Detection of airflow (inhalation) in tube using laminated piezo film element

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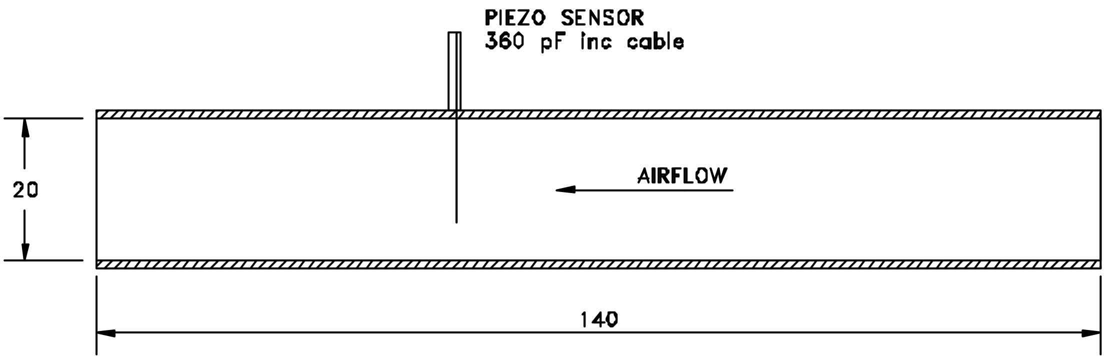
Introduction

Thermal and vibration responses from a simple piezo film element subjected to inhalation and exhalation of air through a tube were recorded and analysed.

Description

A laminated piezo film element (type "LDTC", preliminary) with blade dimensions 12.5 mm (width) x 15 mm (length) was introduced into a cylindrical tube of bore 20 mm, "broadside on" to the airflow, as shown below.



The sensor was initially buffered by a charge preamplifier (B&K Type 2635) set to 0.102 mV/pC, equivalent to an open-circuit gain of -30.6 dB. This means that the "true" output voltage of the sensor, measured into infinite impedance, would be 34X greater than the output observed from the charge preamplifier. The lower limiting frequency (to -10%) for this experiment was set to 0.2 Hz.

This arrangement was used to check the thermal response from the film. Some vibration response could be seen using this set-up, but for the vibration-only tests, the film was connected directly to a 1 Megohm analyzer input, giving a low frequency response (to -3 dB) of 440 Hz.

(a) Thermal Response

With the blade of the sensor fully inserted into the tube (occluding 55% of the cross-sectional area of the tube), the response from the sensor was observed for inhaling and exhaling. Fig (1) (lower trace) shows the time record, with an initial negative dip (corresponding to first inhalation) of -0.326 V, followed by a positive peak (from exhalation) of 2.39 V. These results were taken from the charge preamplifier: they correspond to +11 V and -81 V open-circuit voltages from the sensor. These results demonstrate the impressive sensitivity of piezo film to thermal transient events.

Fig (1) (upper trace) shows an average magnitude spectrum computed from the entire time record. The very low frequency signals from inhale/exhale are "off scale" at the extreme LHS of the trace, but the vibration reponse (slight boost in level at around 375 Hz) can be seen.

Fig (2) shows a "waterfall plot" of spectra at different time intervals using same data, showing bursts of "noise" in the 250 to 500 Hz region for each inhale and exhale event.

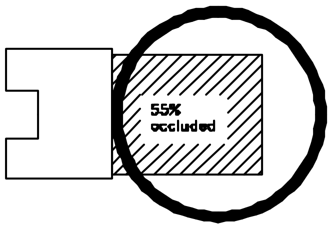
(b) Vibration response

To eliminate the low frequeny thermal response, the sensor was connected directly to 1 Megohm input of the analyzer. Fig (3) shows the average magnitude and compressed time record for inhale/exhale repeated 3 times. In the time record, the bursts of noise from each event can be clearly seen. This "noise" corresponds to vibration induced in the "cantilever beam" sensor element by airflow. Note that the underlying vibration sensitivity spectrum was not measured directly for these experiments, but the absence of a distinct resonance frequency is believed to be partly due to the curved "clamp" of the beam.

