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COMPUTER SIMULATIONS AND LABORATORY TESTS OF PROPOSED GHOST CANCELLING SYSTEMS

Communications Canada

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COMPUTER SIMULATIONS AND LABORATORY TESTS

OF

PROPOSED GHOST CANCELLING SYSTEMS

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by

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Résumé

Cinq différents signaux de référence ont été proposés pour permettre l'élimination des fantômes que l'on peut observer sur les images de télévision. Il est nécessaire de choisir un de ces signaux pour en faire une norme.

Ce rapport présente les simulations sur ordinateur et les tests en laboratoire qui ont été fait au CRC pour évaluer et comparer l'efficacité des différents signaux proposés. Les résultats obtenus démontrent qu'un système d'élimination des fantômes permet d'améliorer de façon significative la réception d'images de télévision. Il semble cependant que des tests supplémentaires pourraient être requis pour s'assurer de choisir le meilleur signal pour l'établissement d'une norme.

Abstract

Five different video Ghost Cancelling Reference signals have been proposed to improve television reception in North America. One of them must be selected as a standard.

This report presents the computer simulations and laboratory tests performed to evaluate and compare the effectiveness of the proposed video Ghost Cancelling Reference (GCR) Signal. The results have demonstrated that a ghost cancellation system can significantly improve television service. It appears however that more tests may be required before the best GCR signal can be selected as a standard.

RESULTS OF COMPUTER SIMULATIONS AND LABORATORY TESTS OF GHOST CANCELLING SYSTEMS PROPOSED FOR TELEVISION

Executive Summary

Five different video Ghost Cancelling Reference (GCR) signals have been proposed to improve television reception in North America. After evaluation one of them is to be selected as a standard.

Computer simulations and laboratory tests were performed at the Communications Research Centre (CRC) in Ottawa, Canada to assess the performance of each proposed GCR signal.

The computer simulations were done for the GCR signals proposed by Philips Laboratories, Samsung Electronics and Sarnoff/Thomson. Each GCR signal was impaired by 10 different combinations of ghosts. The results have shown that all 3 GCR signals can characterize channels very well. One of the simulations demonstrated that it was possible to characterize a channel in 1 TV field (1/60 sec). Some minor differences from the ideal channel characterization were observed but may not be due to the characteristics of each GCR signal.

The laboratory tests were completed on prototypes from AT&T/Zenith, BTA/NEC (Japan), Philips Laboratories, Samsung Electronics and Sarnoff/Thomson. The prototypes were at different levels of development. Therefore in most of the cases the results from the laboratory tests did not show the ultimate capabilities of a GCR signal but the limitations of the hardware available for the tests.

All the ghost cancellation systems tested improved the subjective quality of the picture, sometimes very significantly. On a scale of 5, the impairment rating could go from as low as 2 before correction to as high as 4.8 after correction. Ghosts with a delay as long as 40 microseconds could be eliminated. Pre-ghosts with a delay of -5 microseconds were also cancelled. The time required for the cancellation of ghosts could be as short as 2 seconds. Prototypes from AT&T/Zenith and Philips Laboratories required less time than the other ones to complete ghost cancellation. BTA/NEC was the slowest unit with a 45 second convergence time. A test also demonstrated the potential of ghost cancellation to greatly improve teletext reception.

The prototypes from BTA/NEC, Philips Laboratories and Sarnoff/Thomson operated well under almost all the test conditions. The ones from AT&T/Zenith and from Samsung were at an earlier stage of development and did not operate well for all of the tests. When the ghost cancellers were tested within their range of operation, the difference in performance between them was relatively small.

In conclusion more tests could be required if the selection of the best GCR signal is to be based on differences in the potential of each GCR signal. Tests are required to establish the limits of each GCR signal for ghosts with very long delay, high amplitude or time variation. To complete these tests the proponents may have to develop appropriate versions of their ghost cancelling systems.

It is hoped that all the necessary tests can be completed quickly so that the best GCR signal can be selected as soon as possible.

RESULTS OF COMPUTER SIMULATIONS AND LABORATORY TESTS OF GHOST CANCELLING SYSTEMS PROPOSED FOR TELEVISION

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1.0 Introduction

Broadcasters have been looking for a long time for a device or a system which could reduce or eliminate video ghosts. These ghosts are created when television signals are reflected one or more times from obstacles such as hills or buildings. A television picture received under these conditions will be degraded and may be annoying to watch. Viewers are particularly sensitive to this kind of degradation since they have access to ghost free sources of video such as video cassette recordings.

Video ghosts were accepted as a fact of life until the Broadcasting Technology Association (BTA) in Japan developed a video ghost cancelling system. This system was evaluated in the Atlanta area in the the United States [1] and found generally effective in nearly all test locations. However, some weaknesses were also identified and several organizations made proposals for an improved system. A formal request for proposals was issued by the NAB in July 1990 and five different proposals were received which are listed in Table 1. A more complete description can be found in the bibliography [2-6]. Each system requires a different Ghost Cancelling Reference (GCR) signal, illustrated in Fig. 1, to be included in the Vertical Blanking Interval (VBI) for television transmission. For obvious practical reasons a single one has to be selected as a standard.

To do so, it was planned to evaluate the proposals in three different ways, namely through computer simulations, laboratory tests and some field tests. This paper will present the results of the computer simulations and laboratory tests which were performed at the Communications Research Centre (CRC) in Ottawa, Canada. These tests were done in collaboration with the proponents and were part of the evaluation process of the Advanced Television Systems Committee's (ATSC) Specialist Group on Ghost Cancelling (T3-S5).

The specialist group on ghost canceling (T3-S5), is eventually to recommend one of these reference signals for use as a training waveform in specially equipped NTSC receivers for cancelling ghosts in the received signals.

The ATSC Specialist Group on Cancelling will select the best Ghost Cancellation Reference (GCR) signal based on criteria such as the following:

- Cancellation Range (Target: -2 to 45 µsec)
- Convergence time
- Ultimate correction
- Robustness
- Complexity (cost)
- VBI requirements

The information required to select a ghost cancelling system was to be obtained from:

1. Specifications provided by each proponent.
2. Computer simulations to evaluate the performance of each proposed GCR.
3. Laboratory tests of ghost cancellation systems.
4. Field test.

This report presents the results obtained from computer simulations and laboratory tests.

TABLE 1: List of GCR Signal Proponents

PROPONENTS	TYPE OF GCR
1) AT&T/Zenith	Pseudo-Random Binary Sequence (PRBS)
2) Broadcast Technology Association (BTA)	Integrated Pulse
3) Philips Laboratories	Deterministic Sequence
4) Samsung Electronics	Complementary Binary Sequence
5) Sarnoff/Thomson	Pseudo-Random Binary Sequence (PRBS)

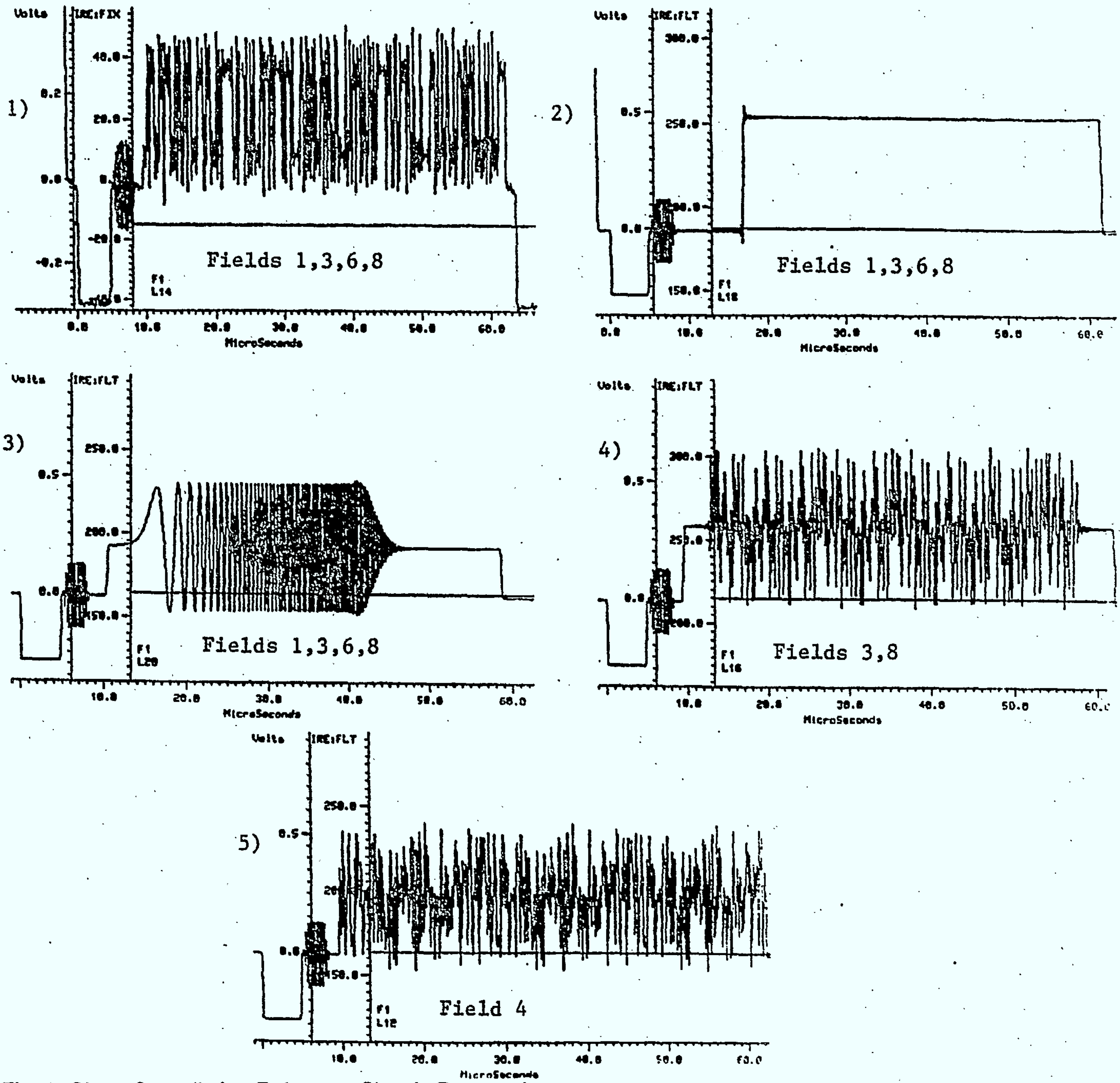


Fig. 1: Ghost Cancellation Reference Signals Proposed
(1) AT&T/Zenith, (2) BTA, (3) Philips, (4) Samsung, (5) Sarnoff/Thomson

