Brass wind instrument impulse response measurements. A. H. Benade (Case Western Reserve University, Cleveland, OH 44106) and J. H. Smith (SUNY Albany, Albany, NY 12222)

Apparatus has been built for pulse reflectometry of brass instruments. The current version uses spark excitation and an electret microphone at the mouthpiece rim terminating plane. Selectable low pass filtering in the microphone channel reduces noise and aids in the visual interpretation of reflected pulses via control of signal bandwidth. Discontinuities of air column cross section, taper, etc. can be located and identified using familiar techniques from electrical reflectometry. Multiple-reflection patterns characteristic of prototype musical shapes must be taken into account. These are being worked out. Reflectogram FFT's give input impedance functions in good agreement with those obtained via swept frequency capillary excitation methods. Studies of several tubas show that availability of both time and frequency domain representations of the response function greatly increases diagnostic power for the evaluation and correction of instruments. Comparisons will be made with reflectometer data of Krüger (Zwota, DDR) and the tuba impedance measurements of Caussé (IRCAM, Paris). [Work supported by NSF.]

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Back in 1966 one of us (AHB) put together a very simple pulse reflectometry apparatus which was first used by a student (John Rosenberg) who did a Junior Lab experiment with it (as so often has been the case for preliminary bright ideas in the acoustics work in Cleveland).

Robert Pyle was probably the stimulus for this early effort, since we had corresponded about similar experiments of his own already by 1965-66.

TRANSPARENCY 1 Traced from Rosenberg's CRT Polaroid Photo. My interest at the time was centered in the relation between round trip group and phase repetition times which are required for decent playing, so the modification of pulse shape by the bell alone was of considerable interest. A paper on this was read at an ASA meeting back in 1968.

Another use of this original reflectometer had to do with scattering at valve ports, etc. in brass instruments. Observations on this were presented at the 1968 wind instrument symposium which was part of the Fall ASA meeting in Cleveland.

When my colleague Jack Smith was negotiating to spend a sabbatical semester in Cleveland this spring, his interest in tubas fit rather well with my own desire to make a new stab at the reflectometry business -- especially since now the FFT makes it worthwhile to deduce the input impedance $\sim p(\omega)$ calculated as a transform of the impulse response $p(t)$.

The present discussion is in the nature of a status report, as much to tell you about unsolved problems as to describe solved ones.

TRANSPARENCY 2 This shows the general nature of our set up. In addition we used a cascaded 1kHz, 2kHz low pass pair of filters to make sure the electrical crud was down to a reasonable (negligible) level. Note the electret mike ($3.00 from Radio Shack). These are made on a printing press and are as like as peas in a pod! They have become work horses around our lab. B and K equipment serves us mostly for calibration.

TRANSPARENCY 3 We see here the first two reflections in a cylindrical pipe. The data here are read from the digital (t) storage (before the transform) from a Unigon 4512 RTA.

(a) Notice that the detailed shapes of the reflected pulses look like the initial pulse -- (radiation is almost negligible in the 1kHz band width of the signal). This similarity of initial and later waveforms proves that the nonpropagating near field coupling between source and mike is negligible -- spark at center, mike halfway out as recommended by Keefe and Benade in our recent paper.

(b) If we look at a longer time span, e.g., 250 msec, we often see a base line drift that changes from one pulse to the next. This is due to local heating effects, etc.

TRANSPARENCY 4 Here is a similar, short-term trace for a King Tuba.

This instrument was given to AHB in pieces by the manufacturer, measured by JHS, before everything was carefully fitted together for soldering.

(a) Note the complicated shape of the initial pulse. We see a back-kick plus heavily damped ringing near the mpc popping frequency (358Hz) (period = 2.8 msec). The complicated pulse shape has to do with the very non-cylindrical entry way of the horn.

(b) Note that the first return pulse is inverted as one would expect from the open bell, but also note the immediately-following noninverted pulse. Thé lip-reed thus gets its next same-polarity stimulus at a time a little longer than the simpleminded round trip time.

One can make up some 2-bit theories from hornology as to how the bell at one end [recall Transp. 1] and mouthpiece at the other can appear to quasi-differentiate the pulse once per round trip.

TRANSPARENCY 5 This trace of p(t) covers a longer time.

(a) Notice all the features remarked on before -- but also notice that the interpretation -- remarks just made don't quite hold up in the light of experimental fact.

