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LB-936

INVESTIGATION OF UHF TELEVISION AMPLIFIER TUBES

RADIO CORPORATION OF AMERICA

RCA LABORATORIES DIVISION

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Investigation of UHF Television Amplifier Tubes

Approved

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Introduction

This bulletin discusses and demonstrates the degree of improvement in u-h-f receiver performance which may be obtained by adding an r-f stage which uses currently available u-h-f amplifier tubes.

The planar type tubes tested offer good noise figure and gain at v-h-f as well as at u-h-f, and exhibit a high degree of amplifier stability. The developmental cylindrical-type tube (pencil triode) which was used for the comparative tests intentionally sacrificed some performance to achieve moderate cost. It gave stable performance but its gain and noise factor were not as good as those of the planar-type tubes. The presently available miniature tubes tested are limited by feedback within the amplifier stage for high gain operation.

The stability of u-h-f amplifier operation can be evaluated, with a fair degree of accuracy, by observing the variation of input impedance while detuning the plate circuit. Such variation also affects the input match and input circuit detuning.

Based on the present status of amplifier tubes, no really substantial advantage is insured by using u-h-f amplifiers in television receivers, particularly when considering the important element of cost. None of the existing tubes is completely adequate when judged in terms of cost and performance. This status, however, might be changed if and when miniature tubes of improved design become available or low-cost versions of the other types of tubes are developed.

General Discussion

Field observers are in substantial agreement that the present television coverage on ultra high frequency (u-h-f) channels is inferior as compared to that on very high frequency (v-h-f) channels. One of the major limiting factors of television coverage is the signal-to-noise ratio of the picture on the receiver screen. On that basis the *approximate* difference between the present v-h-f and u-h-f television pictures can be calculated. The *approximation* is largely caused by two uncertain factors affecting television coverages.

1. Cosmic and man-made noises - These noises generally decrease rapidly as frequency increases. However, cosmic noise depends upon the installation and the site of the receiving antenna, and man-made noise is highly irregular in amplitude and duration. The exact effect of such noises on receiver performance cannot be evaluated exactly.

2. The power absorption coefficients of different objects standing in the way

of the wave travel are complicated functions of frequency. V-h-f waves would lose relatively less power to such obstacles as trees, buildings, and others. In free space and within the line of sight, this factor does not make a great difference in v-h-f and u-h-f television coverages.

Under conditions relatively free of cosmic and man-made noises and free of obstacles in the way of wave travel, the relative signal-to-noise ratios of present-day v-h-f and u-h-f receivers with typical antennas at a distance of 50 miles from the respective stations are analyzed graphically in Fig. 1.

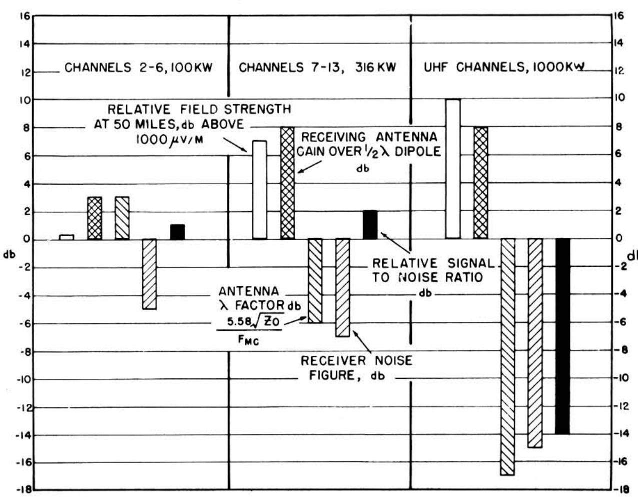

Fig. 1 - Relative signal to noise ratios of VHF and UHF television receivers at 50 miles from stations.

1. Relative Field Strength

The field strength in db above 1.0 mv/m at a given distance at uhf is comparable to that at vhf for the same effective radiated power (e.r.p.) and the same transmitting antenna height. According to FCC regulations, the maximum permissible e.r.p. is 100 kw on channels 2 to 6 inclusive, 316 kw on channels 7 to 13 inclusive, and 1000 kw on channels 14 to 83 inclusive; therefore, the maximum u-h-f free space field strength is greater than the v-h-f field strength, [based on FCC F(50,50) curves].

2. Receiving Antenna Gain

The receiving antenna strengthens the signal at the receiving point without substantially degrading the signal information. Among the popular television antennas now in use commercially, the u-h-f antenna gain over a $\frac{1}{2}$ wave dipole is greater than that of the v-h-f antennas.

3. Receiving Antenna λ Factor

The receiver antenna λ factor converts the signal field strength in µv/m to signal voltage in µv across the receiver input impedance because, with a given receiver noise factor, the signal-to-noise ratio of a television picture depends chiefly upon the signal which is developed across the receiver input impedance. This factor with $\frac{1}{2}$ λ dipoles is inversely proportional to the signal frequency; therefore it is highly in favor of v-h-f.

4. Receiver Noise Factor

The average noise factor of present commercial u-h-f receivers is about 10 db higher than that of v-h-f receivers.

By taking these four factors into consideration, it is found that the present u-h-f television receiver performance, insofar as signal-to-noise ratio is concerned, is approximately 15 db inferior as compared to v-h-f receiver performance.

