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Research Report

Signal Processing Analysis of the Kennedy Assassination Tapes

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Abstract: On the basis of analysis by two research groups of impulses identified as "shots" on a 5-minute continuous recording of Dallas Police Department Channel I, the House Select Committee on Assassinations concluded that "scientific acoustic evidence establishes a high probability that two gunmen fired at President John F. Kennedy." The Report of the Committee on Ballistic Acoustics of the National Academy of Sciences (May, 1982) demonstrated that the signals in question were recorded about a minute *after* the assassination, that they contained an image of words (from DPD Channel II) spoken well after the assassination, and that the overlying words were recorded from the radio together with the impulses (and hence were not added later). This report documents the objective computer signal-processing approach we used in correlating two-dimensional sound spectrograms, expands on the effect of Channel-I heterodynes on Channel-I audio and on the Channel-II imprint, and details the use of fortuitous Channel-II "brief tones" to measure the transmission from Channel II to Channel I. We demonstrate also the [sic] the notorious "bell" on Channel I is present on Channel II at the same instant, as determined by a cross-talk tiepoint between channels, but is not cross-talk. It must be electrical interference superimposed on both channels. Our digital data have been deposited with the National Academy of Sciences.

I. INTRODUCTION

On the day of the President Kennedy assassination, two Dallas Police Radio Channels were active and communications on these were routinely recorded. These channels were designated as Channel I and Channel II. Channel II was assigned to communications related to the presidential motorcade and was embossed on a Gray Audograph plastic disk. Channel I was to handle other routine Dallas Police radio communications and was embossed on a Dictaphone belt recorder model A2TC. Both recorders were sound-activated. At the time of the assassination, a microphone on a police motorcycle was stuck in the open position and transmitted continuously for about five minutes on Channel I, making a recording on the belt recorder.

The House Select Committee on Assassinations suspected that the motorcycle with the stuck-open mike may have been in the presidential motorcade and the officer may have incorrectly tuned his radio to Channel I. If this was indeed the case, the stuck-open mike may have picked up the gun-shot sounds, which would have been recorded. Although no shots could be heard on the recording, an acoustic analysis of the recording might reveal information as to the number of shots fired and their direction.

At the request of the House Select Committee on Assassinations, the Dictabelt recording was studied by James Barger, Scott Robinson, Edward Schmidt and Jared Wolf (BRSW) of Bolt Beranek and Newman Inc., and later by Mark Weiss and Ernest Aschkenasy (WA) of Queens College. In an initial report to the committee on Sep. 11, 1978, and in a later report in January 1979, BRSW concluded that the recording contains four sounds, which they attributed to probable gun shots and that with a probability of 50%, the third was due to a shot from the grassy knoll area of Dealey Plaza. Later WA studied the echo pattern of the "third shot" analytically and their conclusion was that with a 95% probability it represented a shot from the grassy knoll area. However their timings differed from BRSW timings by about 200 ms. BRSW subsequently reviewed WA results and agreed with their findings. This conclusion, together with the known shots from the Texas School Book depository, was the basis of the finding by the House Select Committee on Assassinations that "scientific acoustical evidence establishes a high probability that two gunmen fired at President John F. Kennedy."

On December 1, 1980, the Federal Bureau of Investigation (FBI) released a report, prepared by its Technical Services Division and dated November 19, 1980, with the findings that the above conclusion of the House Select Committee on Assassinations was not valid and that the acoustical evidence presented "did not scientifically prove that the Dictabelt recording on Channel 1 . . . contains the sounds of gunshots or any other sounds originating in Dealey Plaza. . . ."

The Committee on Ballistic Acoustics was established by the National Research Council in the fall of 1980 in response to a request from the Department of Justice for a review of the methodology employed in the evaluations of the recorded acoustic data and the conclusions about the existence of a shot from the grassy knoll. One of the authors of this report (RLG) was a member of this committee and the other two authors have collaborated with him in the investigation reported in this paper.

In the first months of its existence the Committee studied the analytical techniques used by BRSW/WA. As a result of these studies, Committee members, working from magnetic-tape copies of the embossed plastic recordings, found errors in the previous studies and faults of methodology. These faults were sufficiently serious that, by the end of the first Committee meeting, no member was convinced by previous analyses that there was a grassy knoll shot.

The Committee was greatly helped in its studies by the suggestion volunteered by Steve Barber, a private citizen of Mansfield, Ohio, that on Channel I overlying the relevant acoustic impulses there was an almost unintelligible voice communication which he thought was cross-talk from the Dallas Police Department Channel II, as heard on the tape copy of the Gray Audograph disk. The relevant phrase on Channel II was "hold everything secure until the homicide and other investigators can get there." We shall refer to this phrase as the "Hold-Everything" phrase. On Channel II this phrase occurs about a minute after the assassination. If the messages on the two recordings are the same and if they were recorded simultaneously, then the acoustic impulse pattern on Channel-I recording would be a minute too late to be shots. This is a very important piece of evidence and should be examined very carefully.

A natural explanation of this cross-talk is that the motorcycle with the stuck-open mike may at times have been close to another motorcycle which had its radio tuned to Channel II. Thus the stuck-open mike may have picked up parts of the Channel II communications and rebroadcast them on Channel I. If this was indeed the case, we might get a series of tie points between two radio recordings with identical "real" timings. This will of course not give absolute timings on the two channels but at least provide relative timings between the two.

The two recording machines were sound activated by the audio arriving at the DPD radio room over telephone lines from remotely located receivers. They would stop recording if the silence between communications lasted more than 4-6 seconds. During the critical minutes, the Channel-I recorder worked continuously because the transmitter with the stuck-open mike was transmitting continuously. Most of the time, it transmitted only motorcycle engine noise and other ambient noise picked up by the stuck-open mike. Occasionally it would transmit cross-talk from Channel II if a receiver tuned to Channel II was its vicinity. In any case, during those five minutes, because of the continuous recording, time differences on Channel I tape should equal "real" time differences (although the speed of neither recorder was closely controlled nor even precisely constant). On the other hand, Channel II recording was not continuous; on the tape, there are several silences of more than 4 seconds which might represent Channel-II recorder silent periods of any duration greater than 4 seconds. Thus the time differences between tie points on Channel-II tape may be less than (or at most equal to) time differences on corresponding tie points on Channel-I tape.

On Channel II, the "Hold-Everything" phrase is about 3.5 seconds long. During this part of the Channel-I recording, there is fairly heavy noise, presumably due to the motorcycle engine, and the Committee could not (by listening) confirm the presence of cross-talk in this region of the recording. Therefore, spectral analysis of the relevant portion of the recordings was done in order to confirm or deny the hypothesis of cross-talk. By visual inspection of the two spectra, 27 spectral features were identified and matched. Their relative timings and frequencies were compared. Timing and frequency *independently* indicated a speed difference of 6.7% between the recordings. After correcting for this speed difference, timing and frequencies of these features on both the recordings matched with good accuracy. Since feature matching is a subjective process, a more objective experiment of cross-correlating the two spectra was carried out at IBM. This experiment is described in more detail in the next section.

Another instance of cross-talk is present in the phrase "You want me to still hold this traffic on Stemmons until we find out something or let it go?" ("Stemmons" phrase). For this phrase, just by listening alone, the cross-talk is clear and the two spectra match very well (after correction for the difference in recording speeds on the two channels). This phrase is about 4.5 seconds long and occurs 170 seconds after the "Hold-Everything" phrase on Channel I. On Channel II, the time difference is only 125 seconds. This difference of 45 seconds is, as explained above, due to the Channel-II recorder stopping during several silences.

II. CROSS-CORRELATION OF POWER SPECTRA

Spectral feature matching is a subjective process. A more objective experiment is to compare the two spectra by calculating a measure of their similarity. The cross-correlation coefficient ρ between two functions X and Y is defined as

$$\rho = [\, \Sigma X \cdot Y \,]/[(\, \Sigma X^2 \,)\cdot(\, \Sigma Y^2]^{1/2}$$

where the summation is carried out over a suitably placed window on the spectra X(t,f) and Y(t,f). One can compute ρ as a function of time displacement between the two spectra by sliding one spectra over the other, if the relative timing of the two sources is not known.

Because of phase distortion introduced by various communication/recording processes, we did not look for phase correlation between the two spectra. Therefore, the calculation of correlation was limited to spectral intensities (squared magnitudes of the Fourier transform). For the purpose of power spectral computation, the signal was sampled at 20 kHz; length-400 blocks (equivalent to 20 ms) were formed for Fourier transformation; before transformation the sequences were multiplied by a window and then transformed using length-400 FFT. This resulted in power spectra with 50 Hz resolution. The effect of the window is to broaden pure tones to about 2-3 frequency bins (100-150 Hz). In the time domain, these blocks were 50% overlapped, thus a new FFT was computed every 10 ms.

Let $S_1(t,f)$ and $S_2(t,f)$ represent power spectra of the two channels, where t is a multiple of 10 ms and f is a multiple of 50 Hz. Although FFT computes power spectra up to 10 kHz (the Nyquist rate), there is very, little energy in Channel-I spectra beyond 3 kHz and in Channel-II spectra beyond 4 kHz.

Assuming that the two spectra contain a common audio signal, they should correlate well if they are properly aligned and corrected for difference in the recording speeds of the two devices. On the other hand, the two spectra would not correlate well if they are not properly aligned in time or if the speed difference is not properly corrected. It is sufficient to correct only one of the recordings for the speed difference; without loss of generality, we apply correction to the Channel-II spectra and introduce another parameter W, the spectral warp factor which is the ratio of the two recording speeds.

The spectral warping essentially stretches one of the axis (time or frequency) by W and compresses the other axis by W (W may be less than or greater than 1). ρ (τ,W) is computed as a function of W and the time difference τ between the two spectra. For a particular value of W and τ, $\rho(\tau,W)$ will be maximum, indicating correct speed compensation and time alignment.

