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WHICH QS TO CHOOSE: QUESTIONS OF QUALITY IN BIOACOUSTICS?

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ABSTRACT

Two Q factors are in common use in bioacoustics: Q, the Quality Factor and $Q_{10\text{ dB}}$. The usage, definitions and separate application of these two terms can be traced back for more than 30 years. The two terms provide different measurements of the sharpness of tuning of e.g. acoustic systems. The two terms have been used in separate contexts and they measure different things. In view of the confusion that arises from the shared use of the letter Q, it is important that whichever Q is used is defined clearly in all publications.

Key words: Q; Quality factor; sharpness of tuning; $Q_{10\text{ dB}}$; resonance.

INTRODUCTION

The Quality Factor, Q, was used to describe properties of the resonators involved in cicada sound production in three recent papers on the mechanism of cicada sound production (Young and Bennet-Clark 1995, Bennet-Clark 1997, Bennet-Clark and Young 1998). In every case, our use of the term Q was queried by referees, one of whom suggested that there was confusion with the Q we used and “the more generally used $Q_{10\text{ dB}}$.”

Is $Q_{10\text{ dB}}$ more generally used—and if so by whom? What are the origins of this term? How does it relate to the Quality Factor, Q, that we used (Young and Bennet-Clark 1995) and that has been used since the 1930s by acousticians and radio engineers? This note attempts to answer these questions.

THE QUALITY FACTOR, Q

This factor, which describes the properties of damped resonant or

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oscillatory systems, is well defined in textbooks of electronics (e.g. Terman 1932, Harnwell, 1938, Langford-Smith 1953, Simpson 1974) or of vibrating mechanical systems (e.g. Morse 1948, Blitz 1964) or of bioacoustics (Sales and Pye 1974, Fletcher 1992). It is clear that Q was a well-established term nearly 70 years ago because Bayly (1931) considers it in the context of the selectivity of tuned circuits and Terman (1932) refers to the "... ratio frequently called Q ". I have failed to trace earlier uses of Q . Whatever the system, the Quality Factor Q is used in a consistent way and it allows the properties of one type of system to be equated readily to those of another. Furthermore, Q values found by one of the methods given below will be the same as and can be readily related to measurements obtained by another method.

The Quality Factor, Q , of a simple resonant or tuned system is found by several inter-related methods:

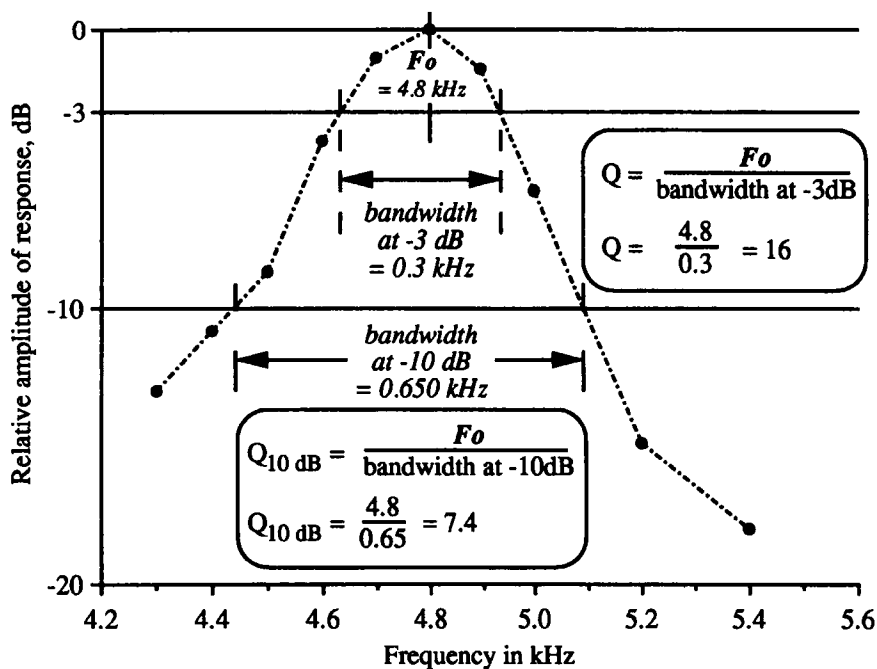


Figure 1. Graph of the relative amplitude of vibration of the harp area of the forewing of the cricket *Gryllus campestris* when driven by 145 dB sound at different frequencies. The frequency of maximal amplitude of vibration (or resonant frequency) is shown as F_o and the bandwidths at -3 dB and -10 dB are also shown. The quality factor Q is calculated from the -3 dB bandwidth using Method 1 (see upper inset) and $Q_{10\text{dB}}$ is calculated from the -10 dB bandwidth (see lower inset). The graph is plotted from data obtained from Nocke (1971) which have been converted to relative values in dB. Nocke (1971) also calculated the Q of the harp using Methods 2 and 3.

