provide this band, so a number of suitable receivers were distributed. In retrospect, noting that propagation in this band is virtually identical to the upper end of the MF broadcast band, it may have been adequate to instead make use of the existing MF transmitter to provide short range skywave service at night.

During commissioning, insufficient resources were available to determine the accuracy of the HF propagation predictions used to select operating frequencies, by measuring field strengths in target areas. However, it was noted that prediction software is of limited use because it does not deal with the anomalous propagation which can occur in the tropics. In one observed incident, transmitters operating in four different frequency bands gave equally very low signal levels at 300-km range, in complete disagreement with predictions, for several hours. In practice, Radio Vanuatu have arranged for some distant listeners to provide feedback on reception quality, as the best means of assessing frequency choices.

In practice, maintenance difficulties—particularly with the now rare skills of maintaining valve transmitters—have at times resulted in a need to operate on one unchanging compromise frequency at all hours of the day. The 60 meter band (4.7–5.06 MHz) was adopted for this purpose and was reported to be a workable choice. This appears to be the band most commonly used by the world's remaining tropical band HF broadcasters. Analysis has confirmed that this would be the best compromise, with the penalties that daytime signals would be weak (but listenable) near solar cycle maximum, and that night service would fail for shorter distances near solar cycle minimum (when MF would provide a service anyway).

Use of somewhat higher frequencies in the international HF bands may offer better propagation at times, but broadcasters more accustomed to the unchanging frequency usage in the tropical bands have to cope with interference from higher powered international broadcasters who expect to change frequencies often and at short notice. In a few cases, frequencies allocated to Radio Vanuatu under international co-ordination have had such interference problems.

IX. Conclusion

The introduction of frequency versatility and antennas designed specifically for national coverage has enhanced the service that the national broadcaster can provide. Some support issues have arisen, particularly the maintenance of valve transmitters. The antenna systems have been found to need little maintenance, due to the choice of minimal maintenance design solutions, except for the biconical antennas themselves. The provision of frequency versatility has uncovered new problems of HF tropical band broadcasting, including practical difficulties in the use of the lowest tropical band, interference in the international bands, and the difficulties of notifying remote listeners of frequency changes.

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Analysis of ATSC Field Test Results in Taiwan

Chai-Chin Lin, Chih-Ming Chen, Jenn-Hwan Tarng, Hsueh-Ming Hang, and Hsiao-Cheng Yu

***Abstract*—Field tests of the transmission performance of the ATSC DTV system have been conducted in Taiwan. The test results as well as comparisons against the NTSC system performance are reported and analyzed. From the measured results the reception characteristics of the DTV can be deduced and can provide guidelines for television stations to design transmission system, schedule equipment deployment, plan service coverage areas, and improve the reception quality of the digital signal.**

***Index Terms*—DTV, field strength measurement, field test, multipath fading.**

I. Introduction

The rollout of the DTV service is expected to bring us into a new era of digital terrestrial television broadcasting. In May 1998, the Ministry of Transportation and Communication (MOTC) in Taiwan adopted the ATSC Digital Television (DTV) Standard as its digital terrestrial broadcasting standard.[1] An aggressive DTV broadcasting schedule was also set forth. Overall implementation of terrestrial DTV broadcasting is expected in the year 2006.

The characteristics of the DTV signals over irregular terrain, the impact of various types of interference, and the relationship between the signal power and video quality play an important role in optimization of the service coverage and the robust transmission of DTV terrestrial broadcasting. The ability to predict the minimum power necessary to transmit from a given DTV station at a given frequency band, to provide an acceptable quality of coverage over service area, and to estimate the effect of such transmissions on existing adjacent service is crucial for the success of DTV service. Hence, there is a need for better understanding of RF propagation characteristics and the influence of the different terrain factors on the DTV radio signals and their variability.

In this correspondence, the infrastructure of the measurement system is briefly outlined in Section II. Details of the test plan, test facility, and field test operations can be found in [1] and [2]. Test results of ATV system in Canada can be found in [3]. In Section III, the field test results and analysis are presented, including carrier to noise ratio (C/N), site margin, multipath distortion, and channel characterization of DTV and NTSC Systems. In Section IV are the conclusions.

II. The Infrastructure of Measurement System

Based on [1] and [2], we designed a test plan and set up a measurement system to conduct the field test. One major task of the DTV field test was to measure the performance of the DTV system which was

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[1]1 MOTC changed to a technology neutral position in 2001.