When the Channel-II recording (on its Gray Audograph disc) was played back on the Audograph, the reproducing needle frequently slipped resulting in "repeats." The reproductions of Channel II first used by the Committee had several repeats, as did those used by previous investigators. To avoid this problem, Committee members played the Gray Audograph disc on an audio turntable which gave a repeat-free recording but resulted in another problem because the Gray Audograph was recorded at a constant *linear* speed. Since the audio turntable operated at a constant *angular* speed, the resulting variable warp had to be compensated during power spectra computation. This variable warp (speed linearly varying with time due to turntable playback) is combined with the fixed warp W (to compensate for the speed difference in original recordings) in computing the Channel-II power spectra which is on the same time and frequency scale as Channel I. From now on we shall not refer specifically to the variable warp introduced by the playback mechanism as it is predetermined and fully compensated during processing, but we shall search for the fixed warp factor W which maximizes the correlation peak.

On examination of the two spectra, we noticed that Channel-I spectra fell off faster with frequency than Channel-II spectra, indicating that the frequency response of the transfer function from Channel II to Channel I dropped with frequency. To compensate for this drop in Channel-I spectral level, high frequencies of Channel-I spectra were boosted at a rate of 6 dB per 1000 Hz. We also noted large Channel-I energy in low frequency region, presumably due to the motorcycle engine noise. Since this is not expected to be correlated to Channel II. we did not consider power spectra below 600 Hz for the purpose of correlation. Similarly, since there is very little Channel-I energy beyond 3500 Hz, higher frequencies were neglected for the purpose of correlation. Another characteristic noted was that while Channel-II energy remained fairly constant from frame to frame (10 ms), there was a wide fluctuation in Channel-I energy (as it later turned out in our work, this was due to AGC action in Channel-I receiver, discussed in a later section of this report). To compensate for this variation, we normalized Channel-I energy to remain constant from frame to frame. To summarize, for the purpose of computing correlations, only frequency bins in the range 600-3500 Hz were considered, and high frequencies of the Channel-I spectra were boosted at a rate of 6 dB per 1000 Hz and, then normalized to a constant energy in the band of interest.

Correlation as a Function of Time

The two phrases ("Hold-Everything" and "Stemmons") on Channel I were correlated against the corresponding segments on Channel II. To do this, first Channel-II power spectra was compensated by a warp factor which gave the largest correlation peak and then a 2.5 seconds segment of Channel-I spectra was slid against a corresponding 10 seconds segment of Channe1-I1 spectra. This gave 750 correlation coefficients (different values of τ spanning a period of 7.5 seconds with a spacing of 10 ms) which are plotted in Figs. 1 and 2.

If the two spectra were identical, the peak value of ρ would be 1, which is the maximum possible value of the correlation coefficient. But because of the extraneous noise and sounds present in Channel I, this value will never be achieved. Since both the spectra are positive valued functions, their correlation will always be positive and this explains the background level present in these figures. Superposed on this background is a narrow large peak and several broad minor peaks. For both the phrases, the main peaks are similar and narrow (about 70-80 ms wide) and stand out clearly against the background. For the "Hold-Everything" phrase, the absolute value of the peak is somewhat low because during this phrase Channel I is very noisy. During the "Stemmons" phrase, Channel I is less noisy and this is reflected in a higher correlation peak. But for both the phrases, the background level is about the same and the shape and width of the central peak is similar. This clearly proves that the two channels have a common audio signal.

Correlation as a Function of Warp

We also computed correlation for different values of warp (W). For each value of warp, $\rho(\tau,W)$ was computed and its peak compared with the peak for the optimum value of warp ($W_{,opt}$). Table 1 summarizes these results.

	$\rho(W)/\rho(W_{opt})$	
W/W_{opt}	"Hold-Everything"	"Stemmons"
0.96	0.669	0.452
0.97	0.738	0.616
0.98	0.789	0.758
0.99	0.913	0.922
1.00	1.000	1.000
1.01	0.922	0.896
1.02	0.851	0.777
1.03	0.772	0.615
1.04	0.648	0.462

Table 1. Cross-correlation Coefficient vs. Warp W.

From this table we note that the correlation peak decreases sharply as move away from the optimum warp. This also strengthens our conclusion that these large correlation peaks were not obtained by chance. This clearly establishes that there is an imprint of Channel II on Channel I. But the spectral matching is not perfect; in particular for the crucial "Hold-Everything" phrase (the so-called shots are supposed to be present on Channel I during this phrase), there are several instances of poor match. Also, the wide variation in Channel-I signal level is not explained.

At this stage of the Committee investigation, BRSW put forward another hypothesis to explain the cross-talk. They suggested that the cross-talk may have been picked up accidentally during a rerecording of the two channels. Their hypothesis was that at some time after the assassination, the Channel-I recording was being rerecorded acoustically, while Channel II was being played across the room. Although it is not a very tenable suggestions and it does not explain most of the detailed findings, the possibility that Channel II cross-talk was superimposed later (perhaps by design!) was investigated.

III. ANOTHER COMMON PHRASE

As mentioned earlier, the time interval between the two phrases is not identical on the two channels. The difference is 45 seconds and causes difficulties for the rerecording hypothesis. More such instances would provide very significant evidence for or against the rerecording hypothesis. Therefore, we looked for more instances of a common phrase (tie points) on the two channels. One more such instance was found in the phrase, "I am up on Stemmons. I will check all these motorcycle radios." This is about 3 seconds long and occurs just before the "Stemmons" phrase; therefore, we shall refer to it as the "Pre-Stemmons" phrase. This occurs about 16 seconds earlier than the "Stemmons" phrase on Channel I and about 13 seconds earlier on Channel II. This 3 seconds difference in relative timings is important. It is very unlikely that in a later superposition, relative timings would differ by 3 seconds over such a short interval. This is however consistent with our hypothesis that the Channel-II recorder stopped during the silence between these two phrases, as it was designed to do.

We sought additional ways to test whether the cross-talk was added to an existing recording or whether it could be shown that the cross-talk was already present in Channel I when it was being recorded over the radio. This would eliminate the possibility of its being superimposed later and thereby conclusively show that the impulse pattern on the tape is not due "Shots."

IV. CROSS-TALK ANALYSIS

Figures [3, 4 and 5] are plots of spectra of two channels for the three phrases in question (we have deposited data on magnetic tape for these and other spectra referred to in this paper with the National Academy of Sciences Archives). In these figures, the spectra for the two channels are placed side by side, on the same time/frequency scale, and are time aligned. The horizontal scale is in seconds but actual numbers have no significance; they are only for reference purpose. Figures 4 and 5 have a common time origin. Note that the time scale on Figure 5 is compressed by a factor of 2 to accommodate a longer duration on this segment. On Figure 4, the time difference between two channels is 4.38 seconds. On Figure 5, the time difference is 7.15 seconds, indicating that the Channel-II recorder had stopped for (7.15 - 4.38) = 2.77 seconds. The vertical scale is frequency in kHz. As mentioned earlier, a spectrum is computed every 10 ms with 50-Hz resolution. Each of these value is plotted, if it is above a certain threshold, with a grey dB-scale for each plot. Values above a second threshold give completely black area. The grey scales also indicate the two thresholds for each plot. The frequency range is restricted to 4 kHz.

Channel-I Heterodynes

On Channel-I spectra, several narrow-band high-energy tones are intermittently present for short durations. These tones are not on Channel II. Also at the end of each tone. there is evident a sharp drop in total Channel-I energy. This indicates some kind of AGC (Automatic Gain Control) action.

These narrow-band tones are called heterodynes. They were generated when another transmitter came on the radio channel, while the transmitter with the stuck-open mike was transmitting. The difference in their carrier frequencies resulted in the heterodynes. If the second carrier is strong. it should also activate the AGC action in the IF (Intermediate Frequency) stage of the radio receiver. The following table lists all the heterodynes on Channel I for the spectra segments shown in Figures [3(a), 4(a) and 5(a)].

Table 2. Channel-I Heterodynes.

Figure	Heterodyne Timings Seconds
3(a)	9.52 - 9.64
3(a)	10.78 - 10.93
4(a)	7.91 - 8.83
5(a)	20.17 - 21.23
5(a)	22.41 - 22.49*
5(a)	25.81 - 26.30

*Note this heterodyne is around 1200 Hz.

Channel-I AGC

Most radio receivers have an AGC circuit at IF stage to maintain a steady IF signal level at the detector or discriminator. If there is a sudden increase in the RF signal (such as caused by switching on a strong carrier). AGC acts rapidly to reduce the IF amplifier gain to bring down the signal within acceptable limits. On the other hand if there is sudden decrease (such as caused by switching off a strong carrier) in the RF signal level, AGC acts more slowly to restore the IF amplifier gain. This is a typical characteristics [sic] of an AGC circuit: fast attenuation and slow recovery. The AGC action also affects the audio output level because of the drop in overall gain of the system. Therefore, when a heterodyne begins, we should expect a sudden drop in the recorded level of the signal picked up by the stuck-open mike. And after the heterodyne ends, we should expect a slow recovery in the audio signal to its original level. This phenomenon is indeed observed in Channel-I spectra.

If the Channel-II cross-talk was indeed picked up by the stuck-open mike, its level should change to reflect Channel-I receiver AGC action. To test this hypothesis, we estimate the level of cross-talk as a function of time and compare with timing of Channel-I heterodynes. Before we look at it quantitatively, let us examine the spectra again.

Channel-II Brieftones

On Channel-II spectra (Figs. [3, 4 and 5]) we note that during voice transmissions there are no silence gaps between words. The signal level of Channel II is fairly constant. This could result from the presence of nearby motorcycle radios tuned to Channel II, while someone is transmitting on Channel II. A radio receiver close to a transmitting mike could form a closed loop having greater than unity gain. This will excite a natural frequency of the loop and it will act as an oscillator. The resulting oscillations will be recorded on the Channel-II recorder. We notice this phenomenon on Channel-II recording. During these periods, the spectra consist of a strong sinusoid (in the frequency range 1300-1800 Hz) and its harmonics. There is virtually no other signal present during these periods. We call these "Brieftones." Being high energy and very narrow-band, these are extremely valuable in determining the cross-talk level. On Channel II spectra (in Figures 4(b) and 5(b)) I second harmonics of brieftones are quite prominent, while on Channel I spectra, all the Channel-II brieftones are present but their harmonics are not visible, indicating the limited frequency range of Channel I (even in the normal recording of Channel-I communications, the Channel-I recording has a similar roll-off at high frequencies.).

