CHAIRMAN SCHATZEL: Thank you very much. I think this team from Hughes Aircraft Company given us an extremely worthwhile progress report a development that I am sure we will see a great al more of as the years go by, the FCC willing, and hope that they will be willing.

Due to the rather limited time we have available s morning, I am not going to be able to entertain re than perhaps two questions of Mr. Stokes or r. Ozaki, and then we must move on with our agenda. I believe, however, that both of these individuals ll be very happy to answer any questions that you ay wish to put to them privately after they have left e platform.

Are there questions now?

MR. EDWARD DAVIS (CBS Television): Your Di- sion Director's question was uppermost in my mind. In his own terms, do you suppose you could give s a comment, just in round numbers, what the kind of mparison, let us say, between that which we might e interested in, that is, in terms of ground base uipment, microwave or standard microwave equip- ent as compared with this particular unit, would dicate?

I am asking, in effect, for a comment on the cost ot in precise terms, but in round numbers or in com- rative terms between what we now know as terms of e cost of a single microwave length?

DR. OZAKI: First of all, any number that we give ur Division Direction turns out to be too high by def- ition.

We have looked at the relative cost of this system n terms of our extrapolation of these costs, in quan- ity production versus a similar type, perhaps not a ultiple-channel but a microwave system that con- ains all 12 channels. We believe that this system is less expensive than that kind of approach.

In terms of going the full 12 channels in the sys- tems versus having 12 single channels, I believe that there would be a marked difference in the cost.

Does that answer your question?

MR. DAVIS: You have said it is less than or comparable to?

DR. OZAKI: It is less than. It is my belief that it is less than; and, of course, here again is the ques- tion of how many do you make at one time?

MR. DAVIS: Certainly.

CHAIRMAN SCHATZEL: We have time for one more question.

MR. SIMMONS (Jerrold): With regard to the inter-modulation, do we understand that this is what we call cross-modulation; that is, modulation trans- ferred from one channel to another? And, did if fol- low the theoretical law of two for one?

DR. OZAKI: This matter of inter-modulation, with respect to TV pictures, is slowly becoming more and more clear to us. The inter-modulation we are talking about does follow the two-to-one law. They are what are commonly called third order products.

CHAIRMAN SCHATZEL: Thank you very much.

(Announcements)

The next topic is truly a "bread-and-butter" topic for people in the CATV business.

The subject is TV SIGNAL PROPAGATION, and this is almost the first question we have when we consider a CATV system. We want to know what sort of signals we are getting at the head end.

The gentleman who is going to discuss this for us this morning is the Manager of the Antenna and Microwave Products Division of Scientific Atlanta, Inc., which has a wide reputation in the antenna field, as you know.

He is an engineering graduate of Mississippi State University, and has been working for the past 10 years in the field of antenna microwave. It is my pleasure to introduce Mr. Thomas D. Smith, of Scientific Atlanta, Inc.

MR. TOM D. SMITH (Scientific Atlanta, Inc.): First, I would like to express my appreciation for allowing Scientific Atlanta to participate in NCTA's Technical Sessions.

THE THEORY OF TELEVISION SIGNAL PROPAGATION

by

T. D. Smith

Introduction

Cable technicians need a knowledge of the propa- gation of television signals when performing signal surveys, locating head-end sites, determining sources of interfering signals, and in the designing or specify- ing of antenna arrays. The purpose of this paper is to review basic propagation theory with the hope it will provide better understanding of the propagation of television signals. First, this paper defines and discusses the various regions of propagation. Second, the propagation medium and its influence on signals is discussed.

Regions of Propagation

For convenience, the distance from the transmitting antenna is divided into several regions; the boundaries of the regions cannot be sharply defined. The names given to the various regions denote some pertinent property of each region.

The region immediately next to the transmitting antenna is known as the "line-of-sight" region. This region extends out to radio horizon. The distance from the transmitting antenna to the radio horizon is given by the formula:

$$D = \sqrt{2h_T}$$

where D is the distance to horizon in miles and h_T is the height of the transmitting antenna in feet. The radio horizon is assumed to be on the ground, if the earth is a relatively smooth sphere. Any obstruction along any given path must be taken into consideration.

If the receiving antenna is also elevated, the maximum line-of-sight is given by the formula:

$$D = \sqrt{2h_T} + \sqrt{2h_R}$$

where h_R is the height of the receiving antenna in feet.