When considering cosmic and man-made noises, and the wave absorption coefficients the obstacles, the 15-db figure has to be revised. The signal-to-noise ratios indicated by the solid black blocks in Fig. 1 are relative. At a distance of 50 miles away from a 1000-kw station with a transmitting antenna height of 1000 feet above average terrain, the absolute or actual signal-to-noise ratio of a u-h-f receiver would be high enough to give a good picture. Pictures at approximately 50 miles from stations WEEU on channel 33 and WFPG on channel 46 will be illustrated later.

The UHF Problem

The big problem now is how to liquidate the 15-db deficit. Careful examination of important factors affecting television coverage reveals that the antenna λ factor, the cosmic and man-made noises, and the wave absorption coefficient characteristics are inherent, but the maximum e.r.p., the receiving antenna gain, and the receiver noise factor, more or less follow engineering progress.

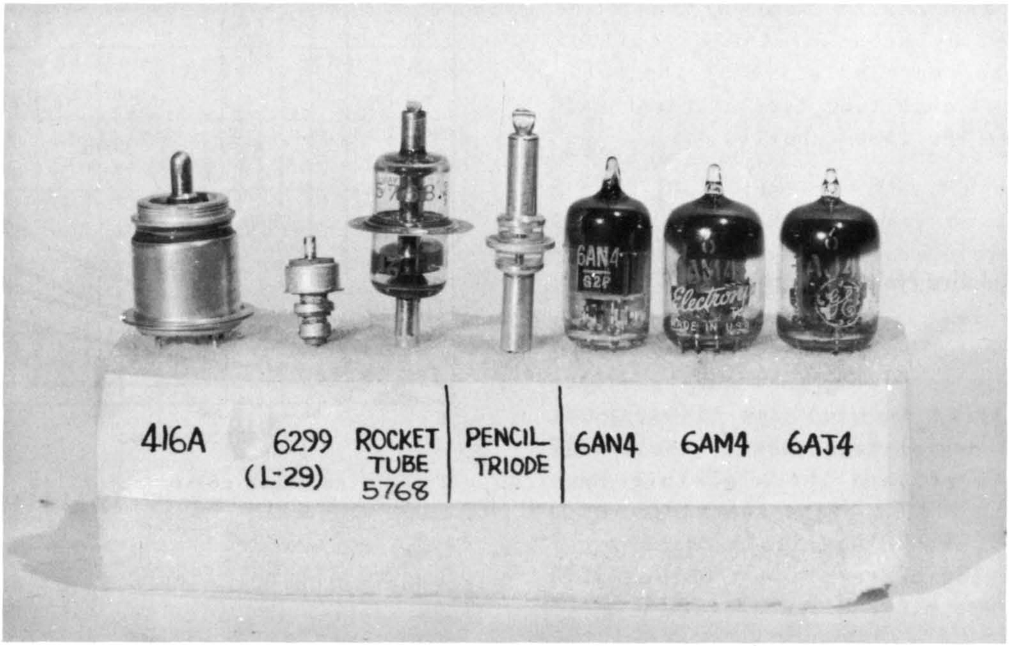

Fig. 2 - Samples of UHF amplifier tubes.

The e.r.p. is limited by the power capabilities of presently used transmitting tubes and is also bound by the FCC regulations, while the receiving antenna gain at u-h-f is limited by the antenna directivity, frequency selectivity, and also by the physical size of the antenna. These two sets of factors are beyond the scope of this bulletin. It is up to the broadcasters and antenna designers to think of new approaches. At present, practically all commercial u-h-f tuners employ a crystal diode mixer without r-f amplification. The tuner noise factor ranges from 12 db to 20 db. The wide range of tuner noise factors is largely due to the variations between crystal diodes and variations in mixer loss and mixer impedances with varying oscillator excitation and other operating conditions. More uniform and somewhat lower receiver noise factor may be secured by using one or more stages of r-f amplification preceding the mixer.

UHF Amplifier Tubes

For the purpose of this investigation, a number of tube types both commercially available and in developmental status were tested. These are arbitrarily classified into three general groups. Sample tubes of each group are shown in Fig. 2.

1. Miniature-type tubes including 6AJ4, 6AM4 and 6AN4, and an RCA developmental version.
2. Cylindrical-type, RCA developmental version, (pencil triode).
3. Planar-type tubes including 416A, 5768, 6BA4, and the 6299, frequently referred to as the L29.

These tubes were tested and compared in commercial-type circuits at frequencies below 890 Mc. A typical circuit used for this investigation of u-h-f television amplifier tubes is shown in Fig. 3. The unloaded Q of this circuit is considerably lower than the Q of a resonant cavity; therefore, some of the advantages of the planar and cylindrical types of

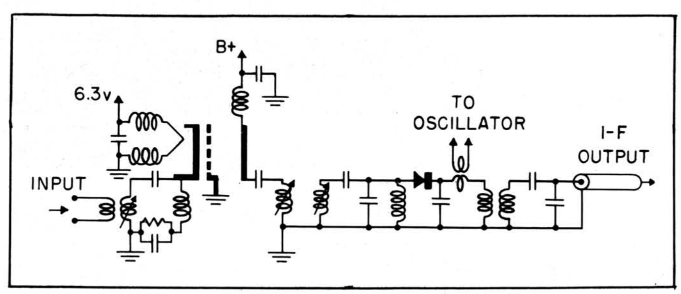

Fig. 3 - A typical UHF TV tuner using commercial circuits.

tubes are jeopardized to some extent. The results obtained by means of the circuit of Fig. 3 may not be representative of the optimum performance of each tube type although each is operated under the same conditions.