2. Computer Simulations

This section covers the results which were obtained from computer simulations completed by 3 of the 5 proponents with the help of the Canadian Communications Research Centre (CRC). The 3 GCR signals evaluated by simulation were the ones proposed by Philips, Samsung and Sarnoff/Thompson. BTA (Japan) could not participate because the software for ghost cancellation had been developed many years ago and was no longer available anymore. AT&T/Zenith participated in the simulations at the beginning but could not complete them.

2.1 Description of the Computer Simulations

Computer simulations were carried out to compare the proposed GCR with respect to their effectiveness to characterize a video channel. The objective was to isolate the channel characterization performance of the proposed GCR signal from the performance of a complete Ghost Cancellation system limited by hardware implementation. For the purpose of this simulation and to make comparisons under the same conditions, the proponents were asked to assume that the following Finite Impulse Response (FIR) filter described in Table 2 was used.

TABLE 2: Finite Impulse Response (FIR) Filter Characteristics Assumed for the Simulation

Number of Taps:	640 (44.75 μsec.)	Signal:	10 bits
Sample Frequency:	14.3 MHz	Coefficient:	10 bits

In order to carry out the simulations the proponents provided CRC with a digitized version of their proposed GCR signal in an agreed upon computer file format. These digitized GCR files were used by CRC to create 10 different impaired versions for each GCR. For this purpose, after consultation with all proponents, a computer program was used, which had been created by the David Sarnoff Research Center. Each proponent received 10 files containing their GCR, impaired by the filters of an NTSC transmission and the multipath and noise combinations of Table 3. The details of these combinations were known only by CRC. Each file contained 304 lines of the digitized impaired GCR. It was assumed that a black burst was on the lines preceding and following the GCR. Except for one ghost in the first combination, all simulated ghosts were static. The first combination included one ghost which varied over time to reproduce dynamic ghosts sometimes observed in the field.

The combinations 2, 3 and 4 were representative of average over-the-air reception (A) for 3 different levels of noise. The combinations 5, 6, 7 and 8 represented more severe conditions (B) where 4 ghosts are received. Each combination has a different signal-to-noise ratio. Combination 9 represent microreflections (C) similar to those which could be observed on a cable network. Finally the last combination included a very long ghost (D) to evaluate the range covered by the GCR signal. Similar combinations of ghosts were used for the laboratory tests as to enable some comparisons between the two experiments.

The proponent used a computer simulation of their channel characterization scheme to produce an in-phase (real) impulse channel response for each of the 10 combinations of ghosts. The proponents then provided CRC with the channel responses obtained after: (a) the minimum number of iterations to get an acceptable approximation; and (b) the number of iterations required to converge to a maximum of 304 iterations.

The evaluation was then carried out by comparing the channel responses calculated by the proponents with the one directly obtained from the computer simulation of the multipaths. The channel response of combination 5 was provided to the proponents so that they could use it to confirm the correct operation of their software.

TABLE 3: Combinations of Ghosts Used for the Computer Simulations

COMBINATION	#	DELAY	AMPLITUDE	PHASE	SNR
F(Dynamic)	1	0.80 µs 1.50 µs 4.25 µs	-18.4 dB -21.9 dB -30.5 dB	0° 0° -80°	40 dB
A(Typical)	2	0.45 µs 2.30 µs	-21.9 dB -28.0 dB	30° -80°	40 dB
	3	0.40 µs 2.80 µs	-19.2 dB -24.4 dB	30° -80°	35 dB
	4	0.45 µs 2.30 µs	-19.2 dB -24.4 dB	30° -80°	25 dB
B(Typical)	5	0.20 µs 1.60 µs 3.40 µs 8.70 µs	-14.0 dB -16.5 dB -23.1 dB -18.4 dB	-40° 0° 30° -60°	50 dB
	6	0.20 µs 1.90 µs 3.40 µs 8.20 µs	-14.0 dB -18.4 dB -23.7 dB -21.9 dB	-40° 0° 30° -60°	40 dB
	7	0.30 µs 1.90 µs 3.90 µs 8.20 µs	-16.5 dB -18.4 dB -23.1 dB -21.9 dB	-40° 0° 30° -60°	35 dB
	8	0.20 µs 1.90 µs 3.90 µs 8.70 µs	-16.5 dB -18.4 dB -23.1 dB -19.2 dB	-40° 0° 30° -60°	25 dB
C(Micro-reflections)	9	-0.70 µs 0.10 µs 0.15 µs 0.25 µs 0.40 µs	-26.0 dB -26.0 dB -30.5 dB -28.0 dB -28.0 dB	-40° -70° 0° 30° -50°	35 dB
D(Long Delay)	10	-1.80 µs 2.20 µs 38.90 µs	-23.1 dB -10.5 dB -20.0 dB	-50° -20° 70°	35 dB

2.2 Results of the Computer Simulations

The results of the computer simulations have shown that the 3 GCR signals which were evaluated could provide very good, if not excellent, channel characterization. An example is shown in Fig. 2 where the reference and the channel impulse responses calculated by the 3 proponents for combination 8 are superimposed. No difference can be seen.

The few discrepancies found were for ghosts with either very short or very long delays. Fig. 3 illustrates such discrepancies for the very short delayed ghosts in combination #9. The differences between the reference and the channel responses estimated by the 3 proponents are however very small. They may have been caused by differences in the techniques used to process the calculated channel response.

Differences were also noticed for the long delay ghost of combination #10. The ghost with the long delay was correctly located by each proponent but its amplitude was properly estimated only by Sarnoff as illustrated in Fig. 4. Samsung and Philips, could not complete the channel characterization as accurately because the file required for this case should have included data up to 38.9 µsec after the end of each GCR signal. It was found after the completion of the simulations that the files created by CRC provided only 9.43 µsec of data after the end of the line.

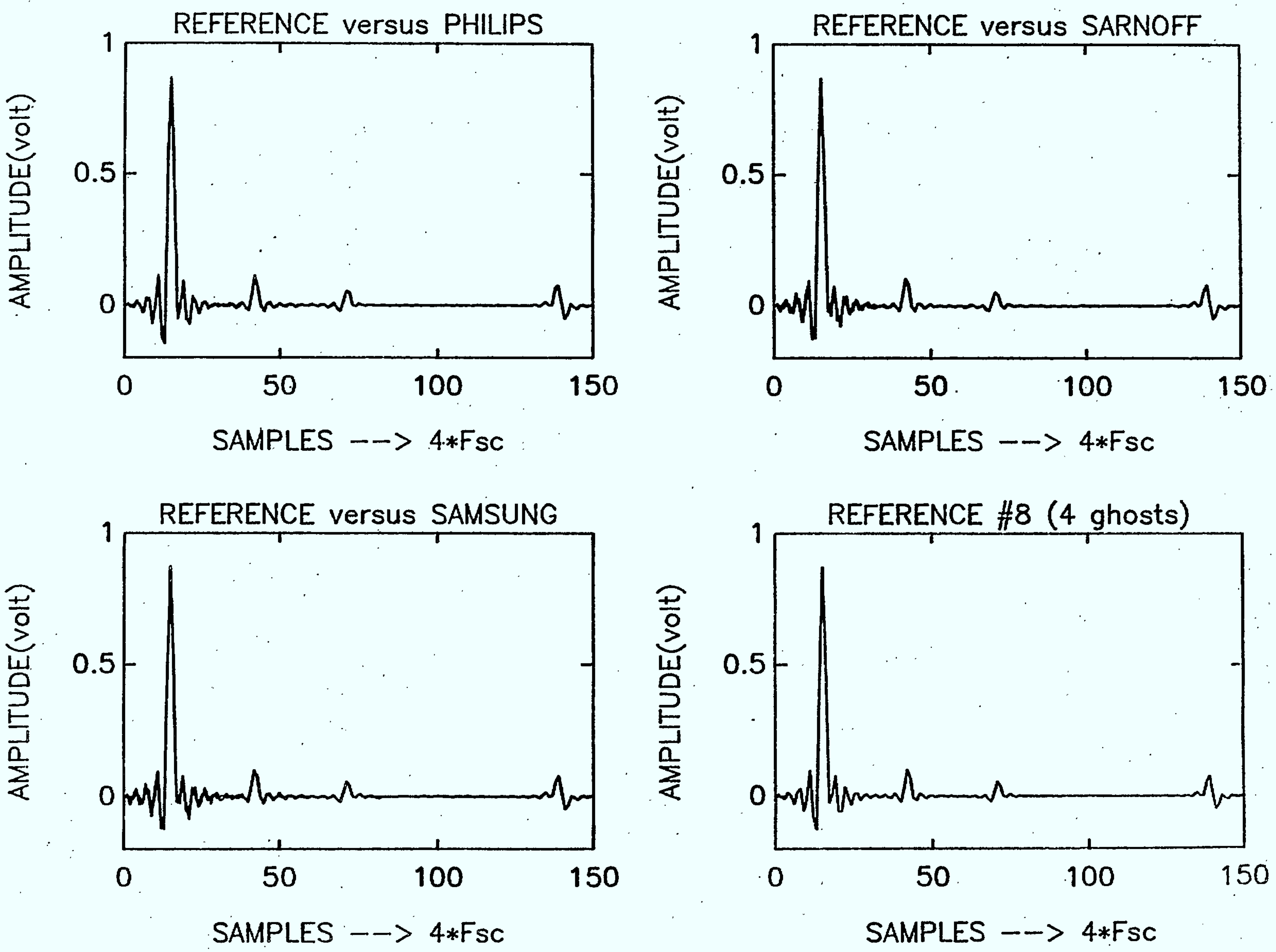


Fig. 2: Comparison between the reference and the channel responses obtained by Philips, Samsung and Sarnoff/Thomson for Combination #8 (Typical).