It the propogation path in the line-of-sight region is sufficiently free from objects that might absorb or reflect radio energy, this region can be further subdivided into a region known as "free space." The free-space region is seldom realized, because of the presence of the earth's surface. Briefly, the usual condition is such that one wave travels directly from the transmitter to the receiver. A second wave from the same transmitting antenna strikes the ground between the two antennas and then is reflected to the receiving antenna. In this instance, the ground acts as partial reflector and as partial absorber. The ground-reflected wave has traveled farther, therefore the phases of the two waves at the receiving antenna are different. The result of this phase difference is an oscillatory signal level whose amplitude and frequency vary with respect to the height and distance from the transmitting antenna. As the energies of these two paths unite in phase, the resultant is a maximum. As they unite out of phase, the resultant is a minimum. A typical plot of signal level of height for "line-of-sight" conditions is shown in Figure one.

The space beyond the line-of-sight region is known as the "beyond-the-horizon" region. This region is shadowed from direct rays by the curvature of the earth, or other obstruction. Beyond-the-horizon region is subdivided into the diffraction region and scatter region.

The diffraction region lies adjacent to and below the radio horizon. This is the region in which most CATV towers are constructed. Energy reaching this region must be bent or reflected by some process. One such process is diffraction, which is a fundamental property of wave motion. Sharp shadows, such as would be created by a beam of light striking a solid object, are not created when RF waves encounter large obstructions. Reception is possible behind the obstruction for a short distance, but there is a shadow which is somewhat fuzzy and there is a gradual transition in signal level, rather than a sharp transition as there is in very short wavelengths such as light. While diffraction does make transmission beyond the line-of-sight possible, it introduces large losses. In the diffraction region the mean field strength decreases approximately exponentially with distance; while the mean field strength increases exponentially with antenna height.

In the past, diffraction was considered the only mechanism whereby VHF and UHF energy was supplied beyond the horizon. However, during World War II and into the late Forties, other mechanisms were discovered. One of these mechanisms is known as "tropospheric scatter." Tropospheric scatter is caused by random irregularities of the dielectric constant of the atmosphere, or "blobs."

These blobs are always present and cause faint signals to be reflected to the ground. The reflections fall well beyond the horizon in much the same way that the overhead light beam of a searchlight can be seen from the ground, or the lights of a distant city can be seen as a glow from beyond the horizon.

It should be noted that two types of signal fading are encountered in scatter propagation. The first is the rapid fade caused by multi-path transmission in the atmosphere. The multi-path condition is caused when a signal is reflected from many blobs which are random in location and have random motions. The received signal is the sum of these random reflected signals. The received signal may change from maximum to minimum and back to maximum in a matter of seconds. Fast multi-path fading tends to reduce the allowable bandwidth to less than five MHz. This reduction in bandwidth is caused by the time delay associated with the different paths.

The second type of fading encountered in scatter propagation is slower. It has a period of hours, or even days. These slow changes in signal level result from a combination of variations in atmospheric refraction from day to night and of humidity and temperature changes along the scatter path.

There is one other important mechanism by which s are propagated beyond-the-horizon. Waves can ropagated by reflections from a portion of the ion- ere known as the "Sporadic-E" layer. Occasion- , clouds of very high ionization are found in the ion of the E-layer. The effects of these clouds are e well known -- their cause, however, is still sub- to speculation. Sporadic-E skip distances vary n a minimum of 500 miles to a maximum of about 0 miles for a single hop.

Propagation Medium

For purposes of discussion, the atmosphere is ided into various layers or regions; these are osphere, stratosphere, and ionosphere as shown Figure . The portion of the earth's atmosphere nding from sea level to a height of about six miles he troposphere, or weather layer. This is the re- n of winds, storms, and rain. The temperature of troposphere decreases about 20°F per mile of in- asing altitude and reaches a minimum value near F at the upper limit of the region. Meteorological nges in this part of the atmosphere are responsible many variations in the received signal levels.

Directly above the troposphere is the stratosphere, constant-temperature zone. The stratosphere ex- ds to a height of about 40 miles. This region has le effect upon VHF propagation.

The E-Layer of the ionosphere is located 50-70 les above the surface of the earth. Bombardment this region by radiation from the sun produces ized molecules. Sometimes clouds of very high ization are sufficiently dense to reflect signals in e 50-100-MHz range, as was discussed above.

In free space, or a vacuum, a wave expands out- rd from its source. Each part of the wave travels ong a radial line and has a constant velocity equal that of light. In a homogeneous, isotropic dielec- ic medium, a wave will travel as it does in free ace, but with a reduced velocity. The ratio of the ee space velocity to the velocity in the dielectric edium is called the index of refraction of the med- um.