(b) For future reference I want to point out that the squiggliness of the waveform does not decrease much over the entire 250 millisec. This means that the high frequency damping is not taking much of a toll -- The horn's bell radiation does not really take hold till about 450 or 500 Hz (by calculation and other data that will be presented shortly).

(c) The conclusion from (b) is that we expect the Fourier transform and thence $Z_m(\omega)$ to have well-developed peaks and dips out to $\simeq$ 450 Hz or so.

(d) To harp on this a little more: We notice the wiggles on the initial pulse back-kick (associated with a 350Hz f_p) are slower then the very spiky main pulse, and the spikyness of the p trace even to the end of the trace.

TRANSPARENCY 6 Here is the Averaged Fourier transform of a couple of hundred pulses of the sort shown in the preceding slide.

(a) The measured positions of the first half dozen peaks (using a cursor on the UNIGON) match very well with the pianissimo playing frequencies of notes based on these resonances (i.e., playing at a level where inter-mode coupling does not alter the behavior and only one air column mode governs the oscillation). This matching holds for all valve combinations on the horn. It is true also for observations on a dozen other instruments by all makers which were rounded up by Jack Smith with the active connivance of Ronald Bishop, our tubist with the Cleveland Orchestra. His help, interest and advice have been appreciated by one of us for many years, and by the other for several months. For purposes of diagnosing horn diseases via the input impedance curve we have gained something useful.

(b) All is not rosy however. The painstakingly reiterated proofs earlier in this report that we should see resonance peaks out to 450Hz or so, simply does not fit our data on any horn! This fact gave us increasing discomfort as we chewed over its possible causes.

TRANSPARENCY 7 This shows the input impedance Z_{in} for two Alexander F tubas. One belongs to the Cleveland Orchestra and was measured by us. The other was measured by René Caussé at IRCAM in Paris.

(a) Look at our Z_{in} for the first valve position. Note the loss of peaks at exactly the same frequency as we found on the much smaller King instrument. Again this is a general remark which applies to data taken with all valve combinations.

(b) Look now at the direct impedance measurement of the tuba as obtained in Paris. Peaks exist all the way across the graph! Caussé's apparatus is a magnificently documented setup using a Backus type annular capillary. The apparatus is otherwise a much improved version of one which we have used for many years in Cleveland. Caussé's apparatus is the first to surpass, much less equal the one developed by Earle Kent at Conn in the 1950's. In any event the resonance curve shown here is to be taken at face value, as being entirely correct. We need to understand then why our Fourier transformed impulse response curve differs from it.

(c) Notice that the overall pattern at lower frequencies of the Z envelope differs between the two horns. This fits with the fact that the Cleveland Instr. is intensely disliked by Ron Bishop -- stuffy, etc., etc. This part of our measurement is almost certainly correct, since it can be cross-checked in a number of ways.

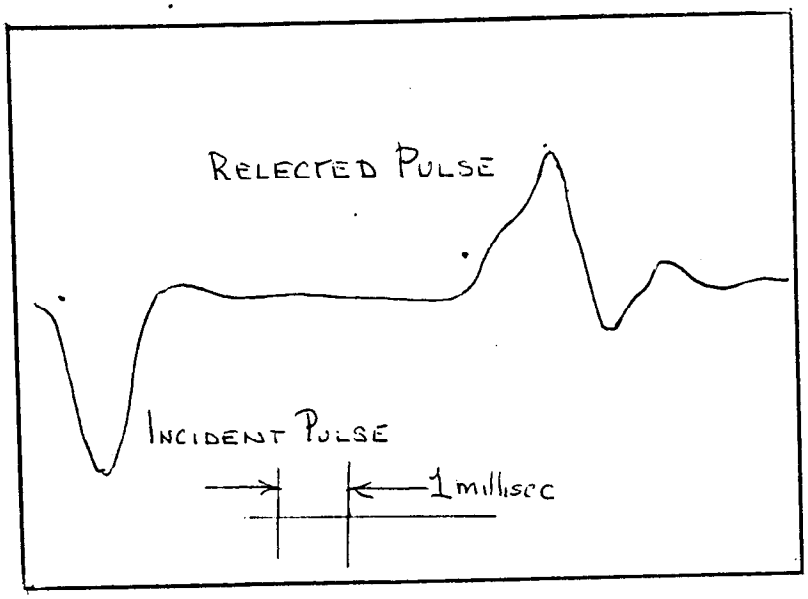
(d) The question remains is the cause of our loss of high frequency Z peaks in the FT when their p(t) precursors are clearly visible in the primary data? The question was troublesome for a long time, and its eventual answer lies in the fact that our synchronization arrangements between spark and analyzer were not adequate. The Unigon machine averages by finding the vector sum of the successive phasors at each analyzed frequency point. Time jitter in triggering leads to negligible phase jitter in the lower frequency components. The high frequency components (whose periods correspond roughly with the magnitude of the jitter) will be washed out by the piling up of random-phase contributions from the successive impulse responses. This phenomenon is an embarrassment. There is another FFT analyzer in the lab with choice of summed-phasor or rms averaging, and its controls have always been set deliberately in a suitable manner for the job at hand. We simply overlooked the problem.

