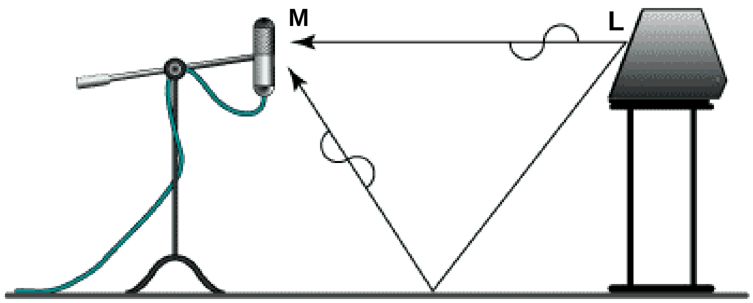
## COMB FILTER EFFECT

The Comb Filter Effect is due to phase and occurs when a signal is mixed with a delayed version of itself. This can be achieved in many different ways. Here are two common examples.

### 1. There are two acoustic paths to the microphone

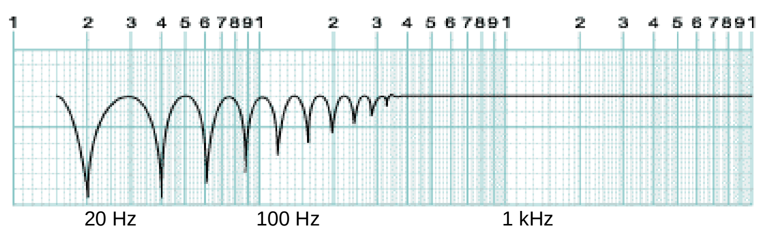
The diagram below shows an acoustic signal being emitted from a loudspeaker, L. One version of the signal arrives at the microphone, M, via the straight-line, shortest, quickest route; and the delayed version arrives via reflection off the floor. (The diagram is assuming that there are no other reflections of any consequence.)




The delayed signal will have some phase relationship with the direct signal. Consider the two extreme possibilities:

i. The delayed signal is one or more whole cycles out of phase with the direct signal. In this case, they are back In Phase. When the two versions of the signal combine at the microphone, they combine Constructively giving a strong signal.

ii. The delayed signal is half, or one and a half, or two and a half, etc, cycles out of phase with the direct signal. In this case they are in Anti-Phase. When the two versions of the signal combine at the microphone, they combine Destructively giving a weak signal.



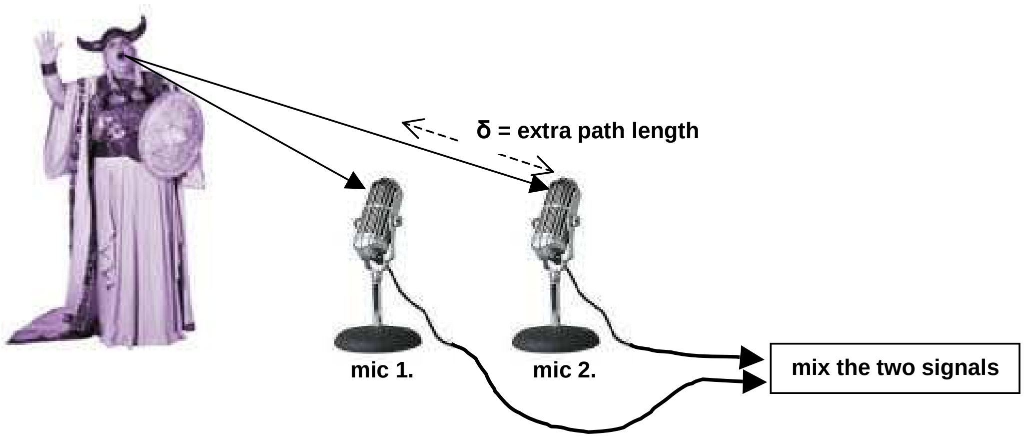

The graph above shows the strength of the combined signal (vertical axis) plotted against frequency. The notches occur where possibility (ii.) above is the case (i.e. the two signals are in Anti Phase and are combining destructively). The maxima between the notches are where possibility (i.) is the case (i.e. the two signals are In Phase and are combining constructively).

### 2. There are two, separated microphones and their signals are mixed

In the diagram below, the acoustic signal from the singer arrives at microphone 1 before it arrives at microphone 2. If the electrical signals from the two microphones are now mixed, the same In Phase and Anti Phase situations will apply as in the previous example. The mixed signal will have some frequencies that are strong (the In Phase ones) and other frequencies that are weak (the Anti Phase ones).