In a windless "standard" atmosphere, the tem- perature and water-vapor content decrease steadily with increasing altitude. This normal gradient is shown in Figure 3. This decrease in temperature and water-vapor content, associated with altitude in- creases, causes a decrease in the index of refrac- tion with altitude. This results in the velocity of transmission increasing with height above the ground, and as a result the wave is bent or refracted toward the earth. As long as the change in dielectric con- stant is linear with height, the net effect of refraction is the same as if the wave continued to travel in a straight line, but over an earth whose radius is 4/3 (1.33) times the true radius.

Most technicians have noticed that signal strengths are higher in the evening and early morning than during mid-afternoon. This phenomenon is caused by the following conditions; as the sun goes down, air immediately adjacent to the earth cools rapidly, while the air at higher altitudes cools much more slowly. This causes the dielectric constant of the air near the earth to increase, thus creating a greater change in dielectric constant with altitude. With this increasing dielectric gradient, the effective earth radius increases. In the early morning hours, the sun warms the air at higher altitudes before the air adjacent to the earth is warmed. Consequently, the effective earth radius is again larger than 1.33 times the true radius.

When the dielectric constant decreases about 10^{-7} per foot of height (in the standard atmosphere the decrease is 10^{-8} per foot), it has the effect of making the earth flat. Under such a condition, a wave that starts parallel to the earth will remain parallel. When the dielectric constant decreases more rapidly than 10^{-7} per foot of height, as shown in Figure 4, radio waves that are radiated parallel to, or at an angle above, the earth's surface, may be bent downward sufficiently to be reflected from the earth. After reflection, the wave is again bent to- ward the earth as it passes through the atmosphere, and the resulting path of a typical wave is similar to the path of a bouncing tennis ball. The radio energy appears to be trapped in a duct or waveguide between the earth and the troposphere. This phenomenon is referred to as either trapping or ducting.

How can one determine on a given day whether or not standard propagation conditions exist? Un- fortunately, this is very different to determine from normal meteorological data published by local weather bureaus. However, the following meteorological conditions are conducive to non-standard or trapping conditions, although they may not necessarily produce non-standard conditions.

1. A barometric high
2. Calm or light winds
3. Clear skies
4. Nocturnal cooling of ground with clear skies
5. Flow of warm dry air over colder air produc- ing a temperature inversion.

The following conditions are conducive to stand- are propagation conditions:

1. Barometric low
2. Strong winds
3. Overcast skies

Conclusions

A detailed study of propagation theory allows one to draw the following conclusions about the propagation of TV signals.

Over propagation paths where the earth can be considered a relatively smooth sphere, and at times of near standard atmosphere or known atmospheric conditions, signal levels can be calculated with good accuracy by the method described in National Bureau of Standards Technical Note 101, Revised May 1, 1966, entitled Transmission Loss Predictions for Tropospheric Communication Circuits. Over mountainous paths, it is usually necessary to resort to actual on site signal-level measurements, because calculations which take into account the effect of rought terrain are complicated.

When signal surveys are being made, the survey should be conducted over a sufficient length of time to allow for the possibility of non-standard propagation conditions that can exist for one or more days. Otherwise, erroneous or misleading data would be obtained.

Sporadic-E can cause severe co-channel interference on Channels 2-6 only. Instances of the E-Layer being sufficiently dense to reflect signals of frequencies higher than 100 MHz have not been confirmed. Consequently, Sporadic-E cannot account for severe co-channel interference on Channel 7-13. In order to have interference via Sporadic-E, the interfering stations must be a minimum of 500 miles away. As a consequence the co-channel beat can be either 20 kHz, 10 kHz, or 0. Sporadic-E occurs most often in the late afternoon. Little, if anything, can be done in the selection of a head-end site, or receiving antenna array design, to minimize Sporadic-E interference.

Most co-channel interference of a prolonged and constant nature on Channels 2-6, and all co-channel interference on Channels 7-13, is caused by propagation through the troposphere. This type of co-channel interference will usually occur from stations within 200-300 miles of the receiving antenna. In most cases, there will be a 10- or 20-kHz beat associated with the interference, and on rare occasions a 0 beat. Proper design of the receiving antenna array and selection of the head-end equipment will minimize this type of co-channel interference.

With a thorough understanding of propagation theory, and a knowledge of its influence on the level of received signals, a technician can better determine which channels can be received with reliable, high-quality pictures.