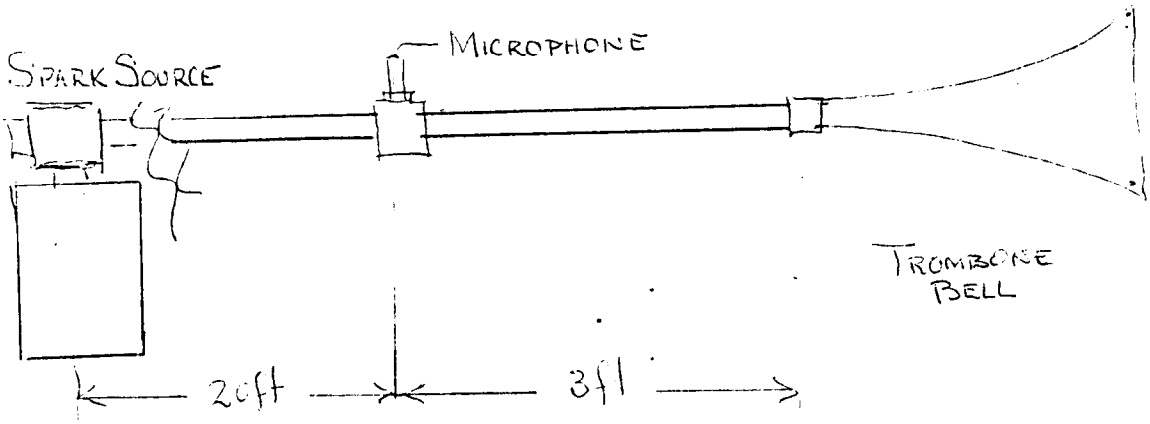
The original pulse excitation apparatus itself, (with improved synchronizing pulse facilities!) is now in Albany. A second version, designed primarily to work with smaller diameter air columns is being constructed in Cleveland.

