

New Measurements and Predictions of UHF Television Receiver Local Oscillator Radiation Interference

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Abstract

A UHF “taboo,” limiting the spacing of television stations separated in frequency by the receiver intermediate frequency (“IF”), has been part of the regulatory landscape in the U.S. and elsewhere for decades. The minimum distance separation requirement between such stations has remained unchanged, despite evidence of continually decreasing levels of local oscillator (“LO”) radiation, which can result in interference to nearby receivers. The local oscillator radiation taboo mechanism is explained, its history reviewed, and trends in local oscillator leakage are examined. New measurement data are presented reflecting the current state of LO leakage that document the continued reduction of local oscillator radiation. A method is presented for combining leakage data from receivers of various vintages to obtain a single value for a typical, contemporary (2002) TV receiver. Interference analysis is provided indicating that there is no longer a need for the local oscillator radiation taboo in the regulatory frequency allocation structure. A suggestion is presented of the alternative analysis that may be required for the $N\pm 7$ channel relationship in the U.S. were the local oscillator taboo to be eliminated.

Keywords

Local oscillator, interference, taboo channel, television receiver, measurement, dipole factor.

INTRODUCTION

Local Oscillator (“LO”) Radiation is unlike any of the other phenomena that resulted in the so-called “UHF Taboos,” that is, the requirements or recommendations of the FCC,¹ Industry Canada,² the ITU,³ and other authorities, for minimum geographic spacing between television stations having certain channel relationships. In the cases of all the other UHF Taboos, the mechanisms involve signals from two television stations on different channels, mixing with one another in various ways to cause interference on those or other channels. The extent of any interference depends both upon the strength of the two TV signals and upon the response characteristics of the receiver. In the case of LO radiation, however, interference occurs when a signal generated in one television receiver tuned to a particular channel falls within the spectrum of another channel tuned by a nearby receiver. The extent of interference due to LO radiation depends *only* upon the strength of the sig-

nal radiated by the first receiver relative to the strength of the desired signal at the second receiver, and is unaffected by the response characteristics of the receiver experiencing the interference. It follows that a reduction in both predicted and actual interference can be expected to occur as the level of LO radiation from receivers decreases with design improvements over time.

Statistical data have been published previously on television receiver performance, including LO radiation data. Although we are aware of no published data since 1987, the technology in television receivers, however, has continued to improve. The improvements have been driven largely by increased cable television penetration in the marketplace and the concomitant need for television receivers that perform well when connected to cable television networks. Since television receiver performance data have not been published in a long time, regulatory agencies may not be able to evaluate properly the continuing need for the UHF Taboos related to LO radiation. In order to correct this situation, a series of measurements of the LO radiation of contemporary television receivers have been conducted and the results are published herein. This contribution begins with a description of the LO radiation taboo, looks at its history, and then delves into the recently taken measurements and their interpretation.

DESCRIPTION OF LO RADIATION TABOO

While most of the UHF taboos involve an interaction between a television receiver and multiple “undesired” broadcast television signals, the LO taboo is unique in that the interference source is entirely due to the television receiver itself. Most television receivers (and indeed most receivers generally, whether FM broadcast, two-way radio, cordless telephone, etc.) use the heterodyne process, generating within them a local oscillator signal that is combined internally with the desired signal to be received.

A block diagram of a simplified heterodyne television receiver is shown in Figure 1. The IF used since the mid-1950s in U.S. television receivers spans 41-47 MHz, with the visual carrier located at 45.75 MHz and the aural carrier located at 41.25 MHz. The local oscillator operates at a frequency 41 MHz above the top edge of the channel being received. In this example, the desired signal is on (NTSC) System M TV Channel 31 (572 – 578 MHz), and is mixed

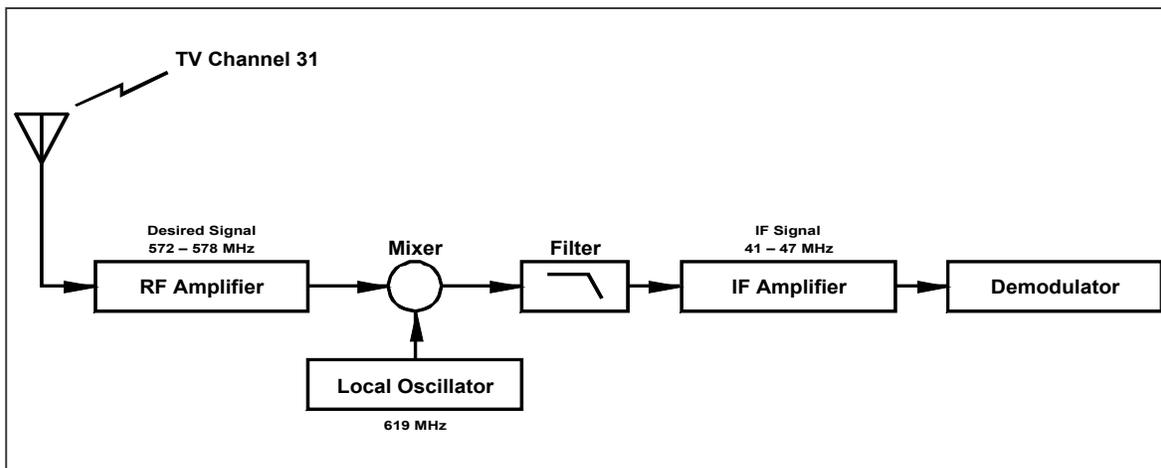


Figure 1 — Simplified Heterodyne Television Receiver

with a Local Oscillator signal at 619 MHz. The LO frequency lies within TV Channel 38 (614 – 620 MHz). After filtering, a replica of the desired signal is produced at the intermediate frequency (“IF”) band of 41 – 47 MHz with its spectrum inverted. Because the LO lies within the seventh channel above the channel being watched, this is called the “N+7” channel relationship.

Although the energy produced by the LO is intended to be used only within the TV receiver, a tiny amount of the LO signal can escape, usually via the antenna terminals.⁴ If two television receivers are located sufficiently close to one another, the LO radiation from the receiver tuned to Channel N could therefore cause interference to the reception on the second receiver of Channel N+7 in System M.

