
# Overview of H. Fletcher and W. A. Munson’s 1933 paper on “Loudness, Its Definition, Measurement and Calculation”

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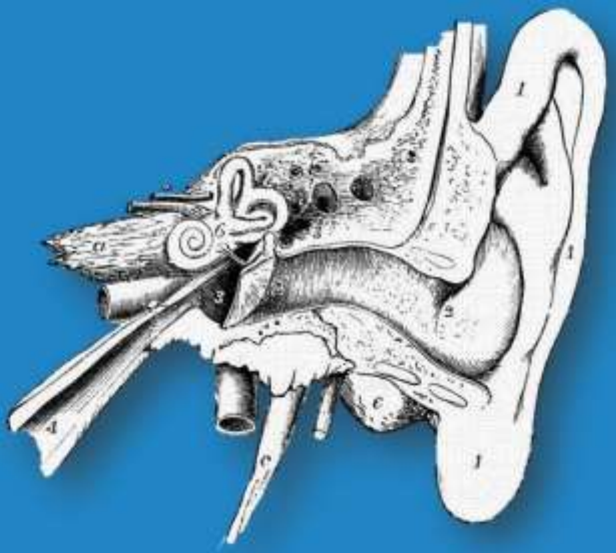
# 1.

# Who were they?

Harvey Fletcher

Wilden A. Munson



# The Big Question

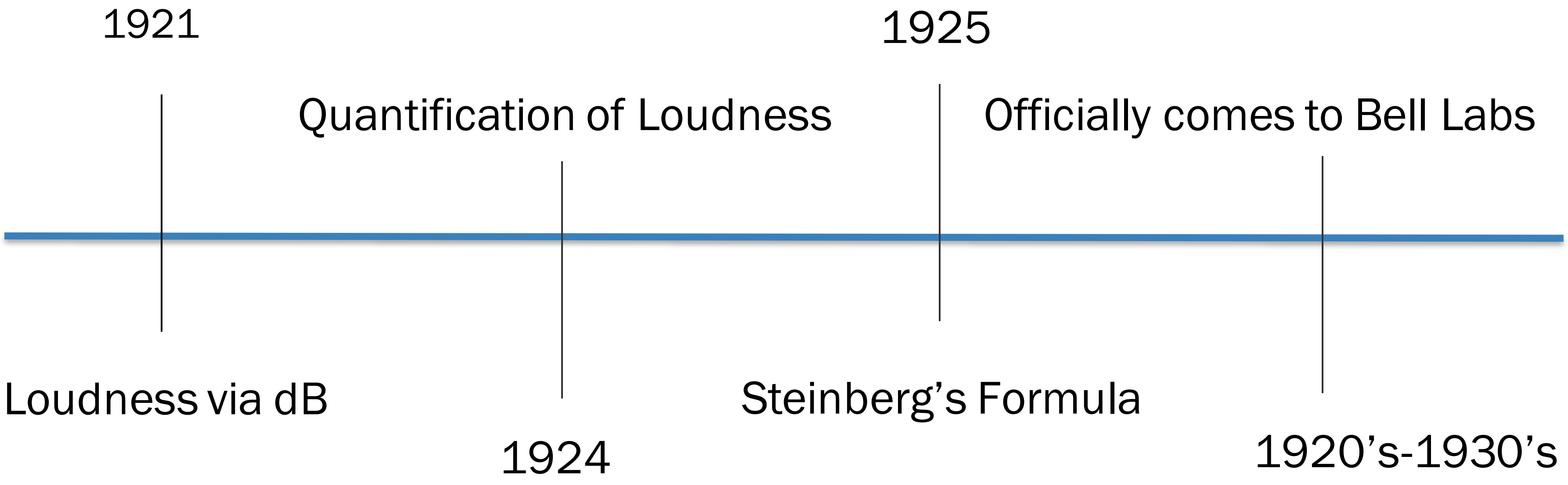
Anatomy, Physiology and Loudness

“

*Fletcher recognized that to improve the quality and efficiency of speech communication systems, one must know how the ultimate receiver, the human auditory system, processes and receives sound.*

