

NOISE-CANCELLING TELEPHONE HANDSET**FIELD OF THE INVENTION**

This invention relates to telephonic handset apparatus and, more specifically, to a handset structured to enhance the capability of noise cancellation circuitry in reducing the energy of ambient noise that interferes with the intelligibility of an incoming voice signal.

BACKGROUND OF THE INVENTION

Handsets which are standard equipment in telephone and other telecommunication stations such as cellular terminals consist basically of a receiver and a transmitter microphone connected by a handgrip. The utility of the conventional handset in a noisy environment such as a construction site, a machine shop, an airport, a bus terminal, or a car telephone station is diminished due to their passing much of the interfering ambient noise to the user's ear. Accordingly, expedients such as a volume control sometimes are used in handsets of the prior art to improve incoming speech intelligibility by increasing the incoming sound signal relative to the noise signal level. The same unwanted noise still passes to the user, however, and the resulting signal-to-noise ratio still substantially interferes with the speech intelligibility.

Although handsets of the prior art typically have not employed noise-cancelling circuits, such circuits may be found, for example, in prior art headsets for aircraft use. Active noise-cancelling circuits typically pick up the ambient noise signal with a noise-cancellation microphone and create an inverted version of the unwanted noise signal. This is applied to the receive channel where it subtractively interferes with the noise signal. The difficulty, however, in designing a handset which incorporates electronic cancellation techniques, has to do in part with the acoustic properties of a handset and specifically with matching of the phase and amplitude of the noise-cancelling signal to the noise itself. The handset must be designed to have an amplitude and phase response that is compatible with a practical control circuitry for the noise-cancelling operation.

SUMMARY OF THE INVENTION

According to this invention, there is provided an ambient noise-reducing telephone handset as claimed in claim 1. The earpiece of the handset receiver cap formed as a central aperture in which is mounted a housing. This housing contains



the noise-cancellation microphone. A portion of the housing extends outwardly of the earpiece to fit into a user's outer ear. Microphone thus directly samples ambient noise in the immediate vicinity of the user's ear canal. The noise-cancellation circuitry responds to the ambient noise by producing a noise-reduction signal which is optimally phase-related to the ambient noise signal.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic side view of an illustrative handset;

FIG. 2 is a schematic side diagram in partial section of the receiver cap detail of the illustrative handset;

FIG. 3 is a frontal view sketch of the receiver cap detail;

FIG. 4 is a graph showing a magnitude and phase delay relationship between the receiver input drive voltage and the output voltage of the noise cancellation microphone; and

FIG. 5 is a plot showing active noise-cancellation performance of an illustrative inventive embodiment.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENT

The noise-cancelling apparatus of the present invention is illustrated in a telephone handset denoted 10 in FIG. 1. Handset 10 is of basically conventional design and includes a transmitter cap 11 and a receiver cap 12. A quantity of acoustic blocking foam 13 is disposed in the handle portion 14 of the handset 10. Foam 13 may be of a material such as an open pore polyurethane having substantial resilience, good compliance and high acoustic damping properties. The foam 13 is a necessary part of the acoustic circuit in order to reduce as much as possible transmission of the user's spoken sound energy from the transmitter portion of the handset to the receiver portion. The foam also suppresses acoustic resonance in the handset interior by effectively controlling the air volume behind the receiver.

As seen in FIGS. 2 and 3, the receiver cap 12 contains a telephone receiver 15 which is connected by wire 16 to a telephone line 9 of communications network through a noise cancellation control circuit 40. Receiver 15 is contained within a speaker mounting sleeve 17 which fits snugly into an annular housing 18 of the receiver cap 12.

Receiver cap 12 is fabricated with a slightly domed earpiece 19 on the exterior surface 20 which contacts the user's ear. A series of radial slots 21 seen in FIG. 3 provide an acoustic grill through which the incoming signal from receiver 15



is passed to the user's ear canal. The slots 21 also are configured and positioned to pass sound over the shortest possible route from the receiver 15 to an error microphone 22 disposed in microphone housing 23.

The microphone housing 23 includes a flange 24 for positioning housing 23 on earpiece exterior 20, and a sleeve 25 within which microphone 22 is fixedly mounted. Housing 23 also includes a series of sound ports 26 formed through an extension 27 of housing 23. Extension 27 is intended to fit and protrude slightly into the user's outer ear to aid in positioning the handset on the user's ear, and to place the microphone 22 as near to the ear as possible so that it senses the precise sound field which impinges on the user's ear. This degree of fit is needed in order to achieve an optimum noise-cancelling performance over the bandwidth reaching from approximately 100 Hz to 1,000 Hz which is most critical to control for improved speech intelligibility.

Further, as seen in FIGS. 2 and 3, sound ports 26 in combination with acoustic grill slots 21 form an acoustic path between receiver 15 and microphone 22 which is short and direct, and therefore presents relatively little acoustic resistance and phase delay. Minimizing the acoustic resistance between receiver 15 and microphone 22 is highly desirable to minimize phase delays between the control signal received by microphone 22 and the noise-cancellation signal generated in circuit 40. These signals should have as little phase difference as possible. The juxtaposition as illustrated in FIG. 3 shows the sound ports 26 and the elongate acoustic grill slots 21 as being located with respect to each other in the requisite proximity.