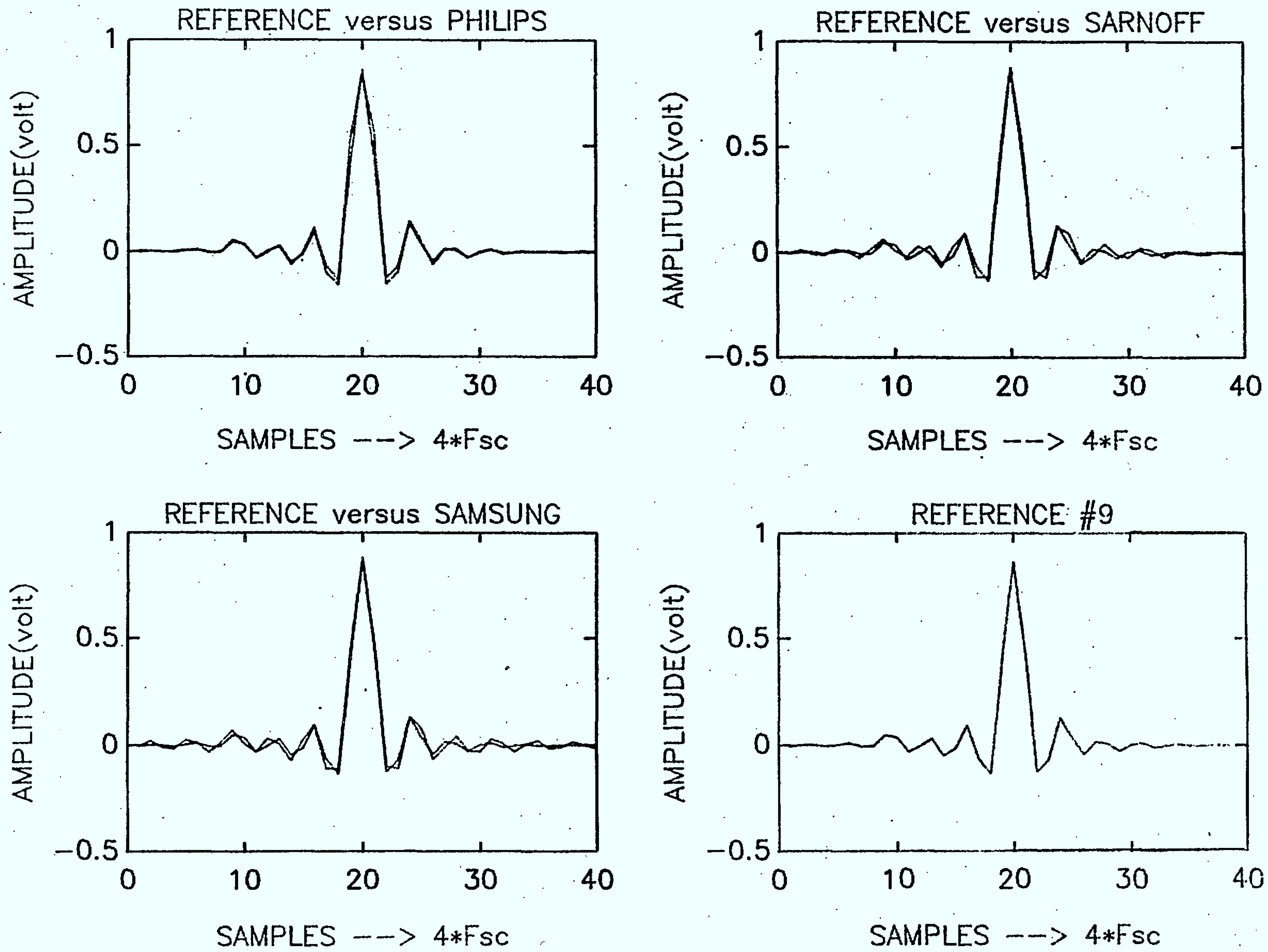
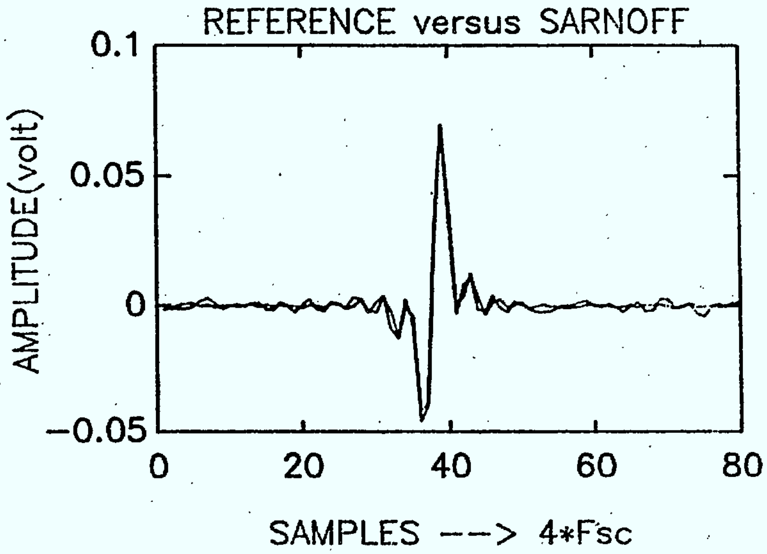
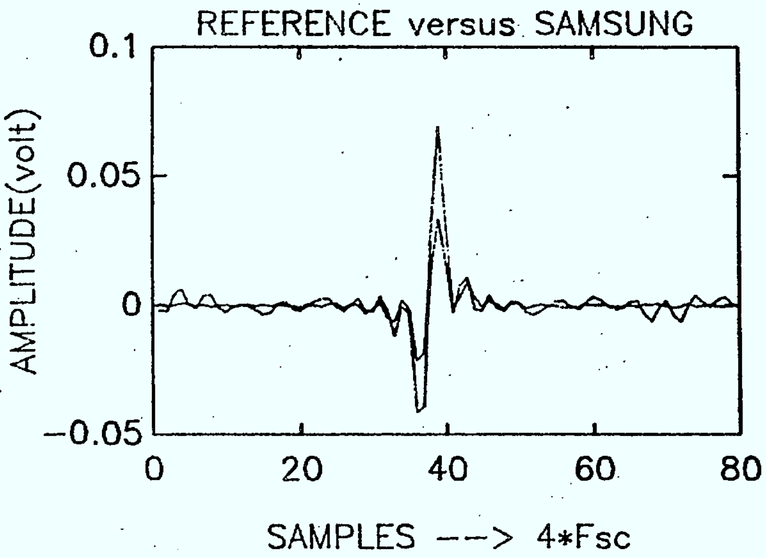


Fig. 3: Comparison between the reference and the channel responses calculated by Philips, Samsung and Sarnoff/Thomson for Combination #9 (Microreflections).

Philips Laboratories requested not to present this result because of invalid data (see note below)





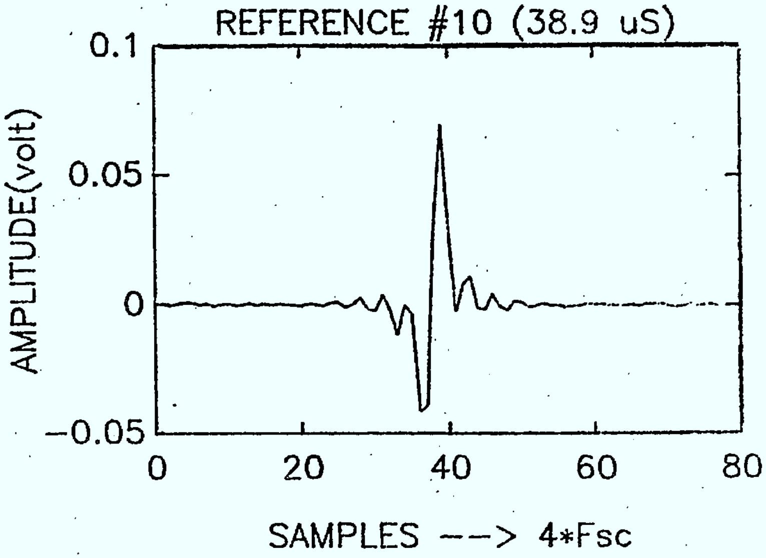


Fig. 4: Comparison between the reference and the channel responses calculated by Philips, Samsung and Sarnoff/Thomson for Combination #10 (only the ghost with the 38.9 µsec delay is shown.)

Note: Samsung and Philips could not complete the channel characterization accurately because the file provided by CRC should have included data up to 38.9 µsec after the end of each GCR signal. It provided only 9.43 µsec.