Relative Noise Factors

With the so-called commercial circuits, the tuner noise factor using a planar type tube as an r-f amplifier is still relatively the lowest, the cylindrical-type tube of the pencil triode variety next, and the miniature-type tube the highest. Fig. 4 plots the tuner noise factors on u-h-f channels as well as on v-h-f channels when using a one-stage grounded-grid amplifier and 14-db mixer noise factor.

The shaded areas illustrate the noise factor ranges of some television receivers now on the market. A television receiver using a developmental pencil triode amplifier stage offers a lower noise factor on all channels than present commercial receivers. On u-h-f channels the noise factors of the 5768 rocket tube and the L29 tube are about 2 db lower than the pencil triode tested, and the 416A is about 4 db lower. The commercial miniature-type tubes are comparatively inferior, about 2-3 db higher in noise factor than the pencil triode tested, although some developmental miniature tubes have shown improved performance. The present

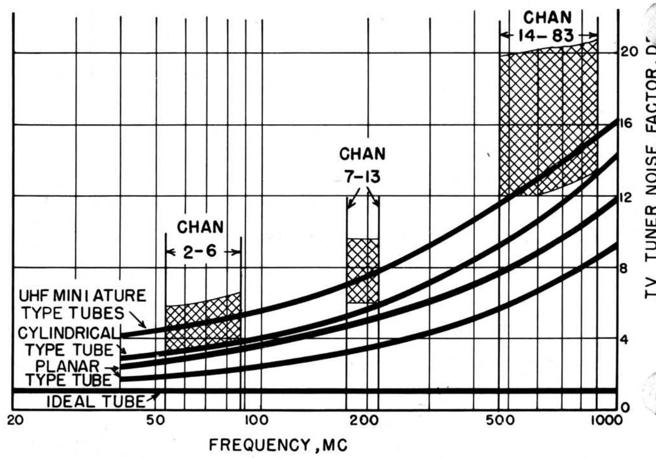

Fig. 4 - Receiver noise factor, db, using one-stage grounded-grid r-f amplifier.

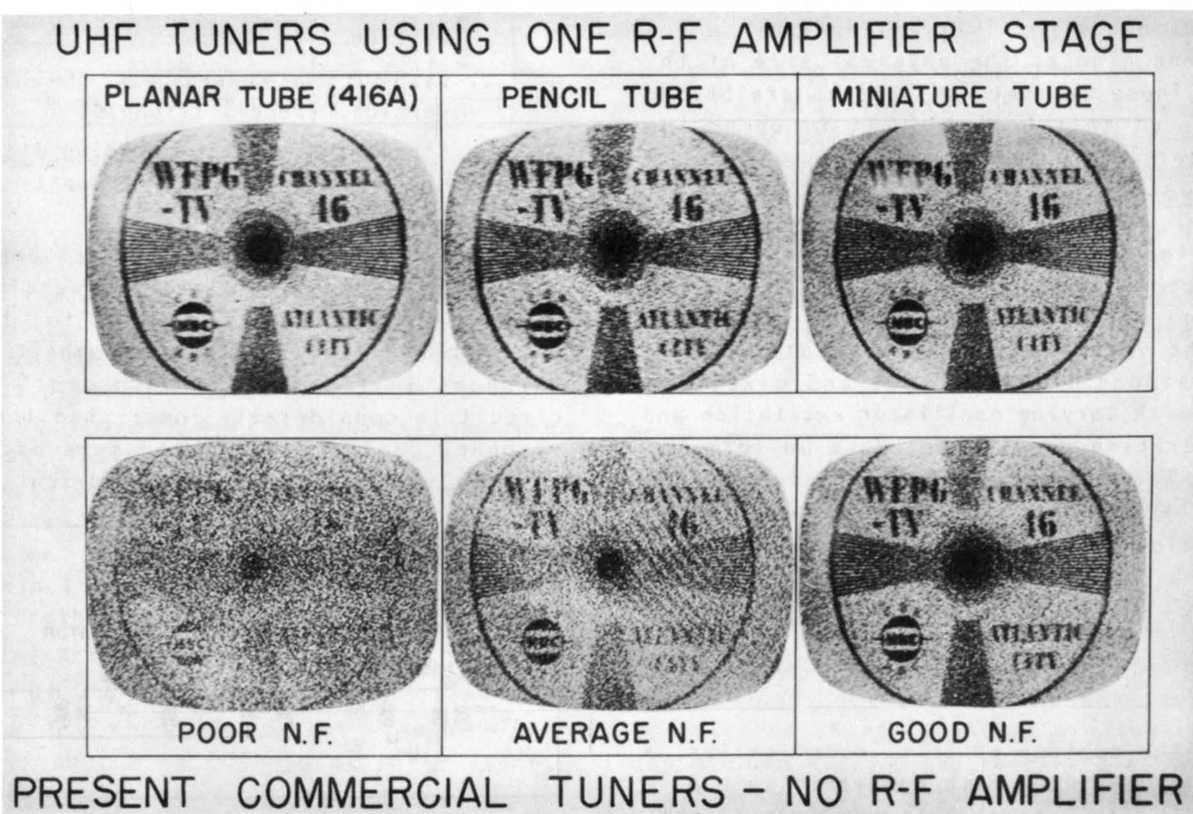

Fig. 5 - Picture qualities of Station WFPG, channel 46, Atlantic City, N. J.; received at Browns Mills, N. J.

developmental pencil triode is a compromise between performance and cost; it does not represent the best that can be achieved by a cylindrical-type tube.

