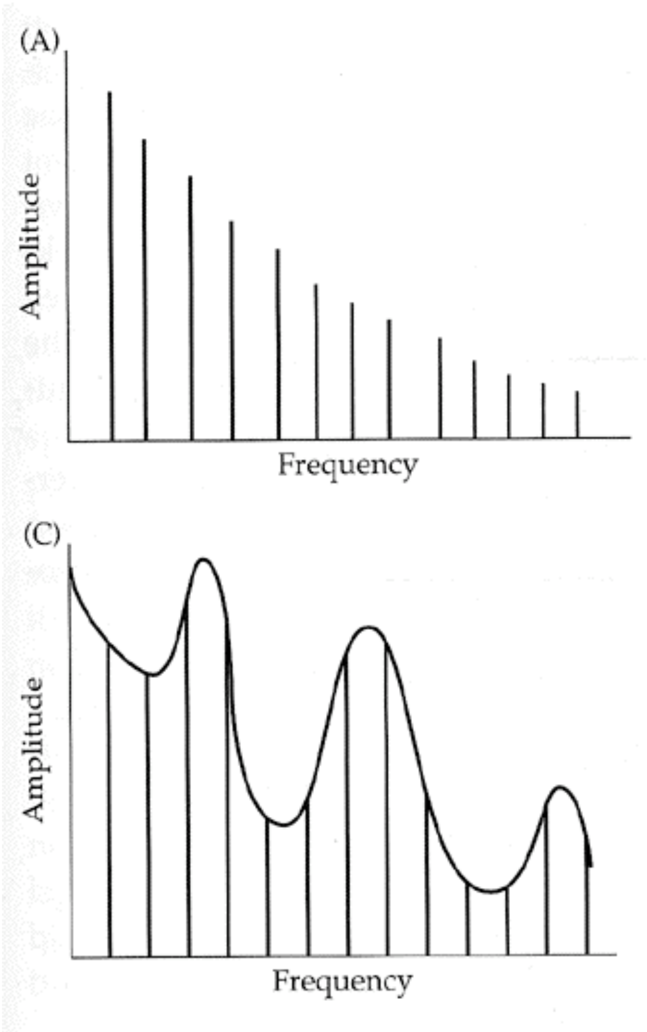
- Vibration created with air flow over a membrane in a tube
- Four interacting forces: intrusion, air-flow, elastic, and Bernoulli

Sound production in mammals



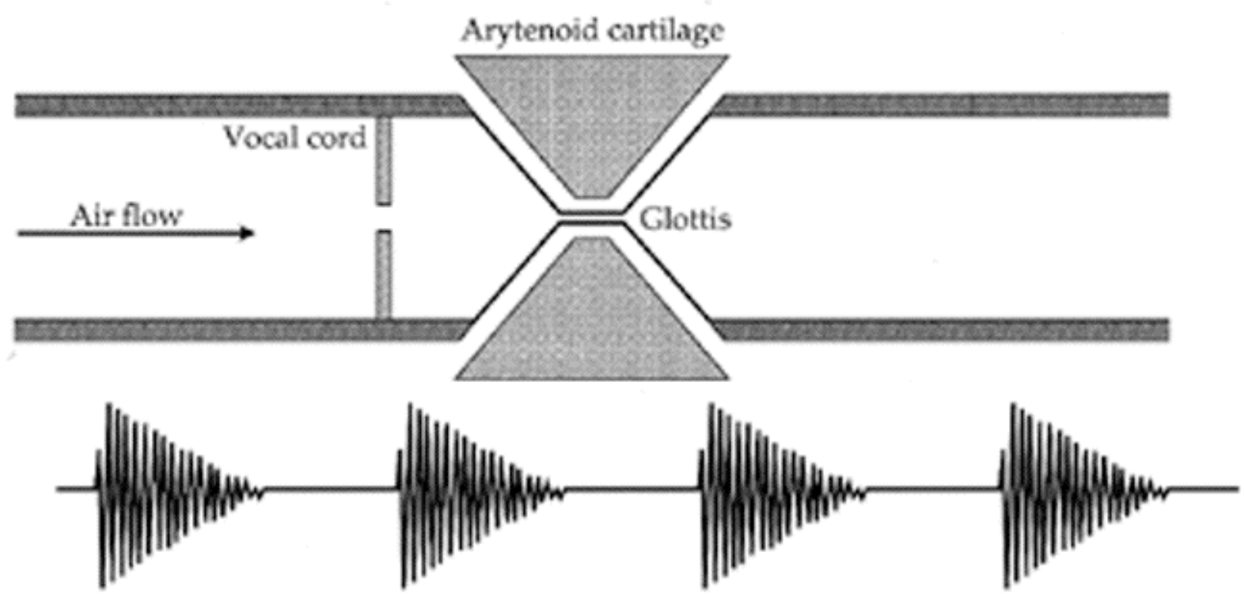
- Sound produced in larynx with twin vocal cords
- Cords forced into airflow during exhalation
- Puffs of air created when airflow pressure opens cords, then Bernoulli forces closes them
- Periodic but non-sinusoidal waveform