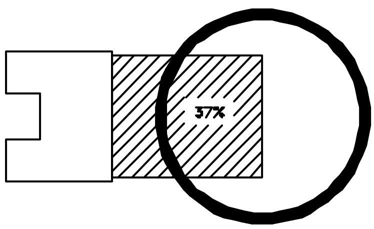
Fig (4) shows corresponding waterfall plot, with the noise bursts now even more distinct than in Fig (2), due to the removal of the high amplitude low frequency components.

To investigate the effect of different occlusion areas, the sensor element was then withdrawn progressively from the tube, as indicated below:

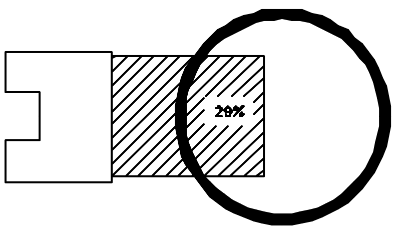
A



B



C



Case "A" represents the initial thermal trial, and first vibration tests.

In Case "B", the weak "resonance" frequency (or band) was shifted upwards, as can be seen in Fig (5). The sensitivity of the sensor was somewhat reduced: less area was stressed, and part of the sensor represented a passive capacitive load on the active area.

In Case "C", the resonance flattened out even further, leaving almost broadband response up to about 1200 Hz - but with yet further reduced sensitivity. Fig (6) refers.

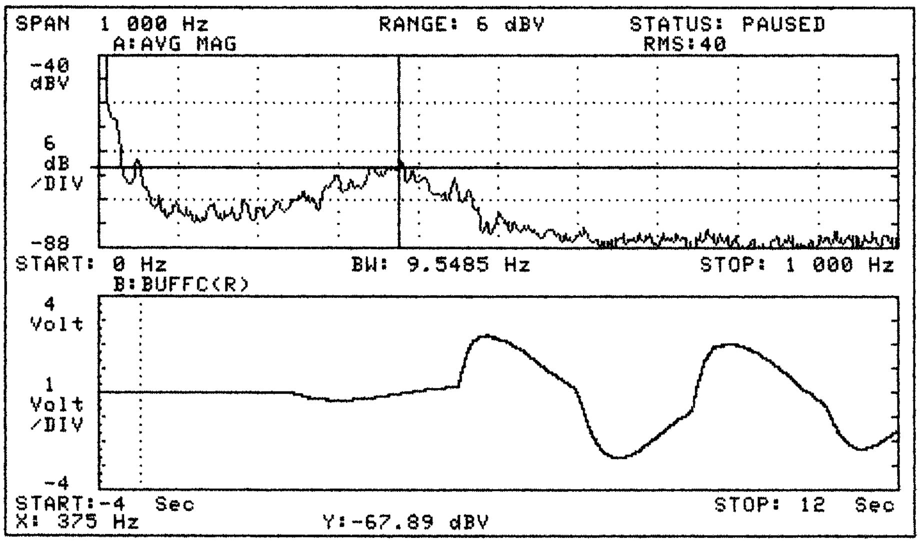
Fig (7) shows the sensor re-set to approximately Case "B", with a single inhalation. The lower trace shows the compressed full time record, with dotted vertical cursors showing the portion which is expanded in the upper trace. A low-amplitude positive-going signal can be seen just before the vibration commences: this is the residual thermal response "breaking through", despite high attenuation caused by the RC filter at 440 Hz. The vibration becomes detectable at around 120 ms after the onset of the thermal transient. Fig (8) shows an expanded waterfall plot for this single event.