Five u-h-f tuners were constructed; each tuner consists of an r-f amplifier stage, a 1N82 crystal diode mixer, a 6AF4 oscillator, and a triode-connected 6CB6 grounded-grid i-f amplifier. The r-f amplifier stage uses a 416A, 5768 rocket tube, L29, pencil triode, and a good miniature tube, respectively. The mixer noise factor of all five tuners is 14 db.

Field Observations

The first field comparison was made at Browns Mills, N. J. on channel 46, station WFPG from Atlantic City, N. J., radiating about 20 kw, having an antenna height of 430 feet above average terrain. Browns Mills is 41 air miles northwest of the station, and the receiving antenna is 90 feet below the line of sight. Fig. 5 shows the picture qualities of these tuners, together with a good, an average, and a poor commercial receiver. The difference in noise factor between the 416A planar-tube tuner and the miniature-tube tuner is about 6 db on channel 46, which makes an apparent difference in signal-to-noise ratio at Browns Mills. The picture of the miniature-tube tuner is comparable to, or may be slightly better than that of the good commercial receiver; it is definitely superior to the pictures of the average and poor commercial receivers. The picture produced by the tuners using the L29 and the 5768 rocket tube respectively are slightly better than that of the pencil triode tuner but somewhat poorer than that of the 416A tuner.

The second field observation was made at Haddon Heights, N. J., on channel 33, station WEEU, from Reading, Pennsylvania, radiating about 130 kw and having an antenna height of 1050 feet. The receiving antenna is 53 air miles from station WEEU and 290 feet below the line of sight. The comparative results on channel 33, as shown in Fig. 6, at Haddon Heights are in substantial agreement with those

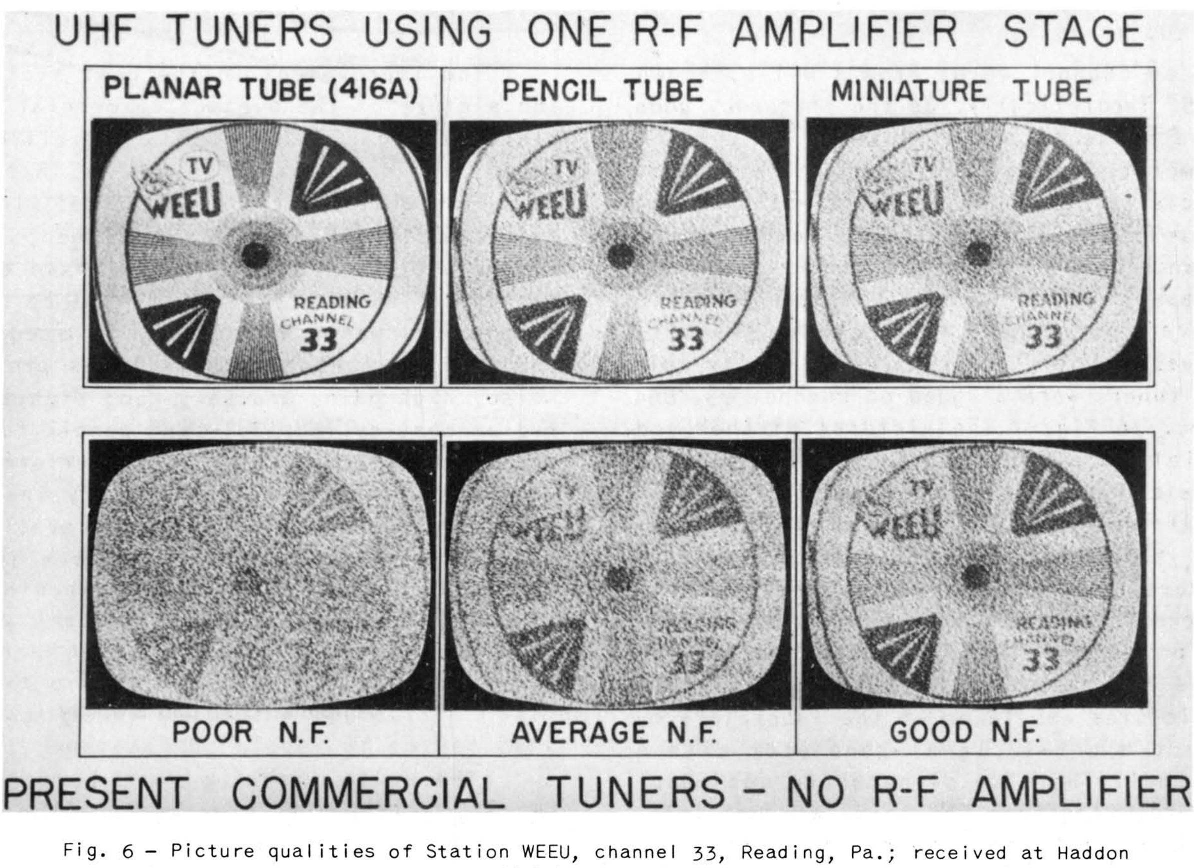

Fig. 6 - Picture qualities of Station WEEU, channel 33, Reading, Pa.; received at Haddon Heights, N. J.