Estimation of the Cross-talk Level

We can model Channel-I power spectra as follows:

$$S_1(t,f) = S_2(t,f) \cdot F(f) + N(t,f)$$

where,

$S_1(t,f)$ is Channel-I spectra at time t,

$S_2(t,f)$ is Channel-II spectra at time t,

$N(t,f)$ is spectra of additional Channel-I noise, heterodyne, etc.,

$F(f)$ is the frequency transfer function from Channel-II to Channel-I, and

$T(t)$ is the time-varying cross-talk level.

Our main interest is in estimating the T(t) function. As mentioned earlier, we obtain best estimates of T(t) from those time-frequency bins where Channel-II brieftones are present. In these bins, the Channel-II energy density is very high and therefore it is expected that N(t,f) term in the above equation would be small compared to the contribution from Channel II. This assumption may break down if T(t) is small. In any case this analysis gives an upper bound on T(t). Actual T(t) may be smaller reflecting the contribution from N(t,f) term. Since brieftones are confined to a narrow frequency range (typically two or three frequency bins), we can assume that F(f) is constant over this frequency range. Then, T(t) can be estimated from those time frames where a brief tone is present as

$$T(t) = \Sigma\, S_1(t,f) / \Sigma\, S_2(t,f)$$

where the summation is carried out only over the brief tone frequency bins.

T(t) is plotted in Figures [6, 7 and 8 where total Channel I and II energy are also plotted. In these figures, the bottom scale is Channel-II time (same as in Figures [3(b), 4(b) and 5(b)]), the top scale is Channel-I time (same as in Figures [3(a), 4(a) and 5(a)]), the left scale is for T(t) in dB, and the right scale is for total channel energy in dB. Channel-II energy is plotted as a solid line, Channel-I energy is plotted as a broken line, and the triangles represent T(t), which are plotted only for those frames where a Channel-II brief tone is present. Channel-I heterodynes are also marked on these plots.

Now we discuss implications of these plots. We shall begin with the "Pre-Stemmons" phrase (Figure 7). During this phrase, T(t) is generally increasing reaching a value of about 7 dB before the Channel-I heterodyne begins at 7.91 seconds (Channel-I time). For the next Channel-II brieftone (from 3.90 to 4.16 seconds, Channel-II time), T(t) is around -10 dB; a drop of 17 dB. This Channel-II brieftone is clearly visible on Channel-I spectra (Figure 4(a)), although greatly attenuated. This is a clear indication of the effect of Channel-I AGC (due to a Channel-I heterodyne) on the cross-talk level. This also indicates that the Channel-II cross-talk was already present in Channel-I signal when it was being received by the Channel-I radio receiver/recorder. In the other two phrases also we find similar indications of cross-talk being received over the radio. This rules out the possibility of it being superimposed later acoustically or electrically.

Next, we examine the "Stemmons" phrase (Figure 8). In this segment, a Channel-I heterodyne ends (at 21.23 seconds, Channel-I time) just before the Channel-II communication begins (at 14.18 seconds, Channel-II time). During the first Channel-II brief tone (14.25 to 14.51 seconds, Channel-II time), T(t) function is increasing rapidly, registering a gain of about 10 dB. This indicates recovery of Channel-I AGC at the end of the heterodyne. There is a brief Channel-I heterodyne from 22.41 to 22.49 seconds, Channel-I time). This heterodyne is different from others in that it is around 1200 Hz while others are around 2500 Hz. Nevertheless, this heterodyne also activates the Channel-I AGC which is evident from the total Channel-I energy plot as well as the T(t) plot. Following this heterodyne the recovery is slow, taking about a second or so. There is another Channel-I heterodyne from 25.81 to 26.30 seconds, Channel-I time. A Channel-II brieftone was already present when this heterodyne began. The dramatic effect of Channel-I AGC, due to the heterodyne, is evident in T(t) plot which drops by more than 15 dB over a very short period. This is also clear on Figure 5(a) where the intensity of the Channel-II brief tone dramatically reduces as soon as the Channel-I heterodyne begins.

Finally, we examine the crucial "Hold-Everything" phrase (Figure 6) in the light of the above discussion. On Figure 6, we have also marked the timings of the third and fourth "shots" identified by BRSW and WA. The third "shot" is supposed to be a "shot" from the grassy knoll area. As mentioned before, this segment of Channel-I is very noisy. During this period, total Channel-I energy is also fluctuating widely. Due to the noisy conditions, the T(t) function is less stable, but, still we can see the effect (on T(t)) of the Channel-I AGC due to the two heterodynes present during this segment. This is particularly pronounced during the second heterodyne. This part is expanded and shown in more detail in Figure 9. A Channel-II brief tone had begun just before this heterodyne. Due to the Channel-I AGC action, the T(t) function drops by about 14 dB and then it appears to increase. This increase in T(t) estimate is perhaps due to presence of Channel-I noise in brief tone frequency bins. As explained before, the T(t) estimate is an upper bound, and the actual T(t) is likely to be smaller. The Channel-II brief tone reappears shortly after the heterodyne ends. During this AGC recovery phase, T(t) is steadily increasing, starting from a very low value and almost reaching the pre-heterodyne level. In this part also, some T(t) values are considerably higher than indicated by the general trend, due again to Channel-I noise present during this period. On Figure 3(a), we can clearly see (11.02 to 11.18 seconds, Channel-I time) a gradual buildup of the Channel-II brieftone as reflected on Channel-I.

From the above discussion, we come to a firm conclusion that Channel-II cross-talk was already present in the Channel-I radio signal when it was being received over the radio. This rules out the possibility of it being acoustically or electrically superimposed later. This is also true for the crucial "Hold-Everything" phrase which is supposed to contain the so-called "shots."

V. THE BELL SOUND

On the Channel-I recording, a bell-like sound is heard for about a third of a second, approximately four seconds after the end of the "Hold-Everything" phrase. BRSW have analyzed this sound and suggested it might be from a carillon bell. But no such bell could be located in the region where the motorcycle with stuck-open mike could be expected.

Steve Barber heard a similar sound on Channel-II recording at about the time displacement. On his information, we did a spectral analysis of the two recordings in this region. The two spectra are shown in Figure 10. They are on same scale and are aligned in time on the left which can be recognized as the second heterodyne of Channel I and the last brief tone of Channel II, in the "Hold-Everything" phrase. The bell sound is from approximately 14.45 to 14.80 seconds on Channel I (Figure 10(a), which has same time origin as Figure 3(a)) and 7.70 to 8.05 seconds on Channel II (Figure 10(b), which has a time origin different from Figure 3(b)). The two bell sounds are almost aligned. If there is any time difference, it is difficult to estimate as it is difficult to ascertain the exact starting time of the bell sound on both recordings.

The spectra of the bell sound contain two prominent tones around 1150 Hz and 1600 Hz. To ascertain if the two recordings have the same bell sound, we did a 10-Hz resolution spectral analysis of the bell segment and totaled energy in each frequency bin (up to 2500 Hz) in this segment. This is plotted in Figure 11. The two prominent peaks are at 1150 Hz and 1610 Hz on Channel I and at 1150 Hz and 1620 Hz on Channel II. These peaks are very sharp indicating them to be harmonics (pure tones) with a fundamental frequency of 230 Hz. At 230 Hz, Channel II has a prominent peak, and Channel I has a peak which is not very large in absolute terms but stands out against the background. This is perhaps due to some filtering on Channel-I recording which has attenuated low frequency components. The two prominent tones are fifth and seventh harmonics and their frequencies match exactly (within the 10 Hz resolution).

An interesting feature of this spectral segment is that other than these tones, the two recordings seem to have nothing else in common. This indicates that there was no cross-talk between the two channels during this segment and that *neither* recording was added on the other one at a later time. In this period, Channel-I spectra contain two strong heterodynes less than a second before the bell sound, which are clearly absent in Channel-II spectra. Likewise, during the bell segment itself, Channel-II spectra has very strong signal in 500-800 Hz range, which does not appear on Channel-I spectra. All these rule out the possibility of cross-talk from either channel to the other during this segment, implying that the bell sound was picked up independently by both the channels.

If the bell sound is due to a "physical" bell, the sound must have been picked up acoustically by the two channels. On Channel II, the sound occurs in the middle of a dispatcher transmission ("10-4, Dallas 1, station 5 will be notified.") This implies that the "bell" must be within earshot of the dispatcher's office and must be heard there. This also implies (since a time difference of 50 ms means a path difference of 50 feet) that the motorcycle with the stuck-open mike was not too far from the dispatcher's office which is in the downtown area far from the Dealey Plaza where the shooting took place. This in itself would invalidate the theory that *shots* were recorded on Channel-I tape.

Capt. James Bowles of Dallas Police Department informed us that there was no such bell in the neighborhood of the dispatcher's office and that the office is fairly well soundproofed making it impossible for such a bell to be heard inside the office. Steve

Barber who works with musical instruments insists that this is not a bell sound. Also the duration of the sound is too short (only 350 ms) to be due to a carillon bell. Furthermore, sound from a physical bell will have some sort of exponential decay while this sound exhibits a very abrupt beginning *and* end.

With the above discussion, we conclude that this sound is not from a physical bell but perhaps an electrical disturbance which was independently picked up by both the channels which have many common carriers and components. Nevertheless, the "bell" is strong corroboration of our timing analysis, as this is certainly a tie point between two channels which happened in real time.

If such electrical disturbances are picked up on these recordings, there must be other such examples. Indeed, Steve Barber heard another bell-like sound on the Channel-II recording a little after 12:46 during another dispatcher transmission, "We should know something before long."

This bell sound is broken in two segments, with voice in between, and sounds like ding-dong. Figure 12 is the spectra of the sound. In this spectral calculation, no correction was made for the warp introduced by the turntable playback. Therefore on this spectra, the time scale appears compressed and accordingly the frequency scale expanded. The two bell segments on this figure are approximately from 10.40 to 10.60 and 10.85 to 11.10 seconds. Because of the warp, actual time intervals are longer than indicated.

On these spectra we notice horizontal bars which appear to be the harmonics of some base frequency. To confirm this, we did another high resolution spectral analysis (10-Hz resolution) and totaled the energy in each frequency bin for the two segments separately. This is plotted in Figure 13. The two most prominent tones in the first segment (10.40 to 10.60 seconds) are at 870 and 1310 Hz, which appear to be second and third harmonics with a base frequency of 435 Hz. There is another prominent tone at 1150 Hz which is not harmonically related to the other two tones. For the second segment (10.85 to 11.10 seconds) the two most prominent tones are at 850 and 1280 Hz which appear to be the second and third harmonics with a base frequency of 425 Hz. There is another prominent tone at 1610 Hz which is not harmonically related to the other two tones.