*- Rhona P. Hellman, ASA May 1995*

# Previous Work and Fletcher's Involvement



# 2.

# Empirical Theory & Assumptions Made

# Fletcher and Munson wanted one equation to relate frequency, intensity, and physiology

**Assumptions**

- Auditory Response
- Basilar Membrane
- Psychoacoustics

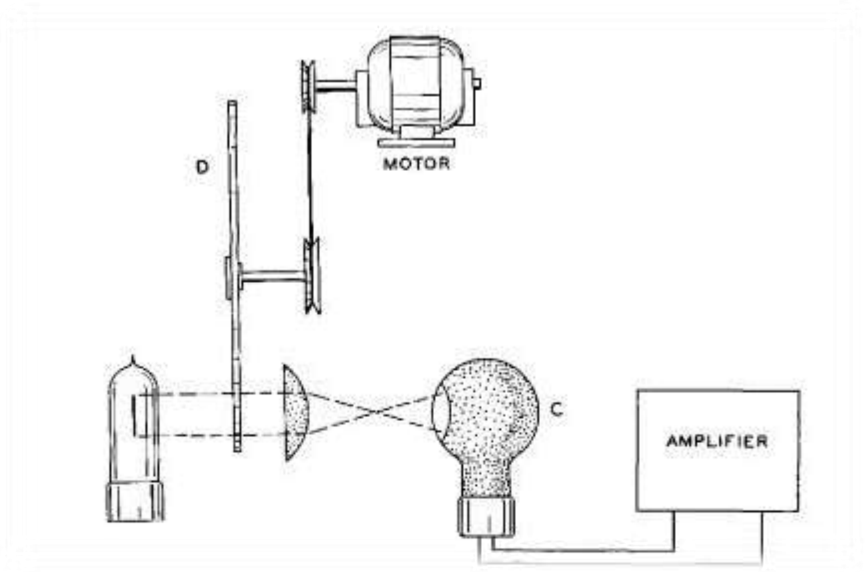
**Factors & Variants**

- Beating
- Bi vs. Monoaural
- Varying Pitches

**(Un)Steady Tones**

- Pure vs. complex
- Noise
- Music and Speech

# The apparatus—the complex tone generator—was developed specifically for this task by E.C. Wente and replaced the vacuum tube oscillators that were used in the initial two-tone comparisons.



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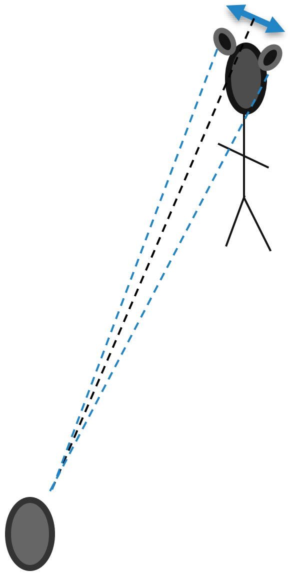
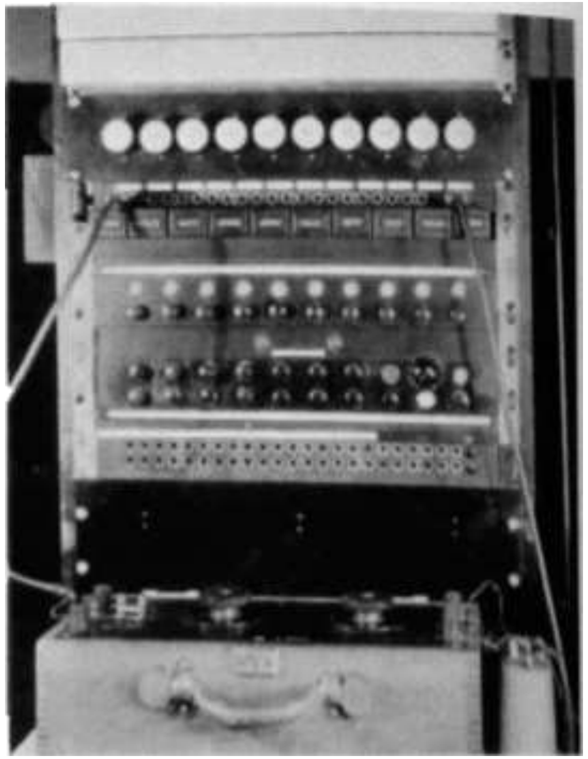
# 3.

# The idea in practice

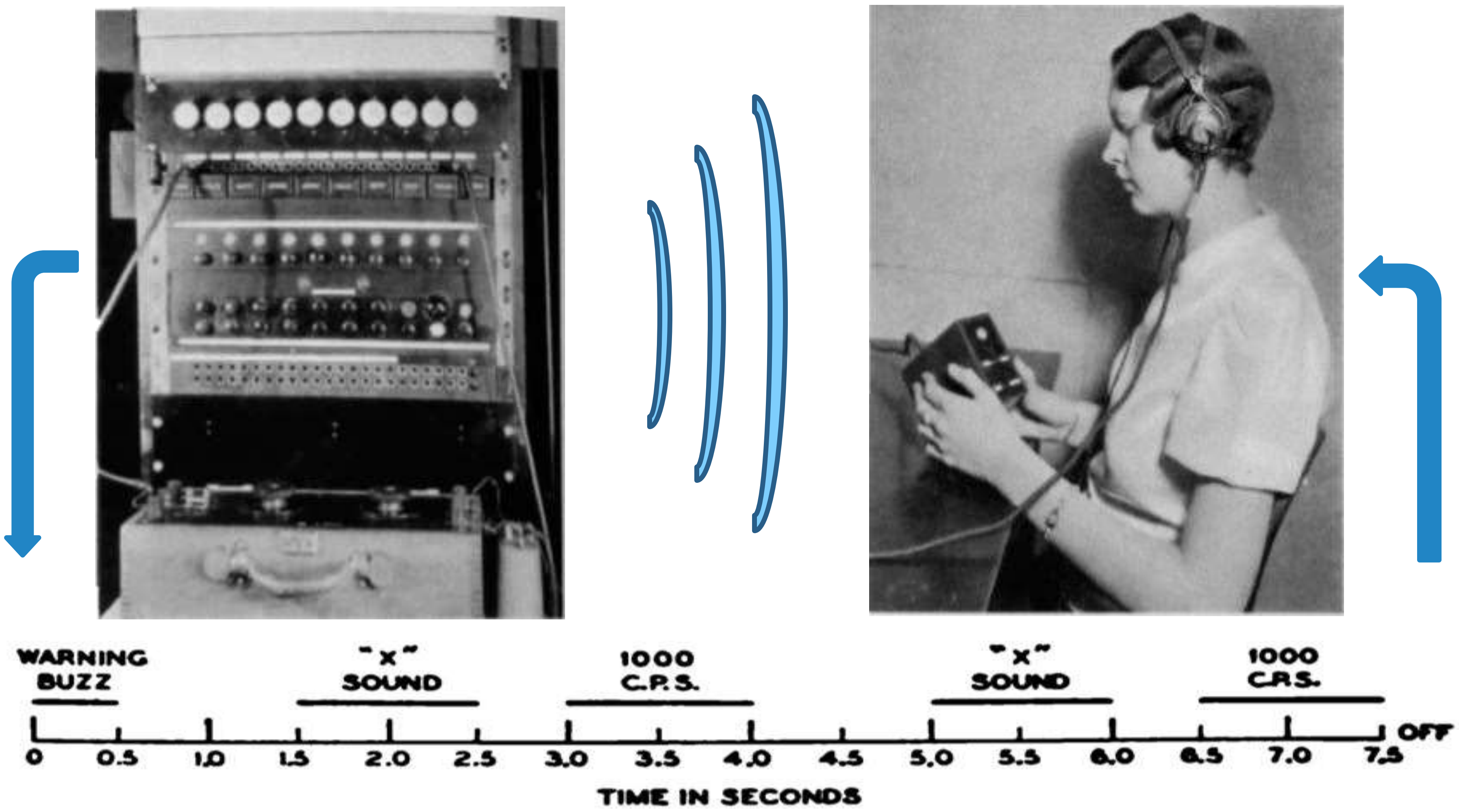
For initial set up of the population, the “average listener” was determined by having the test subjects listen to a source in the acoustic farfield.