Microphone wires 32 connecting microphone 22 to the control circuit 40 may be exited from cavity 29 through a passage 33 formed in annular housing 18. Advantageously, a felt pad 28 is placed between the microphone 22 and the sound ports 26 to prevent dust or other particles from being introduced through the ports 26 onto the microphone 22. A layer of acoustically transmissive material may be added on top of the pad 28 to further insure against dust and moisture intrusion. The acoustic slots 21 likewise should not be so open as to permit particulate matter to be introduced therethrough or to allow users to gain entry into the interior of receiver cap 12 with paperclips or the like. A protective screen 31 advantageously is disposed over receiver 15. Screen 31 may be a perforated metal disc or grill. Acoustically, screen 31 serves the purpose of transmitting the sound emitted by receiver 15 without distortion or diminishment.

As seen in FIG. 2, receiver cap 12 includes a cavity 29 into which foam 30 is placed. Advantageously, the foam has characteristically open cell structure and is light in weight. A reticulated polyurethane foam is one suitable material. Foam 30 prevents dirt from intruding on the receiver 15 and also smooths the phase response, by damping undesirable resonant modes and reflections emanating from the enclosure and the user's ear.

The residual phase delay between the noise-cancelling signal driving receiver 15 and the control signal generated by the microphone 22, may be predetermined.

The handset design of the present invention produces an electroacoustical transfer function from the speaker input voltage to the microphone output voltage that, with the addition of a low complexity compensation circuit of the cited patent application, provides excellent closed loop cancellation performance in the range of from 100 Hz to 1100 Hz. This transfer function, shown in FIG. 4, provides several valuable characteristics. First, it varies gradually with frequency, without erratic or peaked responses. Further, its magnitude rolls off at frequencies above about 1000 Hz such that substantially all resonant peaks above about 2000 Hz are down more than 20 dB from the maximum amplitude. Also, its phase lies between 0 and 360 degrees in the range of from about 100 Hz and in excess of 3000 Hz as seen in the lower curve of FIG. 4. The physical design concepts of the instant invention help achieve these results.

Importantly, the size and shape of the slots 21 and ports 26 must be controlled to avoid acoustic resonance of microphone 22 and the handset receiver enclosure. The volumes enclosed by the microphone housing 23 with associated ports 26 and microphone 22 comprise a potentially resonant acoustic chamber. Resonant response of this chamber at frequencies within the audible frequency range will introduce amplitude and phase response distortions that degrade the acoustic noise reduction performance. The configuration, diameter and length of ports 26 selected to reduce this effect. Similar undesired resonant effects are avoided in the handset receiver enclosure through the configuration of slots 21 which allow passage of sound while preventing access to the speaker.

The utility of the instant invention may be further appreciated by reference to FIG. 5. There, data on noise cancellation vs. frequency taken from an experiment with a single subject, is plotted for the case where the invention is used with a complementary noise cancellation circuit such as described in the cited patent application. Noise cancellation may be defined as the ratio of the noise power



spectrum, at the user's ear, with the cancellation circuit "off," to the noise power spectrum with the circuit "on" measured in dB. The measurements were made at the subject's eardrum using an Etymotic ear probe together with a spectrum analyzer. FIG. 5 shows cancellation performance from 100 Hz to 1100 Hz with over 10 dB of noise cancellation between 130 Hz and 700 Hz; and up to 15 dB at 400 Hz. This frequency band of cancellation is very effective in the typical noisy environments noted earlier. The level of cancellation is sufficient to make otherwise unintelligible incoming speech understandable.

THIS SHEET HAS BEEN
REPLACED



- 6 -

Claims:

1. An ambient noise-reducing telephone handset (10) comprising transmitter and receiver ends, transmitter and receiver caps (11,12) respectively disposed on said ends, a receiver (15) mounted in said receiver cap (12), a noise-cancellation microphone (22), a noise-cancellation control circuit (40), and means (32) connecting said microphone (22) to said circuit (40), CHARACTERISED IN THAT said receiver cap (12) comprises an earpiece (19) formed with a central aperture on the exterior surface (20), and a housing (23) mounted through said aperture and extending into the interior of said cap (12) toward said receiver (15) contains said microphone (22), said housing comprising an outwardly protruding extension (27) which fits into a user's outer ear to position said microphone (22) to directly sample ambient noise in closest proximity to the user's ear canal.
2. A handset as claimed in claim 1 comprising a plurality of radial slots (21) placed around said aperture through said earpiece (19) defining an acoustic grill through which signals from said receiver (15) are passed substantially directly to the user's ear canal.
3. A handset as claimed in claim 2, wherein said housing extension (27) comprises a plurality of sound ports (26), said ports (26) being configured and sized to reduce any resonant response characteristic of said microphone housing (23).
4. A handset as claimed in claim 2 or 3, comprising an acoustically transmissive pad (28) placed between said microphone (22) and said ports (26) to block particulate matter from entering said receiver cap interior through said ports (26).
5. A handset as claimed in claim 4, comprising a layer of acoustically transmissive dust and moisture-impermeable material placed over the exterior-facing surface of said pad (28).
6. A handset as claimed in claim 5 comprising an acoustically non-distorting protective screen (31) placed over the exterior-facing side of receiver (15), for passing sound from said receiver (15) with minimum distortion and energy loss.
7. A handset as claimed in claim 6 wherein said receiver cap (12)

This Sheet Has Been Replaced





THIS SHEET HAS BEEN
REPLACED

- 7 -

comprises an open cell foam (30) contained in the space between said receiver (15) and said microphone (22), said foam being adapted to damp resonant modes and reflections emanating from or originating in the internal space of said cap (12) and the ear of a user.