Broadcast television systems having 7 or 8 MHz channel separations typically have local oscillators that operate at frequencies between 38 and 40.2 MHz above the visual carrier of the desired signal. Hence, the LO radiation taboo typically occurs in those systems on Channel N+4 or N+5.⁵ Because the data collected for this paper is entirely from System M receivers, the focus of the analysis is on the N+7 taboo.

HISTORY OF LO RADIATION TABOO IN THE U.S.

For UHF television stations, the restriction in the U.S. that prohibits two stations seven channels removed from each other from being allotted to the same geographic area has its roots in the nationwide television allocation proceeding of the early 1950s. This restriction precludes a station on Channel N from being allotted within 95.7 kilometers of a station on Channel N+7, and vice-versa. Because the seven-channel prohibition and other prohibited channel relationships preclude the efficient use of the UHF spectrum, the FCC on several occasions has investigated means to eliminate them.^{6, 7, 8} At various times, the FCC determined that certain of these taboos could be relaxed or

eliminated in certain situations.^{9, 10} Indeed, the ATSC digital television system now being deployed in the U.S. retains only restrictions on the allotment of upper- and lower-adjacent channels.

Among the earliest references to television interference from local oscillator radiation is an FCC report from 1949,¹¹ which provides commentary on an industry proposal to limit LO radiation to 25 $\mu\text{V}/\text{m}$ at 1000 feet. At that time, the limitation would have applied only at VHF, since commercial UHF broadcasting had not yet begun in the U.S. The FCC’s Engineering Bureau opined that the proposed limit seemed too high in view of the fact that receivers were available that delivered 40,000 pW¹² and 2,000 pW to the antenna terminals of the receivers – levels stated to be equivalent to field strengths of 3.8 $\mu\text{V}/\text{m}$ and 0.85 $\mu\text{V}/\text{m}$ at 1,000 feet. The document also noted that a proposed rule making had been released by the Commission seeking to establish a limit of 15 $\mu\text{V}/\text{m}$ at 100 feet, which “will limit interference to an area of approximately 0.01 square mile, as compared with 3 square miles for the [industry] proposal of 25 $\mu\text{V}/\text{m}$ at 1000 feet.”

Spectrum allocations for television broadcasting were first made in 1941 using frequencies in the VHF band. At that time, VHF television receivers utilized a 21 MHz IF, which apparently resulted in some LO interference. In 1945, the Commission sought to meet future demands for television service by creating additional channels in the UHF band.¹³ In Appendix A of its Third Notice of Further Proposed Rule Making,¹⁴ the FCC provided a tentative allocations philosophy for establishing a new UHF television service. The Third Notice described certain of the UHF taboos, including that of LO radiation. Although no specific measurement data were presented (presumably because no UHF television receivers yet existed), LO radiation was believed to be likely more severe in the “UHF band than in the VHF band due to difficulty in suppressing such radiation in the higher frequencies.” While the Commission

stated that it expected that continued improvements might eliminate the problem of oscillator radiation in the future, a 7-channel “LO Taboo” was specified, which required such stations to be separated by a minimum of 60 miles. No specific basis was given for that mileage in the Third Notice; although it was stated that the “separation affords substantially the same protection as does the co-channel separation provided [55 miles]”.

In the Sixth Report and Order,¹⁵ the FCC codified the proposed 60 mile separation requirement to protect against LO radiation interference, “based on the principle of non-overlapping Grade A service areas of stations 7 channels apart, so that receivers within the Grade A Service area of one such station would not normally be tuned to receive service from the other station which would not be as good in quality.” The Commission noted that since this protection was confined primarily to the Grade A service areas, “it remains of utmost importance that continuing efforts be made to reduce the magnitude of local oscillator radiation ...” The limit established by the FCC for LO radiation at that time was 1,500 $\mu\text{V/m}$ at 100 feet.¹⁶ Except for a conversion to the metric system in the 1980s, the 60-mile separation requirement has remained unchanged since 1952.

A digest of early FCC-industry correspondence related to the LO radiation issue was published by the FCC in 1953.¹⁷ According to that digest, a Radio-Television Manufacturers Association (RTMA) technical committee recommended that all TV receivers placed in production as of June 1, 1954 have LO radiation levels at UHF channels less than 500 $\mu\text{V/m}$ at 100 feet. The Television Allocations Study Organization (TASO) also studied LO radiation. In its 1959 report,¹⁸ TASO observed that LO radiation presented an interference “difficulty” in the field, “although steady progress is being made toward its alleviation ...” At that time, all local oscillators were based on triode tubes¹⁹ and supplied “a few milliwatts of power” to crystal mixers. Semiconductor (diode) mixers requiring less LO power were just being introduced.

According to a report of the technical group studying “all-channel broadcasting,”²⁰ statistics on UHF local oscillator radiation are given in the minutes of EIA Subcommittee 4.9 on Television tuners, issued June 12, 1964. The reported statistical calculations indicated that 30–40% of the receivers radiated in excess of 500 $\mu\text{V/m}$ (at 100 feet). By 1971, maximum radiation permitted under FCC rules had been reduced by a factor of three since 1952 (*i.e.*, from 1,500 to 500 $\mu\text{V/m}$).²¹ Television manufacturers were responsible for conducting measurements of LO radiation using specified procedures. The requirement was that the average of 10 measurements taken at specified frequencies corresponding to certain UHF channels from 14–83 not exceed 350 $\mu\text{V/m}$, with no measurement exceeding 750 $\mu\text{V/m}$ (at 100 feet). In 1972, the FCC published measurement data

on 56 different UHF television receivers taken during 1971 and 1972.²² The average field strength was 152 $\mu\text{V/m}$, with one single measurement reported at 730 $\mu\text{V/m}$.