“The apparatus at the [left] automatically presents a sound to be measured and a thousand-[hertz] comparison tone…”



# “…the observer records her judgement as to which of the two sounds is the louder”



*Listen to the following tones. On the second go 'round, raise your hand if you think they are equally loud*

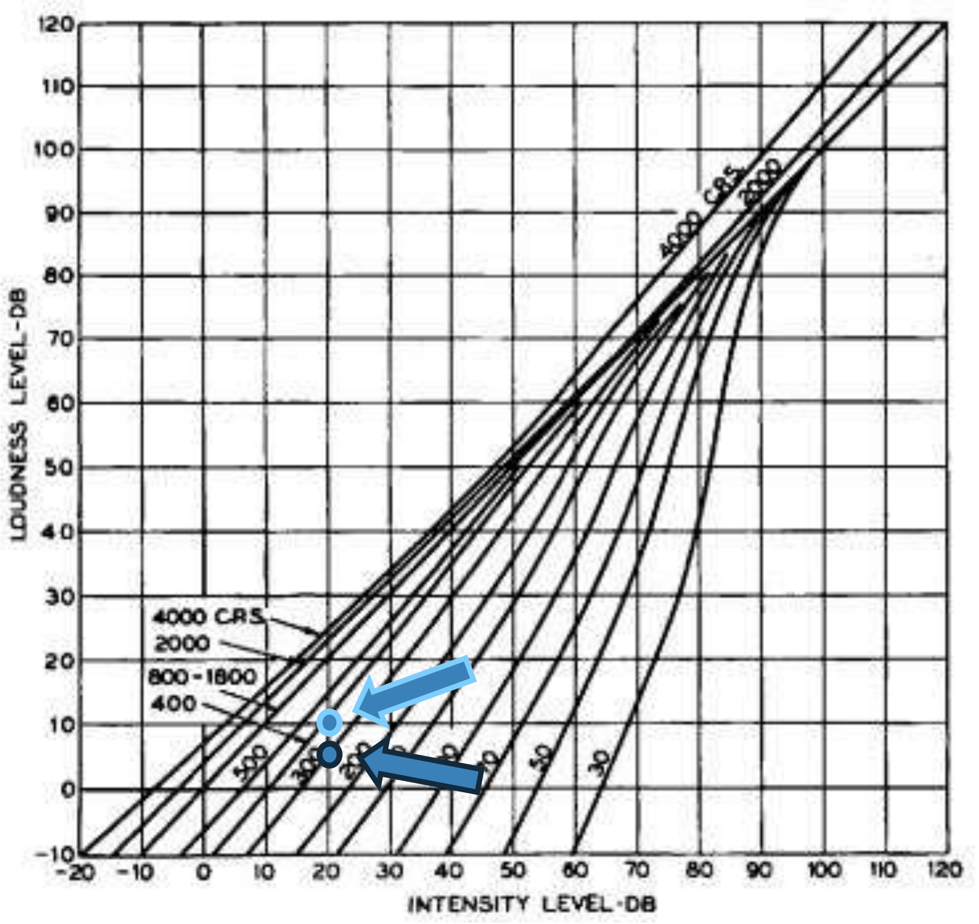
# 4.

# Results and Concerns

# Fletcher and Munson succeeded in developing their unifying equation

$$G(L) = \sum_{k=1}^{k=n} b_k G(L_k),$$

# Let's see an example: Consider two tones, one at 300 Hz and one at 400 Hz, each with intensity of 20 dB




These frequencies and intensities give a loudness level, *L,* of 5 (dark blue) and 10 (light blue) dB respectively

# We can then use these loudness levels to find the loudness of the individual pure tones

| L | 0 | 1 |
|---|---|---|
| −10 | 0.015 | 0.025 |
| 0 | 1.00 | 1.40 |
| 10 | 13.9 | 17.2 |
| 20 | 97.5 | 113 |
| 30 | 360 | 405 |
| 40 | 975 | 1060 |
| 50 | 2200 | 2350 |
| 60 | 4350 | 4640 |
| 70 | 7950 | 8510 |
| 80 | 17100 | 18400 |
| 90 | 38000 | 41500 |
| 100 | 88000 | 97000 |
| 110 | 215000 | 235000 |
| 120 | 556000 | 609000 |