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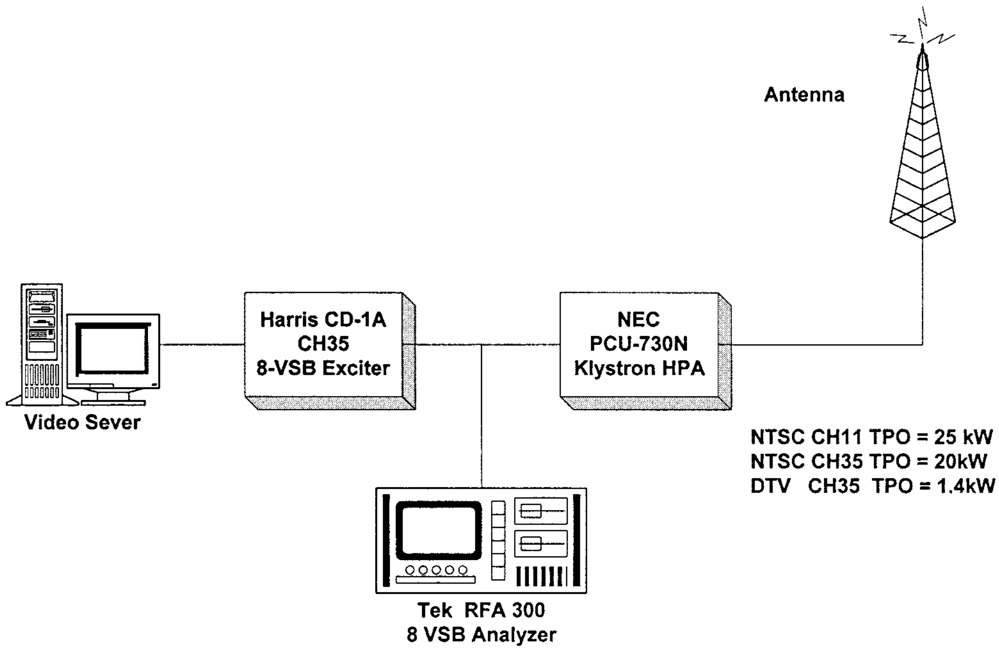

Fig. 1. The system diagram of the DTV broadcasting station.

transmitted over UHF channel 35 (596 MHz–602 MHz). The recorded measurements represent the DTV signal's average power in a 6 MHz band, C/N ratio, tap energy, site margin, and perceived video quality. In addition to the subjective ITU-R 5-point impairment rating, we also used an objective criterion, the segment error rate (SER).

During the entire testing process, the signal of DTV was transmitted from a TV broadcasting station located on Chu-Zue Mountain which is 1040 meters above sea level in Taipei with a tower height of 55 meters above the ground. The broadcasting RF system consists of an antenna, transmission line, and high power amplifiers that had been designed for NTSC broadcasting and which were not altered for the DTV testing. Add-on equipment for DTV testing includes a video server and a digital modulator (Harris CD-1A 8-VSB Exciter). The system diagram of the DTV broadcasting station is shown in Fig. 1. Note that a Tek RFA 300 8-VSB Analyzer was used to monitor the DTV signals before signals access into the power amplifier, and that the eye-diagram, constellation-diagram, amplitude/phase error, and frequency response/group delay error of the signals could be easily measured to estimate the quality of the output signals and to determine whether they meet the technical specifications or not.

A moving vehicle obtained the field test results of over-the-air reception measurements continuously. The system block diagram of the field test vehicle is shown in Fig. 2 [2]. We used a Zenith prototype professional receiver for demodulating the DTV signals and decoding pictures. The performance was measured using a reception margin and bit error rate (BER) reading. A noise generator, shown in Fig. 2, was included for the purpose of determining the threshold of visibility (TOV) of the digital television signal defined as BER at 3×10^{-6}. An RF band-pass filter was used in front of the amplifier to filter out undesired signals. The attenuator prevented overload from very strong input signals which allowed the amplifier to operate in the linear region. The band-pass filter removed out-of-band interference and prevented harmonics generated by the amplifier or the inter-modulation signals from mixing into the operating channel band. The parameter values associated with the whole reception system are listed in Table I.