Method 1: Q is the resonant frequency divided by the bandwidth of the amplitude at 3 dB below the maximum amplitude of the response of the resonator when driven by a constant amplitude driving force. (−3dB is 1/2 peak power or $1/\sqrt{2}$ peak amplitude (Figure 1).)

Method 2: Q is the resonant frequency divided by the bandwidth between -45° and -135° relative to that of the driving waveform. (At

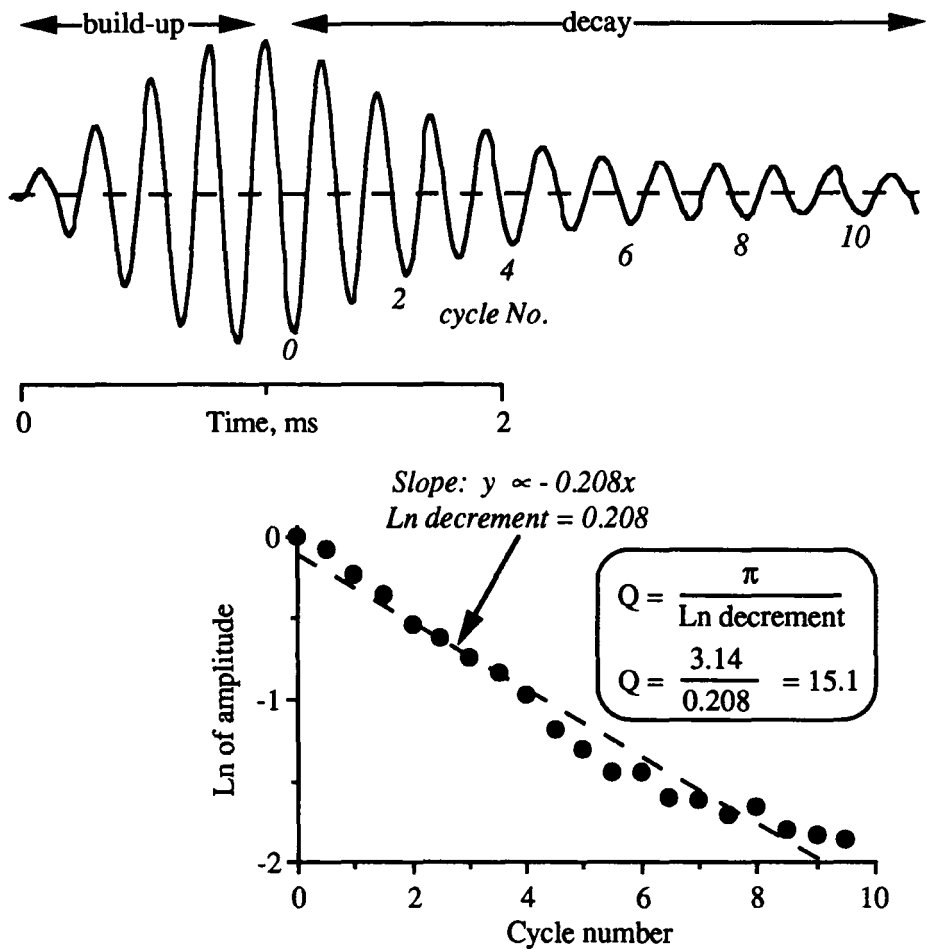


Figure 2. Upper: Oscillogram of a single pulse of the calling song of the cicada *Cyclochila australasiae*, to show the build-up and decay of the waveform. Successive cycles during the decay of the oscillation are numbered 0 to 10.

Lower: Graph of the natural logarithm (Ln) of the amplitude against cycle number of the decaying part of the song waveform, showing that the waveform decays in a nearly exponential manner. The slope of the Ln decrement is used to calculate the Q of the resonance using Method 3 (see inset). This method was used by Bennet-Clark and Young (1992).

the resonant frequency, the phase of the driven waveform relative to that of the driving waveform is -90° .)

Method 3: $Q = \pi/\ln$ decrement of the free decay of an oscillation after the driving waveform has ceased (Figure 2).

Method 4: Q is the ratio between the maximum amplitude of the response of a resonant system and the amplitude of the driving waveform when the system is driven at its resonant frequency. Examples are the ratio between the voltage across a parallel resonant circuit and the voltage of the driving waveform or the amplitude of vibration of a pendulum or tuning fork relative to that of the vibration that drives it.