These frequencies and intensities give a loudness level, *L*, of 5 (dark blue) and 10 (light blue) dB respectively

And the Loudness Levels produce G(L1) = 4.43 Sones, and G(L2) = 13.9 Sones

# We must then relate the intensity level and the frequency by a curve fitting value, *Q*

Values of $Q(X)$

| X | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 0 | 5.00 | 4.88 | 4.76 | 4.64 | 4.53 | 4.41 |
| 10 | 3.82 | 3.70 | 3.58 | 3.46 | 3.35 | 3.33 |
| 20 | 2.64 | 2.52 | 2.40 | 2.28 | 2.16 | 2.05 |
| 30 | 1.60 | 1.53 | 1.47 | 1.40 | 1.35 | 1.30 |
| 40 | 1.09 | 1.06 | 1.03 | 1.01 | 0.99 | 0.97 |
| 50 | 0.90 | 0.90 | 0.89 | 0.89 | 0.88 | 0.88 |
| 60 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| 70 | 0.90 | 0.91 | 0.92 | 0.93 | 0.94 | 0.96 |
| 80 | 1.04 | 1.06 | 1.08 | 1.10 | 1.13 | 1.15 |
| 90 | 1.27 | 1.29 | 1.31 | 1.34 | 1.36 | 1.39 |
| 100 | 1.51 | 1.53 | 1.55 | 1.58 | 1.60 | 1.62 |

Note: $X = \beta_h + 30 \log f_h - 95$.

These frequencies and intensities give a loudness level, *L*, of 5 (dark blue) and 10 (light blue) dB respectively

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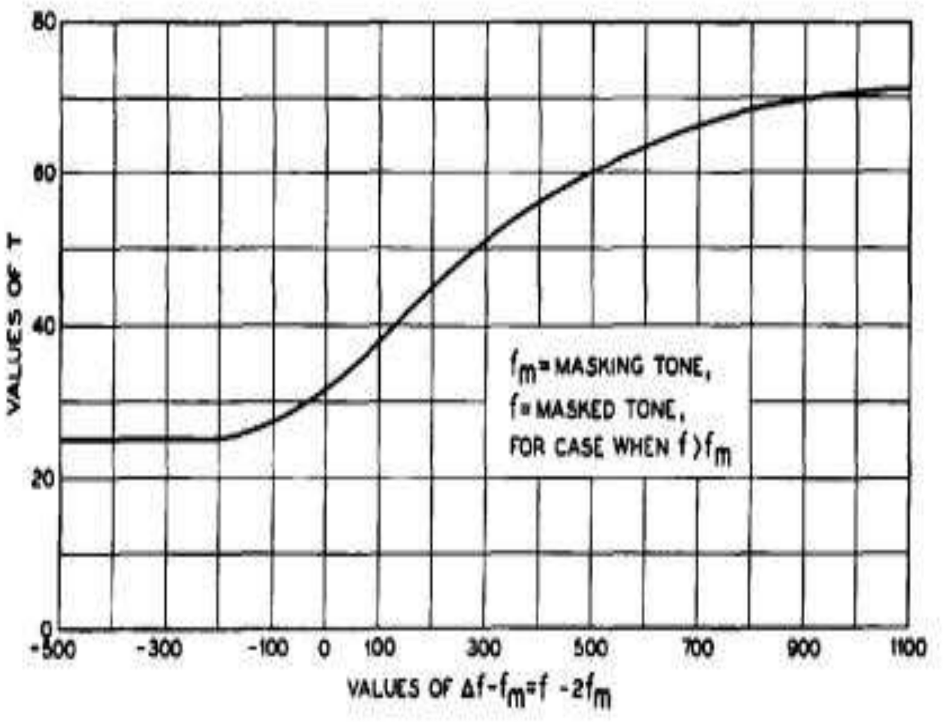
We can find the values of Q for each tone to be -0.7 and 3.1.

# Considering the minutiae of the complex tone in question, one may consider other factors, such as masking



# Finally, we can use all of these values to compute the fractional reduction in loudness, *b*, for each term

$$b_k = [(250 + f_k - f_m)/1000]10^{(L_k - L_m)/T}Q(\beta_k + 30 \log f_k - 95) \quad (21)$$