This bell sound is not heard on the Channel-I recording at a corresponding time. One likely explanation is that the Channel-I recorder was in the stop mode at that time. Even in the record mode, this electrical disturbance may not have been picked up by the Channel-I recorder. The presence of this second bell sound interrupted by voice and at *12:46* points to its likely origin as an electrical disturbance rather than an actual bell.

VI. A TIME-DOMAIN PICTURE

In this report, we examined the data only in the frequency domain. Just to complete the picture, Figure 14 is the time envelope of the Channel-I signal for the "Hold-Everything" phrase. The so called "Third-Shot" and "Fourth-Shot" have been indicated on this figure. The spikes represented by these shots do not stand out as clearly against the background as many others in the same *brief* period. In fact they do not appear any different from numerous other spikes present in this brief period. There is no a priori reason to believe that these spikes represent "shots."

The Channel-I AGC behavior, following the two heterodynes at 9.52 and 10.78 seconds, is also clearly brought out by this picture; rapid attenuation and slow recovery is clearly seen in this figure.

VII. SUMMARY

Objective cross-correlation analysis of Channel-I and Channel-II recordings demonstrate common signals on both channels. The content of the signal on Channel II (and on Channel I) at the time of the so-called shots indicates that it originated about a minute after the assassination. Using Channel-II "sing-around" brief tones as probing signals, the transfer function between Channel II and Channel I is objectively estimated. *Heterodynes* on Channel I are demonstrated to reduce the transfer function drastically and to allow it gradually to recover after the heterodyne disappears, demonstrating both the presence of AGC *and* that the cross-talk was present at the radio receiver and could not possibly have been added later to the audio recording. The notorious "bell sound" is shown to be an electrical disturbance recorded simultaneously on both channels, verifying the derived relative speed and timing of the two channels. Therefore, the so-called "shots" are not the recording of *anything* at the time of the assassination.

REFERENCES:

1. Appendix to Hearings Before the Select Committee on Assassinations of the House of Representatives Ninety-Fifth Congress, Volume VIII, U.S. Government Printing Office, Washington, D.C., 1979.

2. N. F. Ramsey, *et al,* "Report of the Committee on Ballistic Acoustics," National Academy Press, May, 1982.

3. Committee on Ballistic Acoustics, "Reexamination of Acoustic Evidence in the Kennedy Assassination," *Science,* pp. 127-133, Oct. 8, 1982.

4. In order to make this material available for other independent studies, digital data for all the spectra referred to in this paper have been deposited on a computer tape with the National Academy of Sciences Archives (202-334-2417). Copies are available from the National Academy of Sciences for a nominal fee.

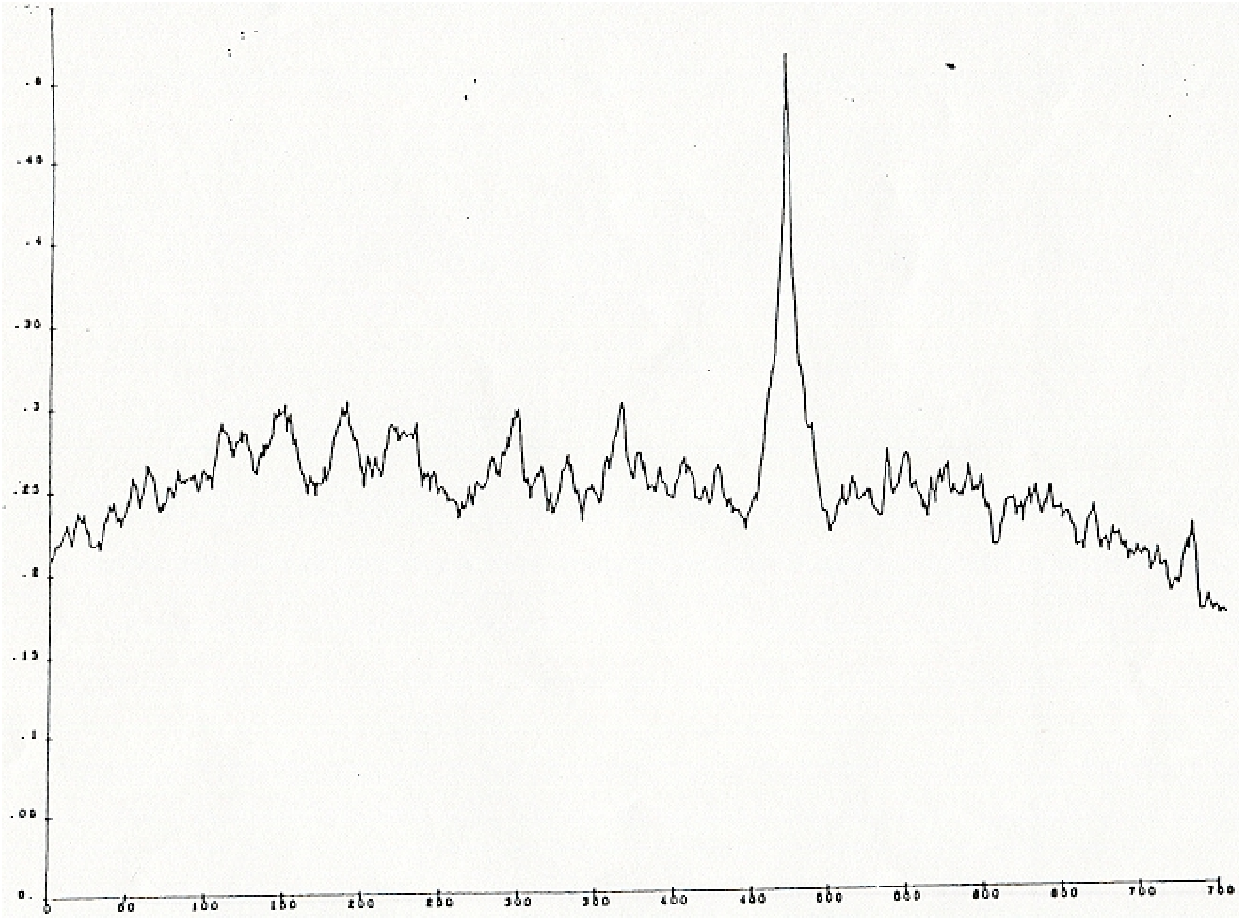

Figure 1. Cross-correlation between "Hold-Everything" segments of Channel I and II spectra. The curve is produced by sliding 2.50 secs of the Channel-I spectra along 10.00 secs of the Channel-II spectra, 0.01 sec at a time, using frequencies in the band 600-3500 Hz. The horizontal axis is time (centiseconds) and the vertical axis is the corss-correlation coefficient (ρ).

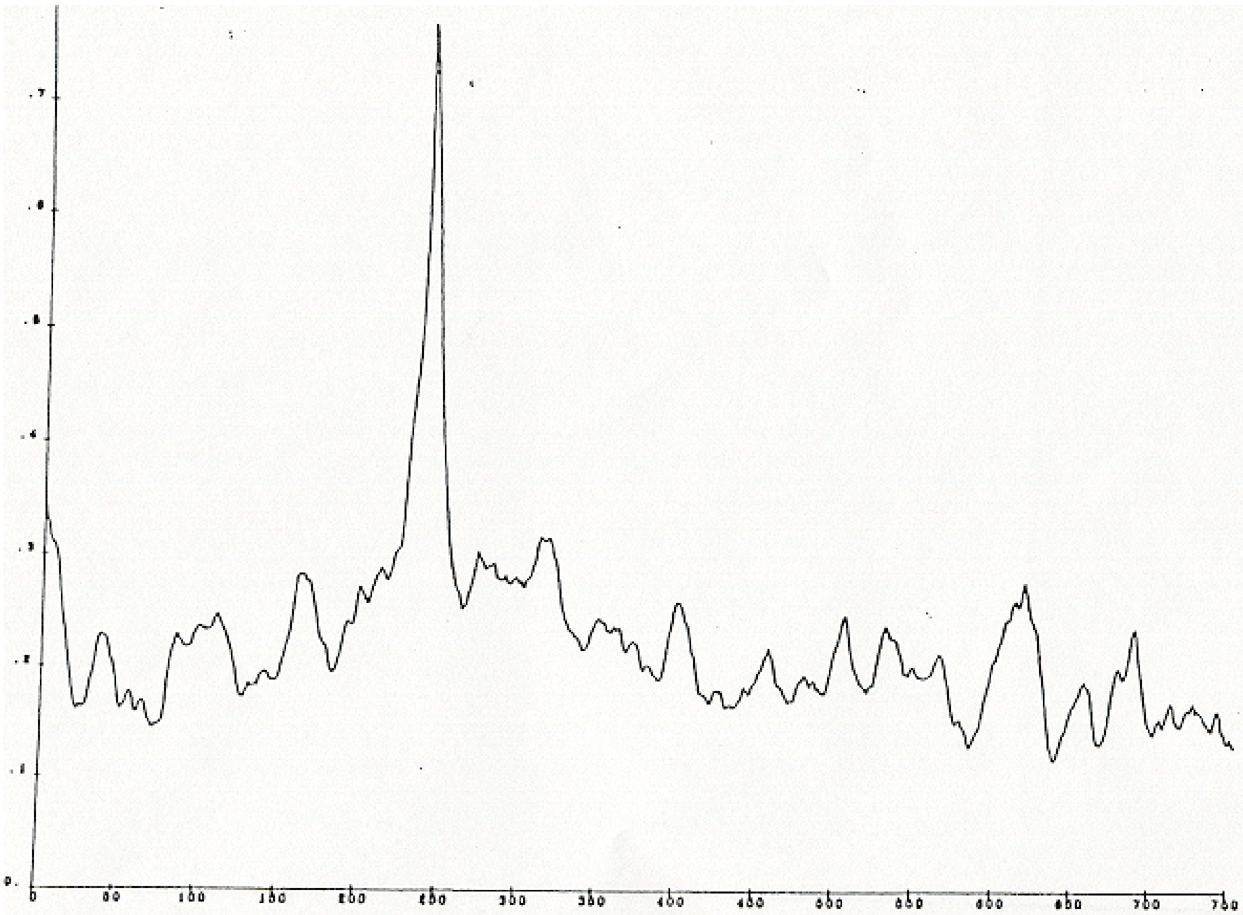

Figure 2. Cross-correlation between "Stemmons" segments of Channel I and II spectra. The curve is produced by sliding 2.50 secs of the Channel-I spectra along 10.00 secs of the Channel-II spectra, 0.01 sec at a time, using frequencies in the band 600-3500 Hz. The horizontal axis is time (centiseconds) and the vertical axis is the corss-correlation coefficient (ρ).