These properties can be used to compare and to analyse the behaviour of different tuned systems. The Quality factor, Q , has been used in bioacoustics to describe elements of insect auditory systems. Michelsen (1971) and Stephen and Bennet-Clark (1982) used Q to describe the sharpness of tuning of the locust ear. In insect sound producing systems, Q has been used to describe the sharpness of tuning of different insect songs (Bennet-Clark 1971, 1989) and also to analyse the resonant system of the cricket fore-wing (Nocke 1971). More recently Q has been measured in the different elements in the transduction chain involved in sound production of cicadas (Young and Bennet-Clark 1995, Bennet-Clark 1997, Bennet-Clark and Young 1998).

Nocke, in his now-classic analysis of the resonant regions of the cricket forewing (1971) measured Q using all the methods listed above, obtaining closely similar results with all methods (Figure 1 shows one example).

Q provides a useful description of the sharpness of tuning of a simple resonant system that produces a symmetrical frequency-amplitude or frequency-power spectrum. Q is not strictly valid in the following cases although I have been guilty of using it as a convenient descriptive term (Bennet-Clark 1971, 1989).

Case 1. To describe the sharpness of the tuning curve of a sound signal composed of a series of transients that have been analysed by a Fast Fourier Transform where the bandwidth of the frequency energy spectrum has "sideband" components due to the brief duration of the signal.

Case 2. If the FFT filter is broader than the true bandwidth of the signal (or if the FFT analysis window is very brief), the -3 dB bandwidth will depend in part on the properties of the filter and will not give a valid measure of the Q of the signal.

Case 3. Where a series of different resonators or sound radiators or different pulses contribute in sequence to the overall frequency-energy spectrum of the song, as in the songs of grasshoppers, the songs of cicadas that produce a sequence of sound pulses of somewhat different

peak frequency as successive ribs of the tymbal click inwards (Fonseca 1991) or the song of *Ephippiger* which produces a train of transients as the plectrum of one wing impacts on successive teeth of the file of the contralateral wing (Pasquinely and Busnel 1952 reviewed in Dumortier 1963 or Bennet-Clark 1975).

Case 4. Where the properties of the sound radiator change during production of the sound pulse, modulating the frequency of the sound. This occurs e.g. in FM bat sonar signals (Sales and Pye 1974), the songs of many birds or in the calls of some crickets (Leroy 1966, Simmons and Ritchie 1996).

In all of these cases, although “Q” has been used to describe the frequency-energy spectrum of all or part of the signal, it would be safer to describe the signal as having (say) a frequency of maximum power of 10 kHz and a bandwidth at 3 dB below this peak of 1 kHz. But it is easy to understand that it is far quicker to describe this as “ $Q_{3dB} = 10$ ” so long as this is clearly stated and defined.

$Q_{10\text{ dB}}$

The term $Q_{10\text{ dB}}$ is widely used in mammalian auditory physiology to define the sharpness of tuning of elements of the auditory system. It is defined in Popper and Fay (1995, p. 196) as “BF divided by the bandwidth of the tuning curve 10 dB above threshold” where BF is the best frequency or frequency of maximum sensitivity of the element under investigation. The term occurs in earlier literature on bat hearing (e.g. Suga et al. 1976, Kössl and Vater 1990) where it is similarly defined. The earliest usage of $Q_{10\text{ dB}}$ that I have been able to find is by Suga (1964) with the same definition. Earlier papers that describe similar phenomena of tuning in the auditory system (Rose et al. 1959, Grinnell 1963) use other types of description of the sharpness of tuning, such as the bandwidth in octaves of the response at various levels above threshold. In Popper and Fay (1995), however, Grinnell and other contributors use $Q_{10\text{ dB}}$, suggesting that during the 30-plus year time span since its early usage the term had acquired general usage. Pickles (1982), in his definition of $Q_{10\text{ dB}}$, indicates that the term is used as an analogy of the Quality Factor used in physics and engineering and makes the point that the measurement of the -3 dB or half power criterion that defines the electrical Q is hard to measure in sensory physiology.

I have also encountered $Q_{10\text{ dB}}$ being used to describe the bandwidth of insect song where its definition is the inverse of that given above: $Q_{10\text{ dB}}$ is obtained from the frequency at which the sound pressure is maximum divided by the bandwidth of the frequency-energy spectrum at -10 dB below the maximum (Figure 1).

In discussion with various bioacousticians, I have been given two justifications for the -10 dB criterion that is used: first, a 10 dB difference, or ten-fold power ratio, can result in responses that are clearly above or below a threshold; second, even in a transient-rich sound signal such as that produced by a grasshopper, the -10 dB bandwidth encompasses most of the effective sound signal.