A total of 100 sites were tested, including 45 locations along three radials, 43 locations on four arcs, and 12 locations within the urban core of Taipei. The figure to show the location of these three radials can be found in a previous paper by the authors [4].

III. DTV Field Test Results and Analysis

This section describes measurements specifically relevant to digital transmission system designs. Various data were collected at each site to evaluate the location availability and also to determine the reception quality of the digital signal under various interference and impairment conditions, including multipath distortion and adjacent channel interference.

A. Carrier to Noise Ratio (C/N)

Under the ATSC standard, a minimum value of 15 dB for C/N (BER $= 3 \times 10^{-6}$ or SER = 2.5 packets/s for a 20-s duration) is required for the TOV [5]–[7]. Additionally, the minimum received signal strength at the antenna should be at least 44.6 dBuV/m in our measurement system. However, it should be noted that the minimum C/N of 15 dB came from subjective assessments of the video TOV performance in the laboratory, under controlled conditions without the presence of multipath or interference. In actual field tests, the threshold value of C/N ratio could be higher.

DTV signals with good reception quality were received at 83 of the 100 sites by using a log-periodic antenna with frequency range 200 MHz to 1 GHz. Fig. 3 shows the relationship between the C/N ratio and the number of test sites with good reception quality. It can be seen that at C/N = 16.1 dB more than 50% of the test sites were able to meet the TOV requirement. The C/N value is 1.2 dB higher than the ATSC standard. This is due to the fact that in addition to the usual indoor white noise, the received DTV signal was distorted by the interference associated with the multipath and the presence of adjacent signals at the test sites.

B. Site Margin

The DTV site margin (white noise margin) is a measure of how far a signal can drop before picture and sound are lost, with the limit being determined by the noise floor of the DTV receiver. Fig. 4 depicts the

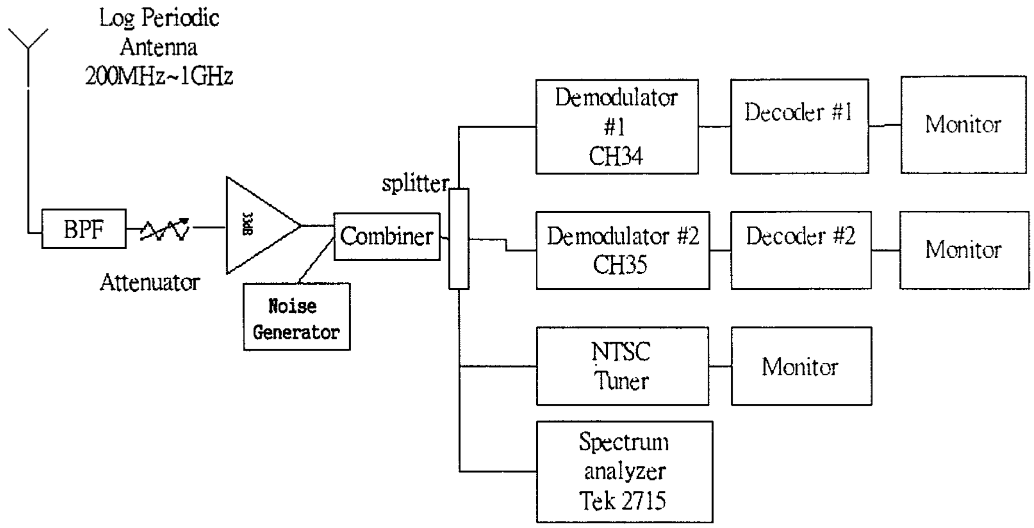

Fig. 2. The system block diagram of the field test vehicle.

TABLE I
THE PARAMETER VALUES ASSOCIATED WITH THE WHOLE RECEPTION SYSTEM

Reception System Parameter	Values
Antenna Factor (AF)	20.65
Cable 1 Loss (dB)	-3.5
Cable 2 Loss (dB)	-1.0
Bandpass Loss (dB)	-0.3
Amplifier (dB)	33.0
Attenuator Loss (dB)	-5.0
Combiner Loss (dB)	-6.5
Splitter Loss (dB)	-5.5
Cable 3 Loss (dB)	-1.6