By 1983, manufacturers were routinely designing television receivers using solid-state integrated tuners and were reporting to the FCC LO radiation at levels less than 1 $\mu\text{V/m}$ (at 100 feet). The Commission’s Office of Engineering and Technology published some of this data in 1987, noting, “[i]t appears that the dominance of local oscillator radiation for a seven channel taboo has been diminished.”²³ The ITU has also noted that “receiver technology is improving rapidly [so that the impacts of LO radiation] are gradually decreasing with improved receiver technology.”²⁴

CONTINUING DOWNWARD TREND IN LO RADIATION LEVELS

Although we are aware of no LO radiation data published since 1987, a continuing downward trend in LO radiation levels would be expected. The principal reasons for this are advances in electronics technology and the use of cable systems for television signal delivery. Technology advances have reduced the signal levels required from the local oscillator and provide greater isolation between the mixer and the antenna connection.

Cable television (CATV) systems are not required to observe the UHF Taboo restrictions and, indeed, such systems typically use every single available channel. By carefully controlling signal levels within the cable system, many of the effects leading to the taboo restrictions can be minimized. Since it is solely a characteristic of the consumer’s TV receiver, however, LO leakage cannot be controlled by the cable system operator.

Commonly, a consumer may have two or more TV receivers sharing a single connection to the cable network. The cable will conduct LO energy from the antenna terminals of one receiver to the input of a second receiver. If significant LO energy is present and the second set is tuned 7 channels above the first, interference to reception on the second receiver can result. The cable industry has studied the possibility of 7-channel LO interference,²⁵ finding that LO signal levels at the antenna terminals are commonly – 20 dBmV or lower. This is equivalent to a field strength of 2.63 $\mu\text{V/m}$ at 100 feet.

The question naturally arises, with such decreases in LO leakage levels occurring in the television receivers being delivered to the viewing public, has the time arrived when the local oscillator radiation taboos can be eliminated or at least limited in some way? To find the answer requires determining the level to which LO leakage has fallen in the contemporary population of television receivers. The remainder of this paper deals with such a determination.

RECENT LO MEASUREMENTS

To confirm the continuing downward trend in the level of LO leakage from consumer television receivers since 1987, the Merrill Weiss Group LLC and Hammett and Edison, Inc. jointly carried out a program of measurements. Measurements were made during calendar year 2002 on a sample of 67 television receivers and VCRs found in consumer's homes. VCRs were included because they now represent a substantial portion of the television tuners in the hands of the public.²⁶ A measurement system was connected to the receiver antenna inputs, and the levels of local oscillator signal were measured with the receivers tuned to eight specific UHF channels. The channels measured were spaced at 6-channel intervals from Channel 15 through Channel 57 (*i.e.*, 15, 21, 27, 33, 39, 45, 51, and 57).

The measurement system comprised a spectrum analyzer, termination and impedance matching pads, cabling, and an amplifier to overcome the losses in the pads. The impedance of the receiver inputs was assumed to be 75 ohms non-reactive. A 3 dB attenuator was placed at the receiver input to stabilize any mismatches that might be present in the tuner input circuitry, acting as the impedance of the signal source for the measurements. A cable then led to a 75-to-50 ohm minimum loss pad at the input to the spectrum analyzer, which has 50-ohm input impedance. When necessary, a nominal 20 dB amplifier having a low noise figure and another cable were inserted after the 3 dB attenuator. The transfer characteristics of the measurement system were measured using traceable instruments, and the LO data reported here have been adjusted by the calibration factors thus obtained.

Typically, spectrum analyzer settings included a resolution bandwidth of 30 kHz, sweep range of 1 MHz, video bandwidth of 30 kHz, and sweep speed of 50 ms. The LO frequency of most of the television receivers tested was very stable. A few of the older receivers, however, had LO signals that swept across a range of frequencies. Some receivers have LOs that sweep as the automatic frequency control ("AFC") searches for a signal to "lock" onto; since the receiver's input was connected only to the measurement system, there was no input signal, and the LO swept continuously during the measurement. In such cases, various methods were applied, such as use of wider resolution bandwidths, of slower sweep speeds, or of peak-hold functions in the analyzer, in order to capture the highest level of signal that could be measured from the receiver's local oscillator.

Uncorrected LO levels in dBm were collected manually as read from the spectrum analyzer. The instrument's marker and peak search functions were used to obtain the value to be recorded. The calibration factor associated with the measurement system and determined separately for each

channel tested was applied during the data analysis process. The final (corrected) LO levels are reported in dBm.

RESULTS OF LO MEASUREMENTS

Receivers tested ranged in date of manufacture from 1975 through 2001. Because it is the *trend* in LO leakage levels that is primarily under investigation, the data are presented relative to the year of manufacture. Figures 2 through 9 show for each of the 67 receivers the corrected LO levels measured on each television channel vs. year of receiver manufacture. Both the individual measurements taken and a least squares linear regression line calculated through the data set are shown in each figure. Figure 10 shows on one chart all of the data collected.

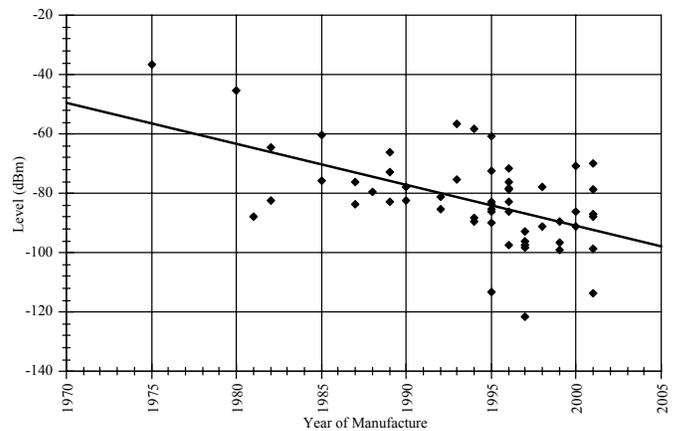


Figure 2. LO Leakage data – Ch. 15.

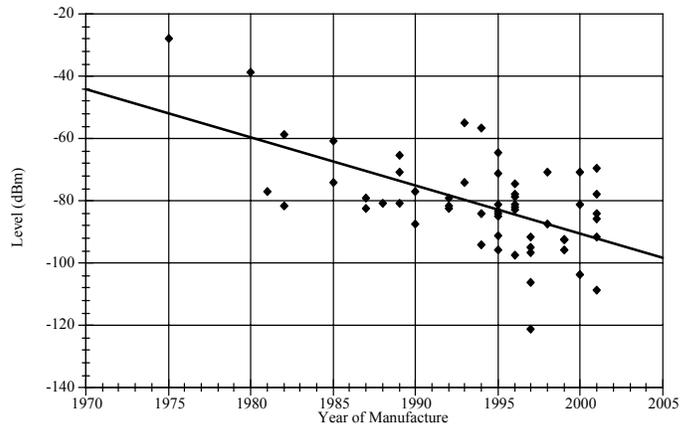


Figure 3. LO Leakage data – Ch. 21.