where

$f_k$ is the frequency of the component expressed in cycles per second,

$f_m$ is the frequency of the masking component expressed in cycles per second,

$L_k$ is the loudness level of the $k$th component when sounding alone,

$L_m$ is the loudness level of the masking tone,

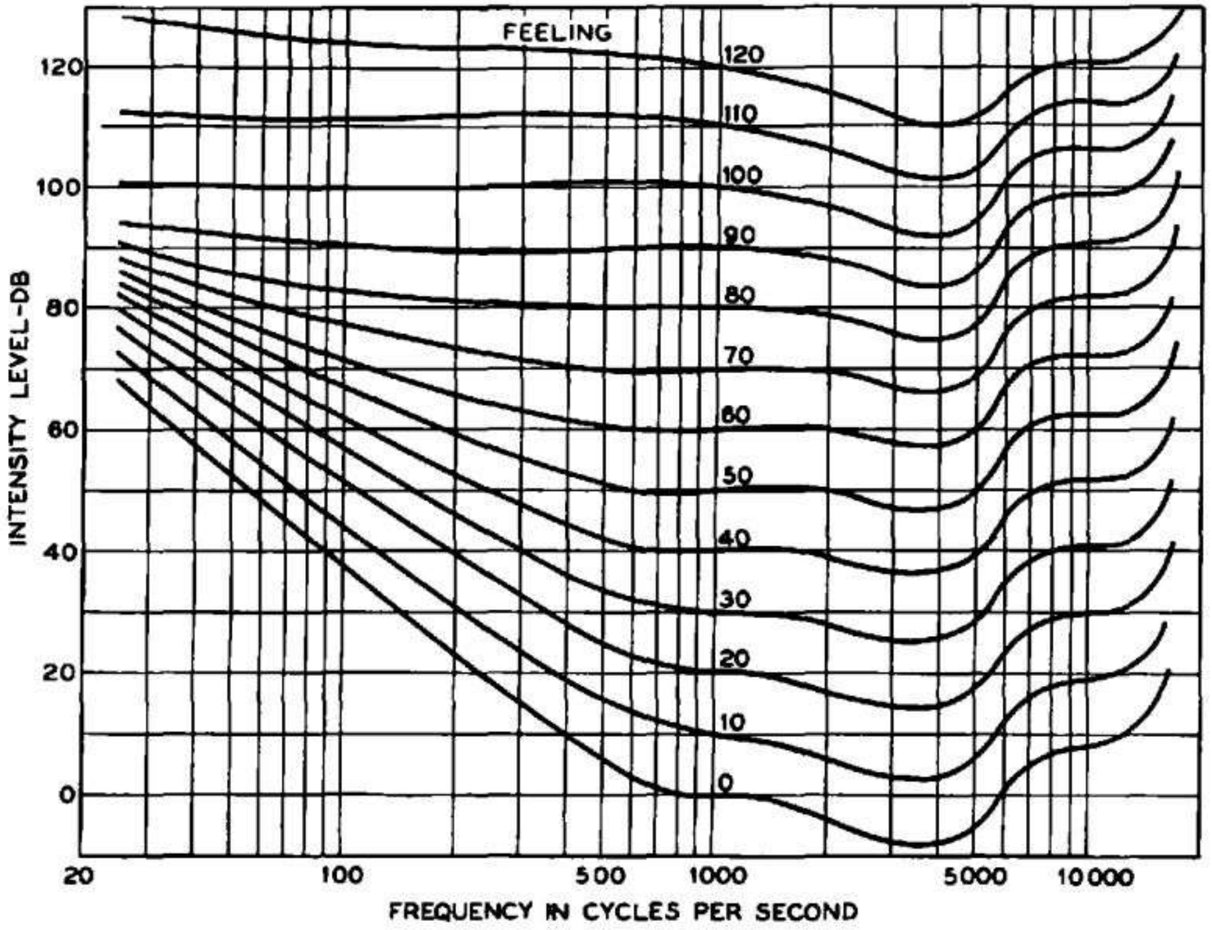
$Q$ is a function depending upon the intensity level $\beta_k$ and the frequency $f_k$ of each component and is given in Table VI as a function of $x = \beta_k + 30 \log f_k - 95$,

$T$ is the masking and is given by the curve of Fig. 12.

This is then all wrapped up in our one unifying equation to produce the loudness of a steady, complex tone

$$G(L) = \sum_{k=1}^{k=n} b_k G(L_k),$$

# No result stands out more than the Equal-Loudness Contours



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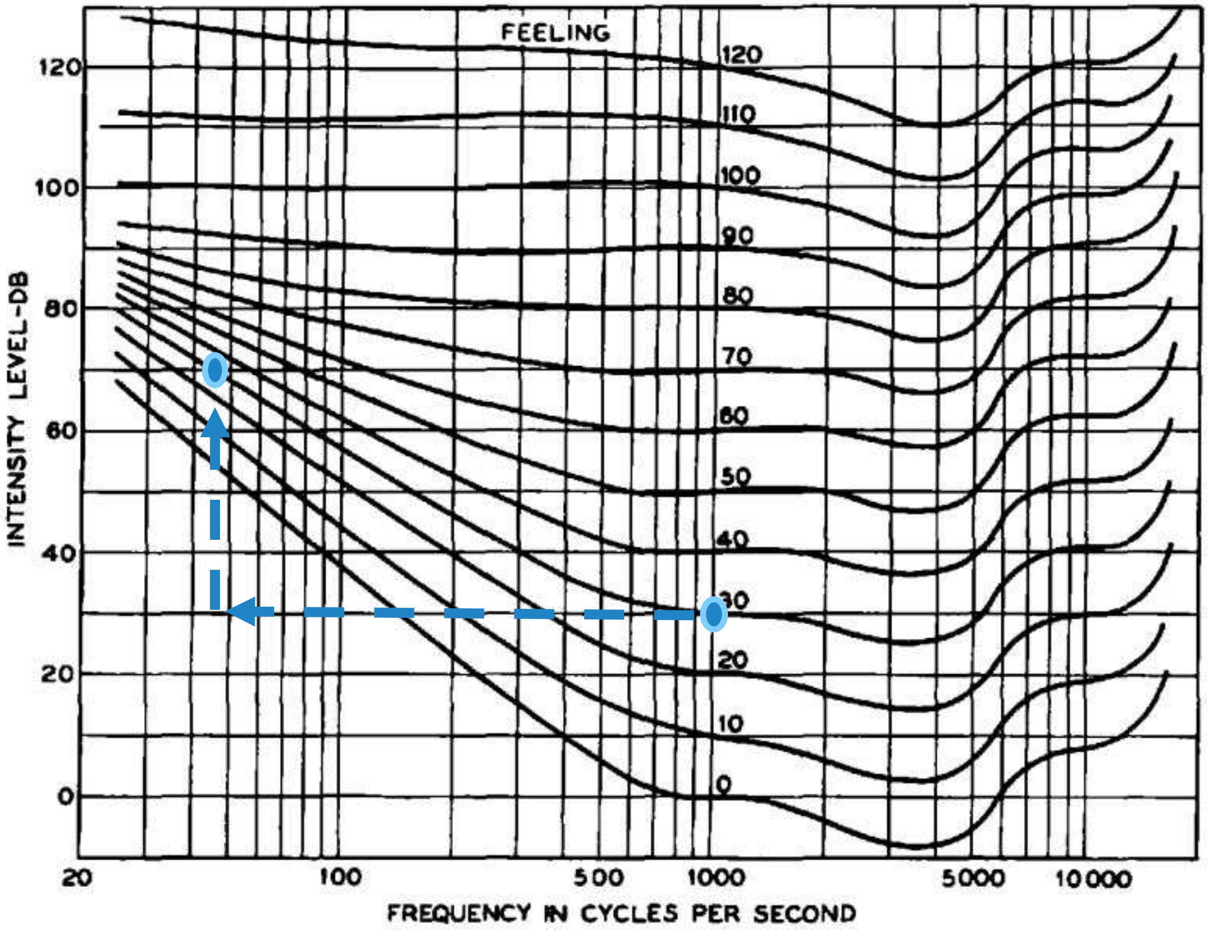