Finally, Figs (9) and (10) show "no vibration" and "max vibration" conditions with spectral band energy computed for 400 to 1000 Hz band, indicating a maximum signal/noise ratio of about 65 dB for this arrangement. Note that the test sensor was unshielded. The noise components visible in Fig (9) are harmonics of 50 Hz mains supply frequency, and could be removed quite easily by adding an additional printed conductive ink electrode in the sensor assembly.

Conclusion

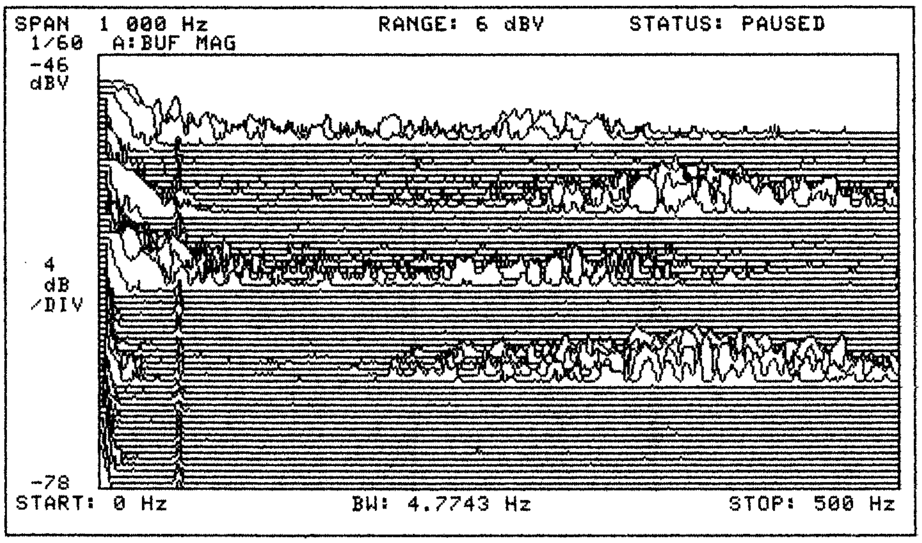
Using a simple laminated piezo film element, inhalation or exhalation through a tube was readily detected by both thermal transient signals, and by vibration signals. The thermal transient due to inhalation exceeded 10 V open-circuit response to slight cooling of the sensor, while exhalation of warmed air gave more than 80 V open-circuit response. Vibration signals were lower in amplitude (typically around 100 to 150 mV peak-to-peak) and showed relatively broad spectral response. The peak frequency could be adjusted by changing the length of the sensor "beam".

FIG 1



SPAN 1 000 Hz
RANGE: 6 dBV
STATUS: PAUSED
A:AVG MAG
RMS:40
-40 dBV
6 dB /DIV
-88
START: 0 Hz
BW: 9.5485 Hz
STOP: 1 000 Hz
B:BUFFC(R)
4 Volt
1 Volt /DIV
-4
START:-4 Sec
STOP: 12 Sec
X: 375 Hz
Y:-67.89 dBV