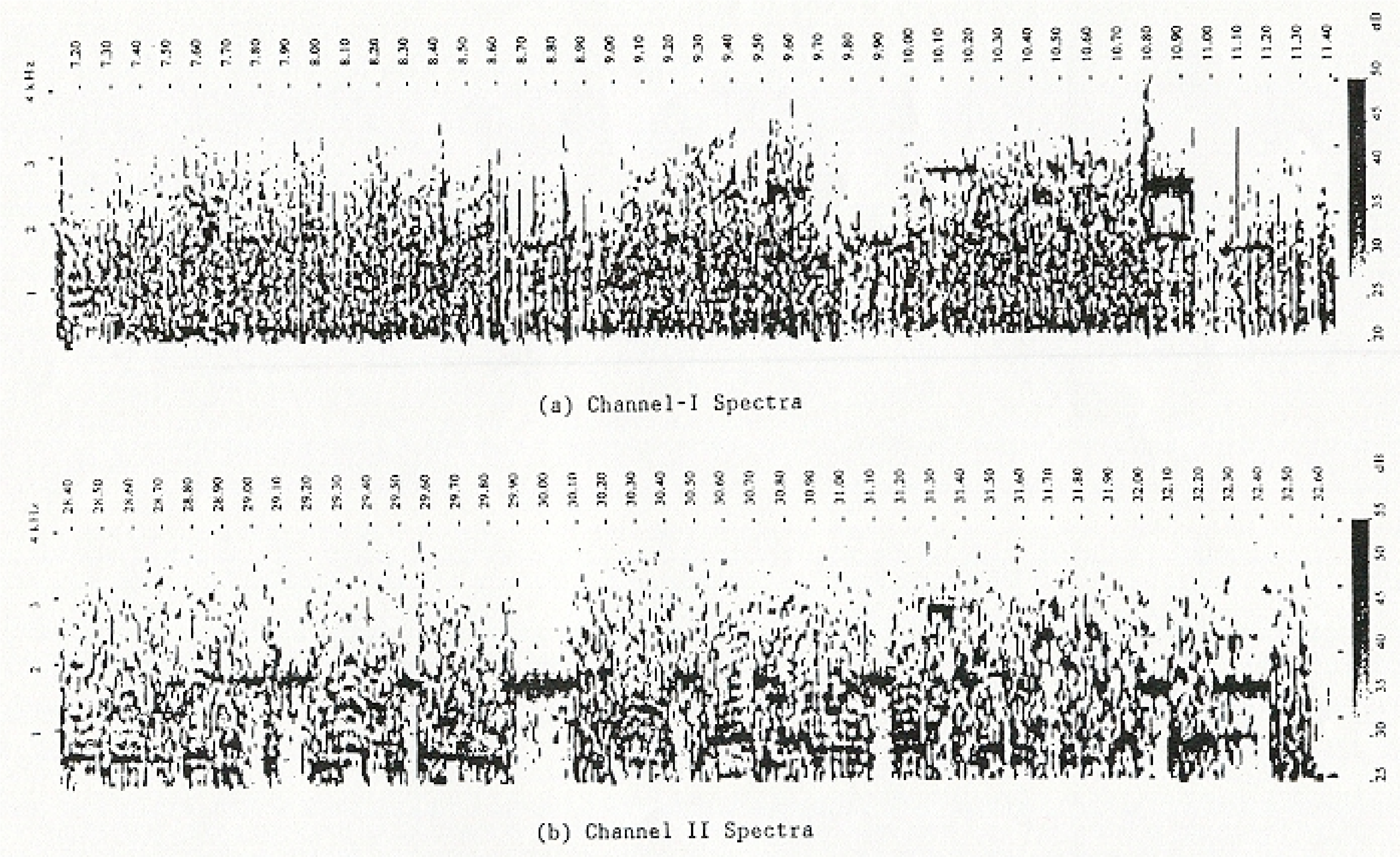

Figure 3. Spectra of Channels I and II for the "Hold-Everything" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The grey intensity-scale (dB) is indicated at right. Note the reduced Channel-I spectral intensity following the two heterodynes (9.52 to 9.64 and 10.78 to 10.95 secs).

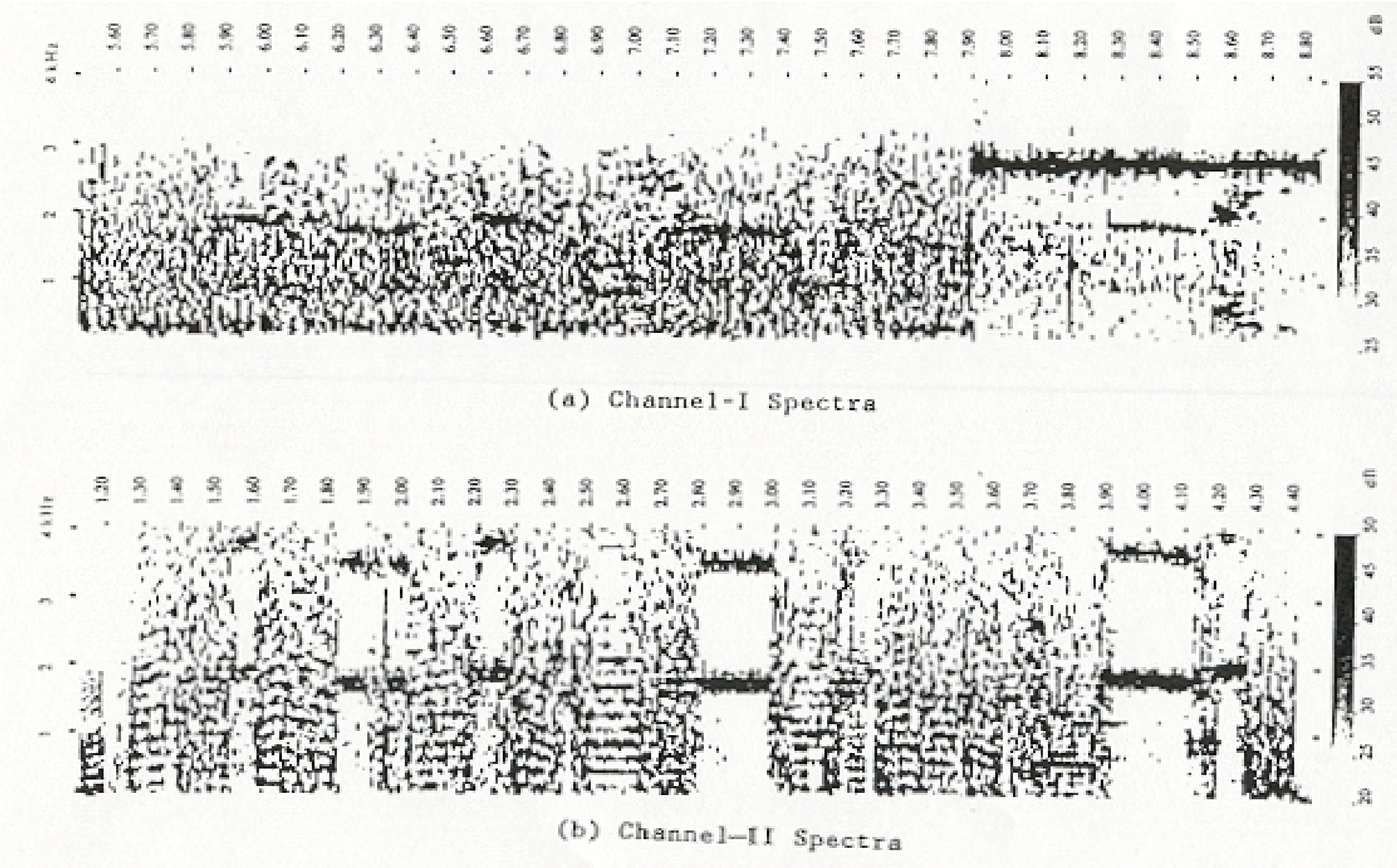

Figure 4. Spectra of Channels I and II for the "Pre-Stemmons" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The grey intensity-scale (dB) is indicated at right. Note the reduction in the Channel-I background and the Channel-II cross-talk level as the heterodyne begins at 7.91 secs.