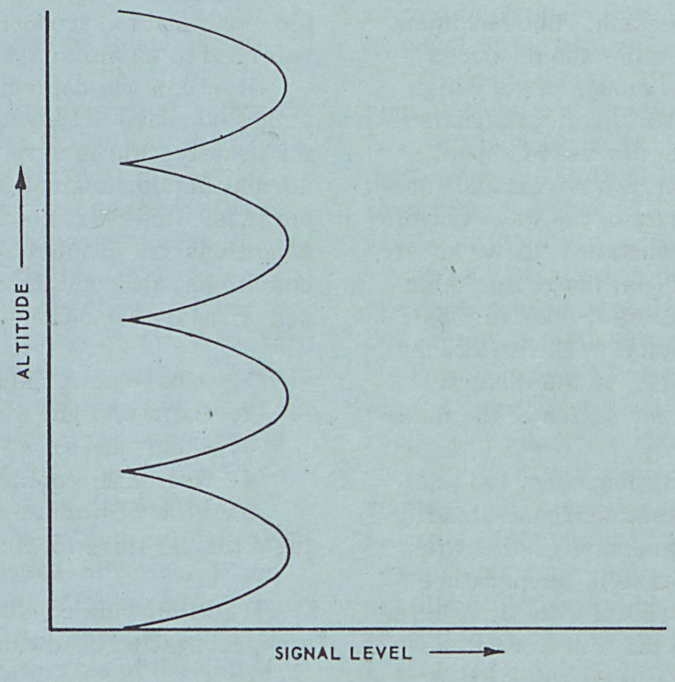

FIGURE ONE

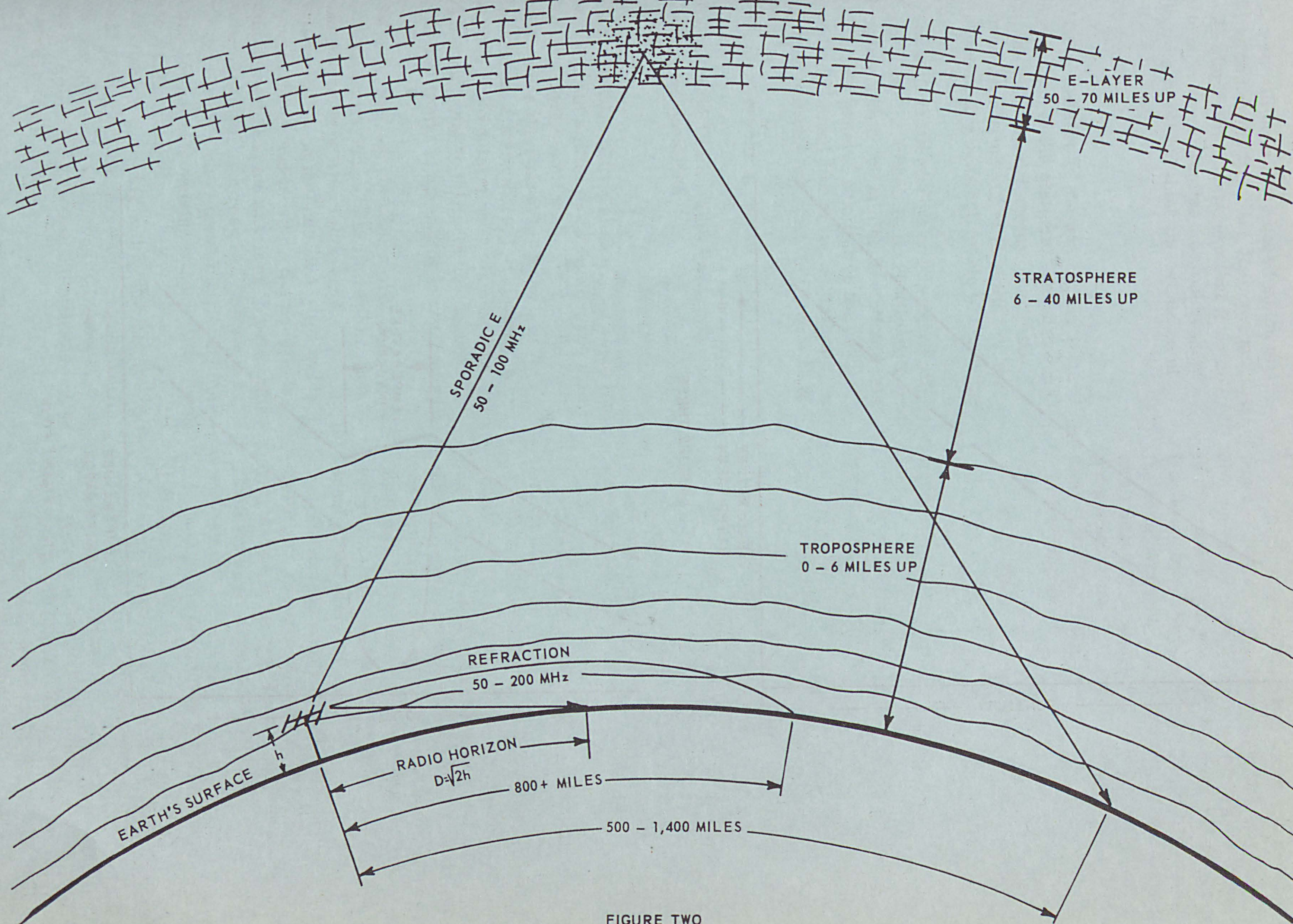
E-LAYER
50 – 70 MILES UP
STRATOSPHERE
6 – 40 MILES UP
SPORADIC E
50 – 100 MHz
TROPOSPHERE
0 – 6 MILES UP
REFRACTION
50 – 200 MHz
h
RADIO HORIZON
D=√2h
800+ MILES
500 – 1,400 MILES
EARTH'S SURFACE

