Correspondence

A Study of Alternative Broadcasting Technologies for the Extension of DTV Coverage in Taiwan

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***Abstract*—In Taiwan, there are six major NTSC terrestrial broadcasting stations and 129 relay stations, which cover about 98% of Taiwan's population. This paper addresses the planning of DTV broadcasting in Taiwan. DTV signals will be broadcast from the same six major transmitting sites and are expected to provide similar coverage. To extend DTV coverage beyond the major transmitting sites, only the existing 9 NTSC relay stations with over 100W transmitting power would relay DTV signals. Residences living beyond the above coverage areas could rely on CATV or DTH to receive terrestrial DTV programs.**

***Index Terms*—CATV, coverage, DTH, DTV, LMDS, relaying, subsidy.**

I. Introduction

An experimental ATSC transmitting station has been on the air since June 2000. Full coverage of DTV terrestrial broadcasting from the six major transmitting sites is scheduled to happen in late 2001.

This paper first summarizes how, in the past, Taiwan's NTSC coverage was extended to hard-to-reach places. Alternative broadcasting technologies were assessed for the extension of DTV coverage in Taiwan. The findings of this research have been recommended to Taiwan's Directory General of Telecommunications (DGT) to be considered as part of Taiwan DTV implementation plan, including: the UHF/VHF taboo channels assignment, the government subsidy policy to households outside of terrestrial TV coverage, and the policy regarding the use of the VHF band after the shutdown of NTSC, etc. Detailed information can be found in Taiwan DGT Report SEC88043 [1].

II. NTSC Coverage Extension

In Taiwan, NTSC signal is broadcast from six major transmitting sites. Because Taiwan has mountainous terrain, there are close to 4 million people, out of the 21.7 million populations, who cannot receive terrestrial TV signal from the six transmitting stations. The DGT of Taiwan has allocated 12 UHF channels (Chan. 37–48) for the purpose of relaying NTSC signals to areas out of reach from the six major transmitting stations. Over the past twenty years, the government of Taiwan has spent 656 million NT dollars (about 21 million US$) building a total of 129 relay stations. These relay stations extended the NTSC coverage to an additional 3.5 million people. Consequently, there still exist about half a million people who have always been deprived of terrestrial TV broadcasts.

Most of the relay stations are located on mountains in remote areas. Due to the high humidity of Taiwan's semi-tropical climate, and the strong typhoon gusts in the summer, maintenance of transmission equipment and the antenna towers has been a difficult and costly task. The maintenance and utility expenses of these relay stations totaled approximately 15 million NT dollars a year (about 500 000 US$). This amount of money used to be paid by the local township government. Recently, Taiwan legislators have cut government budget for this purpose, and ruled that commercial TV broadcasters should take this responsibility. The TV broadcasters wish that less costly alternative broadcasting technologies could be used to extend DTV coverage in Taiwan.

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III. Alternative DTV Coverage Extension Technologies

The DGT of Taiwan has assigned two extra UHF channels to each of the four commercial TV broadcasters for DTV broadcasting. Because the existing six NTSC transmitting stations are located at ideal sites carefully surveyed, the same sites turned out to be the chosen sites for DTV transmission. Other benefits of co-locating DTV and NTSC transmitting stations include availability of land and efficiency in maintenance.

A 2-D wave propagation computer model was used to predict DTV signal coverage. The 2-D model uses ray optics approach, which describes wave propagation in the vertical Transmitter-Receiver plane, including all relevant ray paths along the plane. In addition to the direct ray in the case of a Line-of-Sight link, reflected rays, reflected-diffracted rays, and multiple reflected-diffracted rays are considered. The method used for the calculation of diffraction effect is based on Uniform Theory of Diffraction. The total DTV field strength at a receiver location is the summing of the field strengths of the line-of-sight ray, and the diffracted-reflected rays. The [2, eq. (1)–(8)] were the equations implemented in the 2-D wave propagation computer model to calculate the field strength of multiple diffracted-reflected rays from the DTV transmitter to the receiver. The validation of the 2-D wave propagation computer model is shown in Appendix A.