Let our reference tone be 1000 Hz at 30 dB.

Let there be another tone of 45 Hz.

At what level must our 45 Hz tone be to be of equal loudness?

# Acknowledgement of error and reason for concern

Fletcher and Munson expressed doubt in equation (21), the fractional reduction in loudness

Energy density and closeness of tones may require a more robust treatment

Assumptions were made in terms of calibration between devices and different data sets.

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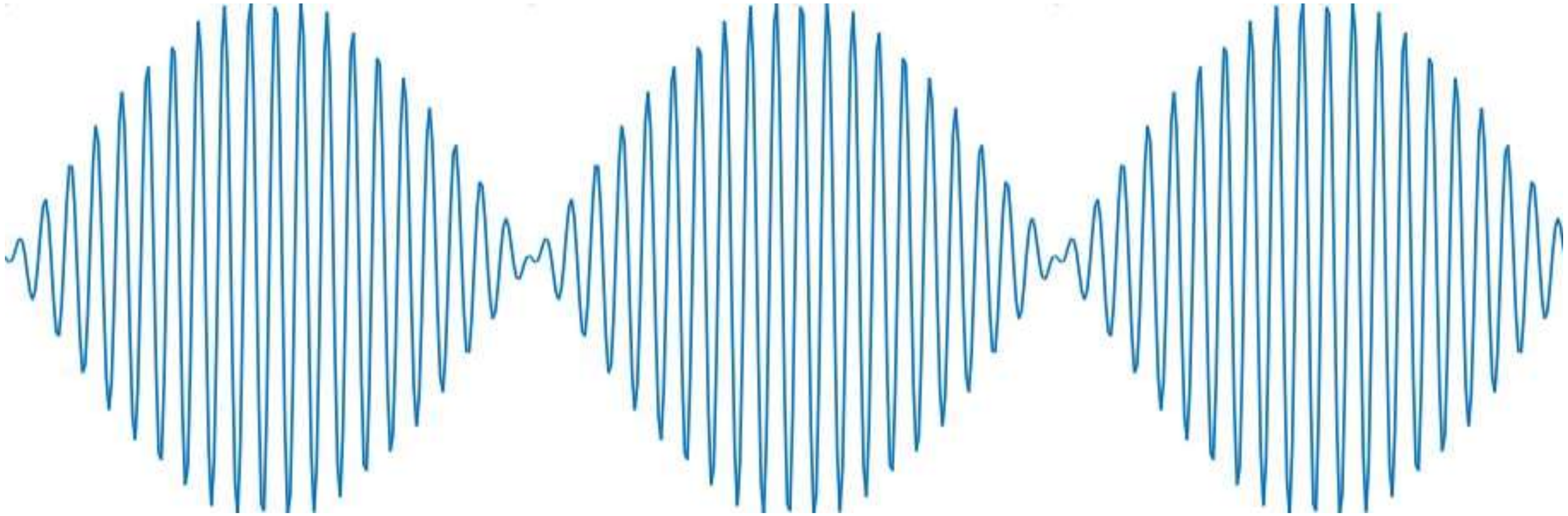
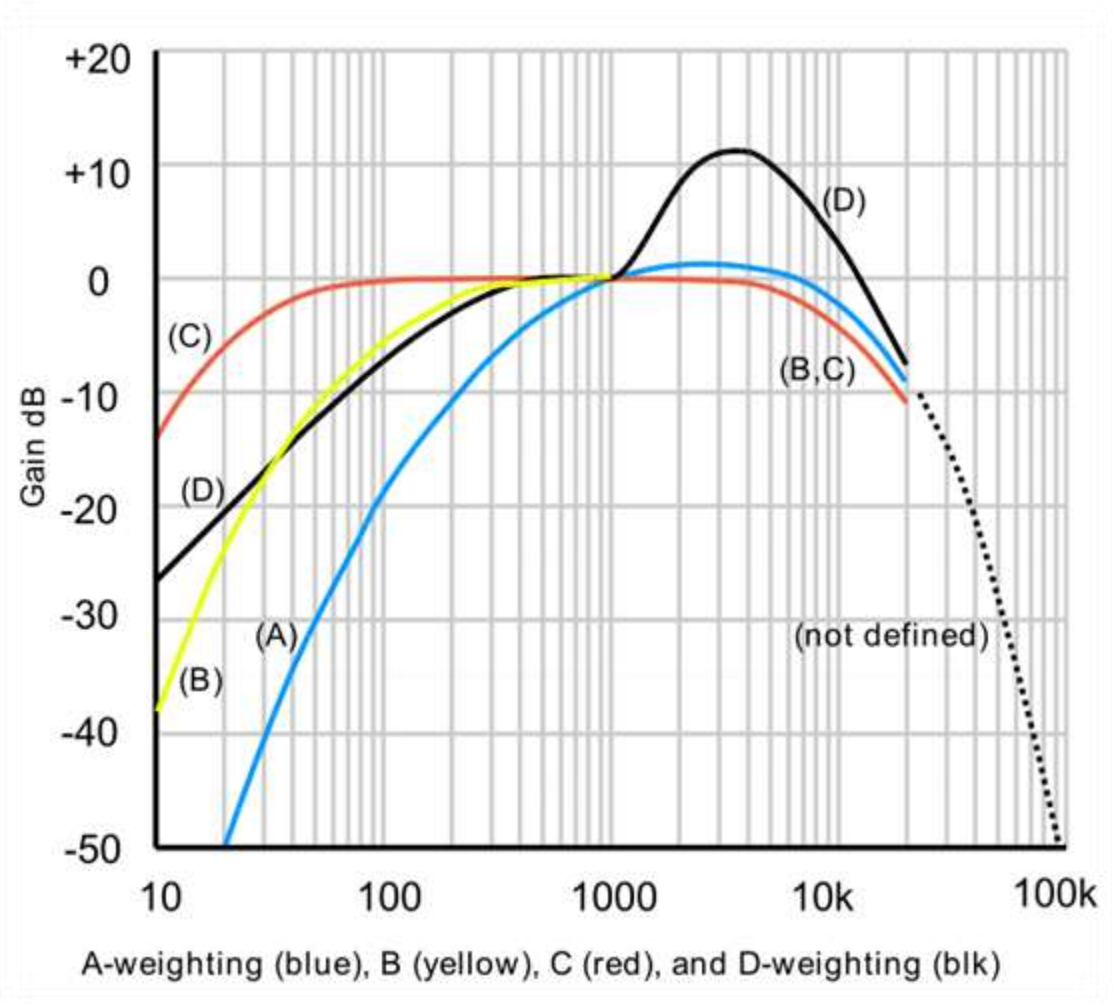