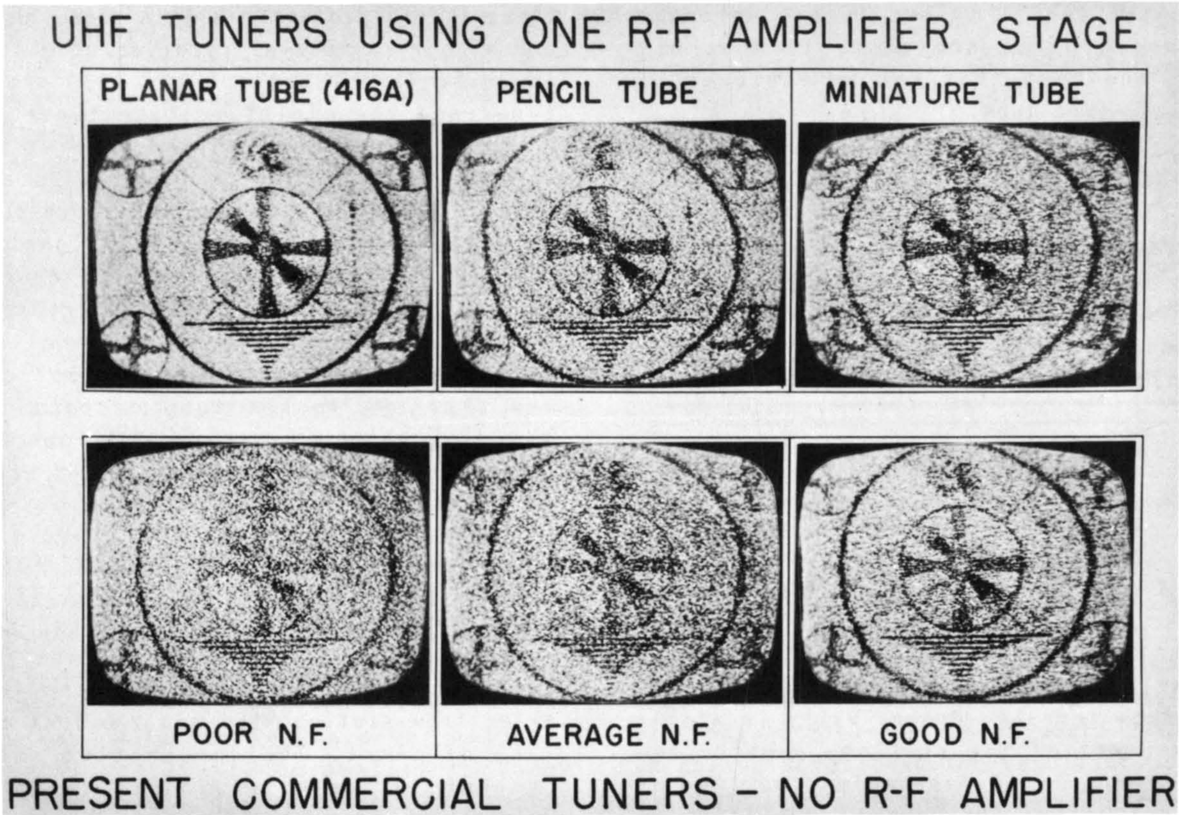

Fig. 7 - Picture qualities of channel 83.

observed on channel 46 at Browns Mills, shown by Fig. 5. Theoretically, as the frequency goes down, the noise factor of a u-h-f tuner with an r-f amplifier stage decreases while that of a commercial tuner using a crystal-diode mixer without r-f amplification would remain practically unchanged if it were properly designed. The decrease in noise factor from channel 46 to 33, however, is no more than 1.0 db; the difference was not very noticeable. To verify this fact the tuners were aligned on channel 83, 884 to 890 Mc. In Fig. 7 the pictures of the good commercial receiver and the miniature-tube tuner are almost of the same quality. The good commercial receiver picture may be even slightly superior if both pictures are examined closely. Furthermore, the difference between the best picture produced by a planar-tube tuner and the picture produced by an average commercial receiver is narrowed down to some extent. This set of pictures was taken at the laboratory by modulating a u-h-f signal-generator with a video signal. The time of exposure was about 1/30 second, therefore the noise was not integrated much during the photographic process.

The improvement in the best picture over the picture of the average commercial receiver closes the gap of the 15-db deficit of u-h-f television as compared to v-h-f. This is good news, but what about the cost? Preliminary cost estimates of these five experimental tuners and an average commercial tuner have disclosed rather unpleasant results. As might be expected, tube performance is closely related to tube cost. The high-cost planar tubes provide low noise, high gain, and very good stability. The medium-cost cylindrical-type pencil tube gives somewhat poorer noise and gain performance but is equally stable. The relatively inexpensive miniature tubes now commercially available are marginal in performance on all three counts.