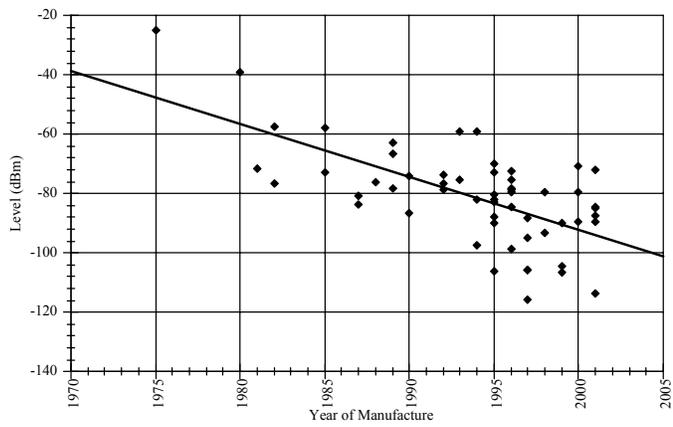


Figure 4. LO Leakage data – Ch. 27.

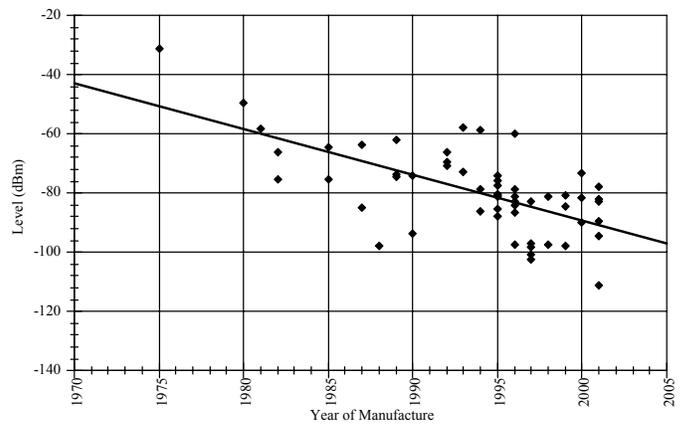


Figure 7. LO Leakage data – Ch. 45.

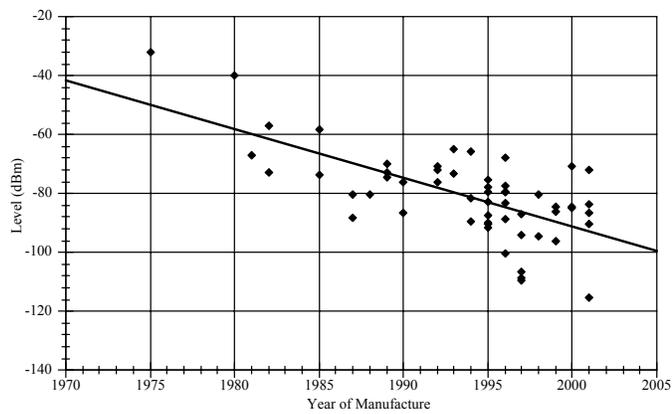


Figure 5. LO Leakage data – Ch. 33.

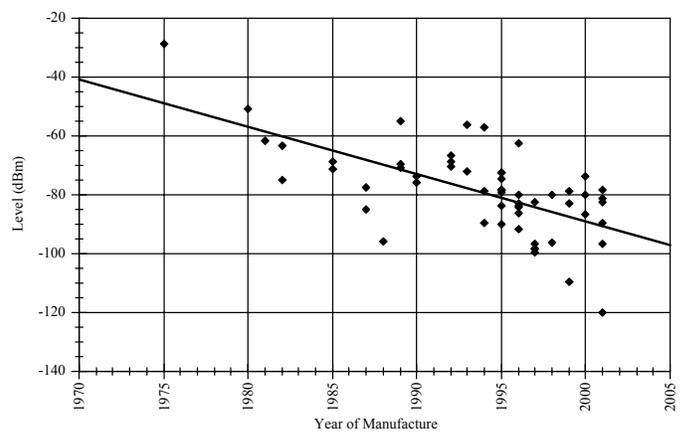


Figure 8. LO Leakage data – Ch. 51.

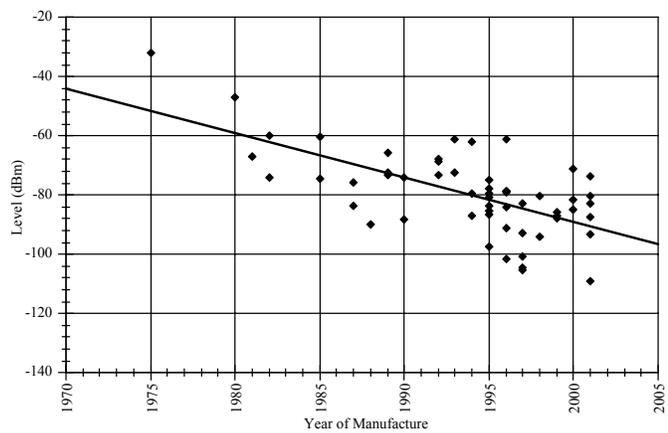


Figure 6. LO Leakage data – Ch. 39.