FIGURE TWO

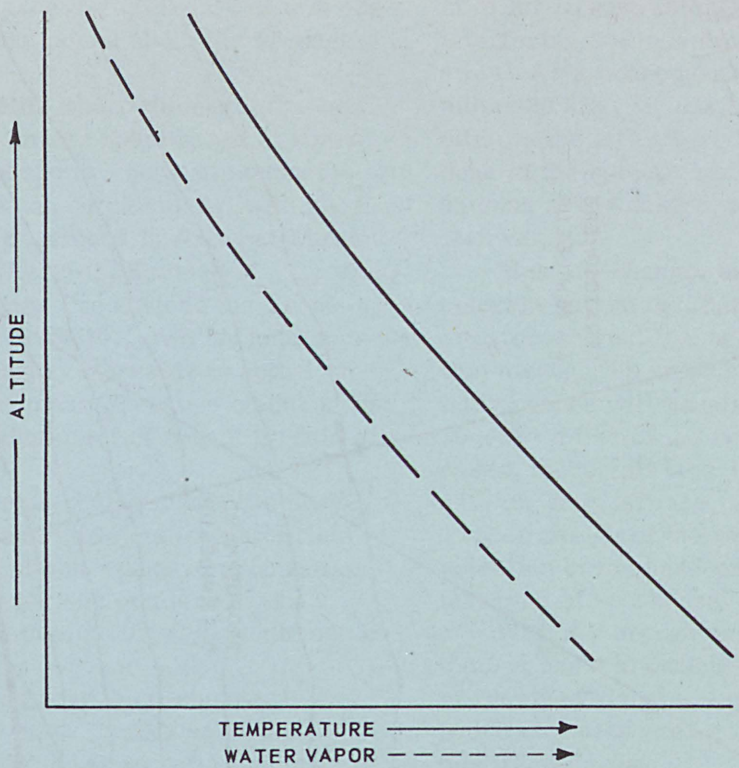

FIGURE THREE

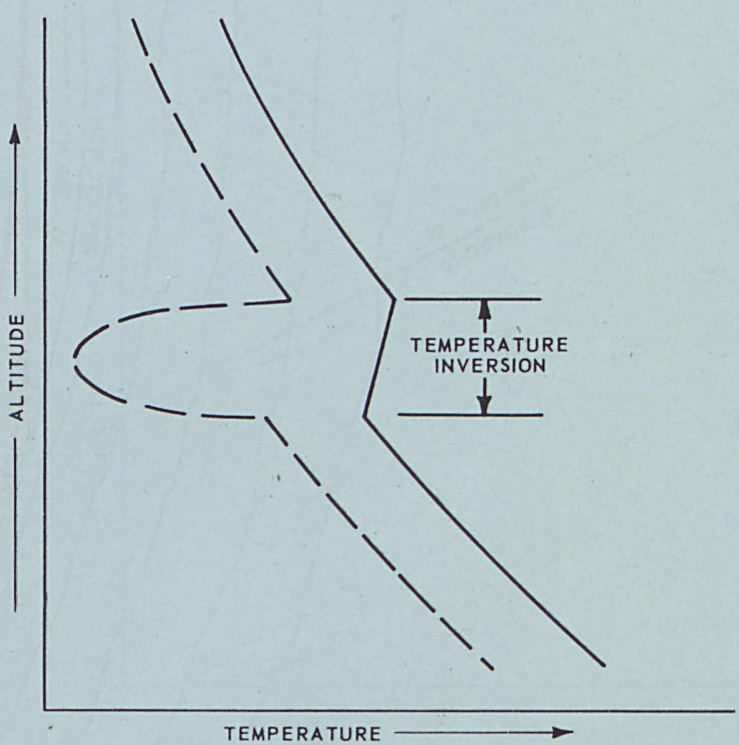

FIGURE FOUR

CHAIRMAN SCHATZEL: Thank you very much, Mr. Smith.

I am sure we will have some questions on this, and I would like to ask the first one, if I may, and that is if you would clarify your statement that from co-channel stations 200 or 300 miles we would expect a 10 or 20 kilocycle offset? I think that would be of interest.

Why not zero beat?

MR. SMITH: Because of the way the FCC has specified frequencies of the stations. Through subjective tests, the FCC has determined that if the frequency of the interfering signal is shifted either 10 or 20 kilocycles, it is less noticeable to the average observer.

I think the FCC in its wisdom has assigned offsets which will result in either 10 or 20 kilocycle beat if the stations are within 300 miles. Sometimes this is violated, but as a general rule this is the case.

Prolonged co-channel interference, however, can occur sometimes between two stations which will result in a zero beat.

Does that answer your questions?

CHAIRMAN SCHATZEL: Yes, thank you.

Are there other questions?

Yes, sir --

MR. KEN ARNOLD (City Cable TV): I would like to have you elaborate a little more on what you said, and ask, are you saying in effect that you could determine the distance the station is by the beat?

In other words, a station has, for instance, a higher beat; you could determine it is more than 300 miles away? Could you do this with any degree of reliability, is really what I am asking in my inquiry?

MR. SMITH: No, I do not believe that is the case. All I am saying is that it is useful, but not completely definitive to know what is the beat.

There is available on the market a filter which will allow you to detect and measure the amplitude of this resulting beat, and identify it as to being either 10 or 20 kilocycles; and as a result of this you can eliminate many possible co-channel interfering stations that are not perhaps causing the particular problem you are encountering.

I am not, however, saying just by the fact you know what the beat is that you can precisely determine where your station is and which one is involved. This is only useful in eliminating a few and providing some clues as to which one it might be.