FIG 2



SPAN 1 000 Hz
RANGE: 6 dBV
STATUS: PAUSED
1/60 A:BUF MAG
-46
dBV
4
dB
/DIV
-78
START: 0 Hz
BW: 4.7743 Hz
STOP: 500 Hz

FIG 3

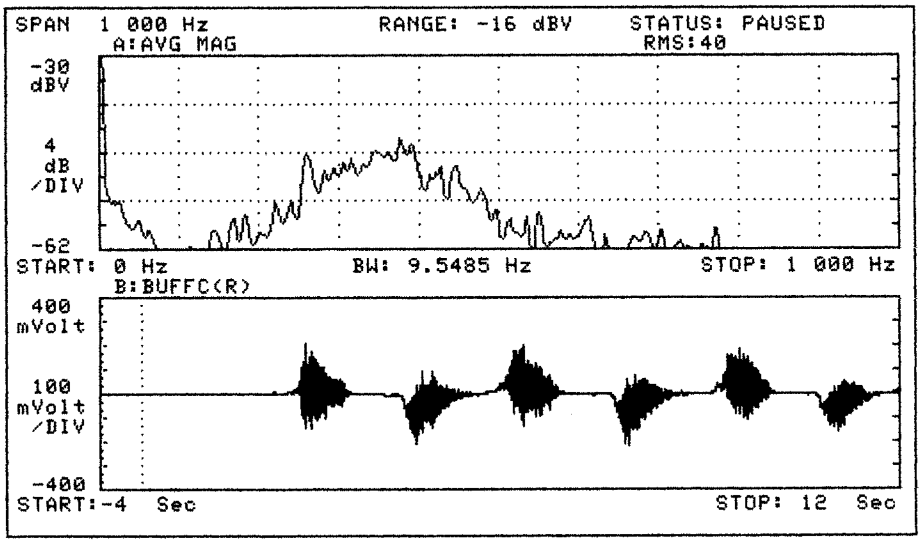
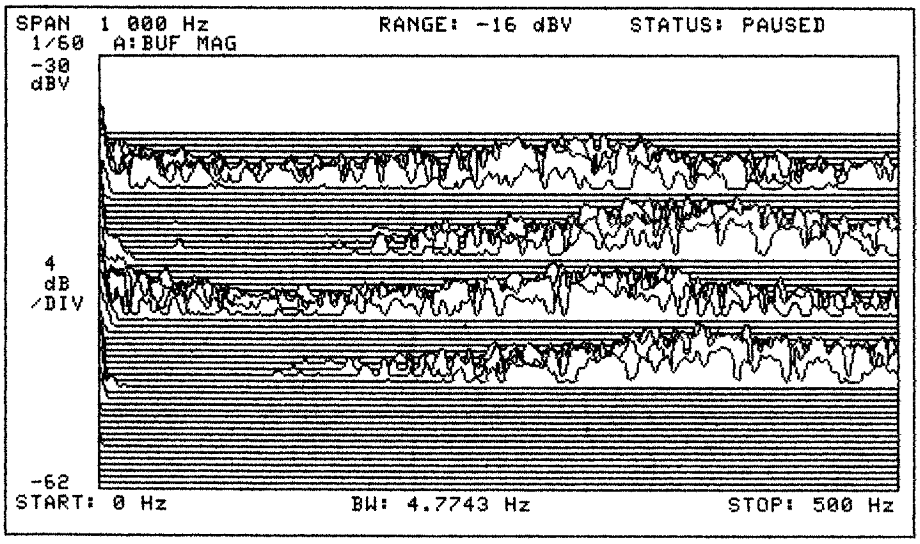
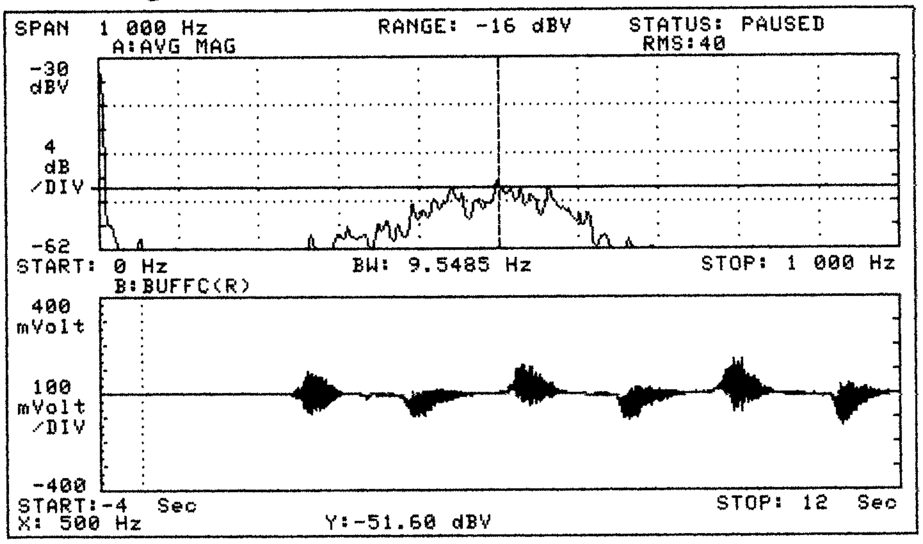