Both the FCC guideline [3]–[5] and the Canadian ATV field test results [6] suggested that if the DTV emission power should be 12 dB below the corresponding NTSC power, then DTV is expected to provide equal or better service than the NTSC Grade B contour with availability F(50,90). Taiwan NTSC broadcast is in the VHF band, while DTV broadcast is in the UHF band. Moreover, UHF signals suffer more severe diffraction losses than VHF signals, especially in the mountainous terrain typical of Taiwan. Through computer simulation explained in Appendix B, the DTV emission power is suggested to be set at 7 dB below that of each of the corresponding NTSC transmitters in order to have similar coverage areas. The computer estimated coverage map of the six DTV transmitting stations is shown in Fig. 1. The comparison of NTSC and DTV coverage areas is listed in Table I. Nevertheless, the challenge of extending the DTV coverage beyond the six major transmitting stations remains to be resolved.

The following technologies have been assessed as candidates to extend DTV coverage in Taiwan, including, terrestrial relaying (UHF/VHF), LMDS (Local Multi-point Distribution System), MMDS (Multi-point Multi-channel Distribution System), DTH (Direct-To-Home), and cable TV system.

A. Terrestrial Relaying

Using UHF channels to relay NTSC signals has been a standard technique for over two decades in Taiwan. Due to the recurrent mainte-

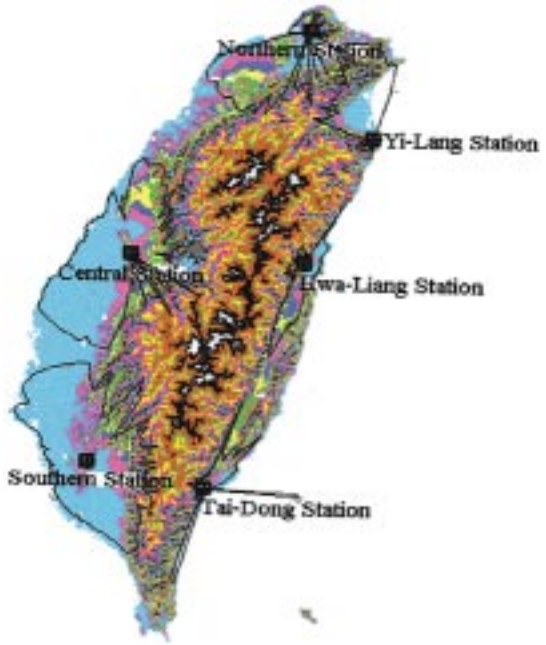

Fig. 1. Coverage map of the six DTV transmitting stations in Taiwan. (α = 90, $E_{\rm th}$ = 41 dB μ V/m).

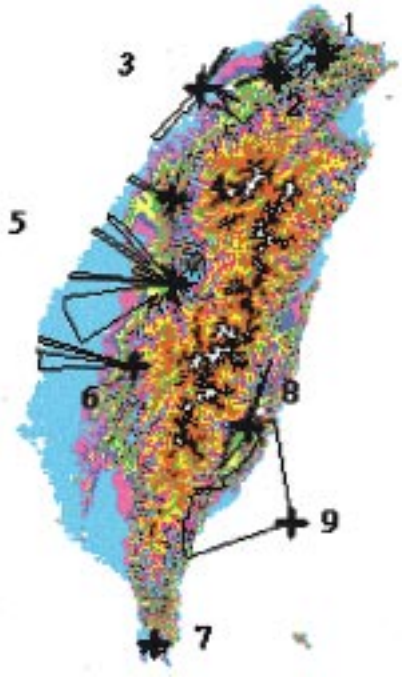

Fig. 2. Coverage map of the nine DTV relay stations in Taiwan. (α = 90, $E_{\rm th}$ = 41 dB μ V/m).