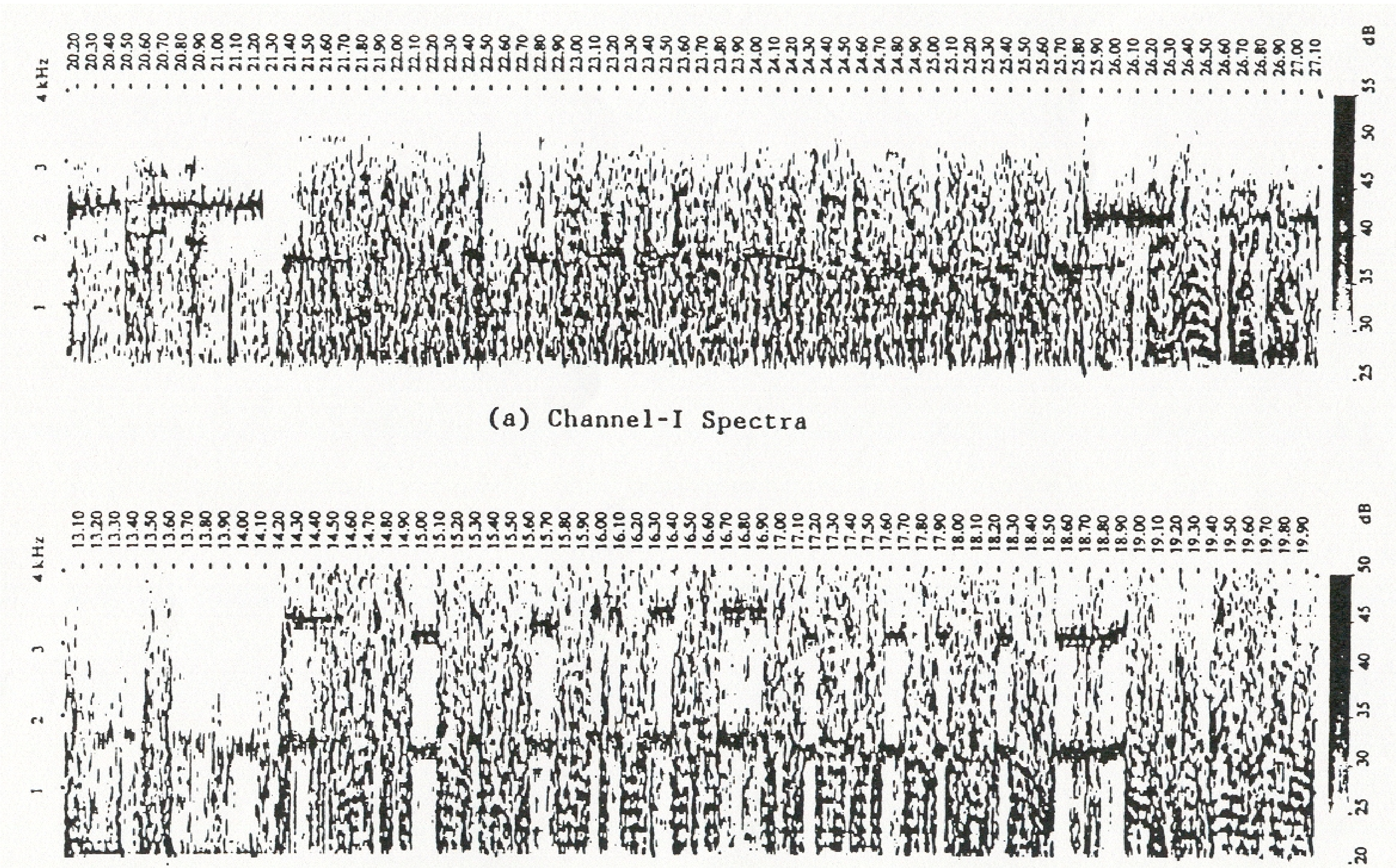

Figure 5. Spectra of Channels I and II for the "Stemmons" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The grey intensity-scale (dB) is indicated at right. Note the abrupt reduction of the Channel-II brieftone level in the Channel-I spectra as the heterodyne begins at 25.81 secs.

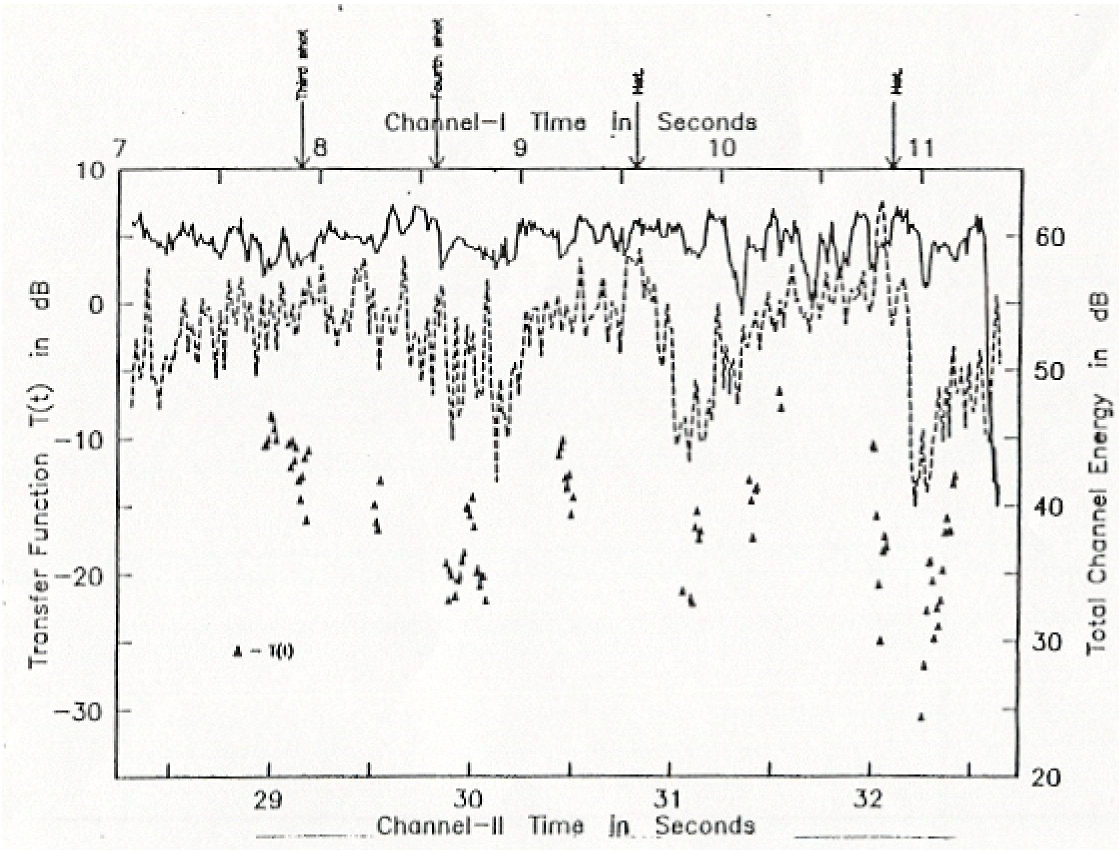

Figure 6. Plot of total Channel energy and the transfer function T(t) from Channel II to Channel I, for the "Hold-Everything" segment. The solid curve is for the Channel-II energy and the broken curve is for the Channel-I energy. T(t) (represented by Δ) is plotted only for frames containing a Channel-II brieftone. Timings of the "Shots" and the Channel-II heterodynes are also indicated. Note the AGC behavior following the second heterodyne.

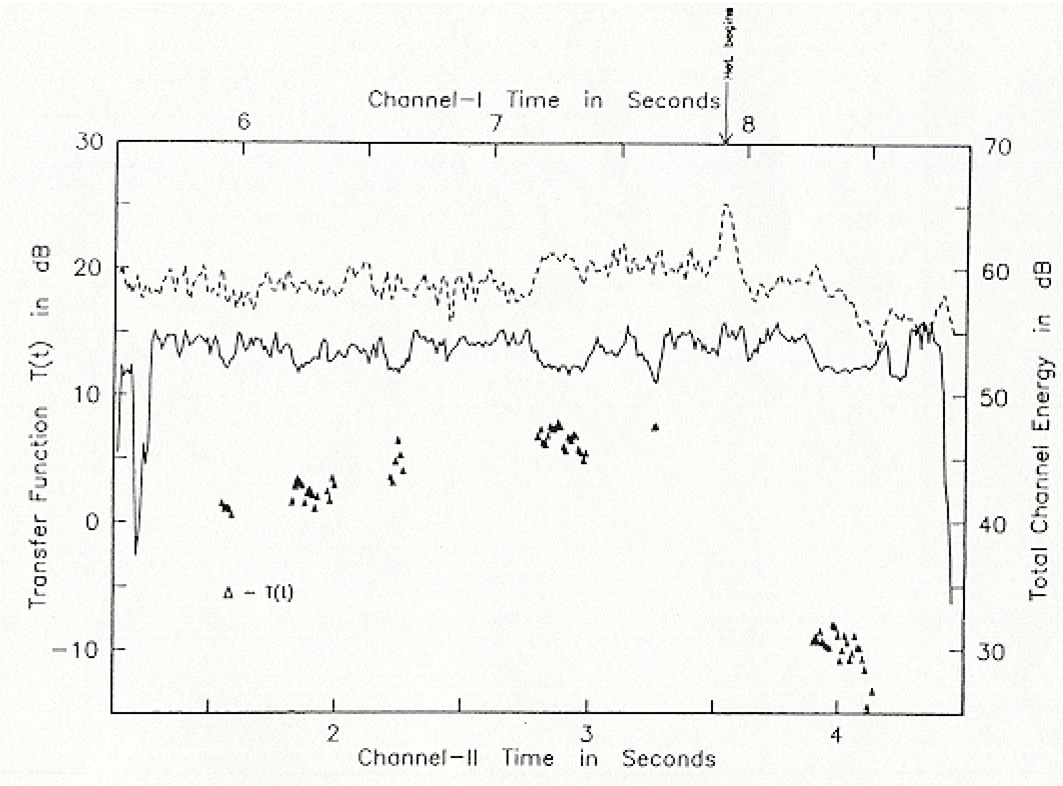

Figure 7. Plot of total Channel energy and the transfer function T(t) from Channel II to Channel I, for the "Pre-Stemmons" segment. The solid curve is for the Channel-II energy and the broken curve is for the Channel-I energy. T(t) (represented by Δ) is plotted only for frames containing a Channel-II brieftone. Timings of the "Shots" and the Channel-II heterodynes are also indicated. Note the large reduction in T(t) after the Channel-I heterodyne begins.