The proponents were also asked to use as few lines as possible to characterize each channel response to show how fast channel characterization could be completed using their proposed GCR signal.

Philips identified all the ghost combinations using 8 lines and 304 lines. The responses computed with only 8 lines were almost all identical to the ones calculated using 304 lines. In particular noise was very well eliminated from the calculated channel responses after processing only 8 lines.

Sarnoff could identify all the ghost combinations (except combination 4) after using only 4 lines. But for some ghost combinations, it required more lines to eliminate the noise from the channel response: 16 lines were required for combination 9 and 60 for combinations 4, 8 and 10.

Samsung could identify all the ghost combinations with only 8 lines. Elimination of the noise on some combinations required more lines however: 24 lines for combination 10 and 80 lines for combinations 4 and 8.

These results are difficult to compare as each proponent may not have used the same criteria to determine after how many iterations (lines) the channel response was correctly identified or if noise was eliminated. It is therefore difficult to determine which GCR provides the quickest channel response estimation.

The simulations with the moving ghost could not be completed as planned because the files sent to Philips and to Samsung were different than the ones sent to Sarnoff. The analysis of the results was made even more difficult because proponents used a different number of fields to characterize the dynamic channel responses.

The file sent to Sarnoff contained the 3 ghosts of combination #1. Every 4 fields, the delay of the second ghost increased by 135 nanoseconds in field 1, decreased by 50 nanoseconds in field 2 and by 67 nanoseconds in field 4. The phase and the amplitude of this ghost also changed in 3 of every 4 fields. Sarnoff decided to use the file to estimate a channel response every 4 fields. One of the impulse responses calculated by Sarnoff every 4 fields is compared in Fig. 5 with the superposition of the reference impulse responses of the 4 fields used in the calculation.

The files sent to Philips and Samsung also contained the 3 ghosts of combination 1. The delay and the phase of the first ghost this time were increased by 100 nanoseconds and by 45° every field. Its amplitude changed within every 4 fields.

Philips decided to compute an impulse response for each field. This calculated impulse response is compared with the reference in Fig. 6. The 2 responses are very similar.

Finally Samsung computed an impulse response every 8 fields. The result of one of this calculation is compared in Fig. 7 with the superposition of the reference impulse responses of the 8 fields used in the calculation.

It is difficult to compare the potential of each GCR signal to characterize moving ghosts based on the above results. More thought may be required to design computer simulations which would enable a fair comparison. Among other things, it may be interesting to repeat a similar test for a lower signal-to-noise ratio than the one used in the simulations (40 dB). However the result of the simulation demonstrated the possibility of characterizing a channel in one field.

In conclusion, it appears that all 3 proposed GCR signals can be used for precise channel characterization. Additional computer simulations may however be required to determine the limits of each GCR signal and to precisely determine how fast each one can accomplish a channel characterization.

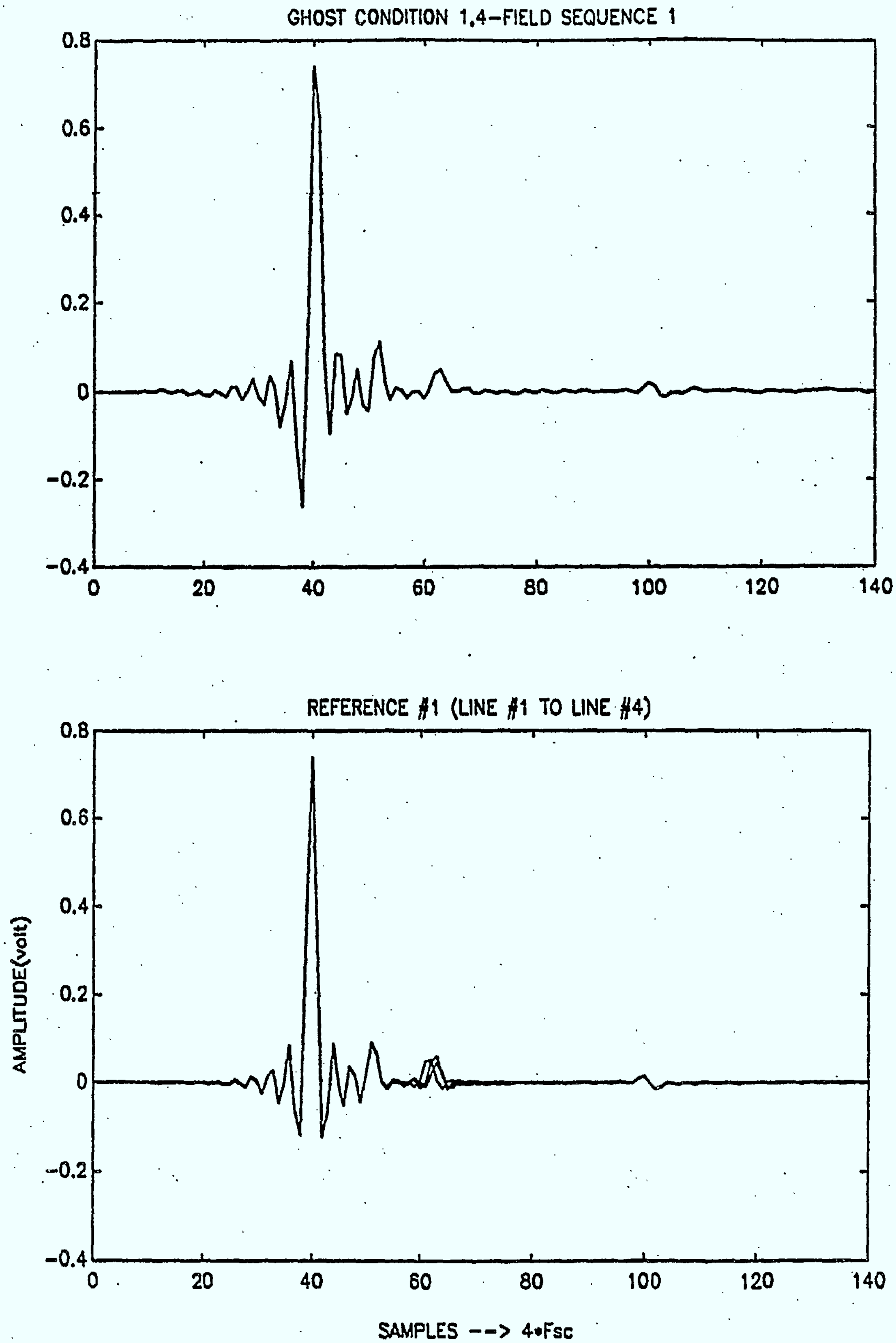


Fig. 5: Comparison between the impulse response calculated by Sarnoff with 4 lines and the superimposition of the references for these 4 lines in combination #1 (Dynamic)

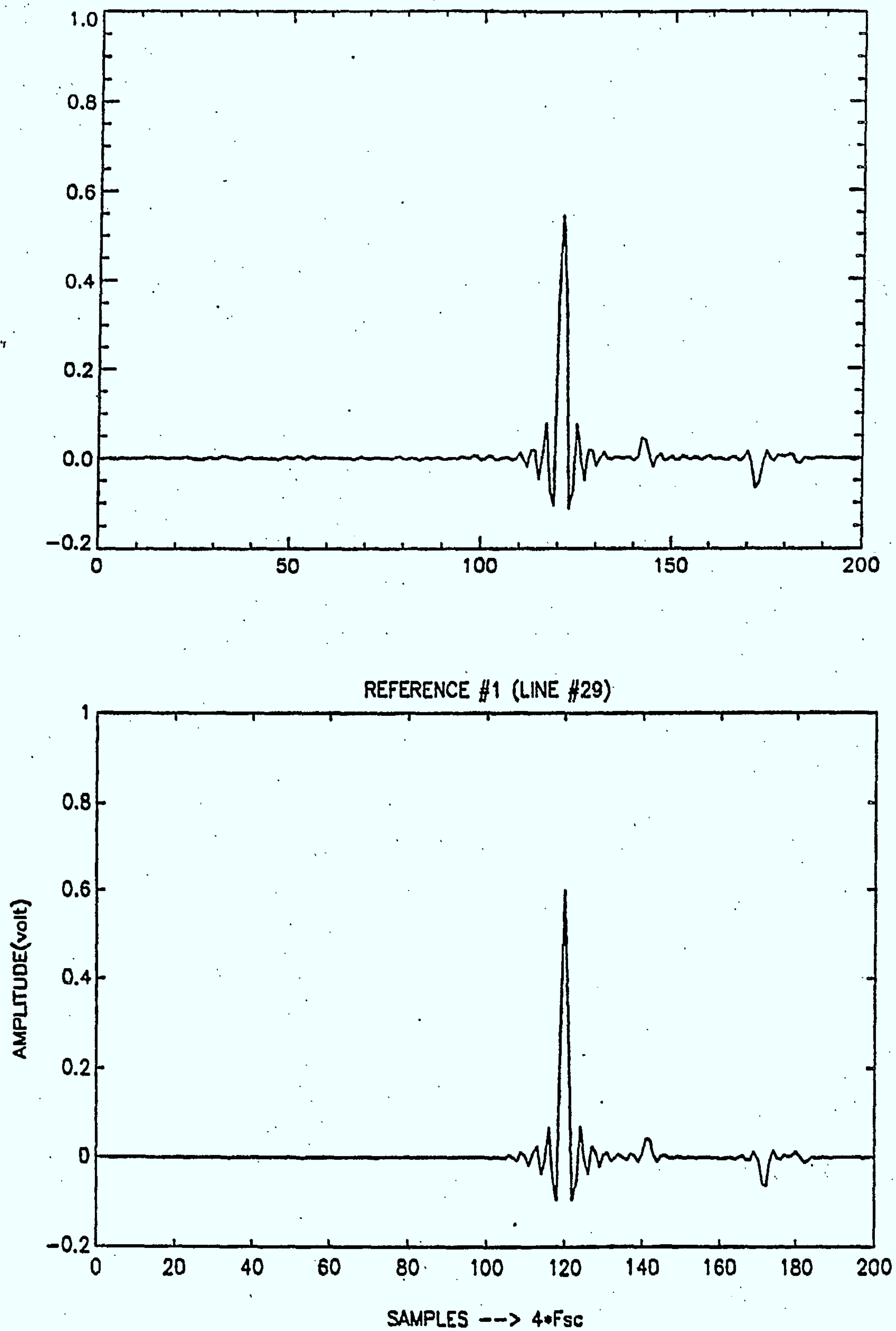


Fig. 6: Comparison between the impulse response calculated by Philips with 1 line and the reference for this line in combination #1 (Dynamic)