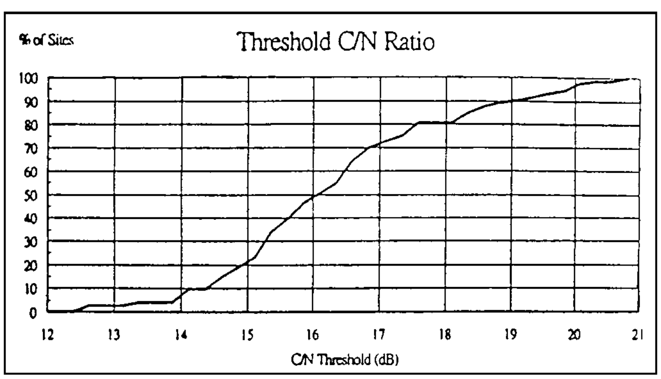

Fig. 3. The cumulative distribution of threshold C/N versus % of test site on channel 35.

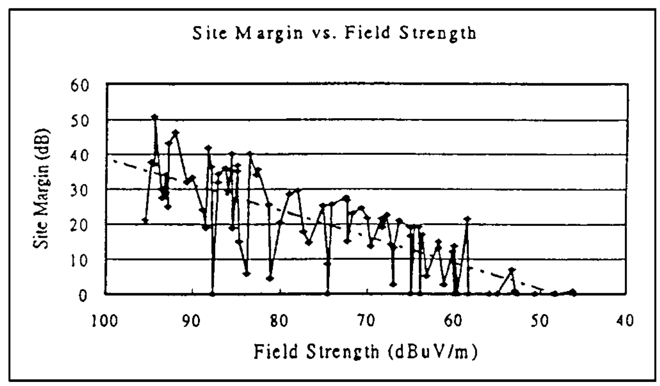

Fig. 4. Site margin as a function of the field strength for all the 100 test sites on channel 35.

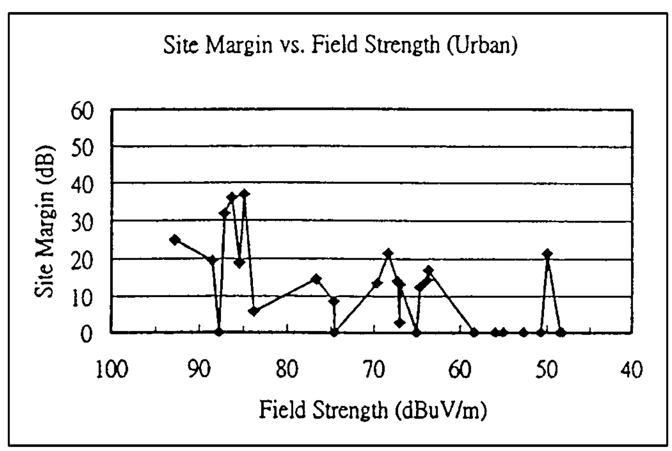

Fig. 5. Site margin as a function of the field strength for the urban area.

site margin as a function of the field strength. It is apparent that the site margin decreases as the field strength decreases. A value of 0 dB for the site margin indicates no reliable reception. The minimum field strength for reception at the test site was 46.3 dBuV/m. The corresponding site margin value was 0.8 dB, which suggests that the reception at this site was so extremely sensitive to the presence of any undesired signal strength or background noise occurring at any level that no signal could be received at the test site. The observed minimum field strength 46.3 dBuV/m was very close to the estimated value 44.6 dBuV/m.

To analyze clearly the site margin for different terrain, these observation sites were categorized by the kind of structures and the amount of vegetation present into three types of region, namely, urban, suburban, and rural areas. Figs. 5–7 present the site margin as a function of the field strength for the urban, suburban, and rural areas, respectively. It can be seen that in the urban area, due to the rapid variations of undesired signals and multipath interferences, the site margin fluctuates as a function of the field strength. Under this situation, the site margin is not linearly proportional to the field strength. This is the main reason for the rapid variations of the site margin in Fig. 5. On the other hand,

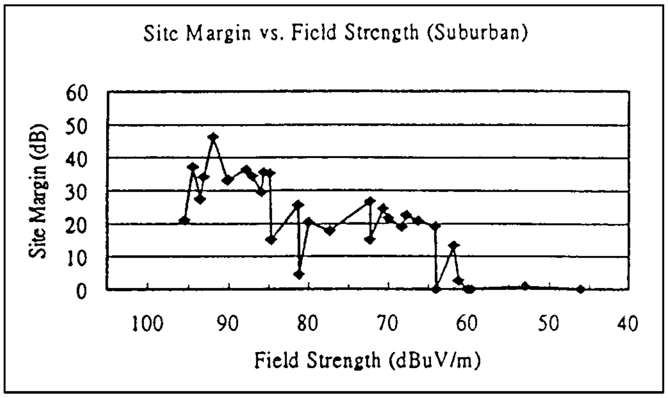

Fig. 6. Site margin as a function of the field strength for the suburban area.