SPAN 1 000 Hz
RANGE: -16 dBV
STATUS: PAUSED
A:AVG MAG
RMS:40
-30
dBV
4
dB
/DIV
-62
START: 0 Hz
BW: 9.5485 Hz
STOP: 1 000 Hz
B:BUFFC(R)
400
mVolt
100
mVolt
/DIV
-400
START:-4 Sec
STOP: 12 Sec

FIG 4



SPAN 1 000 Hz
RANGE: -16 dBV
STATUS: PAUSED
1/60 A:BUF MAG
-30
dBV
4
dB
/DIV
-62
START: 0 Hz
BW: 4.7743 Hz
STOP: 500 Hz

FIG 5



SPAN 1 000 Hz
RANGE: -16 dBV
STATUS: PAUSED
A:AVG MAG
RMS:40
-30
dBV
4
dB
/DIV
-62
START: 0 Hz
BW: 9.5485 Hz
STOP: 1 000 Hz
B:BUFFC(R)
400
mVolt
100
mVolt
/DIV
-400
START:-4 Sec
STOP: 12 Sec
X: 500 Hz
Y:-51.60 dBV

FIG 6

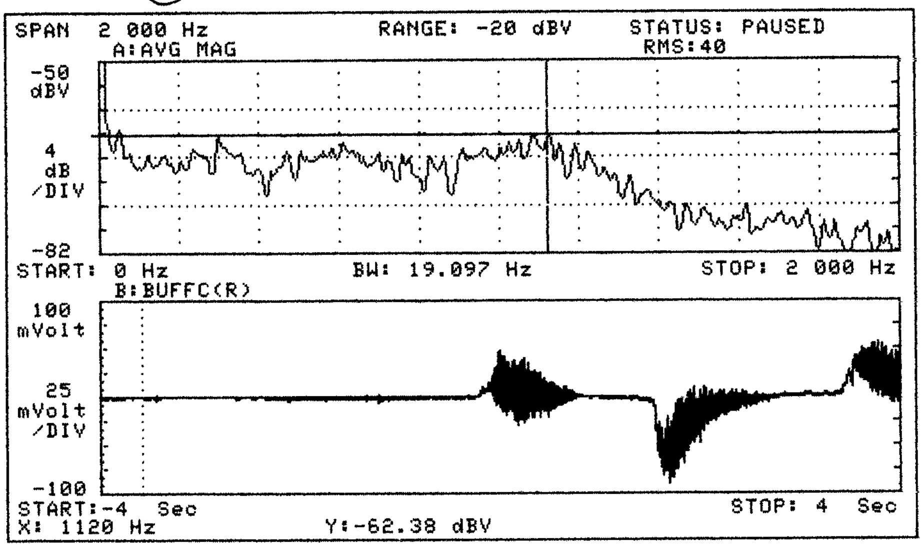
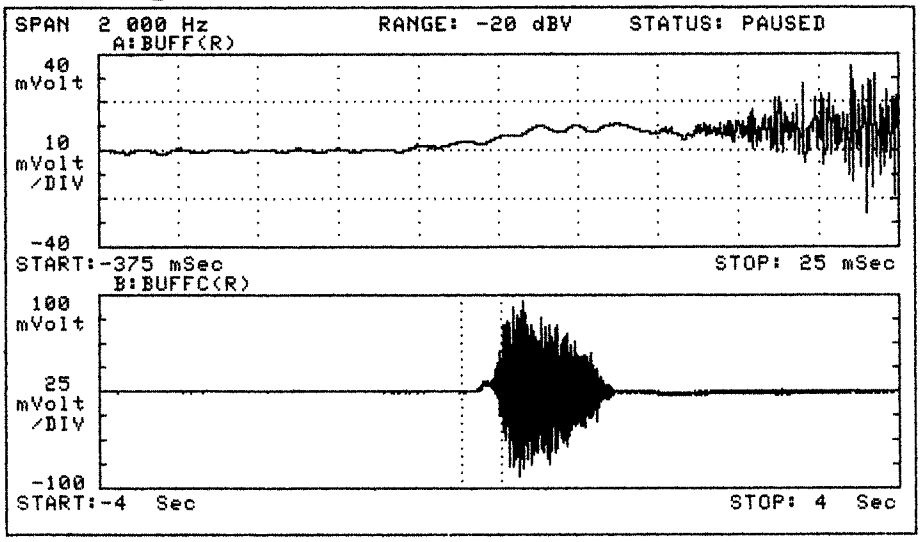