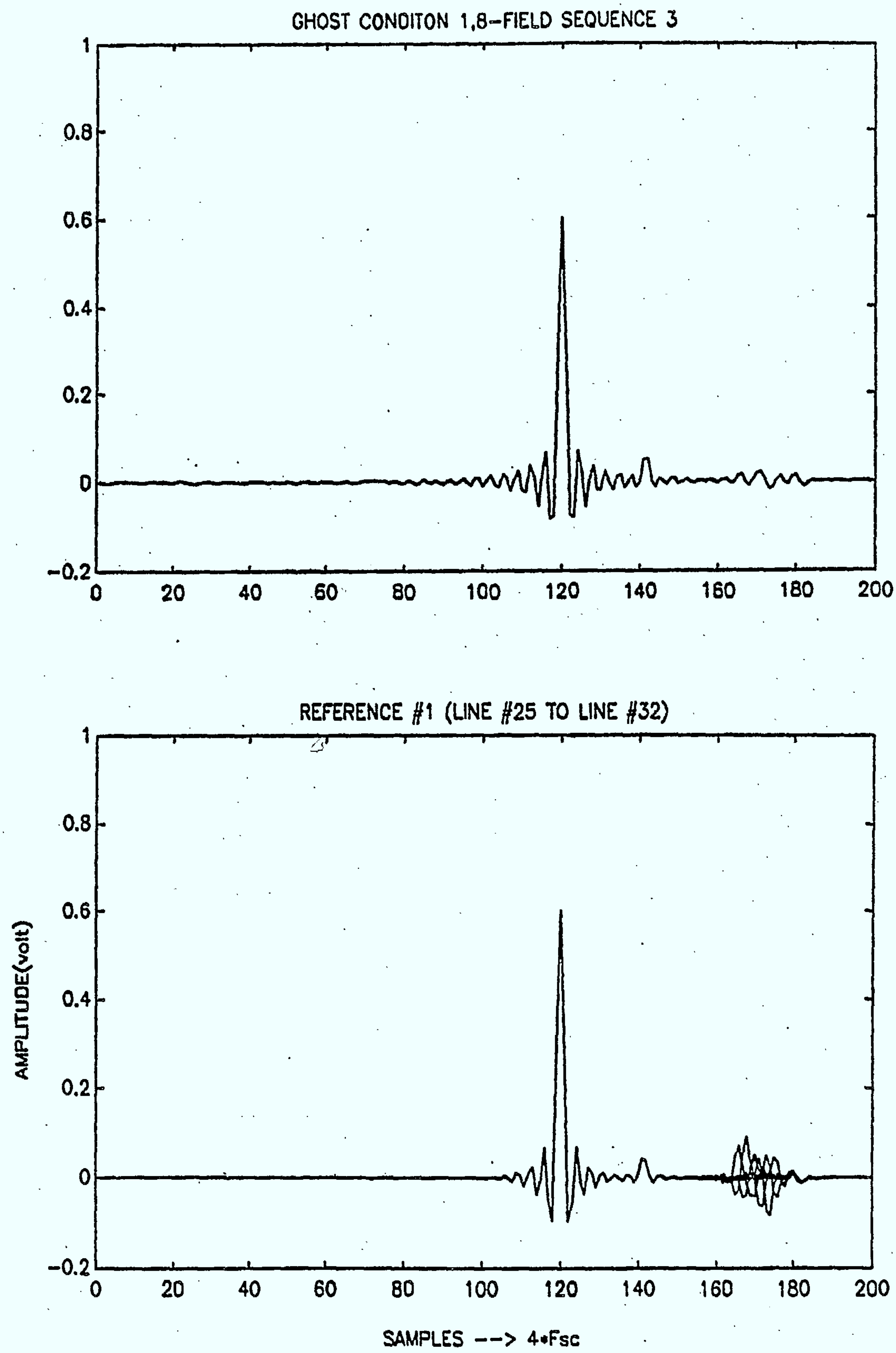


Fig. 7: Comparison between the impulse response calculated by Samsung with 8 lines and the superimposition of the reference for these 8 lines in combination #1 (Dynamic)

3.0 LABORATORY EVALUATION

The results of the field tests and the computer simulations were complemented by the results of laboratory experiments performed on a prototype from each proponent. These laboratory tests were performed at CRC early in 1992. The tests may not be as comprehensive as desirable due to the tight schedule established by T3-S5 which permitted only 1 week to be allocated for the laboratory tests.

3.1 Equipment Set-Up

The equipment set-up for these tests is illustrated in Fig. 8. Video sources included video test signals as well as real television pictures. Seven video sequences particularly sensitive to multipath were selected from a CCIR tape originally prepared to evaluate digital video codecs. The 5 GCR signals were added to the video program, each one occupying a different line in the vertical blanking interval (VBI).

The video signal was then impaired by a ghost signal generator. Up to 7 ghosts with a relative delay times of up to plus and minus 64 µsec and a range of amplitudes between 0 and -55 dB could be generated. The phase of each ghost could also be varied between 0 and 359°.

The intermediate frequency produced by the ghost generator was then up-converted to channel 11 which was free of interferences in the Ottawa area transmitters. White noise was added to the modulated signal.

The impaired signal was demodulated by a Tektronix 1450 synchronous demodulator (Synchronous on Back Porch, Sound Trap: In, Internal Zero Carrier: Off, AGC Speed: Slow, AGC on Synch. Tip, Synch. Time Constant: Normal). Its real (I) output was distributed to the ghost canceller prototype of 4 of the 5 proponents. The Sarnoff Laboratory prototype, was also fed with the quadrature (Q) output of the demodulator as it was operating on a complex signal. The ghost canceller from the Broadcast Technology Association (BTA) had its own demodulator and was fed directly with the RF signal.

The corrected output of each ghost canceller prototype was then monitored and compared with the reference signal on waveform and video monitors (Sony BVM-1910). Finally the video signals were also recorded for future reference.

3.2 Description of the Measurements

The evaluation of each signal was done subjectively and objectively. The subjective evaluation was done by at least 5 expert observers using the CCIR impairment scale shown in Table 4. The observers were proponents' representatives or members of T3-S5. At least 1 representative of 3 of the proponents was present for all the tests. The observers were asked to make an effort to restrict their ratings to the ghost and not to take into consideration some visible hardware problems or the presence of noise.

TABLE 4: CCIR Impairment Scale

IMPAIRMENT SCALE
5 Imperceptible
4 Perceptible but not annoying
3 Slightly annoying
2 Annoying
1 Very annoying

For most of the tests a rating was given by each expert observer on each video sequence. An average was estimated and announced to all the experts. **This average rating was recorded only if it was agreed to by all the observers.** If no agreement was reached, the video sequences were replayed and rated again. The final result was obtained by averaging the rating given to the seven video sequences. The observers were not normally informed of which prototype was under test. They could however guess by identifying the particular artifacts created by each prototype.

The objective measurements done included the unweighted signal-to-noise ratio, pulse-to-bar ratio, the 2T K factor, the luminance non-linearity as well as the group delay and the gain of the Sin x/x. The composite and the multiburst VITS were also plotted. Bit error rate of a teletext sequence could also be measured using equipment provided by PBS.

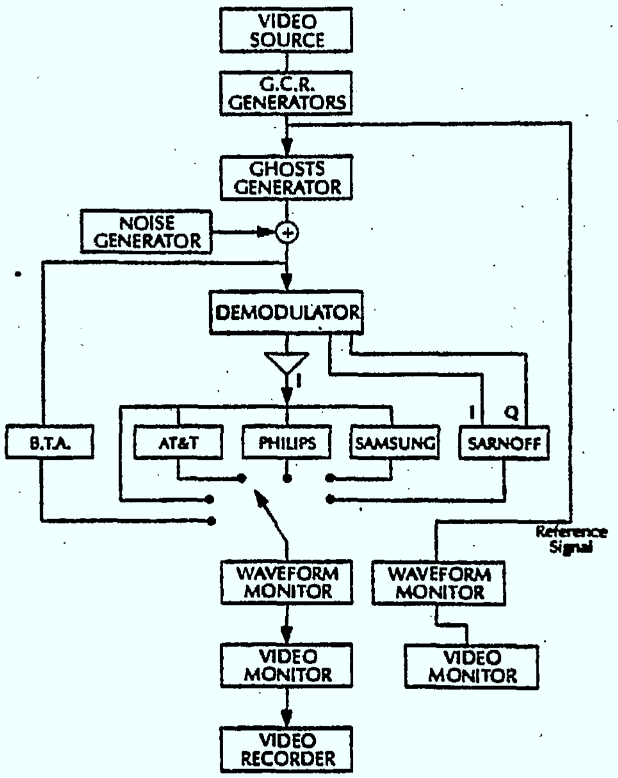


Fig. 8: Equipment set-up for the laboratory tests.