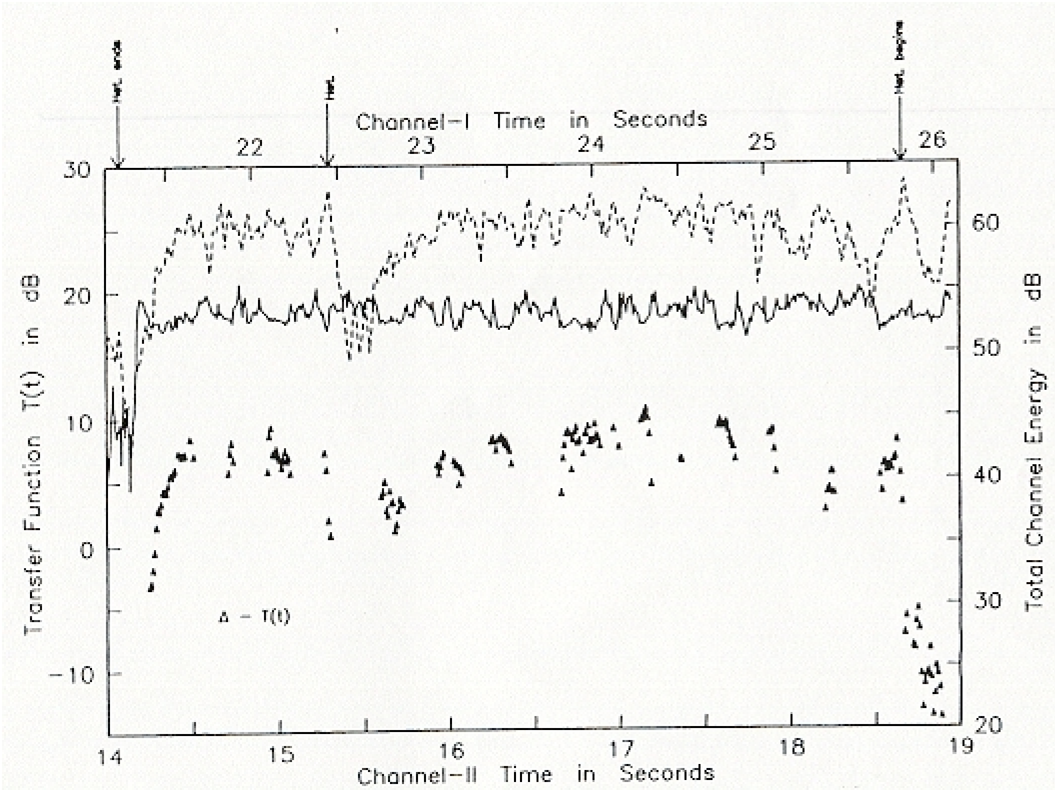

Figure 8. Plot of total Channel energy and the transfer function T(t) from Channel II to Channel I, for the "Stemmons" segment. The solid curve is for the Channel-II energy and the broken curve is for the Channel-I energy. T(t) (represented by Δ) is plotted only for frames containing a Channel-II brieftone. Timings of the "Shots" and the Channel-II heterodynes are also indicated. Note the slow recovery in T(t) at the end of a Channel-I heterodyne at 21.23 secs. Also note the abrupt reduction in T(t) as a Channel-I heterodyne begins at 25.81 secs.

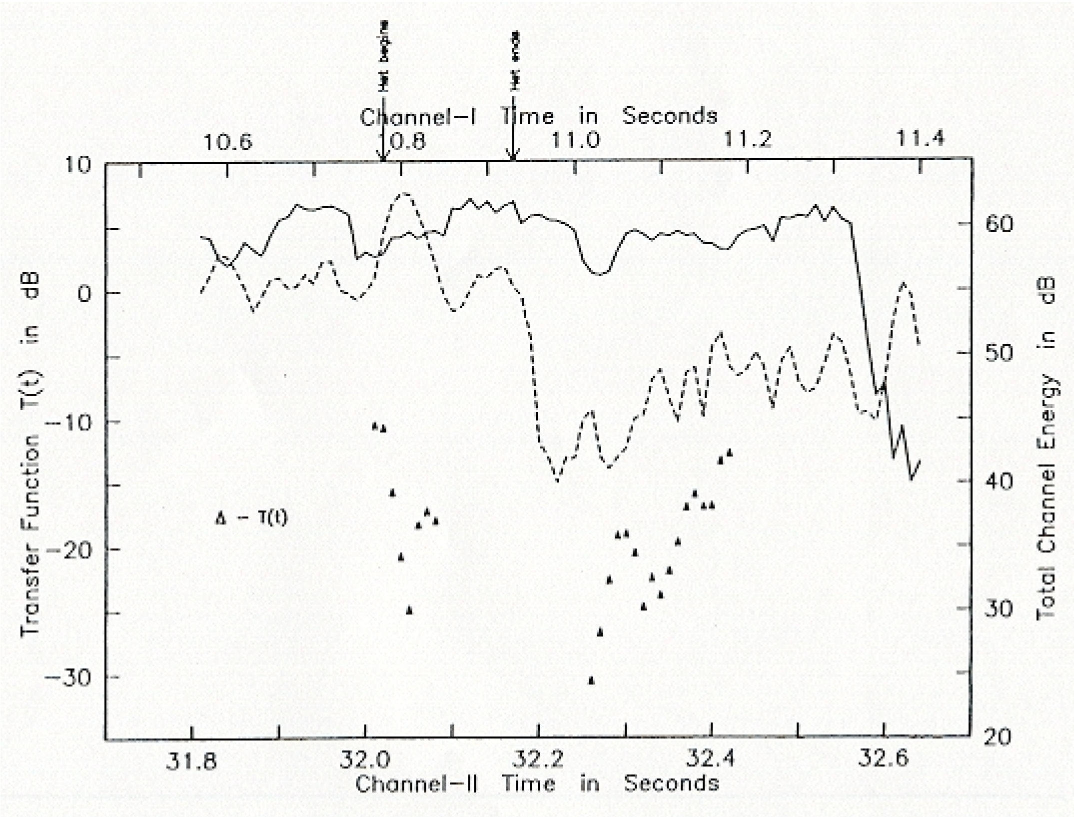

Figure 9. Plot of total Channel energy and the transfer function T(t) from Channel II to Channel I, for the last part of the "Hold-Everything" segment. The solid curve is for the Channel-II energy and the broken curve is for the Channel-I energy. T(t) (represented by Δ) is plotted only for frames containing a Channel-II brieftone. Timings of the "Shots" and the Channel-II heterodynes are also indicated. Note the drop in T(t) as the heterodyne begins and its recovery after the heterodyne end [sic].

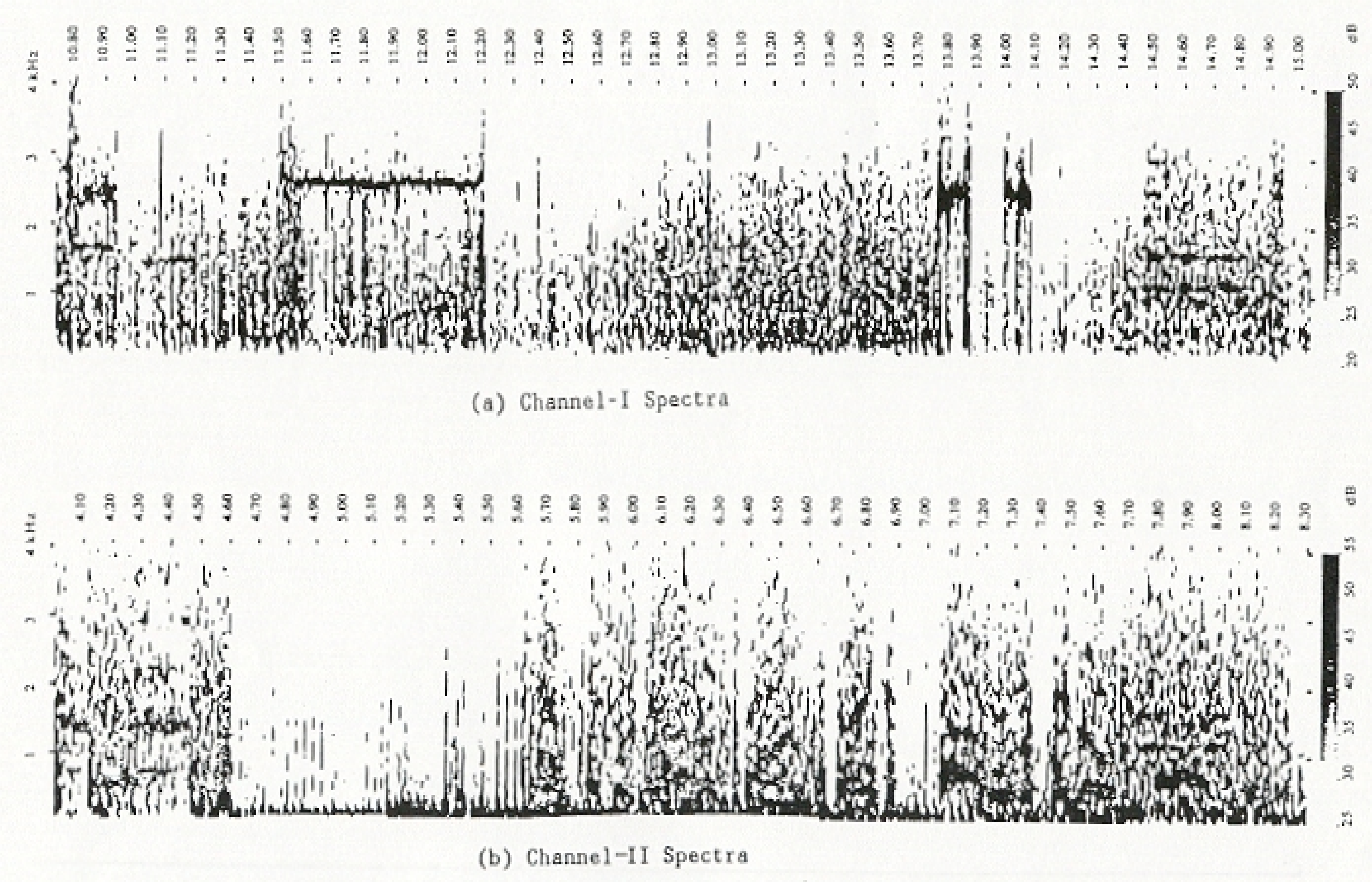

Figure 10. Spectra of Channels I and II for the "Bell" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The grey intensity-scale (dB) is indicated at right. Note the left edge is the end of the "Hold-Everything" segment and for the rest of the period the two spectra have nothing else in common.