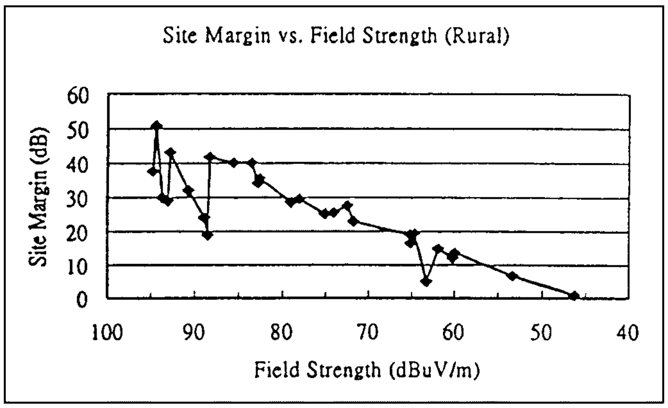

Fig. 7. Site margin as a function of the field strength for the rural area.

the suburban and rural areas (Figs. 6 and 7) show an apparent linear relationship between the site margin and the field strength. Therefore, the field test results obtained from both the suburban and rural areas should be used to predict the service area for the DTV.

C. Multipath Distortion

In addition to the minimum required C/N ratio for reliable DTV reception, multipath distortion has to be taken into account. Both factors are important in determining whether a signal with good reception quality can be received at the test site. Two methods can be employed to measure the multipath distortion. One method is to use the value of the tap energy obtained by a commercially available receiving antenna with an equalizer. Tap energy is the logarithmic ratio of the energy in all the taps except the main one to the energy in the main tap. Hence, the tap energy of the DTV receiver's equalizer provides an indication of the amount of channel distortion that would be correct.

Fig. 8 shows an example of the actual tap energy profile at a test site with poor reception. At this test site, it is shown that the energy associated with the multipath distortion is stronger than the main signal. Fig. 9 presents the tap energy and the corresponding threshold C/N values for all the test sites. It is observed that as the tap energy increases, the C/N ratio also increases gradually. The tap energy was obtained through the equalizer associated with the receiving antenna. A different equalizer would yield a different value for the tap energy. Therefore, estimating the multipath distortion using the tap energy as a parameter is receiver dependent.

Another method of trying to characterize multipath distortion at a given test site is to statistically analyze the test results obtained from the 100-foot runs [1]. The results obtained from the 100-foot runs would illustrate the field strength variations along the path. Constructive and

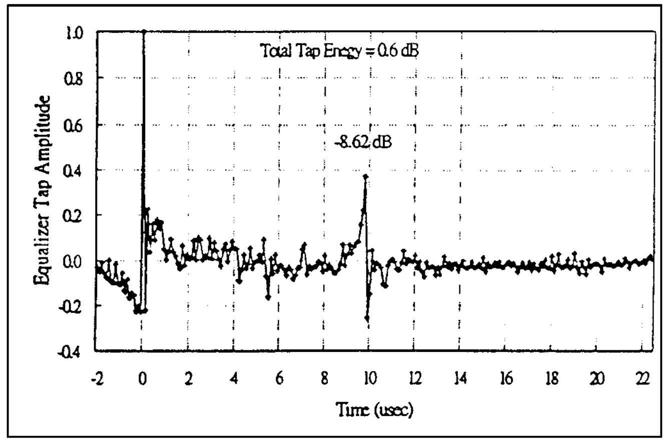

Fig. 8. An example of the actual tap energy profile at a test site with poor reception.