TABLE I
THE NTSC AND DTV COVERAGE AREAS OF THE SIX MAJOR TRANSMITTING STATIONS IN TAIWAN. (NTSC $E_{\rm th}$ = 54 dB μ V/m; DTV $E_{\rm th}$ = 41 dB μ V/m, α = 90)

	NTSC Coverage Area (Km^2)	DTV Coverage Area (Km^2)	(DTV/NTSC-1)%
Northern Station	2309.96	2325.4	0.66%
Central Station	4464.64	4581	2.54%
Southern Station	5084.14	5124.3	0.78%
Yi-Lang Station	1474.61	1511.3	2.44%
Hwa-Liang Station	573.72	589.43	2.67%
Tai-Dong Station	610.31	633.64	3.68%

nance burden and the lack of additional UHF channels, it is not technically feasible or economically attractive for TV broadcasters to consider relaying DTV signals at all of the 129 relay stations. However, at the eleven high-power NTSC relay sites with transmission power over 100 W, relaying DTV is still the most economical way to bring DTV signals to a large number of households. The challenge is to assign the additional four TV channels at each of the eleven sites without causing interference to either the NTSC or DTV broadcasting. For the rest low-power relay stations, alternative technologies were sought to extend DTV coverage.

Because the four commercial TV broadcasters have used the 12 UHF channels for NTSC relaying at each of the 129 sites, only 5 out of the 11 high-power relay sites can find 4 UHF channels available to relay DTV signals. All of the 11 high-power relay sites were considered as potential candidates to use VHF taboo channels for DTV relaying. The 2-D wave propagation computer model was used to predict the DTV and NTSC field strengths in order to check if the NTSC-INTO-DTV and DTV-INTO-NTSC adjacent channel interference constraints [4] are violated. This exercise led to the finding that 7 out of the 11 sites could use VHF taboo channels to relay DTV signals. Unfortunately, only 9 out of the 11 high-power relay sites can have either UHF channels or VHF taboo channels for DTV relaying. The coverage areas of the 9 DTV relay stations are shown in Fig. 2. The cost of investing in DTV relaying at these 9 sites certainly justifies the benefit of extending DTV coverage to additional 700 000 households in 18% of Taiwan's land area.

B. MMDS

MMDS has long been used for TV distribution in rural areas in some countries. Even though the capital investment is low, due to the demand for radio frequency in the 2 GHz band is very crowded; the Taiwan DGT has no plan of allocating MMDS frequency for the purpose of TV relaying.

C. LMDS

LMDS is a new technology designed to offer broadband wireless telecommunications services. Because the current LMDS receiver equipment cost is still prohibitively high for consumers, its initial target customers are urban business offices with broadband communications needs rather than households in remote villages looking to receive TV broadcasts.

Taiwan has liberalized the market of fixed telecommunications network service. 200 MHz has been allocated to each of three fixed telecommunications network operators, specifically for LMDS broadband wireless access service. At least 50 LMDS hubs are expected to go into effect sometime in the year 2001. This timing matches with Taiwan DTV island-wide broadcast schedule. Because LMDS can carry multiple digital video channels, it can relay DTV signals to its recipients. From this point of view, LMDS is certainly a viable alternative to extend DTV coverage. However, it is very unlikely that LMDS deployment will reach the remote mountain villages beyond the coverage of terrestrial TV broadcasting.