Resonant filtering in humans



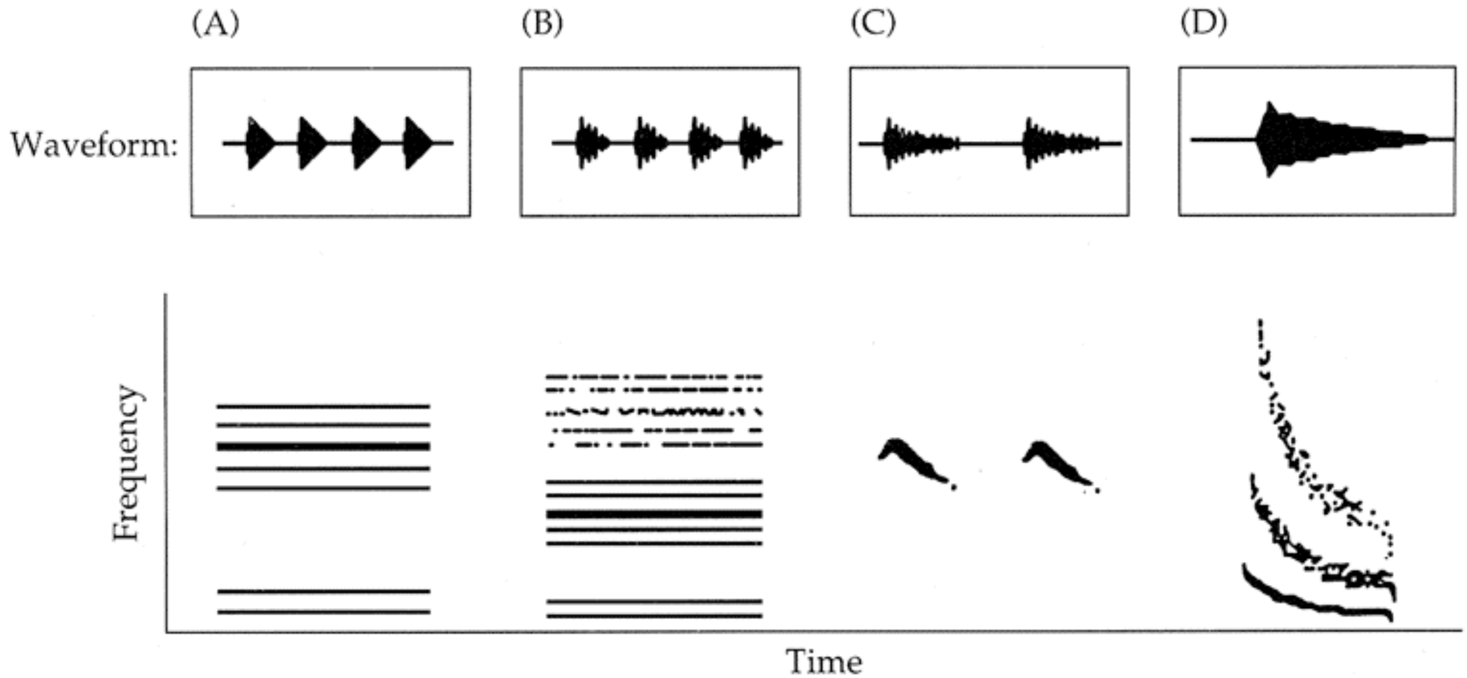
- Nasal-oral cavity creates resonant structure
- Resonant peaks are called 'formants'
- Different vowels are produced by changing resonance

Sound production in anurans (frogs and toads)