Amplifier Gain and Stability

The noise factor of a television tuner using an r-f amplifier stage is also affected by the noise factor of the mixer which follows the r-f amplifier, and by the d-c input power to the amplifier tube. The effect of the mixer noise on the overall tuner noise factor decreases as the amplifier gain increases, and the amplifier gain usually increases with the d-c input power to the amplifier tube. Furthermore, a higher d-c input power also lowers the amplifier noise factor slightly, due to greater cathode current density and probably other effects. The effect of d-c input power on the amplifier noise factor of a miniature tube, a pencil triode, and a rocket tube is indicated in Fig. 8. Unfortunately, there is a practical limit to the maximum amount of d-c input power which can be applied to an amplifier tube. The planar and cylindrical-type tubes are usually limited by the plate dissipation capabilities, while the miniature tubes are usually limited by the stability of amplifier operation. One of the design considerations is, therefore, to secure the maximum amplifier gain without causing excessive dissipation and excessive feedback.

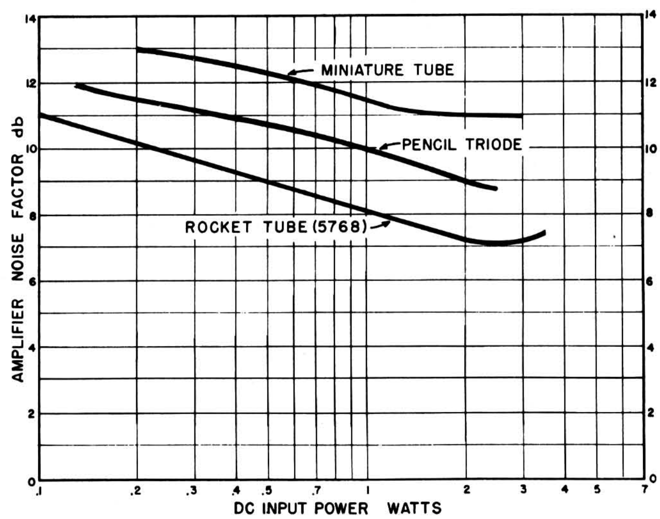

Fig. 8 - Relative UHF amplifier noise factor.

The function of d-c input power on amplifier gain at channel 46 frequency is shown in Fig. 9. The slopes of the curves representing the planar and cylindrical tubes are practically constant or even decreasing, with increasing d-c input power up to the respective maximum ratings, whereas the slopes of curves representing some commercial miniature-type tubes may increase beyond certain d-c input power, as shows by the dotted portions of such curves.

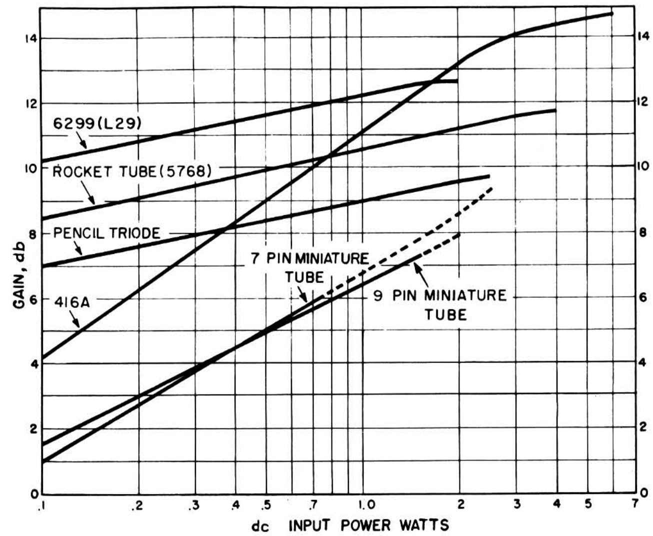

Fig. 9 - Relative UHF amplifier gain.

Regeneration probably takes place somewhere along such dotted portions. Similar results are obtained at 890 Mc at which the useful amplifier gain is slightly reduced, particularly of the miniature-type tubes.

There is no exact way of measuring the degree of amplifier stability. The gain as a function of the d-c input power curve is only an approximate measure. An alternative method is to observe the passband characteristics while increasing the amplifier gain. In the case of the miniature tubes, a high-gain amplifier is often oscillatory when the plate circuit is far detuned. When oscillation takes place, the plate current usually changes, either drawing more current or drawing less current than the plate current under stable operating conditions. The amplifier is aligned to 857-869 Mc, channel 79, using a miniature-type tube. By detuning the plate circuit, one miniature-type tube becomes oscillatory over the frequency bands as indicated by the shaded areas of Fig. 10; while another miniature-type tube also becomes oscillatory, but over fewer and narrower frequency bands, as indicated by the solid areas. In one case the plate current increases and in the other case decreases when oscillation occurs. It is difficult to conclude from such information how stable either tube is; but one tube is relatively less stable than the other. Oscillation caused by plate-circuit detuning does not usually happen to the planar or the cylindrical tubes. Instability

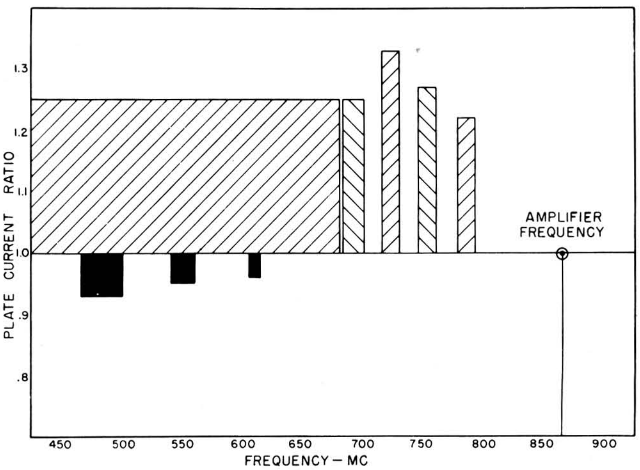

Fig. 10 – Oscillatory frequency bands when amplifier plate circuit is far off-tuned.

is, of course, caused by some form of feedback, either inside the amplifier tube or through the external amplifier circuits. In a typical single-stage grounded-grid u-h-f amplifier usually the feedback inside the tube limits the useful amplifier gain and amplifier performance. Such inside-the-tube feedback, illustrated in Fig. 11, can be divided into at least three paths of considerable importance.