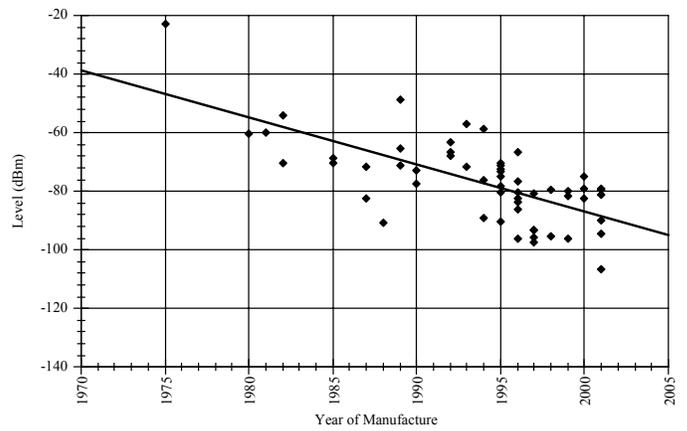


Figure 9. LO Leakage data – Ch. 57.

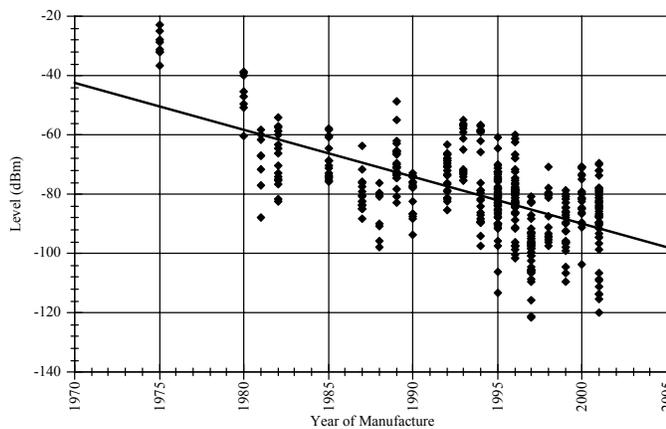


Figure 10. Combined measurement data for all channels vs. year of manufacture, with the least squares linear regression.

INCORPORATION OF AGING INTO THE LO MEASUREMENT DATA

As is apparent from Figure 10, the LO leakage from UHF television receivers, including VCRs, manufactured during the period from 1975 through 2001, has declined by 35-40 dB over that time interval. This fact is borne out by the slopes of the regression lines of Figures 2-9, which vary between -1.3 and -1.6 dB per year, indicating a reduction of local oscillator leakage of about 13 to 16 dB per decade.

Another factor that must be considered when evaluating the reduction in LO leakage levels in the universe of installed receivers is the age of the population of TV sets and VCRs. Television receivers tend to last a long time, so it is important to know when they are retired and replaced. It also may be significant if sales for new applications are increasing or decreasing, thereby respectively lowering or raising the percentage of older receivers in the population. Data from the consumer electronics industry can be used to evaluate each of these factors.

The Consumer Electronics Association (CEA) and its predecessor/parent the Electronics Industries Association (EIA, now the Electronics Industries Alliance) publish data, studies, and reports on the uptake and utilization of various types of equipment manufactured by its members. Among these are a variety of information on television receivers and VCRs. Two types of information are particularly relevant to the question at hand: the number of TV receivers and VCRs sold in each year, and the longevity of the products in use by consumers.

Data concerning longevity were obtained from the EIA's April 1985, "Color Television Replacement Cycle Study."²⁷ That study considered some of the factors driving television set sales going forward. These factors included the effects of the aging of TV sets and their direct

replacement, and the impact of expanding uses of television receivers and their consequent addition to the population of sets in use as consumers moved older sets to secondary and tertiary applications.

The EIA study indicates that the "out of use percentage" was about 46 percent after 15 years.²⁸ Although not explicitly evaluated in the EIA document, analysis of the data provided in Table III.4²⁹ indicates that the fraction of TV receivers taken out of service can be modeled as a square law cumulative distribution of the form:

$$\text{discarded fraction} = 0.2133 \times (\text{years owned})^{1.9887}$$

Using this relationship, it can be shown that a large proportion (over 90 percent) of television receivers are removed from service after 21 years, and that substantially all (approximately 99.7 percent) are out of service after 22 years. These results and those for intervening years can be used to "age" the population of television receivers in order to arrive at a model of a "typical" television set of today.

To calculate the number of television receivers of different ages still in the population, one determines the number sold in each year and then discounts that number using the discard percentage for each year. Sales data are published in the EIA's "This Week In Consumer Electronics (TWICE)." Those data show that the number of receivers sold in any year generally have increased steadily. (There are a few years over the last couple decades that show modest reductions in sales). Use of the increasing sales numbers to weight the aged population of television receivers tends to reduce the value calculated for the local oscillator leakage from the typical television set of today. Therefore, assuming that receiver sales have been constant is a conservative approach, since it results in a higher value for average LO leakage.

Assuming constant sales, the present population of television receivers and VCRs can be calculated and aged according to the discard percentage formula given above. From the population determined, a weighted average of the local oscillator leakage values can be calculated by summing the remaining (undiscarded) populations from each of the years having any significant contribution to the current population and dividing that value into the population for each contributing year. The result of that division is a weighting factor to be applied to the LO leakage for that year, as obtained from the average of the regression lines for the individual channel measurements. The weighted LO leakage values for the years with any significant contributions to the current population can then be averaged to determine the mean LO leakage value for the current population. This procedure can be expressed with the following formula:

$$LO_{avg} = \sum_{i=0}^{i=n} \left(\frac{1 - d_i}{\sum_{i=0}^{i=n} (1 - d_i)} \right) (LO_i) \quad (1)$$

where

LO = local oscillator radiation in dBm

d_i = discard % in year i

n = number of significant years

The partial results of this calculation, the weighting factors, and the annual LO leakage values derived from the regression lines are given in Table 1. The resulting average value for local oscillator leakage of the “typical” television receiver at the end of calendar year 2002 is -81.8 dBm.