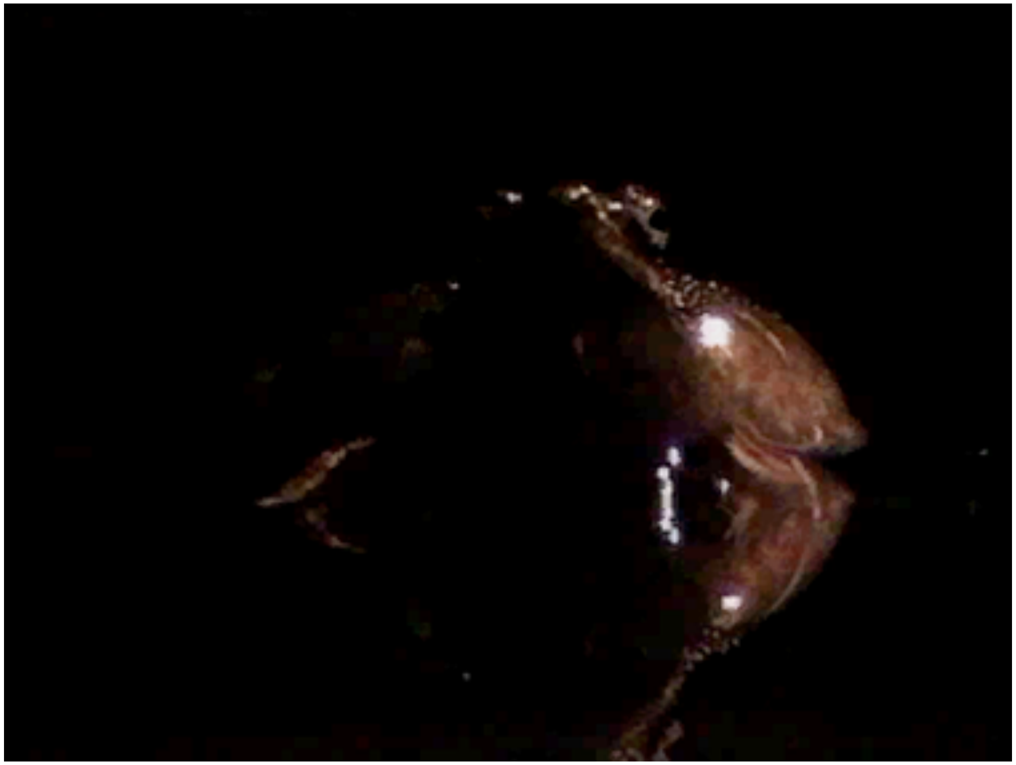
- Sound produced in larynx located at end of trachea
- Two sets of membranes-glottis to block airflow, and vocal cords to vibrate
- Non-sinusoidal periodic AM of carrier
- Air sacs recycle air and provide resonant structure

Examples of anuran calls

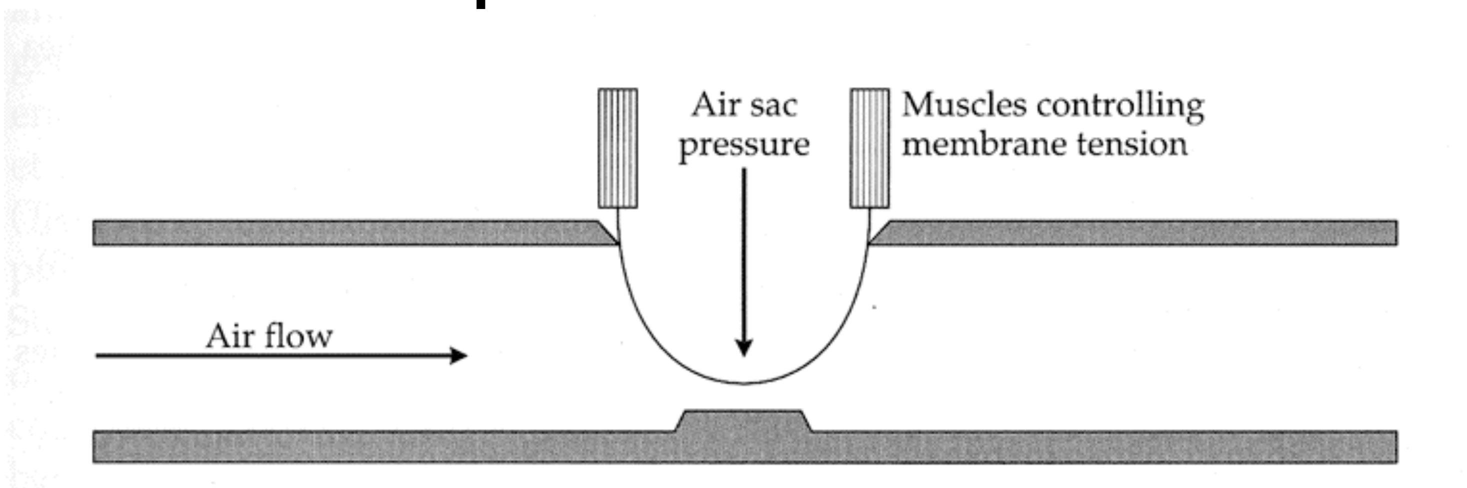


- Glottis modulates net flow and creates sidebands around fundamental
- Carrier may be sine wave, or nonsine, periodic wave
- FM created by increasing tension on vocal cords