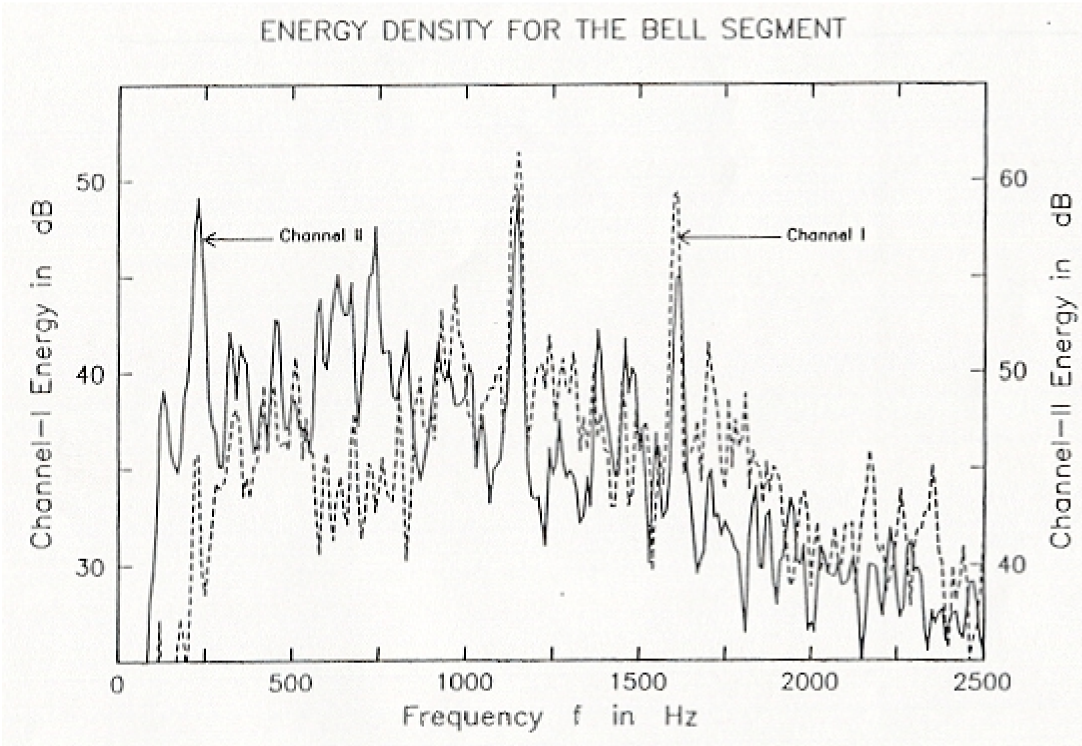

Figure 11. A high resolution energy density plot of the two spectra for the "Bell" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The solid curve is for the Channel II and the broken curve is for the Channel I. Note the prominent fundamental at 230 Hz, and the fifth and seventh harmonics at 1150 and 1620 Hz respectively.

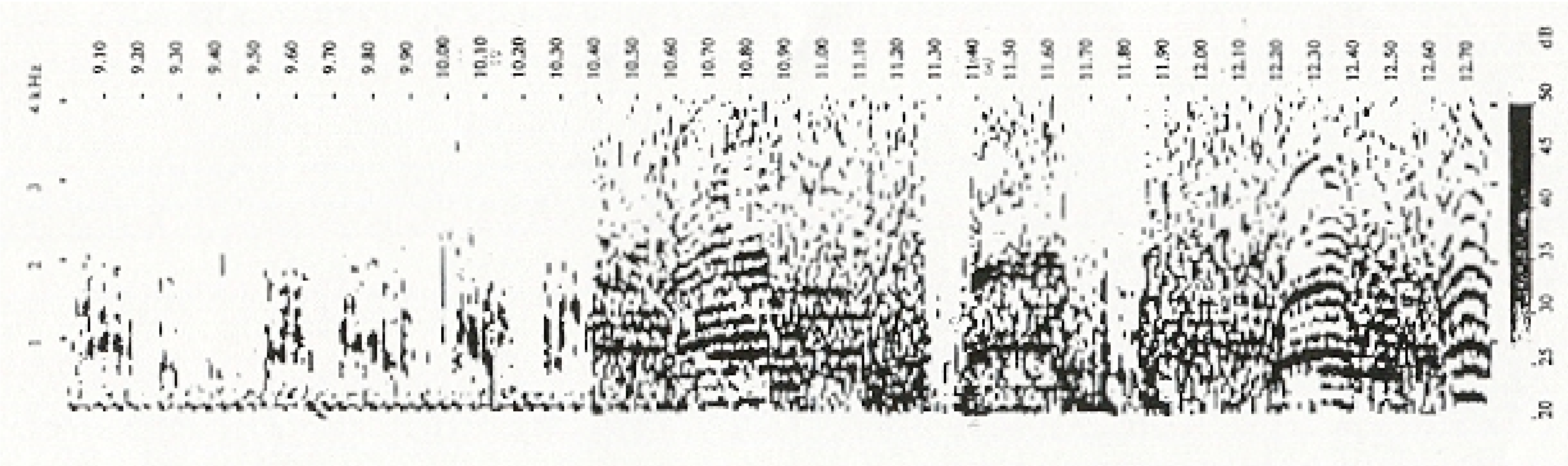

Figure 12. Spectra of Channel II for the second "Bell" segment. The horizontal axis is time (seconds) and the vertical axis is frequency (kHz). The grey-intensity scale (dB) is indicated at right. The bell sound is from 10.40 to 10.60 and 10.85 to 11.10 secs.

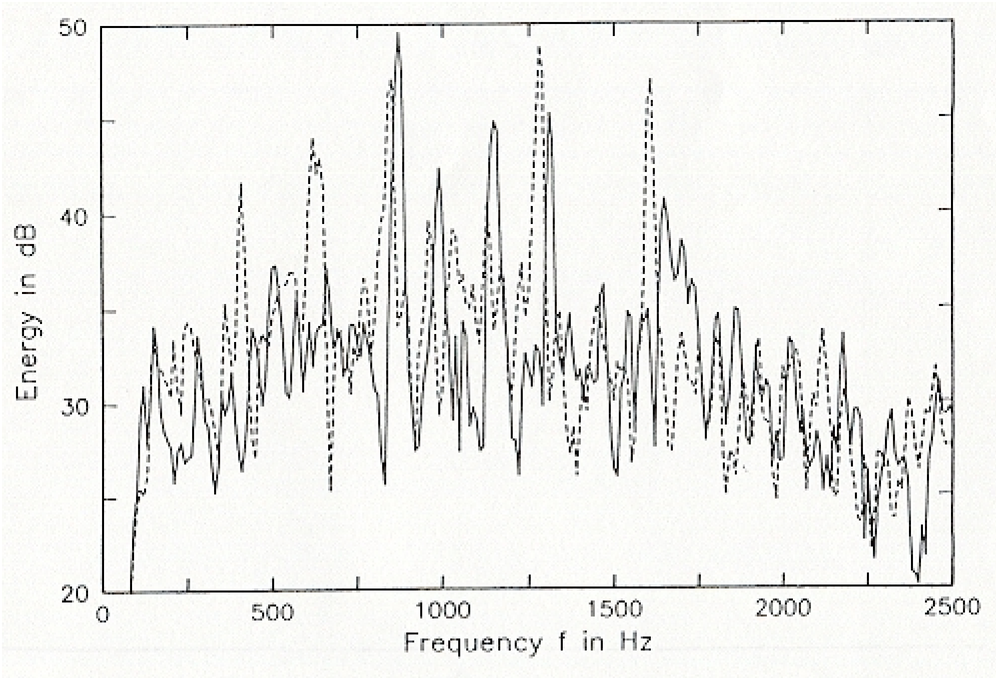

Figure 13. A high resolution energy density plot of the two segments of the second "Bell" sound. The solid curve is for the first segment (10.40 to 10.60 secs) and the broken line is for the second segment (10.85 to 11.10 secs). Note the prominent second and third harmonics around 850 and 1300 Hz respectively.

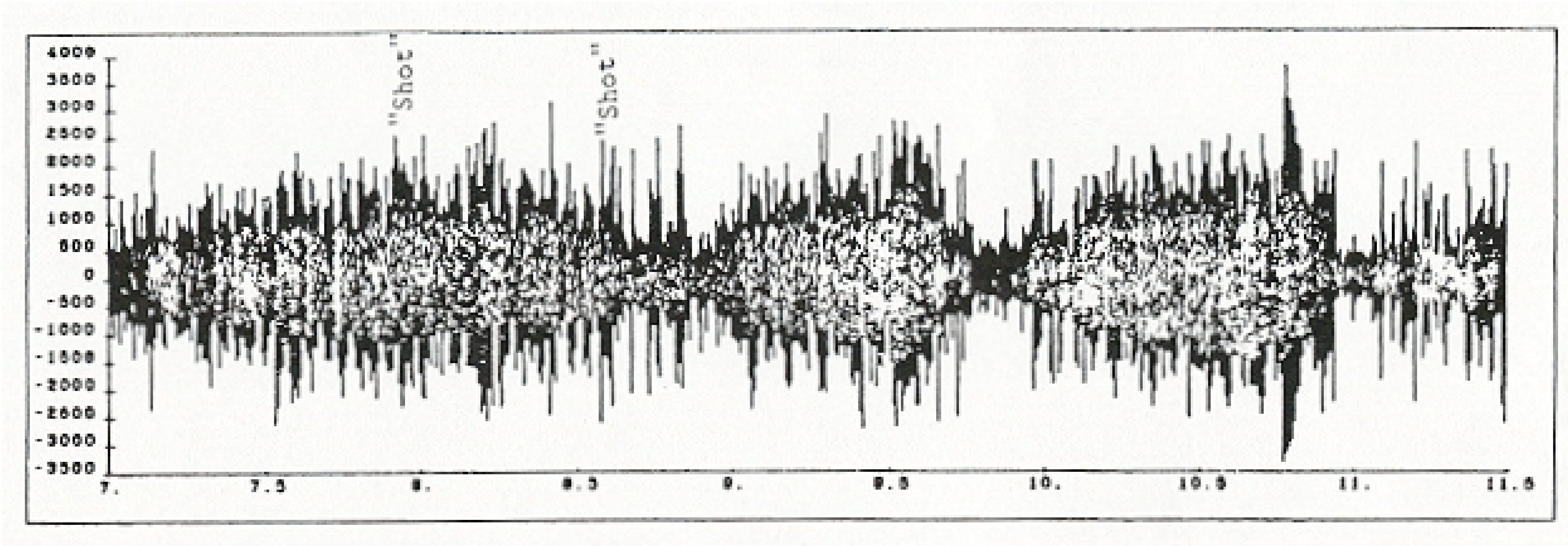

Figure 14. Envelope of the Channel-I signal for the "Hold-Everything" phrase. The horizontal axis is time (seconds) and the vertical axis is the signal amplitude. The timings of the third and the fourth "shots" are also indicated on the plot. Note the AGC behavior following the two heterodynes (9.52 to 9.64 and 10.78 to 10.93 secs).