8. A handset as claimed in claim 6 or 7 wherein said screen (31) comprises a perforated metal disc.

This Sheet Has Been Replaced

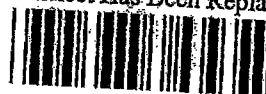


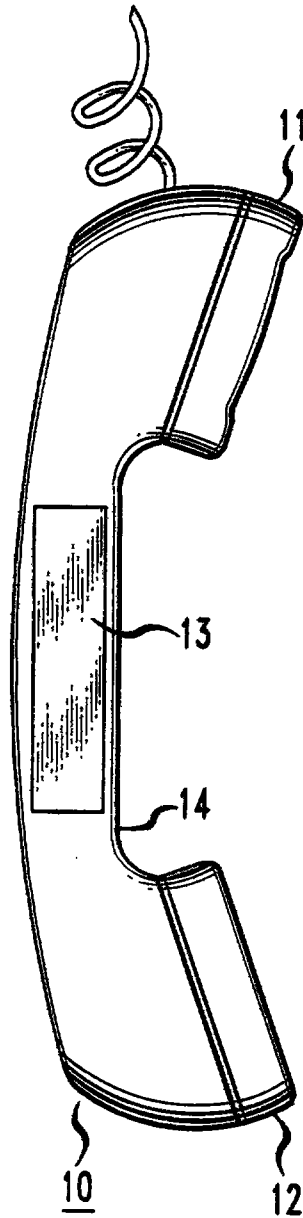
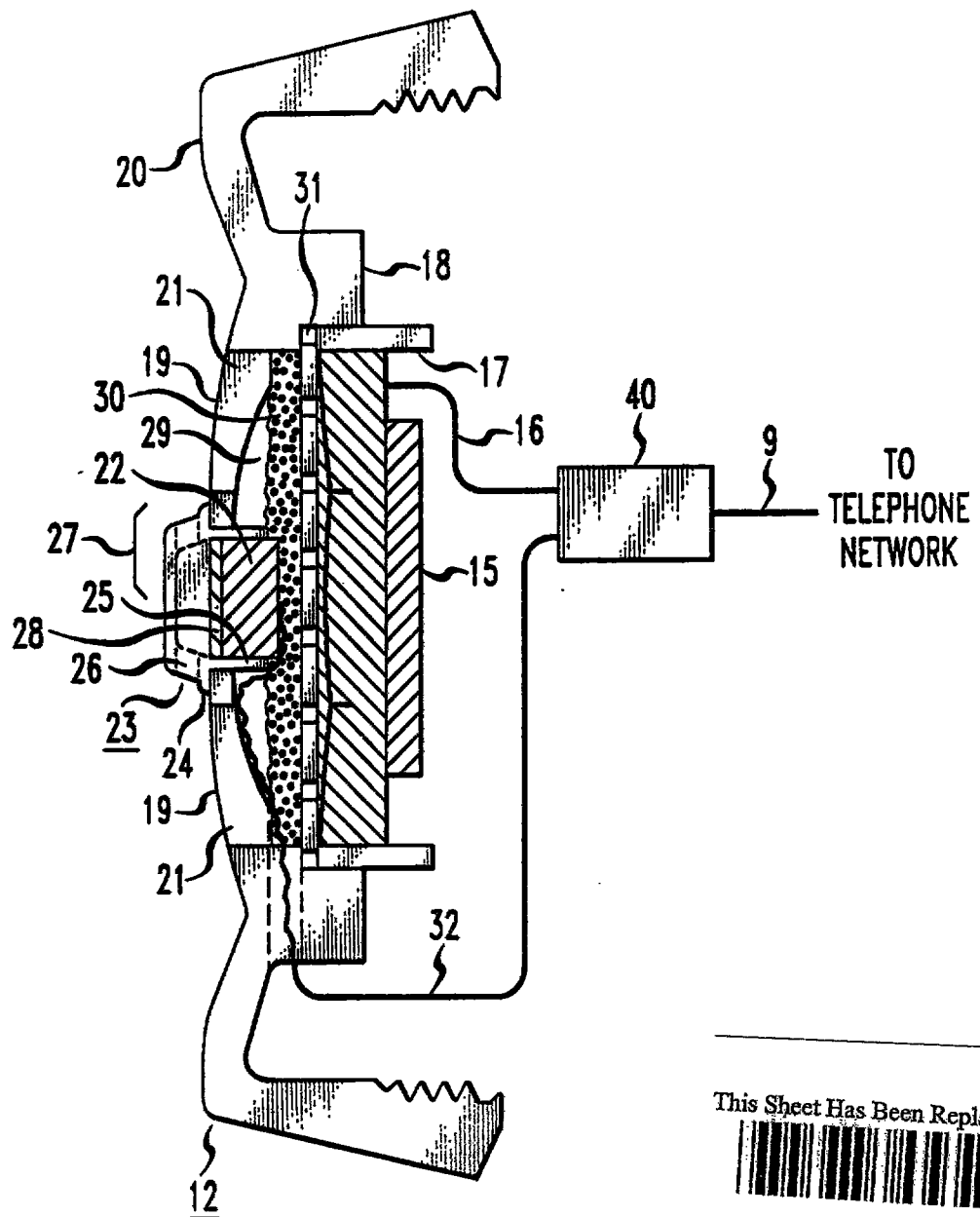
FIG. 1