Table 1. Calculation of Local Oscillator Leakage level (dBm) from Typical Receiver

Year	Age	Discarded Fraction	Retained Fraction	Weighting Value	Regression	Weighted Average Contribution
2002	0	0	1	0.06598	-93.2934	-6.15574
2001	1	0.00213	0.99787	0.06584	-91.8495	-6.04754
2000	2	0.00847	0.99154	0.06542	-90.4056	-5.9147
1999	3	0.01896	0.98104	0.06473	-88.9618	-5.75863
1998	4	0.03360	0.96640	0.06377	-87.5179	-5.58064
1997	5	0.05236	0.94764	0.06258	-86.074	-5.38198
1996	6	0.07525	0.92475	0.06102	-84.6301	-5.16391
1995	7	0.10224	0.89776	0.05924	-83.1862	-4.92764
1994	8	0.13334	0.86666	0.05718	-81.7423	-4.67438
1993	9	0.16854	0.83146	0.05486	-80.2984	-4.40534
1992	10	0.20782	0.79218	0.05227	-78.8545	-4.12172
1991	11	0.25119	0.74881	0.04941	-77.4106	-3.82472
1990	12	0.29865	0.70135	0.04628	-75.9668	-3.51552
1989	13	0.35018	0.64982	0.04288	-74.5229	-3.19531
1988	14	0.40579	0.59422	0.03921	-73.079	-2.86527
1987	15	0.46546	0.53454	0.03527	-71.6351	-2.52659
1986	16	0.52921	0.47080	0.03106	-70.1912	-2.18044
1985	17	0.59701	0.40299	0.02659	-68.7473	-1.82799
1984	18	0.66889	0.33112	0.02185	-67.3034	-1.47043
1983	19	0.74482	0.25519	0.01684	-65.8595	-1.10893
1982	20	0.82480	0.17520	0.01156	-64.4157	-0.74465
1981	21	0.90884	0.09116	0.00602	-62.9718	-0.37877
1980	22	0.99694	0.00307	0.00020	-61.5279	<u>-0.01244</u>
Weighted Average LO Leakage of Typical Receiver						-81.7833

EFFECT OF LO RADIATION IN CONSUMER ENVIRONMENTS

Having determined a representative value for local oscillator leakage in the current population of television receivers and VCRs, it becomes possible to evaluate the potential for interference between receivers tuned to stations that are separated by 7 channels. We consider two cases of interference: one where both receivers are using outdoor directional antennas that are pointed at one another, and one in which the two receivers are on opposite sides of a wall with their set top antennas relatively near to one another. We believe that these are the two conditions that have the greatest possibility for interference to result between receivers. Before treating the details of the two cases just outlined, it is first necessary to understand the mechanisms involved in interference and the threshold at which interference is deemed to occur.

Interference to an NTSC television signal from an unmodulated carrier varies depending upon the relative frequency of the interfering carrier within the channel. The signal radiated by a local oscillator essentially is an unmodulated carrier. Differences in the amount of interference to an NTSC signal arise from the relative proximity of the interfering signal to the three carriers used in the NTSC system, *i.e.*, the visual carrier, the color subcarrier, and the aural carrier. As an interfering signal is moved from the bottom to the top of a television channel, a viewer will perceive a variety of effects. Some of those effects are more apparent than others because of different sensitivities of the human visual system to monochrome and color variations of different spatial frequencies, different patterns, and different orientations.

Measurements have been made of the human visual system's response to interfering carriers having different frequencies within the television channel. Results of those measurements indicate that, if an unmodulated carrier is varied from the bottom to the top of the channel and the ratio between the carrier power of the (desired) television signal and that of the (undesired) interfering carrier is adjusted so that the interference is just barely visible (threshold of visibility – TOV) at each frequency step, a plot of the undesired signal level versus frequency within the channel will describe a “W” shape. Several such “W” curves have been published.³⁰

One family of “W” curves, as measured for three images in 1986 by CBS Laboratories and the National Association of Broadcasters, is shown in Figure 11.³¹ Measurements were made in Channel 23 (524-530 MHz). Sine wave signals, serving as the undesired signal, were injected into the desired signal approximately every 500 kHz starting at the lower band edge. The level of the sine wave signal was adjusted until a panel of expert viewers agreed that the interfering signal was “just perceptible.” The values thereby

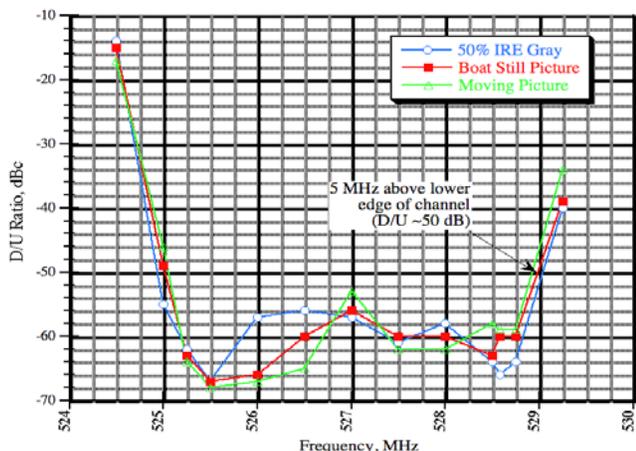


Figure 11. The “W” curve.

obtained were recorded, and the characteristic curves of interfering carrier levels versus TOV were drawn from the data.

The W curve indicates that, at a frequency 5 MHz above the bottom of the channel (529 MHz in the case of Figure 11), the threshold of visibility occurs when the interfering unmodulated carrier power is 50 dB below the peak power of the television visual carrier. Thus, if an interfering carrier from a nearby local oscillator is 50 dB or more below the peak visual carrier power, it will not be visible. Conversely, if the interfering carrier from a nearby local oscillator is less than 50 dB below the peak visual carrier power, it can be expected to be visible to some degree.

CONVERSION OF LO LEAKAGE LEVEL TO LO RADIATION LEVEL

It was shown earlier that the FCC established the minimum distance separation between stations separated in frequency by seven channels based upon their Grade A contours not overlapping, so it is appropriate to evaluate the potential for interference with the signal level that defines that contour (*i.e.*, the lowest level signal that still qualifies as Grade A). For UHF NTSC television stations, that signal level has a median value of 74 dBu. Since the Grade A signal level is expressed as a field strength, while a receiver’s LO leakage is measured as a power level, both signals must be converted to common units so that the desired-to-undesired (D/U) signal ratio can be determined and compared with the TOV of 50 dB.

It is assumed in this analysis that the antenna connected to the potentially interfering receiver efficiently radiates all the power generated by that receiver’s local oscillator that leaks through that receiver’s antenna connection; impedance mismatches and other such factors would tend to reduce the actual radiated LO signal level but are not considered.