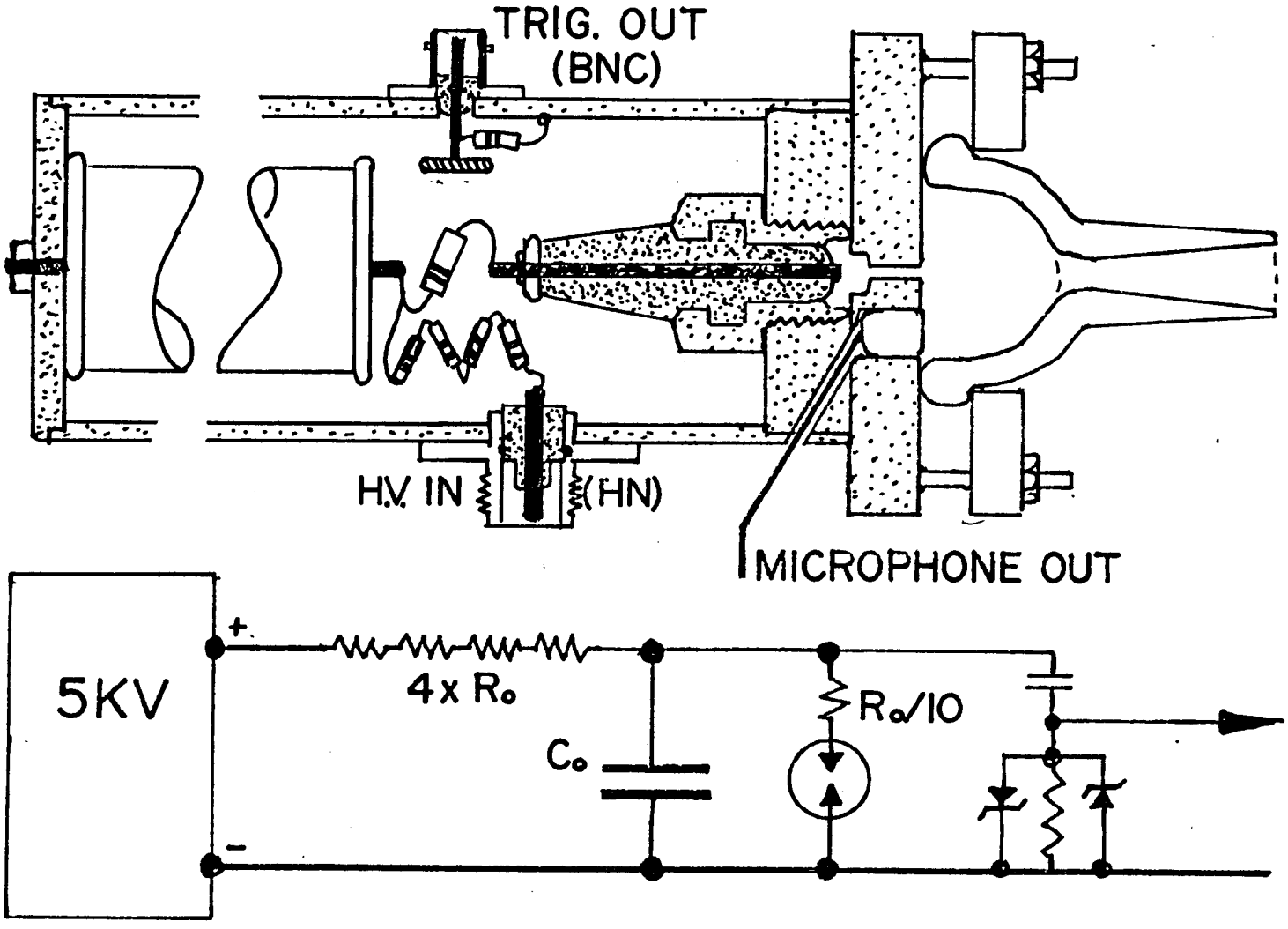
JUNIOR LAB PROJECT, JOHN M ROSENBERG

APRIL 1966

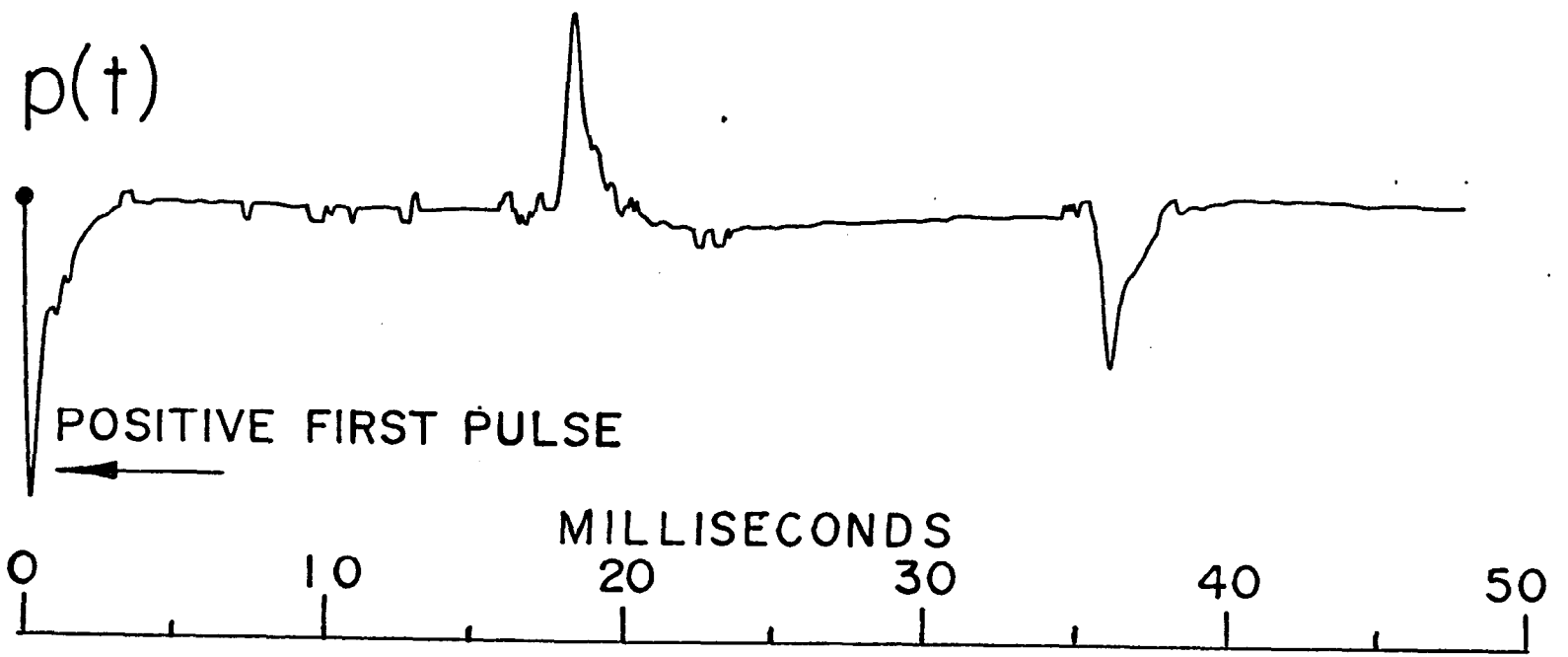
PULSED ACOUSTIC REFLECTOMETER

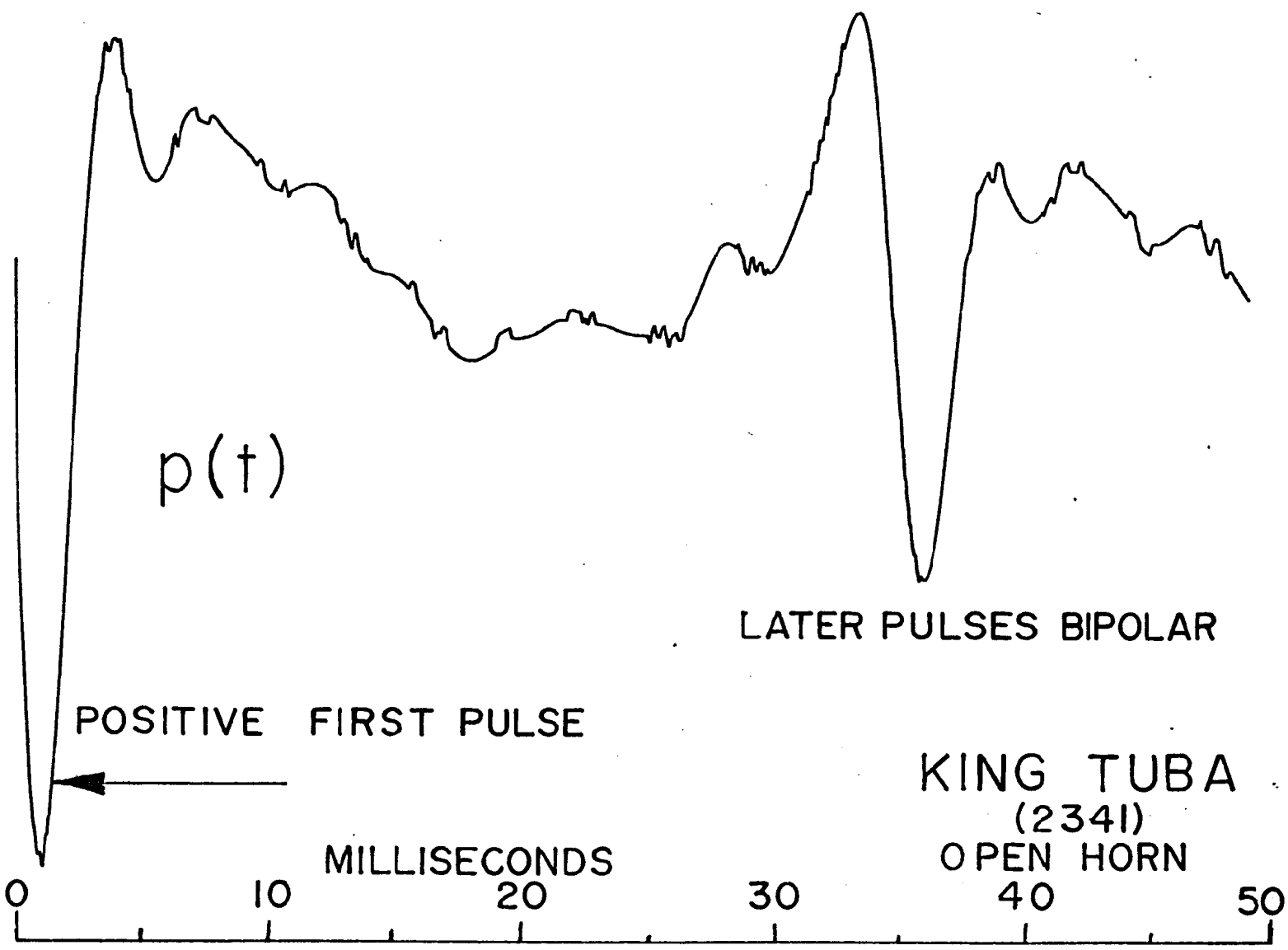