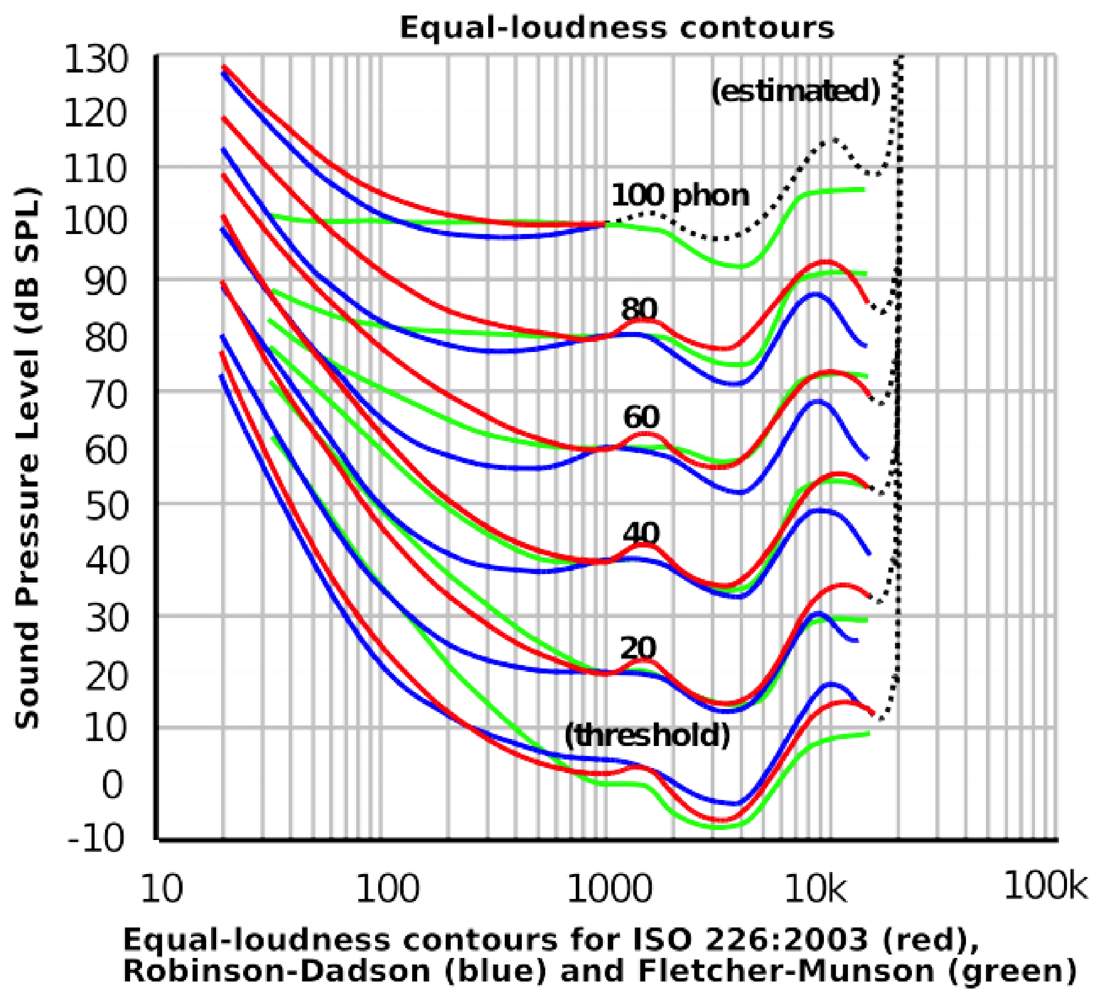
# 5.