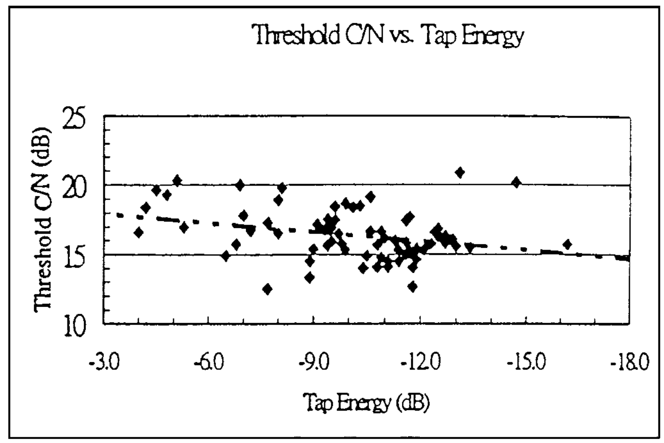

Fig. 9. Threshold C/N ratio versus tap energy for all the 100 test sites on channel 35.

destructive interference due to multipath signals leads to fading of field strength. Severe fading will influence the reception quality of the received digital television signals. In general, fading will have an effect on the reception, and a slight variation of the field strength will lead to transmission error.

Fig. 10 shows the severe fading which occurred at site A1-08 during the 100-foot runs test. Clearly, the UHF channel exhibits fast and slow fading. Generally, slow fading is the result of path blockage and fast fading can be attributed to multipath effects. When the C/N ratio is very small at the site, the variation of the signal strength will cause the C/N ratio to dip below the critical value. As a result, no reception would be obtained at the site. This suggests that the multipath distortion may be a troubling factor, especially for the low field strength locations, which might result in transmission errors.

Fig. 11 plots the standard variation of the 100-foot runs field strength and the corresponding C/N ratio. It is noted that at the site with large standard variation, fading was also severe. It suggests the presence of stronger multipath distortion at the site. It was also observed that as the standard variation increases, a higher C/N was needed against multipath distortion. This conclusion is similar to the one obtained from the analysis using the tap energy as a parameter. That is, signal variations in the 100-foot runs were found to correlate with tap energy indications, making both analyses useful in predicting the presence of multipath.

In addition to the standard variation analysis based on the 100-foot runs results, we also employed the Nakagami distribution analysis to

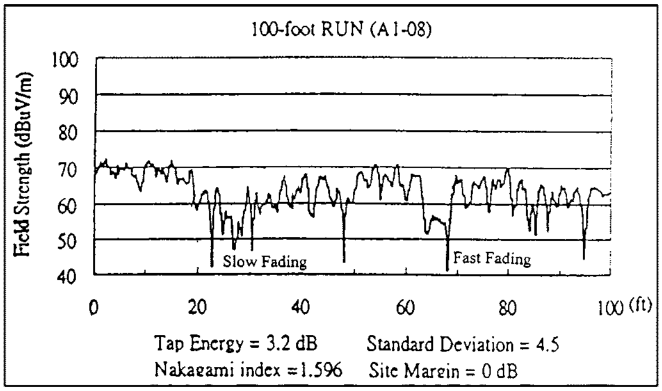

Fig. 10. The field strength of site A1-08 100-foot runs test.

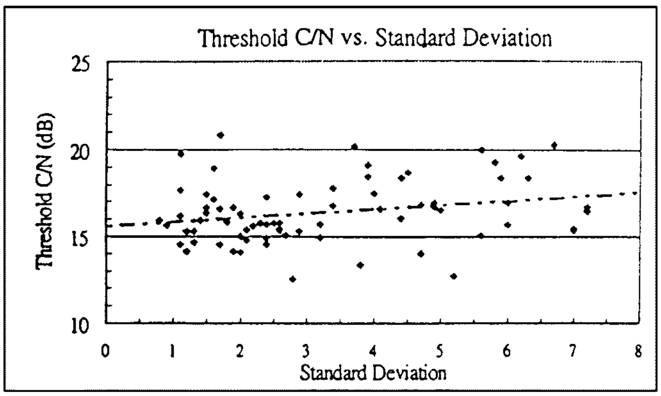

Fig. 11. Threshold C/N ratio versus standard deviation of 100-foot runs field strength.