The fundamental relationship between the power across the terminals of a dipole antenna and the field strength at its location, assuming perfect impedance match and efficiency, is the so-called “dipole factor.” The dipole factor varies with frequency and is generally taken, *e.g.*, in recent calculations of DTV planning factors,³² to be -130.8 dBm-dBu at 615 MHz, the approximate geometric mean frequency of the UHF television band. The dipole factor can be adjusted to specific channels, if necessary, by adding the factor $20 \log [615/(\text{frequency of interest})]$ to the base dipole factor.

This dipole factor is derived from fundamental principals, as follows. The power, P_a , available at the antenna terminals is equal to the power density, S , times the effective area, A , of the antenna:

$$P_a = SA \quad (2)$$

The maximum effective area, A , of any antenna is given by:

$$A = \frac{G\lambda^2}{4\pi} \quad (3)$$

The power density is related to electric field strength, E , by:

$$S = \frac{E^2}{\sqrt{\frac{\mu_o}{\epsilon_o}}} \quad (4)$$

The power, P_r , delivered to a load of resistance, R , from terminal voltage, V , is:

$$P_r = \frac{V^2}{R} \quad (5)$$

For a matched load, $P_a = P_r$, and substituting (3) and (4) into (1), we get:

$$P_a = \frac{E^2}{\sqrt{\frac{\mu_o}{\epsilon_o}}} \frac{G\lambda^2}{4\pi} \quad (6)$$

Rearranging terms and setting $\sqrt{\frac{\mu_o}{\epsilon_o}} = 376.73$ ohms (the impedance of free space), we get:

$$E^2 = \frac{4734}{G\lambda^2} P_r \quad (7)$$

In logarithmic terms, Eq. (7) becomes:

$$20 \log E = 10 \log 4734 + 10 \log P_r - 10 \log G - 20 \log \lambda \quad (8)$$

With $20 \log E$ in dB μ V/m (dBu), $10 \log P_r$ in dBm, and λ equal to (300/615 MHz, Eq. (8) becomes:

$$E_{dBu} = 132.99 + P_{dBm} - G_{dbi} \quad (9a)$$

If G is expressed in dBd, instead of dBi, Eq. (9a) becomes:

$$E_{\text{dBu}} = 130.84 + P_{\text{dBm}} - G_{\text{dbd}} \quad (9b)$$

The FCC rounds the constant term, or dipole factor, to 130.8 dBu-dBm.

EXAMPLES

Two outdoor antennas. Consider two television receivers, both utilizing outdoor antennas, which are pointed at one another so that the receivers can receive television stations located in opposite directions. The television stations are separated in frequency by 7 channels. The receiver tuned to the higher of the two channels may receive interference from LO radiation from the other receiver in the pair. We assume that both receivers are located at the edge of the Grade A contour of the higher frequency (desired) station and that the field strength from that station is therefore 74 dBu. We assume antennas separated by 10 meters with gains of 7.0 dBd,³³ and transmission line losses of 3dB. The field strength of the undesired LO radiation from the lower-channel receiver at the antenna of the receiver tuned to the desired signal is calculated as shown in Table 2.

The D/U ratio is the difference between the field strength of the desired signal and the field strength of the interfering signal. Thus, the D/U ratio in this case is $74 - 4.7 = 69.3$ dB. Since the threshold for interference is 50 dB D/U, no interference is predicted in this case, with a margin approaching 20 dB.

Table 2. Field strength using outdoor antennas.

LO leakage power (dBm)	-81.8
Transmission line loss (dB)	-3.0
Antenna gain (dBd)	7.0
Dipole factor (dBu-dBm)	130.8
Path loss (dB)	48.3
Field strength (dBu)	4.7

Table 3. Field strength using indoor antennas.

LO leakage power (dBm)	-81.8
Transmission line loss (dB)	0
Antenna gain (dBd)	0
Dipole factor (dBu-dBm)	130.8
Path loss (dB)	28.3
Field strength (dBu)	20.7

Two indoor antennas. Consider two television receivers similarly tuned 7-channels apart, with both assumed to be utilizing set top antennas that are located 1 meter apart, perhaps on opposite sides of a wall, and having 0 dBd gain and no transmission line losses. We again assume that the desired station delivers a field strength at the 74 dBu level. Table 3 shows the calculation for this case. The resulting

D/U ratio is 53.3 dB; once again, no interference is predicted, albeit with a much smaller margin.

While it might be argued that the D/U ratio is close (3.3 dB) to the threshold at which interference is predicted to occur, there are a number of factors that make this a very conservative analysis. First, receiver LO leakage levels continue trending downward. Current receivers produce, on average, about 7.1 dB less LO leakage than the value used in the analysis. If there were no further improvements in LO leakage than have been achieved to date, the average LO radiation from the population of receivers in use would continue to drop over the next two decades, falling by at least that amount.

Second, we have ignored the attenuation of the assumed wall separating the two receivers, which, at the frequencies involved, can be several dB. Third, we assume that the polarization of the antennas is aligned and that there are consequently no cross-polarization losses. Finally, we assume that the received signal is sufficiently strong to produce a noise-free image. In fact, there will be attenuation from the wall, the antennas are likely to be misaligned, and with a field strength of 74 dBu and using a dipole antenna, the image produced will be about 6 dB below the threshold of visibility of noise in the picture, resulting in masking of any interference from the radiation of a nearby receiver's local oscillator.

From the foregoing, it can be seen that the analysis of the indoor antenna scenario is truly that of a worst case, and the situation described is highly unlikely to occur in reality. Still, the analysis predicts no interference – even assuming a receiver able to operate at the threshold of visibility.

POTENTIAL FOR RELAXATION OR ELIMINATION OF LO RADIATION TABOO

It has been shown that typical local oscillator leakage levels of the installed universe of NTSC television receivers, as measured for this study, are now sufficiently low that interference from this source is unlikely. This conclusion has been reached after considering the reduction over time of the LO leakage levels of television receivers still in use by consumers and applying a weighted average to account for the aging of the receiver population. When using the resulting LO leakage level determined for a typical receiver in the existing population of receivers, interference was shown not to exist in two worst-case scenarios.