FIG. 2



This Sheet Has Been Replaced



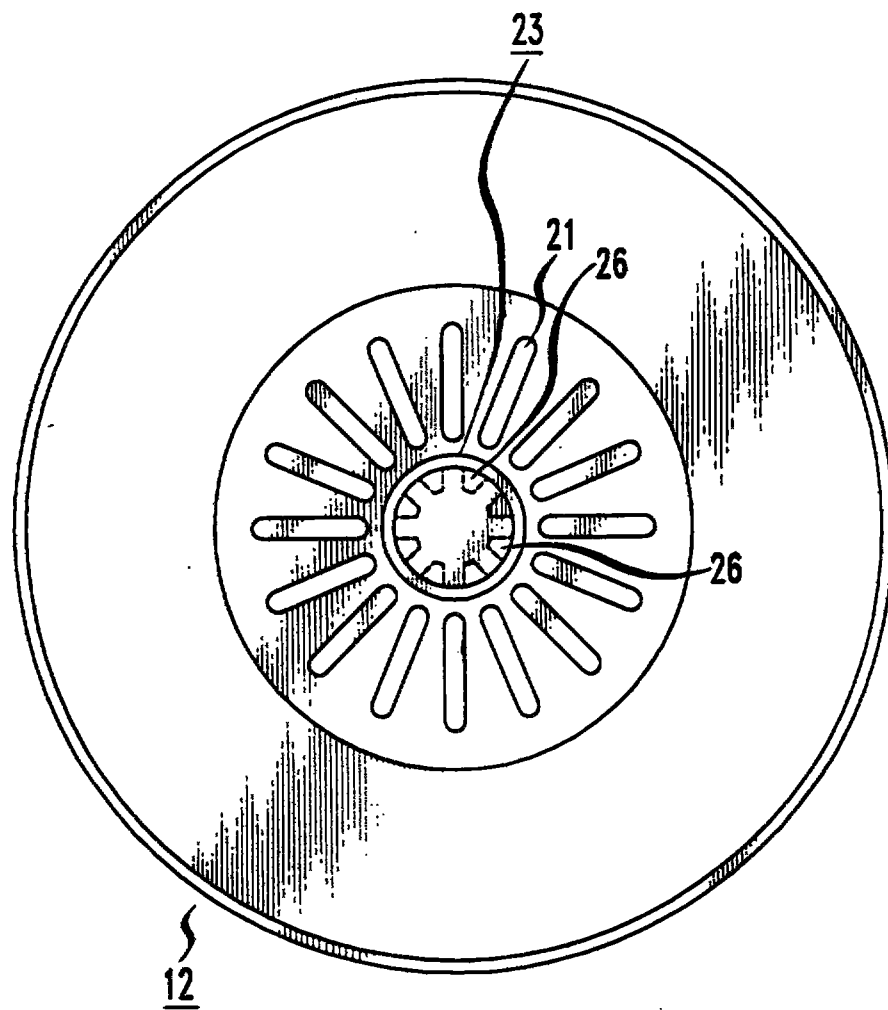
FIG. 3

FIG. 4

AMPLITUDE AND PHASE RESPONSE

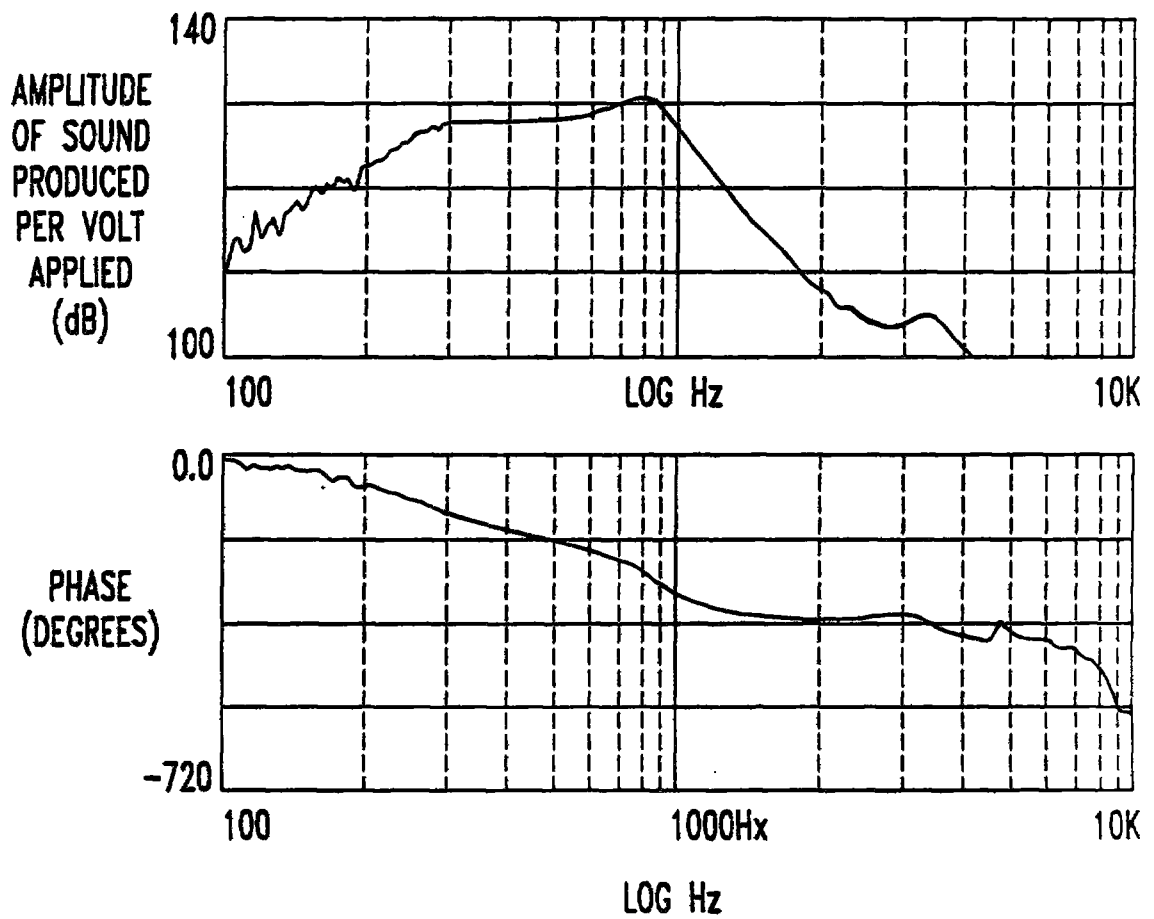
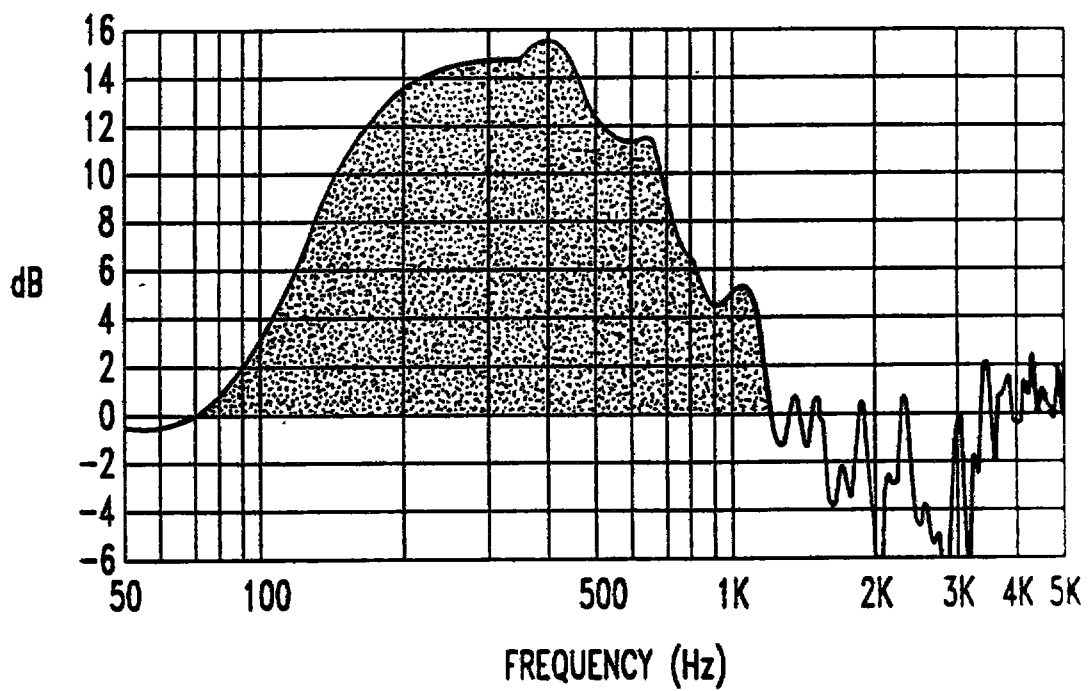


FIG. 5

ACTIVE NOISE CANCELLATION PERFORMANCE
PRODUCT: AT&T HANDSET



NOTE: $\text{dB} = 10 \text{ LOG} \left(\frac{\text{CANCELLATION OFF}}{\text{CANCELLATION ON}} \right)$

MEASURED ON PERSON
WITH EARDRUM PROBE

THIS SHEET HAS BEEN
REPLACED

NOISE-CANCELLING TELEPHONE HANDSET

Abstract

A radio or telephone handset configured with the usual transmitter and receiver (12) ends and connecting handle is designed to have physical characteristics that provide acoustic characteristics to complement noise cancellation circuitry. The receiver (15) is mounted in the receiver cap (12), which is built with a domed, apertured earpiece (19) extending from the exterior surface of the receiver cap (12). A housing (23) mounted into the earpiece (19) and extending out therefrom, contains a noise-cancellation microphone (22). The housing (23) thus extends the microphone (22) into a user's outer ear thereby to enable the microphone to sample ambient noise close to the user's eardrum.