1. The obvious source of feedback is by way of the inter-electrode capacitances. The feedback factor is a minimum at such a frequency that C_3 and L_g are in series resonance. This frequency occurs at about 700 Mc for the 416A tube. It occurs at a considerably lower frequency for the miniature type tube.

2. In miniature types the cathode and plate leads inside the tube are loosely coupled to each other; the flow of current in the plate lead induces a voltage in the cathode circuit.

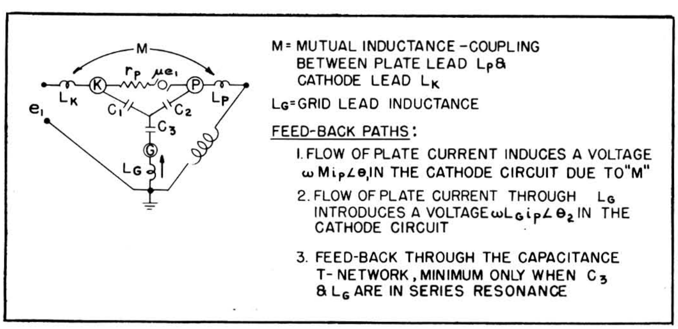

Fig. 11 – Feedback in a UHF amplifier.

3. The grid lead inductance is another potential source of feedback. The flow of plate current again introduces a voltage in the cathode circuit through the grid lead.

These two voltages added to the cathode circuit as a result of the flow of plate current have the same frequency dependence and same general phase relationship. Low grid lead inductance and good shielding between plate and cathode leads are therefore important factors in designing u-h-f amplifier tubes, particularly of the miniature type.

Amplifier Input Impedance

A better method for determining amplifier stability is to measure the input impedance variations when detuning the plate circuit. Fig. 12 shows the input impedance of a grounded-grid amplifier tube consisting of a lead inductance L_k in the cathode, an input capacitance

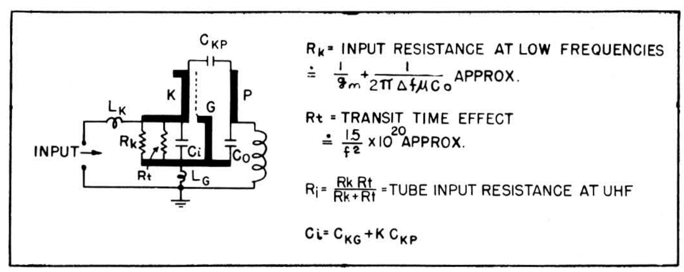

Fig. 12 – Input impedance of pencil triode.

C_i, and two resistances. R_k is the input resistance at low frequencies. It consists of the low-frequency input resistance of the tube when the plate is short-circuited which is approximately equal to the reciprocal of tube transconductance g_m, and an added resistance to take into account the effect of the plate load impedance when the plate is tuned. The added resistance component of R_k is a function of the bandwidth of the amplifier selective circuit, the output capacitance, and the tube amplification factor μ.

In addition to the low-frequency resistance R_k, the transit-time effect at u-h-f can be simulated by adding a resistance R_t across the cathode and grid. The tube input resistance R_i at uhf is the equivalent resistance of R_k + R_t.

This equivalent resistance R_i therefore changes with plate tuning. It is higher with a tuned plate, unless excessive feedback is taking plate in the tube so that a negative resistance is reflected to the input circuit. A stable amplifier and an unstable amplifier will be discussed to illustrate the input impedance variations under these conditions.

1. Pencil Triode Input Impedance

In the case of a pencil triode, the curves in Fig. 13 show how the tube input resistance varies with frequency with either a tuned or an untuned plate circuit. The tube input resistance with a tuned plate is greater than that with the plate untuned. The difference between these two curves decreases as the frequency increases, because the resistance R_t simulating the transit time effect is about inversely proportional to the square of frequency. The dotted curve represents the equivalent tube

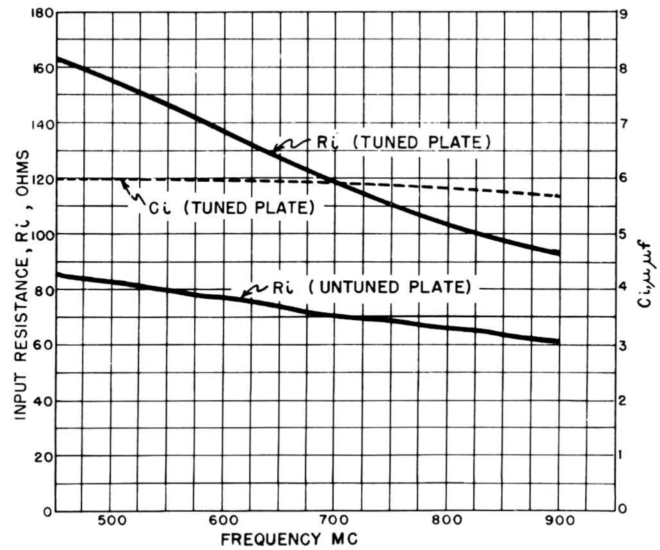

Fig. 13 - Input parameters of pencil triode.