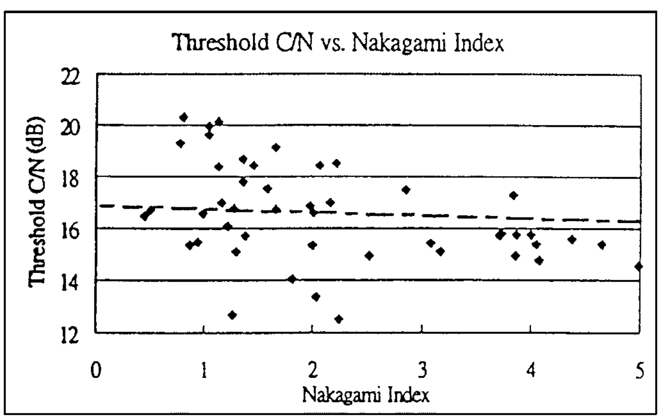

Fig. 12. Threshold C/N ratio versus Nakagami index.

investigate the multipath distortion phenomena. The Nakagami distribution is explained in the Appendix. Fig. 12 illustrates the relationship between the threshold C/N value and the Nakagami index m. It can be seen that the threshold C/N value is inversely proportional to m. This observation suggests that in the presence of multipath distortion, it is necessary to increase the value of the threshold C/N.

D. Channel Characterization of DTV and NTSC Systems

Fig. 13 shows the measured NTSC and DTV field strengths, which the signals are transmitting on channel 35 along R1 with 14 measured points. It is clear that the field strength values of DTV and NTSC have similar behavior along the terrain. This is what we would expect since they both are similar RF signals propagated through the same atmosphere on the same channel. DTV signals are lower than those of NTSC signals since for DTV the transmitter was operated at about 12 dB below the power for NTSC.

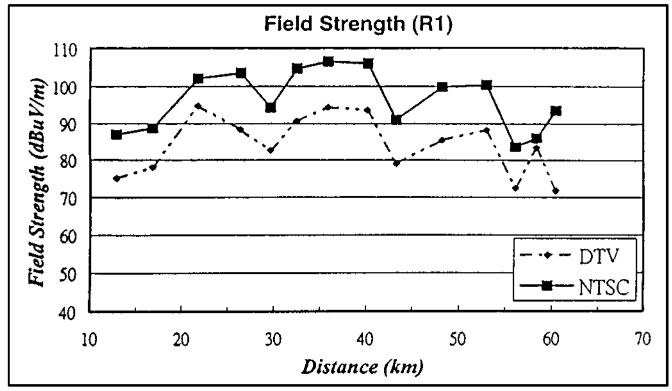

Fig. 13. NTSC/DTV field strength along the R1 track on channel 35.

TABLE II
CCIR IMPAIRMENT ASSESSMENT OF NTSC AND DTV ON CHANNEL 35

	CCIR Scale	NTSC (%)	DTV(%)
5	Imperceptible	0	93.33 (42 Sites)
4	Perceptible, but not annoying	51.11 (23 Sites)	0
3	Slightly annoying	20.0 (9 Sites)	0
2	Annoying	17.78 (8 Sites)	0
1	Very annoying (or Unusable)	11.11 (5 Sites)	6.67 (3 Sites)

To compare the efficiency of DTV and NTSC systems in the service area, 45 sites were chosen to measure the reception quality of DTV and NTSC signals. The ITU-R establishes five different grades for image quality depending on the impairments observed on a picture displayed by a professional TV monitor. The ITU-R scale of 5 to 1 represents: imperceptible, perceptible but not annoying, slightly annoying, very annoying, and unusable. Table II shows a direct comparison of the video quality of the received NTSC and DTV. In NTSC measurements, there was no site which had the ITU-R grade 5 because the picture always contained a certain amount of ghost and snow. However, the NTSC receiver always produced pictures at nearly every test site, although the picture quality may be unacceptable. In contrast, there were only grade 5 and grade 1 in the DTV measurements. That is, if a DTV site had a satisfactory reception, its ITU-R grade gets a 5; otherwise, it is grade 1. This phenomenon is well known as the "Cliff Edge Effect." The conclusion is that DTV service would be available everywhere NTSC reception is presently acceptable, and at many locations where NTSC reception is unacceptable.

IV. CONCLUSION

Field tests were performed for the DTV signal and compared to the results obtained for the NTSC system at 100 test sites in Taiwan. The terrestrial field tests verified that the digital VSB transmission system had better location availability than analog NTSC, even when transmitted with average power 12 dB below NTSC peak power. Urban areas have lower C/N ratio than other sites due to rapidly varying background noise levels. Also, the probability of the multipath distortion in the urban area is quite high, and results in a correspondingly higher probability for poor reception quality.