This Sheet Has Been Replaced

T



22 SEP 1997

- 1 -

NOISE-CANCELLING TELEPHONE HANDSET

This invention relates to ambient noise-reducing telephone handsets.

Handsets which are standard equipment in telephone and other telecommunication stations such as cellular terminals consist basically of a receiver and a transmitter microphone connected by a handgrip. The utility of the
5 conventional handset in a noisy environment such as a construction site, a machine shop, an airport, a bus terminal, or a car telephone station is diminished due to their passing much of the interfering ambient noise to the user's ear. Accordingly, expedients such as a volume control sometimes are used in handsets of the prior art to improve incoming speech intelligibility by increasing the incoming sound signal
10 relative to the noise signal level. The same unwanted noise still passes to the user, however, and the resulting signal-to-noise ratio still substantially interferes with the speech intelligibility.

Although handsets of the prior art typically have not employed noise-cancelling circuits, such circuits may be found, for example, in prior art headsets for
15 aircraft use. A prior art device using active noise cancellation which fits into the ear, is illustrated by U.S. patent 4,945,925. A noise cancelling microphone is mounted in an earplug housing that inserts into a user's ear, and is located in close proximity to a speaker-transducer. Another prior art device intended to fit on or into a user's ear is illustrated in EP-A-0 425 129 A2. In this device, a noise cancelling
20 microphone and speaker may be disposed altogether within a shell which is located outside the user's ear canal. Alternatively, there is shown a custom ear cavity mould in which both the microphone and driver-speaker are mounted next to each other.

Active noise-cancelling circuits typically pick up the ambient noise signal with a noise-cancellation microphone and create an inverted version of the
25 unwanted noise signal. This is applied to the receive channel where it subtractively interferes with the noise signal. The difficulty, however, in designing a handset which incorporates electronic cancellation techniques, has to do in part with the acoustic properties of a handset and specifically with matching of the phase and amplitude of the noise-cancelling signal to the noise itself. The handset must be
30 designed to have an amplitude and phase response that is compatible with a practical control circuitry for the noise-cancelling operation.

According to this invention, there is provided an ambient noise-reducing telephone handset as claimed in claim 1.

The earpiece of the handset receiver cap presents a central aperture in
35 which is mounted a housing. This housing contains

22 SEP 1997

- 2 -

the noise-cancellation microphone. A portion of the housing extends outwardly of the earpiece to fit into a user's outer ear. ^{The} microphone thus directly samples ambient noise in the immediate vicinity of the user's ear canal. The noise-cancellation circuitry responds to the ambient noise by producing a noise-reduction signal which
5 is optimally phase-related to the ambient noise signal.

DESCRIPTION OF THE DRAWINGS

- FIG. 1 is a schematic side view of an illustrative handset;
FIG. 2 is a schematic side diagram in partial section of the receiver cap detail of the illustrative handset;
10 FIG. 3 is a frontal view sketch of the receiver cap detail;
FIG. 4 is a graph showing a magnitude and phase delay relationship between the receiver input drive voltage and the output voltage of the noise cancellation microphone; and
FIG. 5 is a plot showing active noise-cancellation performance of an
15 illustrative inventive embodiment.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENT

The noise-cancelling apparatus of the present invention is illustrated in a telephone handset denoted 10 in FIG. 1. Handset 10 is of basically conventional design and includes a transmitter cap 11 and a receiver cap 12. A quantity of
20 acoustic blocking foam 13 is disposed in the handle portion 14 of the handset 10. Foam 13 may be of a material such as an open pore polyurethane having substantial resilience, good compliance and high acoustic damping properties. The foam 13 is a necessary part of the acoustic circuit in order to reduce as much as possible transmission of the user's spoken sound energy from the transmitter portion of the
25 handset to the receiver portion. The foam also suppresses acoustic resonance in the handset interior by effectively controlling the air volume behind the receiver.

As seen in FIGS. 2 and 3, the receiver cap 12 contains a telephone receiver 15 which is connected by wire 16 to a telephone line 9 of communications network through a noise cancellation control circuit 40. Receiver 15 is contained
30 within a speaker mounting sleeve 17 which fits snugly into an annular housing 18 of the receiver cap 12.

Receiver cap 12 is fabricated with a slightly domed earpiece 19 on the exterior surface 20 which contacts the user's ear. A series of radial slots 21 seen in FIG. 3 provide an acoustic grill through which the incoming signal from receiver 15

22 SEP 1997

- 4 -

As seen in FIG. 2, receiver cap 12 includes a cavity 29 into which foam 30 is placed. Advantageously, the foam has characteristically open cell structure and is light in weight. A reticulated polyurethane foam is one suitable material. Foam 30 prevents dirt from intruding on the receiver 15 and also smooths the phase response, by damping undesirable resonant modes and reflections emanating from the enclosure and the user's ear.