3.3 Description of the Prototypes

The results presented were obtained using the ghost cancellers provided by each proponent. Their characteristics are presented in Table 5. These ghost cancellers were at different levels of development and it has not been possible for the proponents to use in their prototype the same devices for analog to digital conversion, synchronization and clock generation.

The AT&T/Zenith prototype was built using low cost analog components. This was intended to demonstrate their GCR signal's and algorithm's capability to compensate for a low cost implementation. In the tests, their synchronization and phase-lock loop circuits were not able to always perform correctly. A proprietary algorithm was then used to correct for resulting defects as much as possible. However even in the no ghost condition, their prototype degraded the picture quality

TABLE 5: Characteristics Provided by the Proponents for the Prototypes Used for the Laboratory Tests

PROPONENTS	ALGORITHM	VBI LINE	GHOST RESPONSE LEVEL	SAMPLING RATE (MHz)	A/D # OF BITS	D/A # OF BITS
AT&T	Transform Function	14	-6 dB(a)	14.3	10 available, 9 used	10 available, 9 used
BTA-NEC	Feed Forward	18	-6 dB	---	---	---
Philips	Philips 3	20	-5 dB	14.3	8	8
Samsung	Linear Correlation	16	0	14.3	9	10
Sarnoff/Thompson	2 Field Algorithm	12	---	---	10(b)	10(b)

Notes: (a) - Hardware limitations only.
(b) - For in-phase and quadrature component each. This resolution may not be required.

TABLE 5: (continuation)

PROPONENTS	FILTER'S COEFFICIENTS # OF BITS	FILTER # OF TAPS	CANCELLING RANGE		CONVERGENCE TIME (SECONDS)	REMARKS
			PRE-GHOST (μSEC)	POST-GHOST (μSEC)		
AT&T	12 available 10 used	32 for pre-ghost 400 for post-ghost	0.7	28(now) 53.4(future)	0.4 sec (minimum)	Low-cost synch. circuits
BTA-NEC	---	---	1.5	40	45 sec	Equipment provided by CRC
Philips	8	432	8	42(now) 64(future)	1-5 sec	Hardware was damaged in shipping
Samsung	9	8 taps/ghost (up to 9 post-ghosts) & 128 taps for pre-ghosts	8	70(limited to 35 by fault in the prototype)	17 sec (after manual initialization). 3 sec for updates	8 taps/ghost were not enough. Taps were not properly centered
Sarnoff/ Thompson	---	---	---	---	---	More information on hardware configuration could not be disclosed at this time

more than the others. Its cancelllation range was also limited by filter hardware to -1.8 to 29 microseconds. AT&T/Zenith was also not able to participate in all the laboratory tests due to the delay in the shipping of their equipment to CRC.

The Toshiba TT-GC9 was provided by BTA for the laboratory tests. It was found inappropriate for the fast pace of the test as it took several minutes to eliminate ghosts. After agreement by BTA, a NEC ghost canceller, the GCT-900, which was available at CRC, was used to evaluate the BTA GCR signal. It is a fully developed product already marketed in Japan. Its cancellation range was specified to be between -1.5 and 40 microseconds.

The prototype from Philips was damaged during custom inspections. As a result of damage, the synchronization made frequent errors. Some test results were obtained before the prototype was repaired, and when synchronization errors created visible artifacts. This problem disappeared once the unit was repaired.

The Sarnoff's prototype was the only one processing a complex signal (I&Q). Sarnoff claimed however that this is not a requirement of their proposed GCR which can also be used with the in-phase component only. This prototype sometimes displayed white flashing lines near the top of the picture probably due to an improper timing of the loading of the digital filter coefficients. It also displayed some "low frequency noise" due to misalignment of the synchronization circuit. This "noise" was judged to be minor and it was decided not to risk realignment of the circuit at CRC.

Finally the Samsung's prototype was at an earlier development stage compared to the others, as this particular Samsung GCR signal was only conceived late in August 1991. The cancellation time was relatively long and the cancellation range was limited to 35 microseconds by software errors. The hardware had only 8 taps/ghost. The tests indicated a need for more taps/ghost. Sometimes improper DC shift and gain ajustments were done after deghosting. This crushed the synchronization pulses and made the picture unviewable. The current synchronizing circuit could not always handle the ghost impaired video signal.

- WARNING -

Before using the laboratory results to evaluate a GCR it MUST be clear that some deficiencies of the tested prototypes are not related to the proposed GCR signal. It is then very important to remember that the results presented here show the capabilities of presently available hardware. In most of the cases they will not show the limit of the performance of a particular GCR signal. Many observed deficiencies of a tested prototype are not related to the GCR signal for which this prototype was designed. This factor must be considered before using the laboratory tests results to evaluate a GCR signal.

3.3 Ghost Combinations Used for the Laboratory Tests

Table 6 lists the different combinations of ghosts used on the Shibasoku RM-25A ghost generator. These combinations or some variations of them were used for the laboratory tests. They were selected to be representative of typical television reception conditions and are similar to the ones used for the computer simulations.

Combination A is similar to the combinations 2, 3 and 4 used in the computer simulations. Combination B reproduces more severe ghost conditions and is similar to the combinations 5, 6, 7 and 8 used in the computer simulations. Combination C reproduced microreflections which could be found on cable networks. It is similar to combination 9 used in the computer simulations. Combination D included a very long ghost just like the one in combination 10 of the computer simulations. Combination E reproduced very severe ghosting conditions: 7 ghosts with delays ranging from -4 to 40 µsec.

Combination F was used to reproduce dynamic ghosts. In this combination one of the ghost's delay could be dynamically varied from 3.35 to 4.25 µsec. The phase of this ghost also changed from 3 to 30°.

Finally combination G was created to test the performance of the ghost cancellers against strong microreflections after it was found that combination C was relatively benign.

3.4 Convergence Time

The time required for each prototype to complete ghosts cancellation for two different combination of ghosts was measured.

TABLE 6: Ghost Combinations Used in the Laboratory Tests

GHOST COMBINATION	DELAY	ATTENUATION	PHASE
NO GHOST	0 µsec	0°	0°
A(Typical)	0 µsec .45 µsec 2.30 µsec	0 dB -19 dB -24 dB	0° 30° -80°
B(Typical)	0 µsec .2 µsec 1.9 µsec 3.9 µsec 8.2 µsec	0 dB -14 dB -18 dB -24 dB -22 dB	0° -40° 0° 30° -50°
C(Microreflections)	0 µsec -.7 µsec .1 µsec .15 µsec .25 µsec .40 µsec	0 dB -26 dB -26 dB -31 dB -28 dB -28 dB	0° -40° -70° 0° 30° -50°
D(Long Delay Ghost)	0 µsec -1.8 µsec 2.2 µsec 39.0 µsec	0 dB -23 dB -14 dB -20 dB	0° -60° -20° 80°
E(Severe)	0 µsec -4.0 µsec -1.0 µsec 0.2 µsec 0.4 µsec 12.0 µsec 21.0 µsec 40.0 µsec	0 dB -18 dB -26 dB -30 dB -28 dB -20 dB -20 dB -15 dB	130° -20° -60° 170° 30° -90° 0° 50°
F(Dynamic)	0 µsec 0.8 µsec 1.5 µsec 3.35to4.25 µsec	-10 dB -28 dB -32 dB -30 dB	10° 10° 20° 3 to 30°
G(Strong Microreflection)	0 µsec 0.1 µsec 0.25 µsec 0.6 µsec 0.95 µsec 1.1 µsec	-3 dB -12 dB -20 dB -17 dB -14 dB -14 dB	108° 330° 209° 10° 40° 320°

The observers were first shown the picture produced by the prototype under test once it had eliminated ghosts for one particular ghost combination. Then the ghost generator was switched to a no ghost combination. Once the prototype had "corrected" this new condition, the signal was again impaired by the ghosts. Simultaneously a tape recorder was switched to play. The recorder was stopped once the observers judged that the ghost canceller had eliminated the ghost as best as possible. The picture used for this test was a white circle on a flat grey field which made the ghost very visible.

A recording of these tests is available. Table 7 presents the results for this test.

The AT&T prototype was fast. For combination B, it seems to cancel ghosts in two steps: first the close ghosts then, in a second step the longer delayed ghosts were cancelled. For combination D it cancelled the close ghosts in 2 seconds. It could not cancel, however, the longest delayed ghosts as it was outside its delay range. It also could not operate with this combination when it was impaired by a high level of noise.

TABLE 7: Time Required (seconds) to Complete Ghost Cancellation

TEST CONDITIONS	CORRECTED BY:				
	AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
B					
48 dB	4(A)	46	6.5(B)	31	12(A)
25 dB	9(C)	46	6(B)	28	11(A)
D					
49 dB	2(D)	45(E)	5(B)	(F)	19(A)
25 dB	(G)	45(E)	5(B)	(F)	15(A)

Note: A - Close ghosts eliminated after 2 seconds
B - Including about 1.5 seconds to synchronize
C - Close ghosts eliminated after 4 seconds
D - Long ghost was not cancelled
E - Short ghost was not cancelled
F - Could not synchronize because 1 ghost was outside the delay range of the prototype
G - Could not synchronize

The BTA-NEC prototype always took about 45 seconds to complete ghost cancellation. It could not cancel the long delay pre-ghost of combination D.

The Philips prototype performed well for all the tests. The short time it required to complete ghost cancellation included about 1.5 seconds to acquire synchronization.

The Samsung prototype was initialized manually and was controlled by a personal computer. It could not operate correctly for combination D because it included one ghost outside its delay cancellation range.

Finally the Sarnoff's prototype performed correctly for all the tests. Like the AT&T's prototype it cancelled ghost in 2 steps: the short delay ghosts were cancelled in about 2 seconds.