The two microphones will receive acoustic signals that are In Phase for those frequencies where the path to microphone 2 is longer by a whole number of wavelengths.

$$\delta = n \times \lambda \quad \text{where } n = 1, 2, 3, 4, \text{etc}$$




The first maximum occurs when n = 1; i.e. $\delta = \lambda$; and we can work out the frequency, $f$, at which this occurs:

$$c = f \times \lambda \quad = f \times \delta$$

$$f = \frac{c}{\delta}$$

If the extra path length, $\delta$, is 0.1 m and the speed of sound, $c$, is 340 m/s, the first maximum occurs at the following frequency:

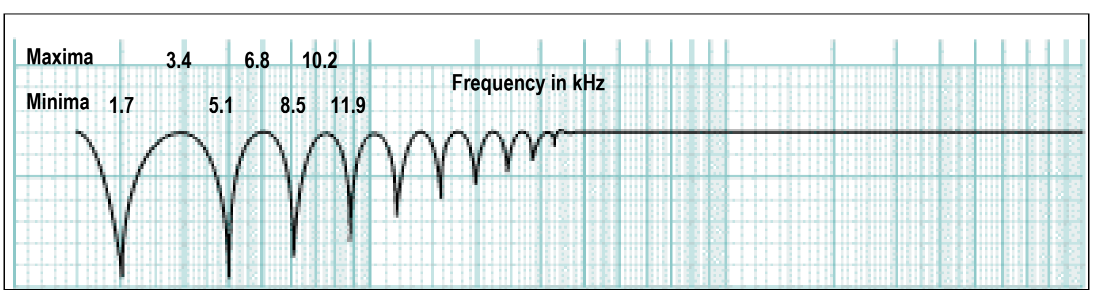
$$f = \frac{c}{\delta} \quad = \frac{340}{0.1} \quad = 3400 \text{ Hz} \quad = 3.4 \text{ kHz}$$

That was for n = 1. For n = 2, 3, 4, etc, the frequencies are: 6.8 kHz, 10.2 kHz, 13.6 kHz, etc.

The minima (or notches) on the Comb Filter characteristic occur midway between the maxima:

| | Frequency in kHz | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Maxima occur at** | | 3.4 | | 6.8 | | 10.2 | | 13.6 | | 17.0 | |
| **Minima occur at** | 1.7 | | 5.1 | | 8.5 | | 11.9 | | 15.3 | | 18.7 |

Shown as a graph, the Comb Filter characteristic for the mixed signals would look like:



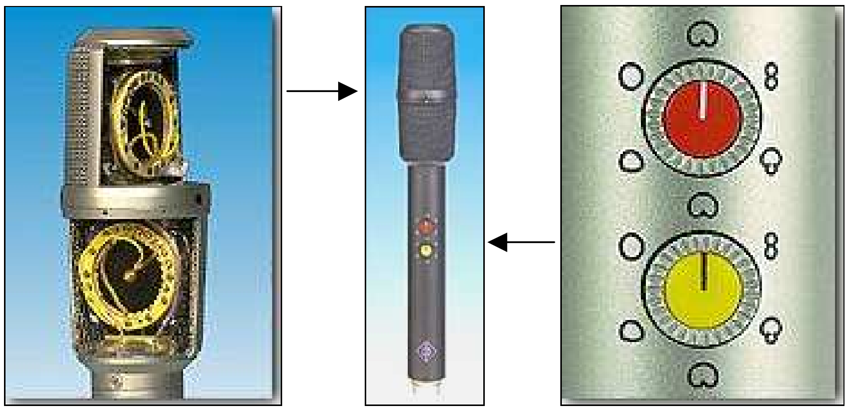

If the singer is at equal distances from the two microphones, there will be no delay; the acoustic signal will arrive at the microphones at the same time. So there will be no Comb Filter Effect.

As the singer moves to one side, one microphone is nearer than the other; a delay has been introduced in the acoustic signals at the microphones; and the Comb Filter Effect occurs.

When the singer is to the left, or the right, of the line joining the microphones, the extra path length, $\delta$, is at its greatest. It is the distance between the microphones. This brings the first notch to its lowest possible frequency on the Comb Filter characteristic for that microphone arrangement.

**Coincident Pair Stereo Microphone**

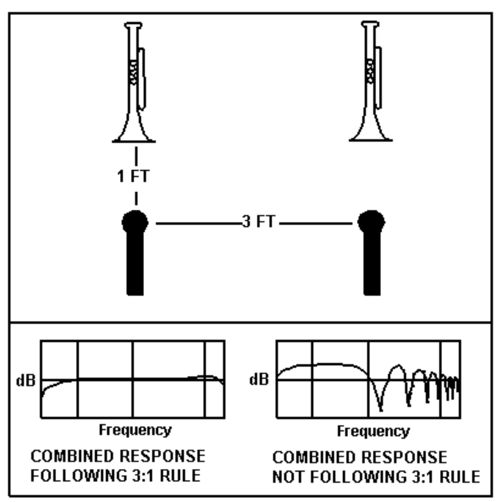
One stereo recording technique is to use a *coincident pair microphone*. The two microphone capsules are contained within the one housing. This places them as close together as possible, so there is only a very small delay between an acoustic signal arriving firstly at one capsule and then at the other capsule. This places the first minimum (notch) of the Comb Filter characteristic, for the microphone, well up the frequency range where it has a less audible effect.