Given this result, it is apparent that the time has come for relaxation or perhaps elimination of the local oscillator radiation taboo in determining the permissible locations of television stations separated in the U.S. by seven channels. It should be recognized, however, that, even if the taboo were eliminated, that would not provide complete flexibility in the location of stations seven channels apart. Rather,

consideration would then be required of the potential for IF beat interference between such stations and any other stations falling between them in frequency.

Consideration of $N\pm 7$ IF beat interference would be required because the frequency relationship between the carriers of the respective channels may cause a visible beat that would fall within the IF bandpass of receivers. In the case of the $N\pm 8$ IF beat taboo, it is the visual carrier of the upper channel and the aural carrier of the lower channel that can cause a product at 43.5 MHz, which translates to 2.25 MHz in the video baseband. In the case of an $N\pm 7$ IF beat, a product at 42 MHz could result from the combination of the two visual carriers and/or the two aural carriers, both of which would translate to 3.75 MHz in the video baseband.

The FCC has previously measured receiver susceptibility to such interference in the context of its measurements of receiver performance.³⁴ It found that receivers responded to

the $N\pm 7$ combination within about 1 dB of their responses to the $N\pm 8$ combination. Thus the same minimum separation Rules could be applied to the $N\pm 7$ situation as are currently applied to the $N\pm 8$ pairing. In situations in which a waiver of the minimum separation was sought and it was proposed to locate stations closer than would be provided by the Rules, analyses of the type already applied to $N\pm 8$ cases could then be applied similarly to $N\pm 7$ situations to determine the actual impact on stations nearby in frequency.

CONCLUSIONS

It has been shown that the Local Oscillator Radiation UHF taboo no longer provides a valid rationale for establishing the geographic separation of television stations in the U.S. separated in frequency by seven channels. Instead, the correct mechanism for setting the necessary spacing of stations related by $N\pm 7$ channels should be based upon the IF Beat phenomenon.

¹ Section 73.698, Table II (47 CFR §73.698).

² Industry Canada, Broadcasting Procedures and Rules, Part IV.

³ ITU-R Recommendation BT.1123, "Planning methods for 625-line terrestrial television in the VHF/UHF bands," (1994).

⁴ When a television receiver is connected to an antenna, the local oscillator signal that escapes will be radiated and is termed "LO radiation" throughout the remainder of this document. When the receiver is connected to a cable system or a test instrument, the signal that escapes from its local oscillator is termed "LO leakage."

⁵ Rec ITU-R BT.1123, *op. cit.*

⁶ Philip M. Walker, "Some Preliminary Recommendations Concerning Study of the UHF Taboos," September 27, 1971.

⁷ "A Study of the Characteristics of Typical Television Receivers Relative to the UHF Taboos," OCE Project No. 2229-63, June 1974.

⁸ FCC Docket 20485, NOI "In the Matter of Re-evaluation and Revision of the UHF TV 'Taboo' Table," June 3, 1975.

⁹ "Report and Recommendations in the Low Power Television Inquiry," (BC Docket No. 78-253), September 9, 1980.

¹⁰ FCC Docket 87-268, MO&O on Reconsideration of the 6th R&O, para. 87ff, February 17, 1998. See also Final Technical Report, FCC Advisory Committee on Advanced Television Service, draft October 30, 1995.

¹¹ Technical Information Division (TID) Report No. 6.1.5, "Radiation from TV and FM Receivers," April 20, 1949.

¹² 10^{12} W, then called a "micromicrowatt"

¹³ Kalagian, Gary S, Robert P. Eckert, and William A. Daniel, "Advanced Technology UHF Receiver Study, Part 2, Effect on UHF Television Allotments," OST Report R84-1, March 1984.

¹⁴ FCC Report 51-244, Third TV Notice of Further Proposed Rule Making, issued March 22, 1951 (adopted March 21).

¹⁵ FCC Report 52-294, Sixth Report and Order, released April 14, 1952 (adopted April 11, 1952).

¹⁶ Hector Davis, "A Study of UHF Television Receiver Interference Immunities," OET Technical Memorandum TM-3, August 1987.

¹⁷ Glen E. West, "Receiver Radiation – A Chronological Digest of FCC-Industry Correspondence with notations Regarding the Development of Standards and Limits," TRR Report No. 6.1.12, June 10, 1953.

¹⁸ TASO, Engineering Aspects of Television Allocations, March 16, 1959

¹⁹ *ibid.* p. 170

²⁰ Robert E. Lee, *et al.*, "Report of Committee No. 1 (Technical Group) of the Committee for the Full Development of All-Channel Broadcasting to the Federal Communications Commission," February 1965.

²¹ Walker, *op. cit.*

²² Sydney R. Lines, "A Survey of Certain Performance Characteristics of Television Receivers," Technical Report T-7201, June 9, 1972.

²³ Davis, OET TM-3, *op. cit.*

²⁴ ITU-R Recommendation BT.804, "Characteristics of TV receivers essential for frequency planning with PAL/SECAM/NTSC television systems," (1992).

²⁵ Ciciora, Walter, James Farmer, and David Large, Modern Cable Television Technology, (San Francisco: Morgan Kaufmann, 1999).

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- ²⁶ The tuner is the part of a television receiver that includes the local oscillator, the first mixer, often a radio frequency amplifier, and the tuning elements that precede the mixer. Its output is usually at the IF frequency.
- ²⁷ “EIA Color Television Replacement Cycle Study,” Electronic Industries Association, Consumer Electronics Group, April 1985.
- ²⁸ *ibid*, pg. 40.
- ²⁹ *ibid.*, pg. 41.
- ³⁰ ITU-R Recommendation BT.655-6
- ³¹ Data and chart provided courtesy of Walter S. Ciciora, Ph. D., Consultant.
- ³² OET Bulletin Number 69 Longley-Rice Methodology for Evaluating TV Coverage and Interference, July 2, 1997, pg. 4, Table 3.
- ³³ Gieseler, Philip B., et al., “Comparability for UHF Television – A preliminary analysis,” FCC Staff Report, September 1979. This is the average power gain figure at UHF for combination VHF/UHF outdoor antennas, which dominate the market by about 2:1.
- ³⁴ OCE Project No. 2229-63, *op cit*.