In conclusion some of the prototypes can already cancel ghost in a few seconds. Some of the proponents however are claiming that their GCR will eliminate ghosts within 1 second once more powerful prototypes are built.

3.5 Cancellation of Typical Ghost Combinations

Some tests were conducted to evaluate the subjective quality of the picture after ghost cancellation. The results are presented in Table 8. They were done for the 6 different ghost combinations listed in Table 6 which are believed to be representative of conditions found in the field. The first tests were done with no noise added to the output of the ghost generators. Other tests were done with an unweighted (NTC7) signal-to-noise ratio of 25 and 35 dB.

A test with no ghost was also done to evaluate the performance of the ghost canceller when it was not required to do any correction. All the prototypes did very well as shown on the first lines of the table. The exception was the one from AT&T which was not rated as high as the others because some kind of ringing and noise was visible on the pictures it produced. AT&T believes that this is due to the use of low-cost analog components. This was intended to demonstrate their GCR signal and algorithm's capability to perform well even with a low cost implementation.

The comparison between the ratings before and after correction shows that all the prototypes improved the picture quality. The improvement is particularly significant when the uncorrected picture was rated as annoying such as for combinations B, D, E and G.

TABLE 8: Impairment Rating (1-5) by Expert Observers

TEST CONDITIONS	NO CORRECTION	CORRECTED BY:				
		AT&T (A)	BTA	PHILIPS (B)	SAMSUNG	SARNOFF
NO GHOST 49 dB 25 dB	5 5	4.1 4.3(C)	4.9 5	4.9 5	4.7&4.8 4.9(E)	4.9(D) 5(E)
A 51 dB 25 dB	4 4.5(G)		4.8 5	4.5(F) 4.5(H)	4.2 5(I)	4.6 5
B 48 dB 35 dB 25 dB	2.5 2.5 3.5(D)	4.0(C) 3.9(C) (N)	4.5 5 5&4.8	4.3 4.6(H) 4.0(H)	4.0(I) 4.5(I) 4.0(I)	4.2 4.8 5
C 46 dB 25 dB	4 4.5(G)	--- ---	4.2&4.4 4.8	4.5 4.5(H)	4.0 4.7&4.9(I&J)	4.6 4.9
D 49 dB 35 dB 25 dB	2 2 2.5(G)	2.6(C&K) 2.5(C&K) ---	3(L) 3.8(L) 4(L)	4.1 4.8(F) 4.5(H)	4.2(P) 1 3	4.4 5 5
E 43 dB 25 dB	1 2(G)	2.6(C&K) ---	1.7 2	3.6&3.8 4&4.8(F)	1 1	3.3 4.8
G 43 dB 25 dB	2.4 2.0	4(C) (N)	4.4 3.4	4.2 4.4	2.6(M) 3.8(O)	4 4.4

Notes: A - The tests for the AT&T system were not done at the same time as the ones for the other systems as it was delivered late to CRC
B - These tests were completed before the Philips ghost canceller could be repaired after being damaged in shipping
C - PLL led is off
D - Low frequency ringing observed
E - Smeared background (low frequency noise)
F - Flashing screen and synch loss (sometimes)
G - Noise hides ghost
H - Ghosts fluctuating in and out
I - White spots on the screen (streaking)
J - Pre-ghosts sometimes visible
K - Long delay ghost remains
L - Does not cancel - pre-ghost
M - Synch. instability
N - Unstable operation. Could not be tested
O - Streaking visible
P - 40 μsec ghost replaced by a 34 μsec one

The exceptions were the cases when the ghosts or the level of noise were outside the operation range of some prototypes.

Most of these tests were performed before the Philips prototype was repaired after it had been damaged during transportation. This explains some of the unstability observed. The Philips prototype was in particular less robust to noise for the tests A, B, C and D which were comducted before its synchronization circuit was repaired.

The tests on the prototype from AT&T could not be completed at the same time as the ones on the other prototypes as it was delivered late to CRC. This is also why not all the tests in Table 8 were done on this prototype. A review of the performance of the AT&T prototype should take into consideration the fact that the rating obtained for this prototype for the two tests with no ghosts was only 4.1 and 4.3. It probably means that for this prototype a "perfect" correction will have a rating of 4 instead of 5 like the other prototypes. The use of low-cost parts probably explains this deficiency.

The prototype from Samsung could not operate correctly for some of the ghost combinations. When a ghost was outside its 35 microseconds cancellation range, it went into a by-pass mode. It also sometimes produced an improper DC shift and gain adjustment which made the picture unviewable.

Recordings of 2 of the 7 test sequences were made for combinations B, D, E and G for each prototype.

3.6 Effect of the Amplitude of the Ghosts

Some subjective rating was conducted to test the effect of the ghost's amplitude on the performance of the ghost canceller. To perform this test the amplitude of all the ghosts in combination B were set to the same attenuation. The test was repeated for 5 different values of attenuation from -6 dB to -14 dB. The results are presented in Table 9.

TABLE 9: Impairment Rating (1-5) of the Effect of the Amplitude of Ghosts

GHOSTS AMPLITUDE	NO CORRECTION	CORRECTED BY:				
		AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
-6 dB	1	N.A.	2	2.7	(A)	1.6(B)
-8 dB	1.2	N.A.	2.6	3.2	(A)	1.8
-10 dB	1.5	N.A.	3.3	3.7	(A)	2.2
-12 dB	1.6	N.A.	3.5	3.9	3.1(B)	3.0
-14 dB	2	N.A.	4.1	4.2	4.5(B)	4.0

Notes: (A) Ghost canceller could not synchronize: By-Pass mode.
(B) Streaking visible but not included in the rating.

As shown in the first column the rating of the picture before correction was quite low. Despite these bad conditions all ghost cancellers, when operating, could provide some improvement. The improvement is significant for all prototypes when the ghosts had an attenuation of more than 14 dB. The prototype from BTA-NEC and Philips were particularly good in cancelling high amplitude ghosts.

3.7 Effect of the Ghost Delay

Some tests were conducted to evaluate the subjective performance of the prototype over a range of delays for one of the ghosts. To perform this test the delay of the 3.9 µsec ghost in combination B was changed. The results are presented in Table 10.

Four tests were done for a long delay post-ghost. No significant improvement was obtained for ghost delays of more than 40 µsecs as this was probably outside the range of all the prototypes. The prototypes from Philips and Sarnoff both improved the signal with a 40 µsec ghost. The improvement for the two other prototypes was significant for ghosts with delays of 35 µsec or less.

Six tests were also carried out for pre-ghosts. None of the prototypes could significantly improve pictures with a pre-ghost of 10 µsecs. The prototype from Philips could significantly improve a picture with a pre-ghost of 5 µsec. The performance of the Sarnoff prototype was similar for a 4 µsec pre-ghost. Samsung's prototype offered the same performance for a 2 µsec pre-ghost and BTA's for a 1 µsec pre-ghost.

TABLE 10: Subjective Impairment Rating for a Long Delay Ghost and a Pre-Ghost in Combination B

GHOST DELAY (μsec)	NO CORRECTION	CORRECTED BY:				
		AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
50	2.8	N.A.	3	3	3	3
45	2.8	N.A.	3	3	3	3
40	2.8	N.A.	3	4.7	1 (A)	4.7
35	2.7	N.A.	4.8	4.8	4.3 (B)	4.7
-1	3.3	N.A.	4.6	5	4.9	5
-2	3.3	N.A.	3.9	4.9	4.5	5
-3	3	N.A.	3.6 (C)	4.9	3.7 (C)	5
-4	3	N.A.	3.4 (C)	4.7	3.9 (C)	4.9
-5	3	N.A.	3.8 (C)	4.7	3.5 (C)	3.7 (C)
-10	3	N.A.	3.4 (C)	3.5 (C)	3.5 (C)	3.5 (C)

Note: (A) The ghost canceller is not operating properly as the ghost is just outside its range of correction.
(B) Streaking visible.
(C) Does not cancel the pre-ghost because it is out of the range of the ghost canceller.

3.8 Effect of Non-Linearities on the Subjective Performance

Cable Labs reported that non-linearities observed in the field tests affected the performance of the ghost cancellers. Some tests were performed in the laboratory to study this problem.

A Rhode and Schwarz Distortion Network (UPF-Z) was used to create the non-linear distortions. Its differential gain was approximately 35%, its differential phase about 9° and its luminance nonlinearity around 11%. The distortion network was connected between the video source used for the tests and the baseband input of the ghost generator.

The results of the tests done on 2 ghost combinations are presented in Table 11. The luminance nonlinearity was 4% for both combinations when the Distortion Network was off. It increased to 16% when the network was on for ghost combination B and to 28% for combination D.

In all cases the subjective performance of all the ghost cancellers was not significantly affected by the increased nonlinearities. More tests may be required to determine the maximum level of non-linearity under which ghost cancellers can still operate correctly.

TABLE 11: Effect of Nonlinearities on the Impairment Rating of the Ghost Cancellers

TEST CONDITIONS (Luminance Non-Linearity)	NO CORRECTION	CORRECTED BY:				
		AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
B						
(4%)	2.5	N.A.	4.9	4.7	4.5 (A)	4.8
(16%)	2.5	N.A.	4.8	4.5	4.1 (A)	4.7
D						
(4%)	2.0	N.A.	3.3	4.5	2.0 (B)	4.9
(28%)	2.0	N.A.	3.2	4.3	1.8 (B)	4.7

Note (A): Visible Streaking.
(B): Out of its cancellation range.

3.9 Effect of the Demodulator Type on Subjective Rating

A professional synchronous demodulator was used for all the tests presented above. In the following tests a comparison was made between the performance of a synchronous demodulator and an envelope demodulator.