In the Neumann microphone, above left, the two capsules are placed vertically one above the other so that, in the horizontal, they are art the same distance from all instruments in the orchestra. The upper half of the head rotates so that the angle between the axes of the microphones may be adjusted according to placement. In the centre photograph you can just make out the two rotary switches which allow the Polar Response of the microphone to be adjusted. The right-hand photograph shows the switches in close-up. Neumann specify: omni-directional, cardioid, and figure-8, plus a hyper-cardioid and a wide-angle-cardioid patterns.

Other types of coincident pair microphones place the capsules side-by-side.

**The Three-to-One Rule**




Consider a percussion kit with a microphone for a drum and another for a cymbal. The drum will be picked up by its microphone, but it will also be picked up with a delay by the microphone at the nearby cymbal. When those two microphone signals are mixed, the result will have a Comb Filter characteristic, changing the tonal sound of the drum.

The Three-to-One-Rule is that the distance to the un-intended microphone should be at least three times the distance to the intended microphone. The sound pressure level at the un-intended microphone will be 9.5 dB lower than the sound pressure level at the intended one. So, the un-intended microphone's electrical signal will be 9.5 dB lower and will produce much milder cancelling and reinforcing effects when mixed with the intended microphone's signal. If, in addition, the two microphones have directional polar responses, the difference in their electrical signals will be even greater, making the Comb Filter Effect even weaker.

# <u>Comb Filter Exercises</u>

Where necessary, assume that the speed of sound is 340 $ms^{-1}$.

1. A performer is recorded via two microphones which are 680 mm apart. He is 650 mm from one microphone and 820 mm from the other. Sketch a fully annotated graph of the comb filter characteristic, up to 10 kHz, for this arrangement, using a linear scale for the frequency axis.

2. The performer in question 1 moves to another position *where the delay is at its greatest*. Sketch a fully annotated graph of the comb filter characteristic, up to 3 kHz, for this arrangement.

3. A *coincident pair* microphone has the capsules arranged at a separation of 34 mm centre to centre.
   (i) Calculate the lowest frequency for the first *notch* on the comb filter due to this arrangement; and
   (ii) Where is the source located, relative to the capsules, when this occurs.

4. A two-way speaker system has a 25 mm diameter treble driver (tweeter) located 300 mm vertically above a 220 mm diameter bass/mid-range driver, measured centre to centre. (Assume the sources are vertically in line.) A listener is located 1 400 mm from the speaker on the axis of the tweeter.
   (i) Calculate the frequency of the first *notch* in the comb filter arrangement of the two drivers.
   (ii) Discuss the relevance of this frequency in relation to the typical cross-over frequency for a 25 mm diameter tweeter. (Which means you need to research typical cross-over frequencies.)

5. A good-practice rule-of-thumb when using two microphones, one for each of two adjacent sources is to have the unwanted microphone at a distance of equal to not less than three times the distance of the wanted microphone from the source.
   (i) By how many decibel does the sound pressure level at the unwanted microphone compare with that at the wanted microphone.
   (ii) How will the signal level from the wanted compare with the unwanted, if the latter has directional characteristics and is pointed towards its source.
   (iii) What is the result of adding two levels where one is 10 dB or more greater than the other.

6. A microphone capsule is 400 mm vertically above a hard, smooth, horizontal table. A newsreader's mouth is at the same height at a horizontal distance of 600 mm from the capsule. Calculate the frequency of the first *notch* in the comb filter characteristic for this arrangement.

**Answers**

1. First minimum (notch) at 1 kHz, then at 3 kHz, 5 kHz, 7 kHz, 9 kHz.
   First maximum at 2 kHz, then at 4 kHz, 6 kHz, 8 kHz, 10 kHz.
2. Minima (notches) at these frequencies: 0.25, 0.75, 1.25, 1.75, 2.25, 2.75 kHz
   Maxima at these frequencies: 0.5, 1, 1.5, 2, 2.5, 3.0 kHz
3. (i) 5 kHz. (ii) The source on the continuation of the line joining the capsules.
4. (i) (∗ = 31.78 mm) 5.349 kHz (ii) Cross-over frequencies are usually around 3 kHz. So at 5.349 kHz only tweeter is radiating; do not have two sources with a path difference, so no comb filter effect.
5. (i) 9.5 dB ( 20log(3) ) (ii) singer is off the axis of the unwanted mic, so latter will have lower signal
   (iii) combined level is effectively the same as the higher of the two.
6. 425 Hz. (two paths: 600 mm from mouth to mic, 1000 mm from mouth to table to mic, ∗ = 400 mm).