CHAIRMAN SCHATZEL: If I understood the question correctly, I believe the query was whether the beat is higher if the station is farther away? I do not think that is the case.

I think the point that Mr. Smith was making was that the FCC allocation plan generally provides that co-channel stations that are within 200 or 300 miles of the station that you are receiving will be offset in frequency by 10 or 20 kilocycles. If it is exactly on the same frequency, or zero beat, it would be farther away than that, because the allocation plan would put a station exactly on the same frequency farther away than 200 or 300 miles.

Isn't that it?

MR. SMITH: Three hundred miles; yes.

CHAIRMAN SCHATZEL: Are there any other questions?

MR. ARCHER S. TAYLOR: I might make a comment on this offset.

The TELEVISION FACT BOOK lists the allocations of channels with a plus or a minus. The plus means that station is 10 kilocycles higher than the nominal frequency for that channel.

The minus means it is 10 kilocycles below.

Therefore, you can look at these channel allocations in the FACT BOOK and determine whether you would expect a 10 or 20 kilocycle beat or a zero beat. In that way you could determine something as to the stations with which you are concerned.

CHAIRMAN SCHATZEL: Thank you very much, Mr. Smith.

We will move now to our next subject, which is really related to some of the information we have just heard, because of the variations in the structure of the atmosphere, which Mr. Smith described, and when we measure signal strength we find that it fluctuates; generally if fluctuates with varying rapidity; and to a varying extent, depending on where we are with respect to the television station.

These fluctuations, particularly as they go downward, are a source of great grief to the CATV industry, and we work very hard to reduce the amount of fluctuation, or at least the depths to which the fluctuations go.

One of the techniques for doing this is diversity reception.

We have various types of diversity reception. There is frequency diversity; height diversity; space diversity, et cetera.

We are going to hear this morning a discussion of SPACE DIVERSITY RECEPTION.

Our speaker comes originally from across the water. He started his career in the British Post Office, in the Telephone Engineering Department.