The envelope demodulator used was the one found in an Electrohome C40-852 television receiver. It is typical of TV sets on the market for the last 10 years. It was selected as being representative of television sets presently in operation in North America.

This test could not be performed on the NEC-BTA ghost canceller as it was using an internal demodulator. The Sarnoff's prototype could also not be tested as it required a quadrature (Q) signal, which is not available from an envelope demodulator.

The results of the tests performed on the other 3 prototypes are presented in Table 12.

As expected the type of demodulator could have a significant effect on the performance of ghost cancellers for some ghost combinations such as combination G. The effect on the other ghost combination, combination B was, however, not very significant.

TABLE 12: Effect of the Type of Demodulator on the Impairment Rating of the Ghost Cancellers

TEST CONDITIONS	NO CORRECTION	CORRECTED BY:				
		AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
B						
Synchronous	2.5	4.0	4.5	4.3	4.0	4.2
Envelope	---	3.8	(B)	4.4	4.0	(C)
G						
Synchronous	2.4	4.0	4.4	4.2	2.6	4
Envelope	---	(A)	(B)	2.4	1.7	(C)

Note: A - Could not operate
B - NEC tested with internal demodulator
C - Required complex (I&Q) demodulator

3.10 Time Varying Signals

It was reported that time varying signals had a very negative effect on the performance of the ghost cancellers used in the field tests.

This was confirmed by a few laboratory tests whose results are presented in Table 13. The first test was performed by manually varying the amplitude of the 4.25 µsec ghost in combination F. The attenuation of the ghost was varied from -30 to -20 dB. Under these conditions the ghost cancellers could not improve the picture very much.

TABLE 13: Subjective Evaluation (1-5) of Ghost Canceller for Time-Varying Ghost(s) (Combination F)

TEST CONDITIONS	NO CORRECTION	CORRECTED BY:				
		AT&T	BTA	PHILIPS	SAMSUNG	SARNOFF
4.25 µsec Ghost Amplitude Variation (-20 to -30 dB)	2.0	N.A.	2.2	2.3	2.2	2.2
1.5 µsec Ghost Amplitude Variable (-20 to -30 dB)	2.0	N.A.	2.5	3.2	3.1	2.6
Signal Variation (±1.5 dB)	2.0	N.A.	N/A(A)	3.0	3.3	3.2
Ghost Delay (3.35 to 4.25 µsec) & Phase Variation	2.0	N.A.	2.0	2.5	2.5	2.0

Note (a): Not possible to vary the gain of the NEC demodulator

In another test the attenuation of the ghost with a 1.5 µsec delay was changed. In this case, the picture quality was improved by one point, because the ghost with a 4.25 µsec delay could be eliminated as it was static.

In the following test the amplitude of all the signal was dynamically varied. This was accomplished by changing the manual gain of the Tektronix demodulator by ±1.5 dB. Again a one point improvement was observed. (This test could not be carried out on the BTA-NEC ghost cancellers as it does not have a manual gain.)

Finally a last test was performed by varying the delay of one of the ghosts between 3.35 and 4.25 µsec. The phase of the ghost was also varied between 3 to 30 degrees. In this case the improvement obtained after correction was limited to half a point. This last test was recorded.

In conclusion, none of the prototypes were fast enough to track ghosts changing over time. Some improvement was however observed because the received signal also included some static ghost which could be eliminated.

3.11 Co-Channel Interference

A very quick test was done to subjectively evaluate the effect of co-channel interference on the performance of the ghost cancellers.

The test was performed by adding a modulated video test signal to the output of the ghost generator to obtain typical level of co-channel interference. The interference has no noticeable effect on the performance of the ghost cancellers. More tests are required, however, to determine the value of interference required to affect the operation of the ghost canceller.

3.12 Ghost Cancellation and Teletext Signals

Tests were also conducted, to see how well a teletext service and a ghost cancellation system could operate together.

The first tests were completed to determine whether a teletext signal (5.72 Mb/sec) transmitted on a VBI line next to a GCR would affect the operation of the ghost canceller. The test was carried out with a teletext signal (a) on the line before the GCR, (b) on the line after the GCR and (c) on the line before and after the GCR for ghost combinations B and D (it was not possiblle to insert a teletext signal on the line following the Philips GCR due to test equipment limitation). In all cases the picture at the output of all the ghost cancellers was not affected by the teletext signals.

Another test was conducted with a teletext signal on the line before each GCR with ghost combination E. This combination was expected to have a serious effect on the GCR. However, again the teletext line was found to have no effect on the performance of all the ghost cancellers.

Some tests were also performed to evaluate how the teletext signal could be improved by ghost cancellation. These tests were carried out using a teletext generator and a teletext error counter provided by PBS. The teletext signal was inserted on one VBI line and impaired by the ghost signal generator. The teletext error counter was either fed with the uncorrected signal or by the signal corrected by one of the ghost cancellers. The tests were carried out for different ghost combinations and with unweighted signal-to-noise ratio of 25 dB. The bit error rate in the order of 10^{-4} which was obtained after ghost cancellation was not as impressive as expected. It was observed however that most of the errors were received in packet. A possible explanation is that since the ghost cancellers are updating the coefficients of their digital filter during the VBI, it could affect the corrected teletext line in such a way that complete teletext packets are lost. A high error rate is then obtained. This was confirmed by stopping the updated of the filter coefficients of the Philips ghost canceller. The bit error rate measurement was then started and the expected error-free teletext signal was obtained.

In conclusion it appears that it will be easy to revise the design of the ghost canceller to assure proper teletext operation. It is already clear however that once this revision is made, ghost cancellers will improve the performance of teletext transmissions as much as the picture quality.

3.13 Objective Measurements

A Tektronix VM-700 was used to carry out some objective measurements before and after ghost cancellation. No measurements could be made on the signals from the AT&T and the Samsung prototypes since CRC's VM-700 waveform monitor could not synchronize on them.

Table 14 presents the results obtained for the Pulse to Bar Ratio. This measurement gives an indication about the difference between the low and high frequencies of a video signal. A 100% value is perfect. The results show that the ghost canceller can provide significant improvement.

TABLE 14: Pulse/Bar Ratio Before and After Ghost Cancellation

TEST CONDITION	NO CORRECTION	BTA	PHILIPS	SARNOFF
B	67.5%	100.5%	98.8%	99.4%
D	74.5%	98.3%	101.3%	96.2%
E	96.5%	108.9%	107.2%	96.8%
G	No Synch.	96.8%	86.9%	102.8%

Similar results are obtained for the 2T Pulse K-factor measurement as shown in Table 15.

TABLE 15: 2T Pulse K-Factor Before and After Ghost Cancellation

TEST CONDITION	NO CORRECTION	BTA	PHILIPS	SARNOFF
B	4.2%	0.9%	1.0%	0.4%
D	1.2%	1.9%	1.3%	0.5%
E	2.3%	2.9%	0.8%	1.0%
F	No Sync.	1.3%	4.1%	1.0%

The unweighted signal-to-noise ratio was measured before and after correction. As expected the results of Table 16 show a slight increase in the level of noise.

TABLE 16: Unweighted Signal-to-Noise Ratio (NTC7)

TEST CONDITION	NO CORRECTION	BTA	PHILIPS	SARNOFF
B	46.0 dB	40.8 dB	42.9 dB	43.4 dB
D	43.2 dB	42.3 dB	43.6 dB	43.8 dB
E	44.0 dB	40.8 dB	40.3 dB	41.8 dB
F	No Synch.	37.3 dB	40.3 dB	38.2 dB

Finally the luminance non-linearity was measured. The results of Table 17 show that the values obtained after correction are sometimes higher than those measured before the correction. It is interesting to notice that in some instances a significant improvement is also possible such as for the ghost combination E. It is not clear, however, why ghost cancellation, which is a linear process, can improve non-linearity. It may be that the measurement techniques used by the Tektronix VM-700 are unappropriate in the presence of ghosts.

TABLE 17: Luminance Non-Linearity Before and After Ghost Cancellation

TEST CONDITION	NO CORRECTION	BTA	PHILIPS	SARNOFF
B	3.52%	3.21%	5.49%	5.89%
D	5.07%	3.84%	4.24%	5.27%
E	22.29%	7.68%	5.52%	7.30%
F	No Synch.	7.68%	8.00%	8.27%

4. CONCLUSIONS

The results from the computer simulations and the laboratory tests carried out at CRC to evaluate GCR signals have been presented.

The computer simulations demonstrate that the 3 GCR signals evaluated could accomplish a very good channel characterization. One of the simulations also demonstrated the possibility of characterizing a channel in only 1 field. It will, however, be necessary to consult the proponents in order to determine whether the slight differences noticed in the details and accuracy of the channel characterization obtained by each proponent is due to the characteristics of their GCR signal or to some difference in the processing technique.

The laboratory tests have demonstrated that all the ghost cancellers tested could improve, sometimes very significantly, the quality of the picture. A test also showed that teletext reception could be greatly improved by ghost cancellation. Some hardware limitations were however responsible for many deficiencies observed during the tests. It is clear that the laboratory tests do not show the limits of the performance of particular GCR signals but the limits of provided hardware.

It appears however that more tests may be required if the selection of the best GCR signal is to be based on the difference between the limits of the performance of each GCR signal.

It is suggested that more tests be carried out to establish the limits of each GCR signal for such parameters as:

- Ghost Delay Range
- Ghost Amplitude
- Ghost Cancellation Time

The performance obtained by each GCR signal for a low cost ghost canceller implementation as well as for a ghost canceller using complex (I&Q) processing could also be investigated.

To carry out these tests the proponents may have to develop appropriate versions (hardware and/or software) of their ghost cancelling systems.

It is hoped that such tests can be carried quickly so that a GCR signal can be selected as a standard as soon as possible.

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