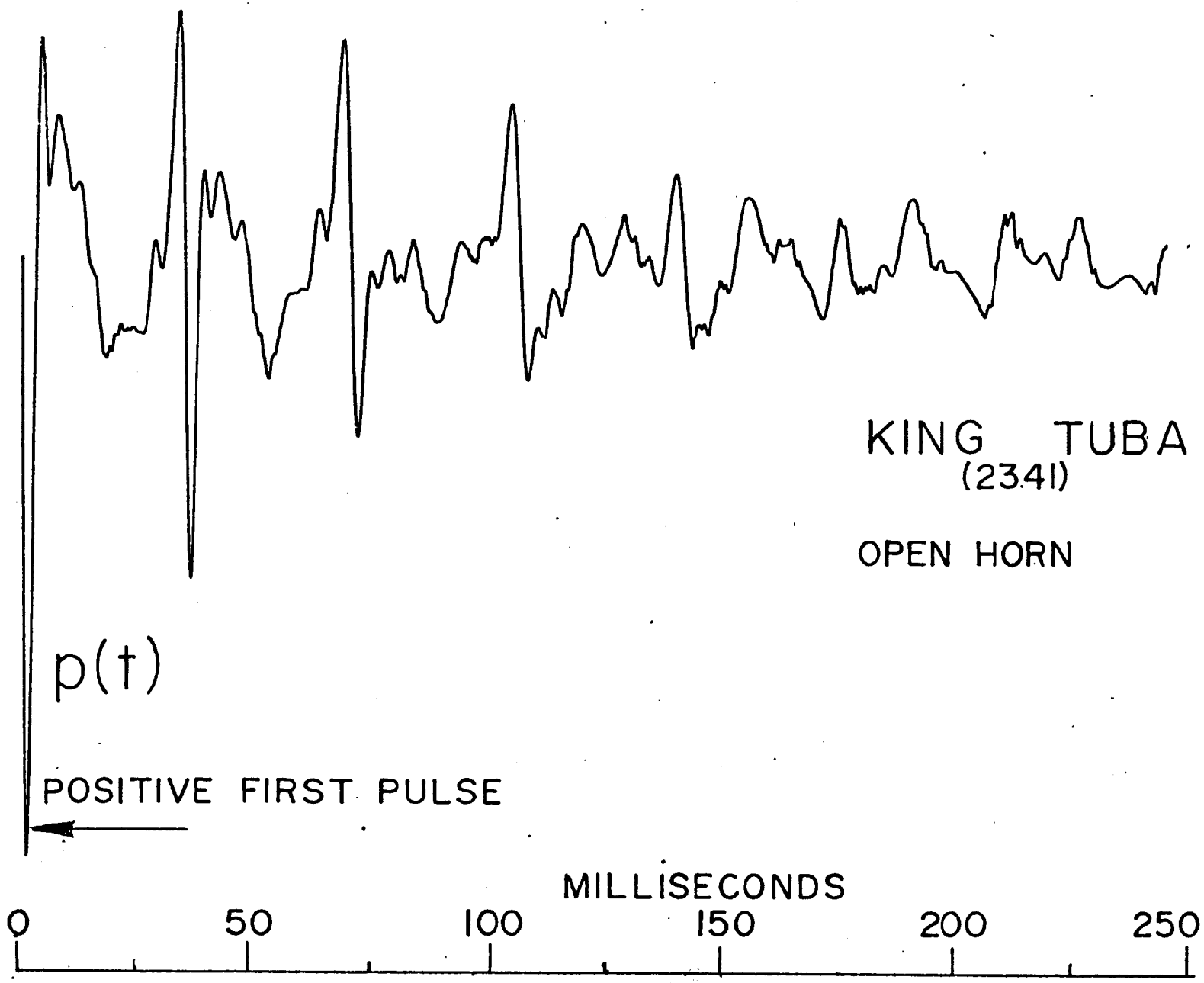


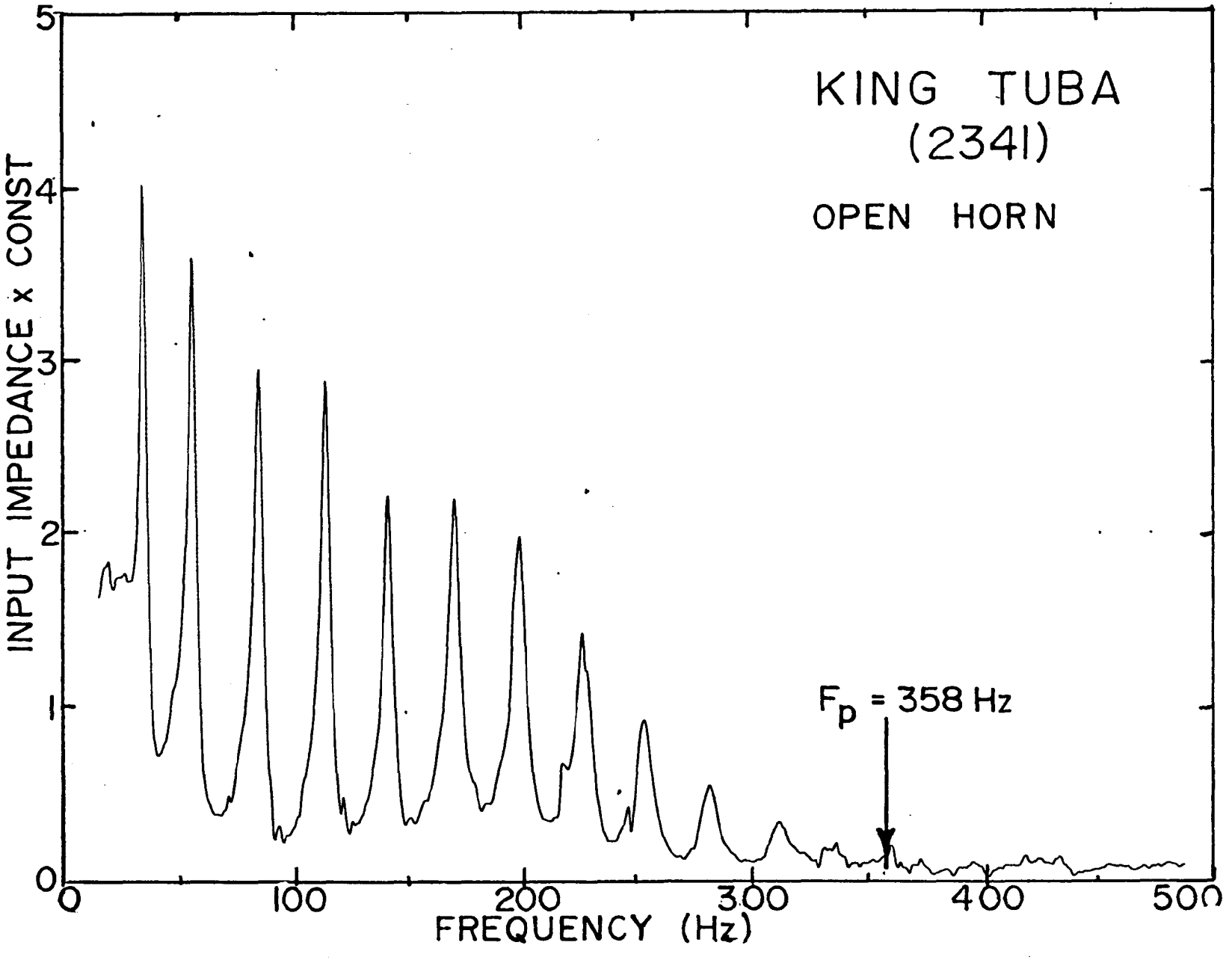

TRIG. OUT
(BNC)
H.V. IN
(HN)
MICROPHONE OUT
5KV
+
4x Ro
Co
Ro/10
-