Example of frog calling

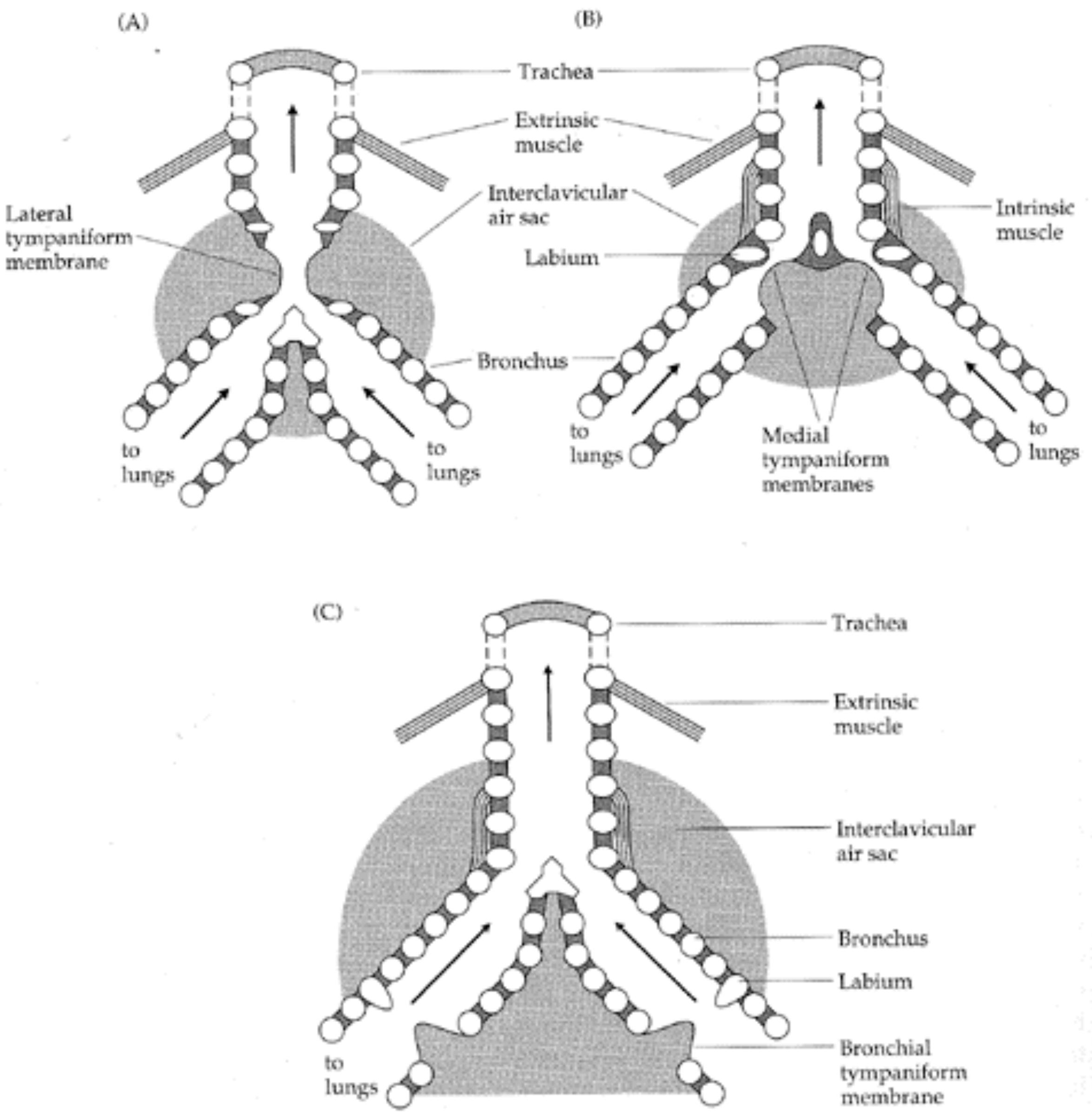


Sound production in birds



- Sound is produced in syrinx, located at juncture of bronchi
- Syrinx is surrounded by interclavicular air sac which forces membrane into air flow, causing vibration of sacs
- Membrane tension and air flow regulate sound frequency

Types of avian syrinxes



- Lateral tympaniform
  - parrots and chicken
- Medial tympaniform
  - Songbirds
  - More efficient
- Bronchial tympaniform
  - Penguins, cuckoos, and some nocturnal birds

Songbirds can produce two independent sounds

Curve-billed thrasher