The residual phase delay between the noise-cancelling signal driving receiver 15 and the control signal generated by the microphone 22, may be predetermined.

10 The handset design of the present invention produces an electroacoustical transfer function from the speaker input voltage to the microphone output voltage that, with the addition of a low complexity compensation circuit, provides excellent closed loop cancellation performance in the range of from 100 Hz to 1100 Hz. This transfer function, shown in FIG. 4, 15 provides several valuable characteristics. First, it varies gradually with frequency, without erratic or peaked responses. Further, its magnitude rolls off at frequencies above about 1000 Hz such that substantially all resonant peaks above about 2000 Hz are down more than 20 dB from the maximum amplitude. Also, its phase lies between 0 and 360 degrees in the range of from about 100 Hz and in excess of 3000 20 Hz as seen in the lower curve of FIG. 4. The physical design concepts of the instant invention help achieve these results.

Importantly, the size and shape of the slots 21 and ports 26 must be controlled to avoid acoustic resonance of microphone 22 and the handset receiver enclosure. The volumes enclosed by the microphone housing 23 with associated 25 ports 26 and microphone 22 comprise a potentially resonant acoustic chamber. Resonant response of this chamber at frequencies within the audible frequency range will introduce amplitude and phase response distortions that degrade the acoustic noise reduction performance. The configuration, diameter and length of ports 26 selected to reduce this effect. Similar undesired resonant effects are avoided in the 30 handset receiver enclosure through the configuration of slots 21 which allow passage of sound while preventing access to the speaker.

The utility of the instant invention may be further appreciated by reference to FIG. 5. There, data on noise cancellation vs. frequency taken from an experiment with a single subject, is plotted for the case where the invention is used 35 with a complementary noise cancellation circuit such as described in the cited patent application. Noise cancellation may be defined as the ratio of the noise power



THIS SHEET HAS BEEN
REPLACED

REPLACEMENT SHEET

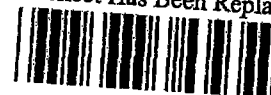
22 SEP 1997

- 6 -

Claims:

1. An ambient noise-reducing telephone handset (10) comprising transmitter and receiver ends, transmitter and receiver caps (11,12) respectively disposed on said ends, a receiver (15) mounted in said receiver cap (12), a noise-cancellation microphone (22), a noise-cancellation control circuit (40), and means (32) connecting said microphone (22) to said circuit (40), CHARACTERISED IN THAT said receiver cap (12) comprises an earpiece (19) formed with a central aperture on / ^{its} exterior surface (20), and a housing (23) mounted through said aperture and extending into the interior of said cap (12) toward said receiver (15)
10 contains said microphone (22), said housing comprising an outwardly protruding extension (27) which fits into a user's outer ear to position said microphone (22) to directly sample ambient noise in closest proximity to the user's ear canal.
2. A handset as claimed in claim 1 comprising a plurality of radial slots (21) placed around ^{central} ~~said aperture~~ ⁽²⁰⁾ through said earpiece (19) defining an acoustic grill
15 through which signals from said receiver (15) are passed substantially directly to the user's ear canal.
3. A handset as claimed in claim 2, wherein said housing extension (27) comprises a plurality of sound ports (26), said ports (26) being configured and sized to reduce any resonant response characteristic of said microphone housing (23).
- 20 4. A handset as claimed in claim 3, comprising an acoustically transmissive pad (28) placed between said microphone (22) and said ports (26) to block particulate matter from entering said receiver cap interior through said ports (26).
5. A handset as claimed in claim 4, comprising a layer of acoustically
25 transmissive dust and moisture-impermeable material placed over the exterior-facing surface of said pad (28).
6. A handset as claimed in claim 5 comprising an acoustically non-distorting protective screen (31) placed over the exterior-facing side of receiver (15), for passing sound from said receiver (15) with minimum distortion and energy loss.
- 30 7. A handset as claimed in claim 6 wherein said receiver cap (12)