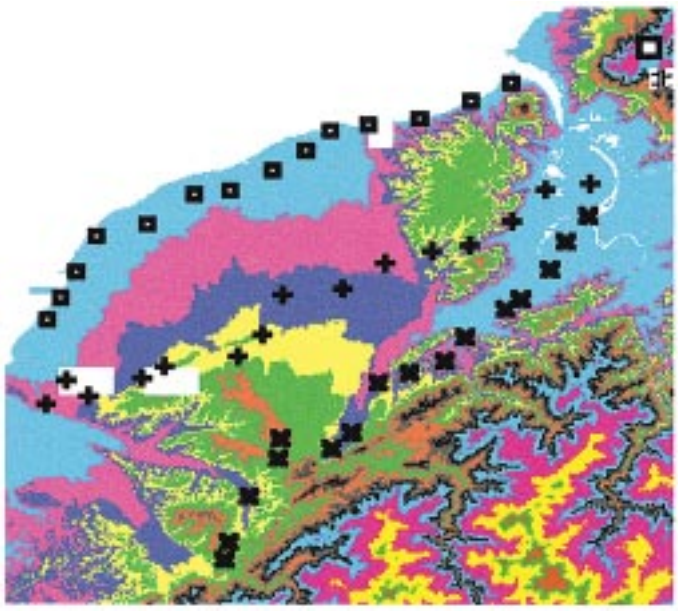

Fig. 3. Layout of the field strength measurement locations along paths P1 (denoted by "□"), P2 (denoted by "+"), and P3 (denoted by "X").

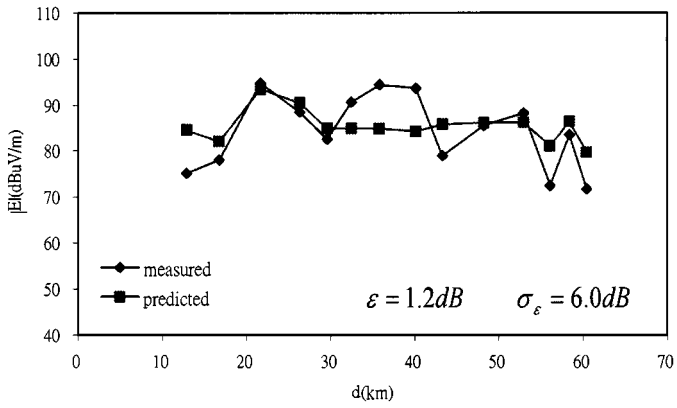

Fig. 4. Illustration of measured and predicted DTV signal strengths on channel 35 along path P1.

D. Cable TV System

Taiwan has about 6 million households on an island of 36 006 square kilometers. The low average cable span per household passed has led to over 90% cable household coverage and over 80% cable penetration in Taiwan. The majority of Taiwan households now receive TV broadcast via cable. Therefore, Taiwan cable TV systems play an important role in delivering terrestrial TV programs to households. However, for some of those really hard-to-reach households, even cable TV operators find it uneconomical to offer service.

Most cable systems might not have additional channels or spectrum space to add DTV channels. There will either have to be enough incentives to squeeze out some of their existing channels to make rooms for DTV channels; or cables have to expand capacity by upgrading to digital.

E. Direct-To-Home

Taiwan's satellite broadcasting regulation was passed in January of 1999. By now, there are four licensed DTH operators. All of them have obtained re-transmission consents from the four commercial TV broadcasters. Households throughout Taiwan can receive terrestrial TV programs in the DTH basic service package via a satellite antenna and a digital IRD (Integrated Receiver Device). Therefore, it is a technically feasible approach to extend DTV coverage to any of the hard-to-reach locations in Taiwan. On the economic side, DTH operators are willing to spare satellite transponders to carry terrestrial TV programs because they believe it is essential to the success of their DTH business. Instead of subsidizing on building UHF relay stations to extend DTV coverage, the government could subsidize households outside DTV coverage areas toward the purchase of satellite IRD.

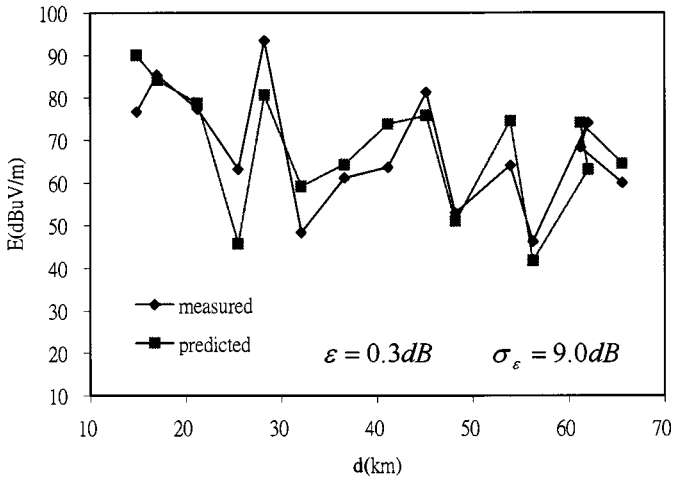

Fig. 5. Illustration of measured and predicted DTV signal strengths on channel 35 along path P2.