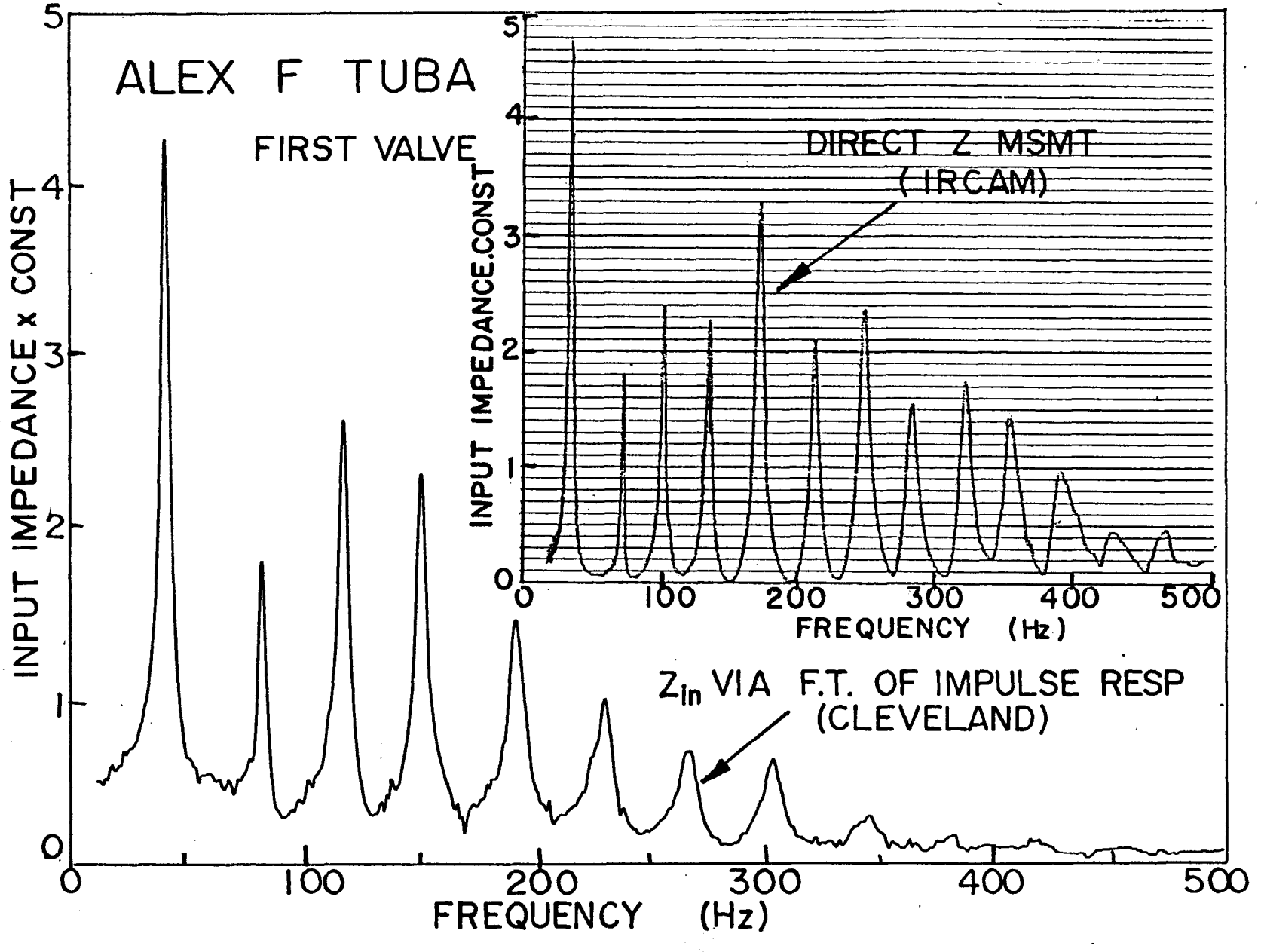
CYLINDRICAL PIPE, OPEN END
LENGTH 3.05M




p(t)
LATER PULSES BIPOLAR
POSITIVE FIRST PULSE
KING TUBA
(2341)
OPEN HORN
MILLISECONDS
0
10
20
30
40
50


KING TUBA
(2341)
OPEN HORN
p(t)
POSITIVE FIRST PULSE
MILLISECONDS
0
50
100
150
200
250


KING TUBA
(2341)
OPEN HORN
F_p = 358 Hz
INPUT IMPEDANCE x CONST
FREQUENCY (Hz)
0
1
2
3
4
5
0
100
200
300
400
500


ALEX F TUBA
FIRST VALVE
INPUT IMPEDANCE x CONST
FREQUENCY (Hz)
0
100
200
300
400
500
1
2
3
4
5
DIRECT Z MSMT
(IRCAM)
INPUT IMPEDANCE.CONST
Z_{in} VIA F.T. OF IMPULSE RESP
(CLEVELAND)