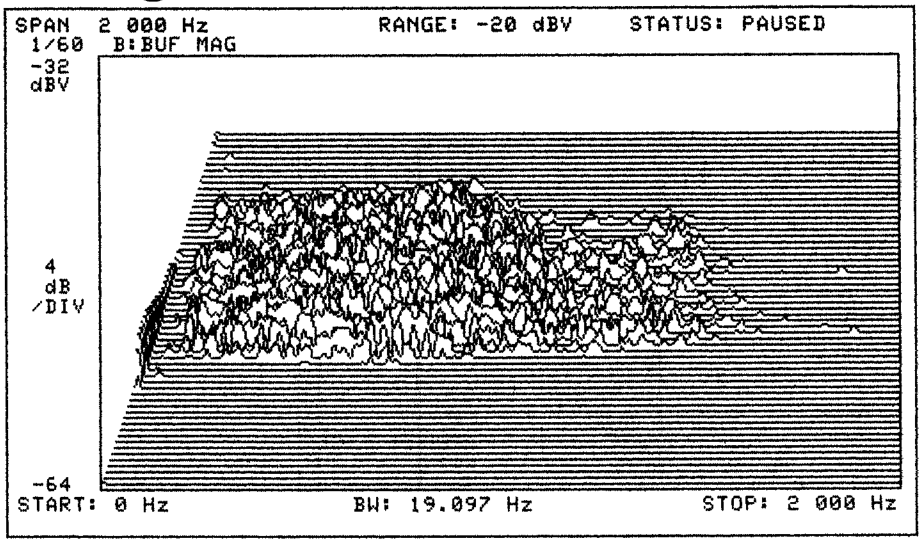

SPAN 2 000 Hz
RANGE: -20 dBV
STATUS: PAUSED
A:AVG MAG
RMS:40
-50
dBV
4
dB
/DIV
-82
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz
B:BUFFC(R)
100
mVolt
25
mVolt
/DIV
-100
START:-4 Sec
STOP: 4 Sec
X: 1120 Hz
Y:-62.38 dBV

FIG 7



SPAN 2 000 Hz
RANGE: -20 dBV
STATUS: PAUSED
A:BUFF(R)
40 mVolt
10 mVolt /DIV
-40
START:-375 mSec
STOP: 25 mSec
B:BUFFC(R)
100 mVolt
25 mVolt /DIV
-100
START:-4 Sec
STOP: 4 Sec

FIG 8



SPAN 2 000 Hz
RANGE: -20 dBV
STATUS: PAUSED
1/60 B:BUF MAG
-32
dBV
4
dB
/DIV
-64
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz