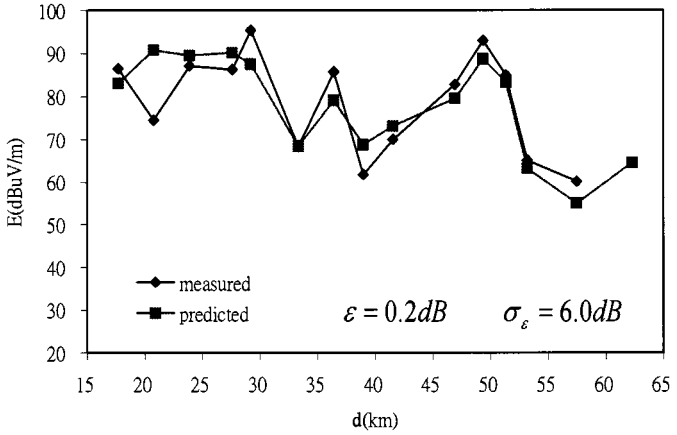

Fig. 6. Illustration of measured and predicted DTV signal strengths on channel 35 along path P3.

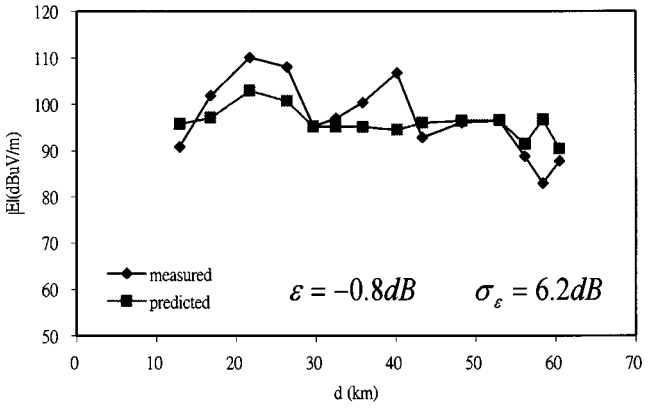

Fig. 7. Illustration of measured and predicted NTSC signal strengths on channel 11 along path P1.

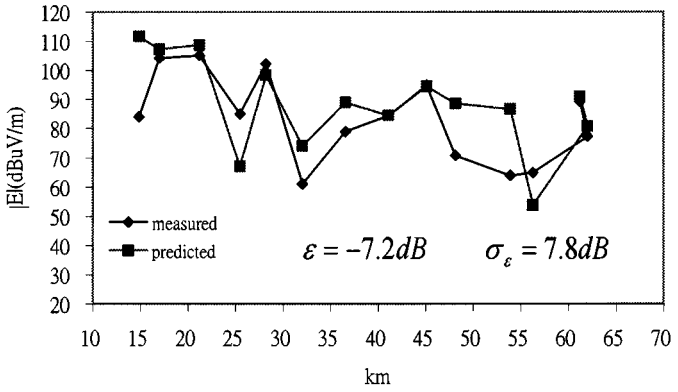

Fig. 8. Illustration of measured and predicted NTSC signal strengths on channel 11 along path P2.

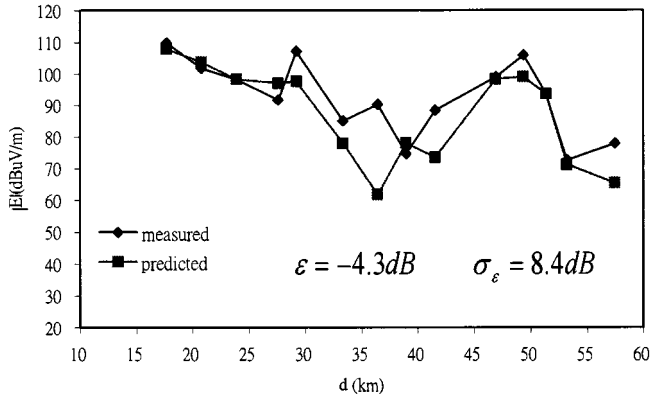

Fig. 9. Illustration of measured and predicted NTSC signal strengths on channel 11 along path P3.