The use of $Q_{10\text{ dB}}$ has been criticised (Calford et al. 1983) because it offers very little information about the shape of the tuning curve. In particular, if a tuning curve is skewed or shows band-pass properties, this will be masked by the use of a term such as $Q_{10\text{ dB}}$ that implies a symmetrical Lorentzian tuning curve. $Q_{10\text{ dB}}$ can only be measured by the first of the methods (listed above) that can be used to measure the quality factor Q . At best, $Q_{10\text{ dB}}$ can only be regarded as a partial analogy of Q .

OTHER Q s

Other Q s, related to the bandwidth of the response of a receptor, but with different criteria, such as $Q_{40\text{ dB}}$, have been used but are fairly rare; their use seems to be confined to auditory physiology. Vertebrate auditory physiology seems to be an area in which comparisons between units and levels encourages the use of special terms. One example of this is Q_{IBP} , which Suga (1994) has introduced, where IBP is the Information Bearing Parameter and the Q describes the *width at 50%* (my italics) of the maximal response. In this case, the dimensions of the IBP might be velocity (as is considered by Suga) but presumably might also be weight or light intensity. The use of the letter " Q " here represents a less obvious metaphor for the Q used in physics and engineering.

In physical acoustics, a very different type of Q has also been used: Beranek (1954: p 109) describes $Q(f)$ as the Directivity Factor for a sound source, such as a loudspeaker, which is defined as "the ratio of intensity on a designated axis of a sound radiator at a stated distance (r) to the intensity that would be produced at the same position by a point source if it were radiating the same total acoustic power as the radiator."

$Q(f)$ could reasonably have been used to describe the beamed sound emission by rhinolophid bats (Schnitzler 1968) or by the singing burrow of mole crickets (Bennet-Clark 1970, 1989) but mercifully this stratum of confusion was not added in either case.

SUGGESTIONS FOR USAGE

Both the older, more widely-used Q , the Quality Factor, and the more

recent strictly biological $Q_{10\text{ dB}}$ occur commonly in biological literature. It seems likely that both terms will continue to be used, even though the letter Q in $Q_{10\text{ dB}}$ appears to have been hijacked by sensory physiologists and then by biologists from a well-established physical measurement.

The purpose of this note is to highlight the differences between the two usages. The best way forward for future publications seems to be to define whichever Q is used at first usage or under "Methods" or "Terminology" with a reference to its source and the method by which it has been calculated.

$Q_{10\text{ dB}}$ should be defined as "best frequency divided by the bandwidth of the tuning curve 10 dB above threshold" or "peak frequency divided by the bandwidth at 10 dB below peak." Suga (1964), Kossi and Vater (1990) or Popper and Fay (1995) provide the precedents for the use of the term. To avoid confusion, $Q_{10\text{ dB}}$ should always be termed " $Q_{10\text{ dB}}$ ", be always written thus throughout the text and on no account be merely termed " Q " or termed "the Quality Factor."

When Q is only being used to describe the relative bandwidth of the response of a resonant system (as in the example shown in Figure 1, as found by Method 1), it may be helpful (though it should not be necessary) to describe it as $Q_{3\text{ dB}}$. The Quality Factor, Q , because it can be defined in a variety of ways, some of which are listed above, may usefully be introduced by a reference to e.g. Morse (1948), Sales and Pye (1974) or Fletcher (1992), all of whom describe and define Q in similar terms. At first usage, it is important to describe it as " Q , the Quality Factor" though subsequently it can merely be termed " Q ".

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REFERENCES

- Bayly, B. de F. (1931). Selectivity, a simplified mathematical treatment. *Proc. Inst. Radio Enginners.*, **19**, 873-881.