# What happened next?

# This had an almost immediate results (1936) for the field of acoustics



# Reevaluation and studies into non-steady complex tones



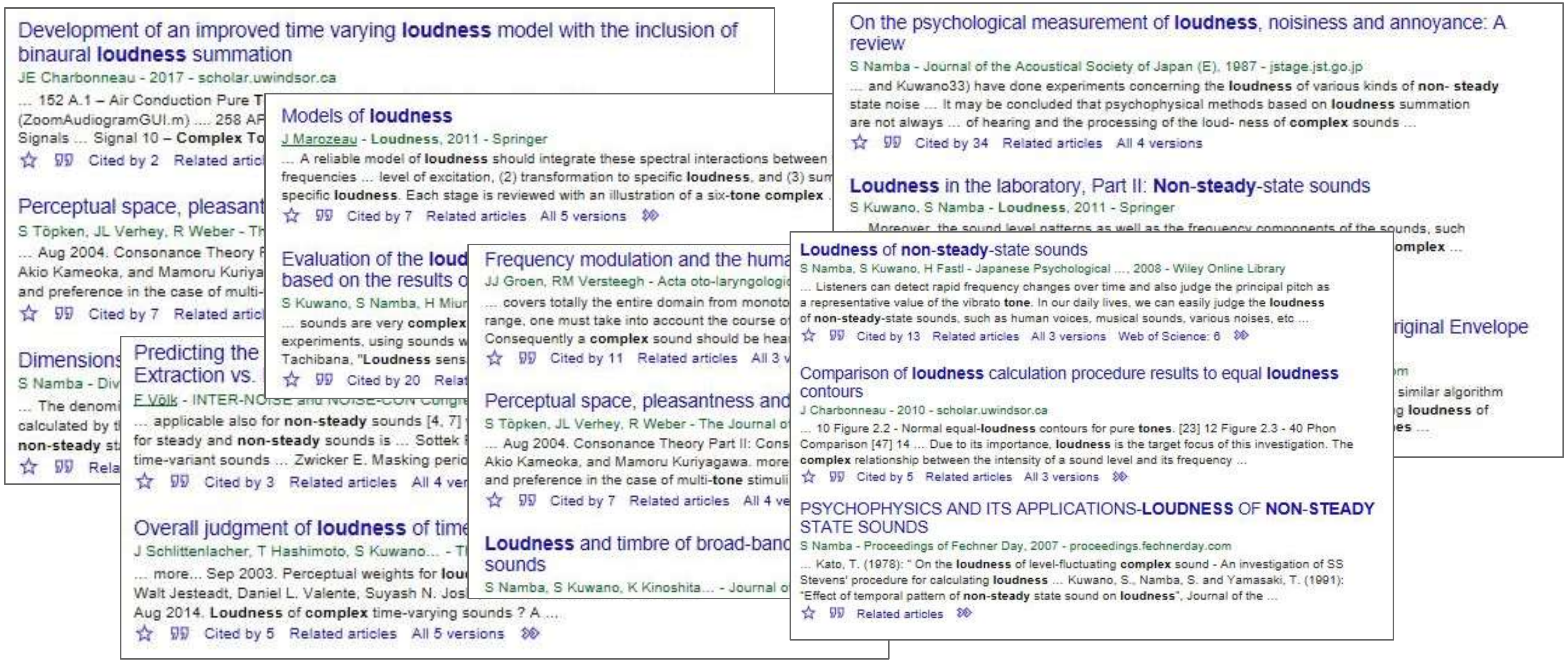

<u>Potentials for Discrepancy?</u>

- The equipment used was not properly calibrated.
- The criteria used for judging equal loudness at different frequencies had differed.
- Subjects were not properly rested, were exposed to loud noise in traveling to the tests

# Reevaluation and studies into non-steady complex tones

A study of the loudness of complex sounds which are not steady, such as speech and sounds of varying duration, is in progress at the present time and the results will be reported in a second paper on this subject.

# Reevaluation and studies into non-steady complex tones



# The Recapitulation

- Developed a method for determining loudness of complex tones
- However, these tones must be steady
- Has had immense impacts on noise control and acoustics
- Still today, over 85 years later, their results show applicability

# Thank You!

## Any questions?

# Bibliography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**Fletcher, H. and Munson, W.A.,"Loudness, Its Definition, Measurement and Calculation," J. Acoust. Soc. of Am., Vol. 5(2), pp. 81-108, 1933.**

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