It was found that the reception quality is determined mostly by the C/N ratio and the multipath distortion on UHF. In general, provided that the C/N ratio is greater than 16.1 dB, most of the test sites were able to receive the digital signal with good reception quality. However, with the presence of the multipath distortion, a C/N ratio of 16.1 dB is not acceptable. In this case, a well-designed equalizer can be employed to reduce the distortion to an acceptable level. If the level of the multipath distortion is increased, then an equalizer with higher C/N ratio should be used to obtain the correct digital signal. Under FCC regulations, the critical value for the C/N ratio is 15 dB, but the field strength and the multipath distortion should still be taken into consideration in real situations. In the future, all of these factors should be considered for DTV development. Finally, we compared the performance of DTV and NTSC systems based on data collected from 45 test sites. Among these sites, 93.33% (42 sites) received the DTV digital signal, while only 71.11% (32 sites) received the NTSC television picture, even though the DTV transmitted power was lower. The ATSC system clearly outperformed the conventional analog TV system in terms of location availability and quality of reception.

APPENDIX

Due to the multipath reflections caused by the presence of natural terrain obstacles, the RF transmission signals reached the receiving antenna through many different paths. A time-varying impulse response of the signal can be represented as follows:

$$h(t, z) = \sum_{i=0}^{\infty} A_i(t) e^{j\phi_i(t)} \delta(\tau - \tau_i)$$

where $\phi_i(t)$ can be modeled with a uniform distribution. In general, $A_i(t)$ can be modeled with the Raleigh distribution when non-LOS conditions prevail and a Ricean distribution under LOS conditions.

The other model for the propagation channel statistics is known as the Nagakami distribution. The Nagakami probability distribution density is given as

$$P_r(r) = \frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m} \exp\left\{-\frac{mr^2}{\Omega}\right\}$$

where $\Gamma(m)$ is the Gamma function, r^2 is the signal power, $\Omega = E[r^2]$, $m = \{E(r^2)\}^2/Var(r^2)$ is the fading factor (Nagakami index).

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A Fast Full Search Motion Estimation Algorithm Using Sequential Rejection of Candidates From Hierarchical Decision Structure

Jong-Nam Kim, Dae-Kap Kang, Sung-Cheal Byun, Il-Lo Lee, and Byung-Ha Ahn

***Abstract*—We propose a new as well as fast full search (FS) motion estimation algorithm for video coding. The computational reduction comes from sequential rejection of impossible candidates with derived formula and subblock norms. Our algorithm reduces more the computations than the FS motion estimation algorithms recently developed.**

***Index Terms*—Decision boundary, full search, partial norms, motion estimation.**

I. INTRODUCTION

Heavy computational load of the full search (FS) motion estimation with very large search range can be a significant problem in VLSI implementation for real-time video coding applications. In order to reduce the computational complexity of the FS algorithm, so many fast motion estimation algorithms which have degraded image quality as compared to the conventional FS algorithm have been proposed [1]–[5]. Inappropriate motion vectors from these fast algorithms can be serious problem in some applications.

In this correspondence, we reduce computations further as compared to conventional fast FS algorithms while ascertaining the prediction quality same by utilizing sequential rejection of impossible candidates from the derived equations and sum of subblock norms. Main contribution of the letter is to present the inclusion relationship between lower-level decision boundaries and higher-level decision boundaries. It means that all the decision boundaries of higher levels include the decision boundary of the lowest level. From the derived relationship, we reject the impossible candidates sequentially from the lowest level to the highest level. Our proposed algorithm as reduces unnecessary computations further for overhead norms and comparison checking compared to successive elimination algorithm (SEA) [1] and multilevel successive elimination algorithm (MSEA) [2].

II. SEQUENTIAL REJECTION OF IMPOSSIBLE CANDIDATES

Efficient algorithms based on FS have been proposed using boundary equations from the sum of reference block, sum of candidate block and minimum sum of absolute difference (SAD) at that time [1]–[4]. The main idea behind the successive elimination algorithm (SEA), is as follows: The algorithm starts from the basic inequality as shown in (1). In first place, the sum of current matching block and candidate blocks are calculated. The sum of candidate blocks are calculated fast by reusing the accumulated sum of overlapped area of adjacent blocks. Then, initial matching error with sum of absolute difference (SAD) for the search origin is calculated. The sum of current block, the sum of candidate blocks, and initial matching error,

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