- Bennet-Clark, H.C. (1970). The mechanism and efficiency of sound production in mole crickets. *J. exp. Biol.*, **52**, 619-652.
- Bennet-Clark, H.C. (1971). Acoustics of insect song. *Nature*, **234**, 255-259.
- Bennet-Clark, H.C. (1975). Sound production in insects. *Sci. Progr., Oxf.*, **62**, 263-283.
- Bennet-Clark, H.C. (1989). Songs and the physics of sound production. In *Cricket Behavior and Neurobiology*. (F. Huber, T. E. Moore & W. Loher, eds.), Cornell University Press; Ithaca and London, pp. 227-261.
- Bennet-Clark, H.C. (1997). Tymbal mechanics and the control of song frequency in the cicada *Cyclochila australasiae*. *J. Exp. Biol.*, **200**, 1681-1694.
- Bennet-Clark, H.C. and Young, D. (1998). Sound radiation by the bladder cicada *Cystosoma saundersii*. *J. exp. Biol.*, **201**, 701-715.
- Beranek, L. (1954). *Acoustics*. McGraw-Hill; New York.
- Blitz, J. (1964). *Elements of Acoustics*. Butterworths; London.
- Calford, M.B., Webster, W.R. and Semple, M.M. (1983). Measurement of frequency selectivity of single neurons in the central auditory pathway. *Hearing Research*, **11**, 395-401.
- Dumortier, B. (1963). The physical characteristics of sound emissions in Arthropoda. In *Acoustic Behaviour of Animals* (R.G. Busnel, ed.). Elsevier; Amsterdam, pp. 346-373.
- Fletcher, N.H. (1992). *Acoustic Systems in Biology*. Oxford University Press; Oxford.
- Fonseca, P.J. (1991). Characteristics of the acoustic signals in nine species of cicadas (Homoptera, Cicadidae). *Bioacoustics*, **3**, 173-182.
- Grinnell, A.D. (1963). The neurophysiology of audition in bats: intensity and frequency parameters. *J. Physiol.*, **167**, 38-66.
- Harnwell, G.P. (1938). *Principles of Electricity and Electromagnetism*. McGraw-Hill; New York.
- Kössl, M. and Vater, M. (1990). Resonance phenomena in the cochlea of the mustache bat and their contribution to neuronal response characteristics in the cochlear nucleus. *J. comp. Physiol.*, **166**, 711-720.
- Langford-Smith, F. (1953). *Radio Designer's Handbook*. Iliffe and Sons; London.
- Leroy, Y. (1966). Signaux acoustiques, comportement et systématique de quelques espèces de Gryllidae (Orthoptères, Ensifères). *Bull. Biol. Fr. Belg.*, **100**, 1-134.
- Michelsen, A. (1971). The physiology of the locust ear. II Frequency discrimination based upon resonances in the tympanum. *Z. vergl. Physiol.*, **71**, 63-101.
- Morse, P.M. (1948). *Vibration and Sound*. McGraw-Hill; New York.
- Nocke, H. (1971). Biophysik der Schallerzeugung durch die Vorderflügel der Grillen. *Z. vergl. Physiol.*, **74**, 272-314.
- Pasquinelli, F. and Busnel, M.-C. (1955). Études préliminaires sur les productions des sons par les orthoptères. *Annales des Épiphyties* (Fasc special de 1954), 145-153.
- Pickles, J.O. (1982). *An Introduction to the Physiology of Hearing*. Academic Press; London.
- Popper, A.N. and Fay, R.R. (1995). *Hearing by Bats*. Springer-Verlag; New York.
- Rose, J.E., Galambos, R. and Hughes, J.R. (1959). Microelectrode studies of the cochlear nuclei of the cat. *Bull. Johns Hopkins Hosp.*, **104**, 211-251.
- Sales, G.D. and Pye, J.D. (1974). *Ultrasonic Communication in Animals*. Chapman and Hall; London.
- Schnitzler, H.-U. (1968). Die Ultraschall-Ortungslaute der Hufeisen-Fledermäuse (Chiroptera-Rhinolophidae) in verschiedenen Orientierungssituationen. *Z. vergl. Physiol.*, **57**, 376-408.
- Simmons, L.W. and Ritchie, M.G. (1996). Symmetry in the songs of crickets. *Proceedings of the Royal Society of London, Series B*, **263**, 305-311.
- Simpson, R.F. (1974). *Introductory Electronics for Scientists and Engineers*. (2nd ed.). Allyn and Bacon; Boston.
- Stephen, R.O. and Bennet-Clark, H.C. (1982). The anatomical and mechanical basis of stimulation and frequency analysis in the locust ear. *J. Exp. Biol.*, **99**, 279-314.

- Suga, N. (1964). Single unit activity in cochlear nucleus and in inferior colliculus of echo-locating bats. *J. Physiol.*, **172**, 449-474.
- Suga, N. (1994). Multi-function theory for cortical processing of auditory information: implications of single unit and lesion data for future research. *J. Comp. Physiol. A*, **175**, 135-144.
- Suga, N., Neuweiler, G. and Möller, J. (1976). Peripheral auditory tuning for fine frequency analysis by the CF-FM bat, *Rhinolophus ferrumequinum*. *J. Comp. Physiol.*, **106**, 111-125.
- Terman, F.E. (1932). *Radio Engineering*. New York: McGraw-Hill.
- Young, D. and Bennet-Clark, H.C. (1995). The role of the tymbal in cicada sound production. *J. Exp. Biol.*, **198**, 1001-1019.

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