This Sheet Has Been Replaced





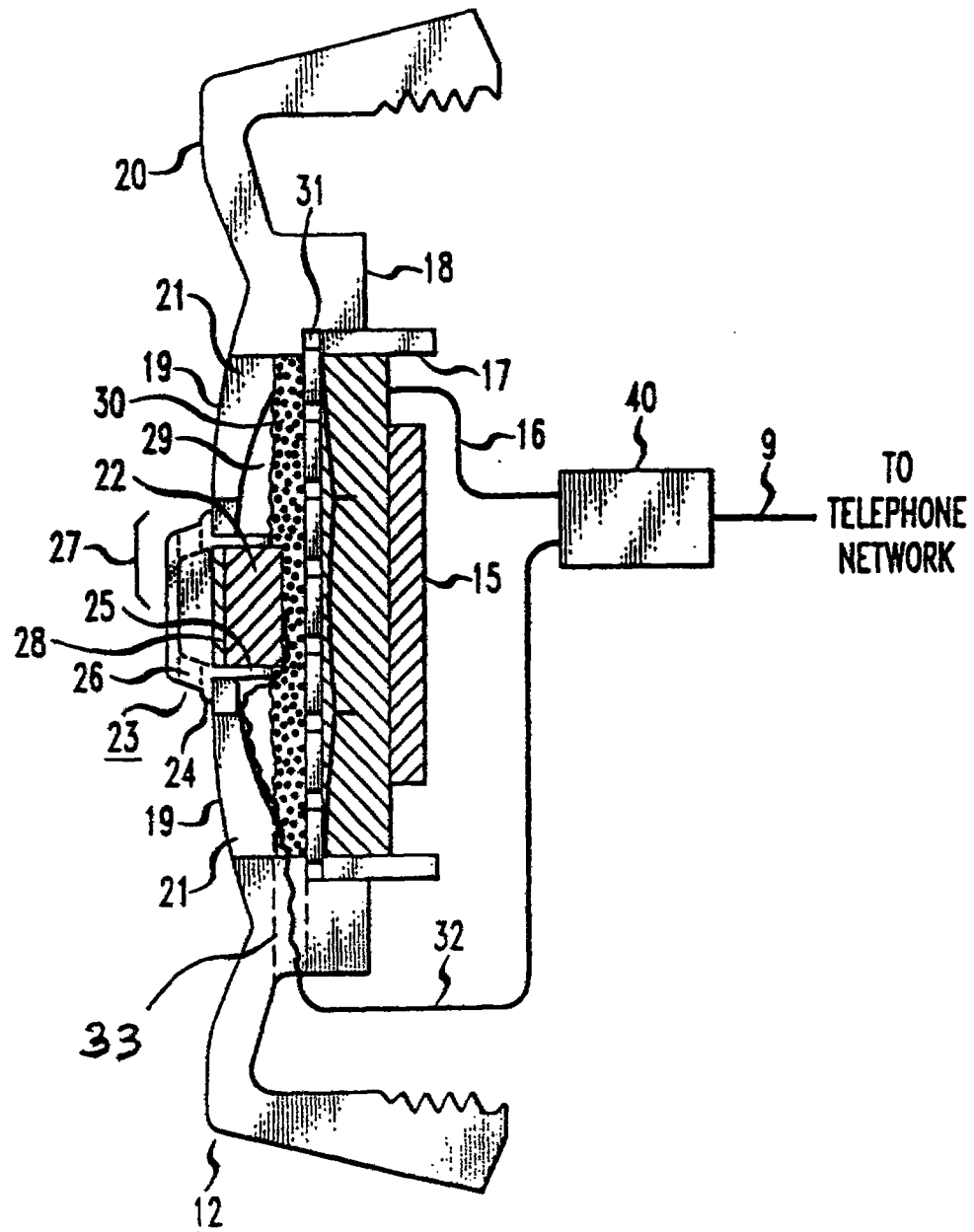
- 7 -

REPLACEMENT SI

22 SEP 1997

comprises an open cell foam (30) contained in the space between said receiver (15) and said microphone (22), said foam being adapted to damp resonant modes and reflections emanating from or originating in the internal space of said cap (12) and the ear of a user.

- 5 8. A handset as claimed in claim 6 or 7 wherein said screen (31)
is a perforated metal disc.



13 MAY 1998



- 6 -

Claims:

1. An ambient noise-reducing telephone handset (10) comprising transmitter and receiver ends, transmitter and receiver caps (11,12) respectively disposed on said ends, a receiver (15) mounted in said receiver cap (12), a noise-
- 5 cancellation microphone (22), a noise-cancellation control circuit (40), and means (32) connecting said microphone (22) to said circuit (40), CHARACTERISED IN THAT said receiver cap (12) comprises an earpiece (19) formed with a central aperture on its exterior surface (20), and a microphone housing (23) mounted through said aperture and extending into the interior of said cap (12) toward said receiver (15), said housing comprising an outwardly protruding extension (27) containing said
- 15 microphone (22), which fits into a user's outer ear to position said microphone (22) to directly sample ambient noise in closet proximity to the user's ear canal.
2. A handset as claimed in claim 1 comprising a plurality of radial slots (21) placed around said ^{central} ~~aperture~~ ⁽²⁰⁾ through said earpiece (19) defining an acoustic grill
- 15 through which signals from said receiver (15) are passed substantially directly to the user's ear canal.
3. A handset as claimed in claim 2, wherein said housing extension (27) comprises a plurality of sound ports (26), said ports (26) being configured and sized to reduce any resonant response characteristic of said microphone housing (23).
- 20 4. A handset as claimed in claim 3, comprising an acoustically transmissive pad (28) placed between said microphone (22) and said ports (26) to block particulate matter from entering said receiver cap interior through said ports (26).
5. A handset as claimed in claim 4, comprising a layer of acoustically
- 25 transmissive dust and moisture-impermeable material placed over the exterior-facing surface of said pad (28).
6. A handset as claimed in claim 5 comprising an acoustically non-distorting protective screen (31) placed over the exterior-facing side of receiver (15), for passing sound from said receiver (15) with minimum distortion and energy loss.
- 30 7. A handset as claimed in claim 6 wherein said receiver cap (12)