IV. Conclusion

A. NTSC Relaying at the 11 High-Power Relay Sites

For the 11 high-power relay sites, the existing NTSC relaying using UHF frequencies should continue because the number of households served by these relay stations is fairly large.

B. DTV Relaying at the 9 High-Power Relay Sites

For the 9 high-power relay sites, which have either 4 UHF channels or 4 VHF taboo channels available, relaying the 4 commercial TV broadcasters' DTV signals is recommended. This can make additional 700 000 households accessible to DTV broadcasting.

C. NTSC Relaying at the 118 Low-Power Relay Sites

For the 118 low-power relay sites with transmission power below 100 W, the existing relaying of NTSC signal using UHF frequency is recommended to continue till the systems break down. Because NTSC is expected to shutdown, continued investment in NTSC relaying may not be as economical as compared with using DTH or cable TV to provide households with access to NTSC programs.

D. DTV Relaying at the 120 Relay Sites

For the 118 low-power relay sites with transmitter power below 100 W and the 2 high-power relay sites, relaying DTV signal is not recommended. One reason is because there are just not enough channels available to relay DTV and NTSC simultaneously during the NTSC-to-DTV transition period. The other reason is because Taiwan commercial TV broadcasters do not think it is economical to invest in DTV relay equipment at so many sites, especially because the potential number of viewers in such areas may be very limited. DTH or cable TV could be a convenient means to allow households in those areas to have access to terrestrial DTV programs. This recommendation is for the initial stage of DTV deployment in Taiwan. Once the TV broadcasters see the great potential of DTV in the future, they may want to invest in terrestrial relaying as a means to extend terrestrial DTV coverage.

TABLE II
Coverage Areas of DTV and NTSC at Different Levels of ERP from Northern Broadcasting Site

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	187.25	852.3
DTV	25	533	997.5
DTV	23	533	902
DTV	21	533	849.8
DTV	19	533	832

TABLE III
Coverage Areas of DTV and NTSC at Different Levels of ERP from Central Broadcasting Site

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	193.25	3083.3
DTV	25	539	3153.9
DTV	23	539	3115.9
DTV	21	539	3050.5
DTV	19	539	3024.2

TABLE IV
Coverage Areas of DTV and NTSC at Different Levels of ERP from Southern Broadcasting Site

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	187.25	3283.4
DTV	25	533	3462.1
DTV	23	533	3438.1
DTV	21	533	3286.2
DTV	19	533	3206.5

E. Government Subsidy Policy

1) Means of Subsidy: It is deemed every taxpayer's right to have access to free terrestrial TV programs. The government could consider subsidizing households residing outside of terrestrial TV coverage areas. Similar to the concept of the "Universal Service Fund" in telecommunications arena, a "Television Universal Service Fund" can be organized to pursue the goal of universal access to terrestrial TV programs by all residences. The subsidy can go to those households toward the purchasing of receiver boxes in order to receive the free TV programs from DTH or from cable TV service offerings.

The subsidy process is recommended to be administered by local township governments, which have detailed information about the DTV reception conditions within their jurisdictions. The DTH operators and the local cable TV operators are welcome to submit proposals for providing re-transmission of terrestrial DTV programs to their customers in an attempt to compete, in an open bidding process, for government subsidy.

2) Priority of Subsidy: Households, which are neither within the six major NTSC broadcasting areas, nor within any of the 129 NTSC relay areas, have never been able to receive terrestrial TV programs, should be subsidized at the highest priority.