FIG 9

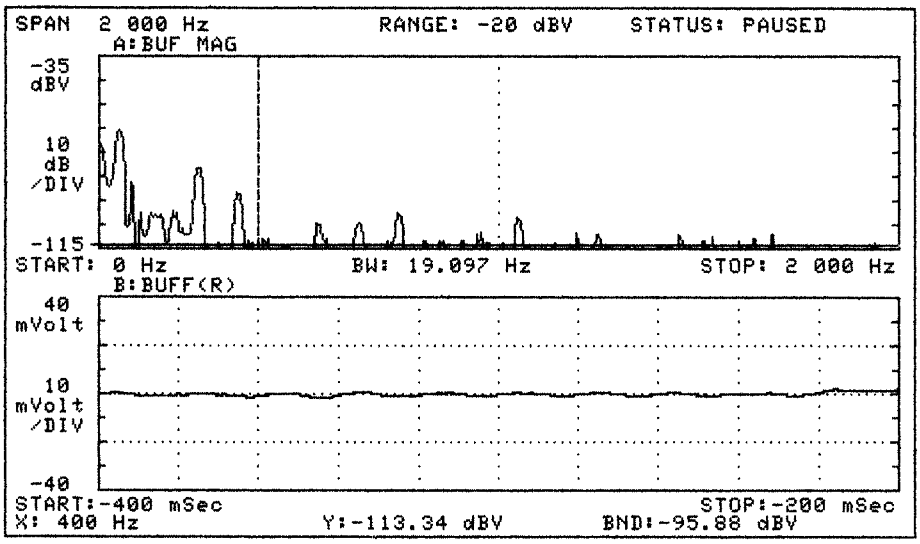
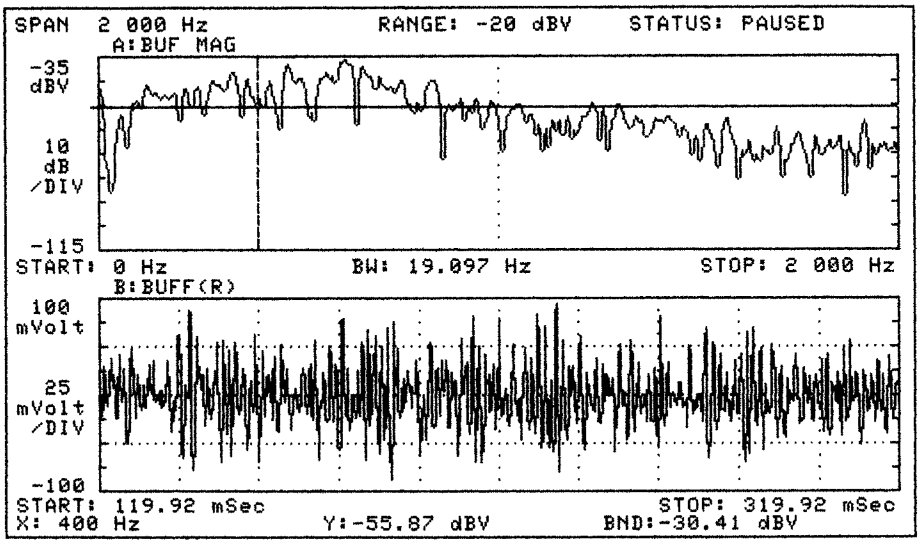

SPAN 2 000 Hz
RANGE: -20 dBV
STATUS: PAUSED
A:BUF MAG
-35
dBV
10
dB
/DIV
-115
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz
B:BUFF(R)
40
mVolt
10
mVolt
/DIV
-40
START:-400 mSec
STOP:-200 mSec
X: 400 Hz
Y:-113.34 dBV
BND:-95.88 dBV

FIG 10


SPAN 2 000 Hz
RANGE: -20 dBV
STATUS: PAUSED
A:BUF MAG
-35 dBV
10 dB /DIV
-115
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz
B:BUFF(R)
100 mVolt
25 mVolt /DIV
-100
START: 119.92 mSec
STOP: 319.92 mSec
X: 400 Hz
Y:-55.87 dBV
BND:-30.41 dBV

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