TABLE V
COVERAGE AREAS OF DTV AND NTSC AT DIFFERENT LEVELS OF ERP FROM YI-LANG BROADCASTING SITE

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	193.25	1347
DTV	25	539	1423.5
DTV	23	539	1381.5
DTV	21	539	1338.4
DTV	19	539	1302.9

TABLE VI
COVERAGE AREAS OF DTV AND NTSC AT DIFFERENT LEVELS OF EREP FROM HWA-LIANG BROADCASTING SITE

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	187.25	473.6
DTV	25	533	490.3
DTV	23	533	481.9
DTV	21	533	465.3
DTV	19	533	437.6

TABLE VII
COVERAGE AREAS OF DTV AND NTSC AT DIFFERENT LEVELS OF ERP FROM TAI-DONG BROADCASTING SITE

	ERP(dBW)	Transmitting Freq. (MHz)	Coverage Area (km^2)
NTSC	30	193.25	436.8
DTV	25	539	475.1
DTV	23	539	466.7
DTV	21	539	436.8
DTV	19	539	426.8

Households, which are neither within the six major DTV broadcasting areas, nor within any of the 9 DTV relay areas, cannot receive terrestrial DTV programs but can receive terrestrial NTSC programs, should be subsidized at the second highest priority.

F. DTV Allotment Plan After the Shutdown of NTSC

Taiwan's four commercial TV stations currently use VHF frequency band (Chan. 5/7/9/11) for NTSC broadcasting. This research recommended using VHF taboo channels (Chan. 6/8/10/12) for DTV relaying at 7 relay sites. After the shutdown of NTSC, channels 5/7/9/11 will be returned to DGT. Because some UHF channels currently used for NTSC relaying shall also be returned to DGT, these vacated UHF channels can substitute for channels 6/8/10/12 suggested for DTV relaying. The entire VHF band will become available by then.

APPENDIX A
VALIDATION OF THE 2-D WAVE PROPAGATION MODEL

In order to verify the accuracy of the 2-D wave propagation computer model, a group of predicted signal strength data is compared with the actual measured signal strength in the field. The validation exercise involves DTV transmission at channel 35 in the UHF band, and NTSC transmission at channel 11 in the VHF band from the Northern Station. Field strength data are measured along three paths in the northern part of Taiwan. Fig. 3 illustrates the 45 measurement locations along the three paths P1, P2, and P3. Figs. 4–6 illustrate the measured and predicted DTV signal strengths along paths P1, P2 and P3 respectively. Figs. 7–9 illustrate the measured and predicted NTSC signal strengths along paths P1, P2 and P3 respectively. From these figures, it is found that the means of the estimation error (ε) range between 0.2 dB and -7.2 dB, and the standard deviations (σ_ε) range between 6 dB and 9 dB. The relatively close match between the measured and predicted field strength data shows that the 2-D wave propagation computer model is an acceptable tool to estimate radio coverage.

APPENDIX B
DETERMINATION OF DTV EFFECTIVE RADIATION POWER (ERP)

The ERP of DTV station is analyzed in order to find a proper value that could provide similar radio coverage as that of the NTSC station located at the same site. An effective radio coverage contour can be expressed by $C(E_{\rm th}, \alpha)$. It means the field strength at any location within the contour should be higher than the threshold value $E_{\rm th}$ with probability a. In this study, α is set at 0.9. In other words, 90% of the area enclosed by the contour C should have field strength above $E_{\rm th}$. Note that, in Taiwan, NTSC broadcast is in the VHF band, while DTV broadcast is in the UHF band. Based on the guidelines from FCC, the $E_{\rm th}$ for NTSC and DTV are set at 54 dB μv/m and 41 dB μv/m respectively.

A preliminary study of the radio coverage by DTV transmitting at different ERP's has been conducted. Tables II–VII list the DTV coverage areas at different ERP's from the six major broadcasting sites. The results suggest that, in order for DTV to have similar coverage as that of NTSC, the ERP of a DTV station operating in the UHF band should be 7–9 dB lower than that of the corresponding NTSC station operating in the VHF band. This study chose 7 dB below as the ERP for DTV in an attempt to be on a more conservative side to estimate DTV coverage.

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