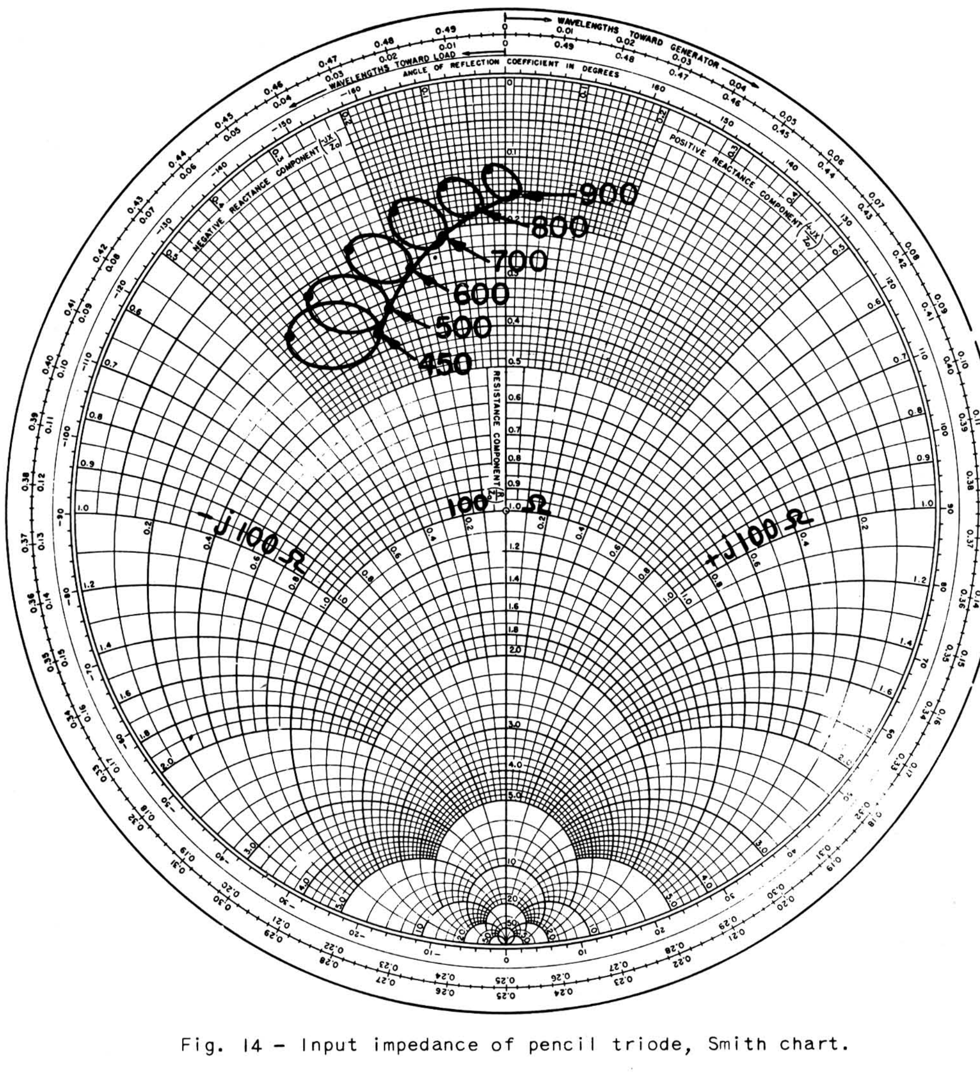

Fig. 14 - Input impedance of pencil triode, Smith chart.

input capacitance C_i which is substantially constant throughout the u-h-f television band. Judging from these results, the tube is operating normally. No excessive feedback is taking place in the tube under these operating conditions.

The tube input resistance R_i and capacitance C_i can be presented in a different form. The Smith chart of Fig. 14 shows the series input impedance of a pencil triode which is mounted in a special tube socket. The inherent inductance of this socket and the chassis return path shifted the input impedance curve in the clockwise direction by a substantial amount, indicating one of the disadvantages of using conventional circuits with the planar or cylindrical types of tubes. The cross-over point from capacitance to inductive reactance under the untuned output condition occurs at about 850 Mc, which should be much over 1000 Mc if no external inductance is added to the tube.

The continuous curve represents the input impedance when the plate load is negligibly small. By tuning the output from one side of resonance, through resonance and then going beyond resonance the input impedance at any particular frequency varies in the form of a nearly closed loop. The size and the direction of such loops depend primarily upon the Q of the output circuit and the type of tube being used. With a passband of 12 Mc, the variation of input impedance due to detuning in the plate circuit is relatively small, and the loops are above the curve in the case of the pencil triode. The tube is considered to be stable. The input impedance curves of the 416A, L29, and the rocket tube 5768 are similar to that of the pencil triode. The total inductance L_k in the cathode of the pencil triode is 0.005 μh. The equivalent series input im-

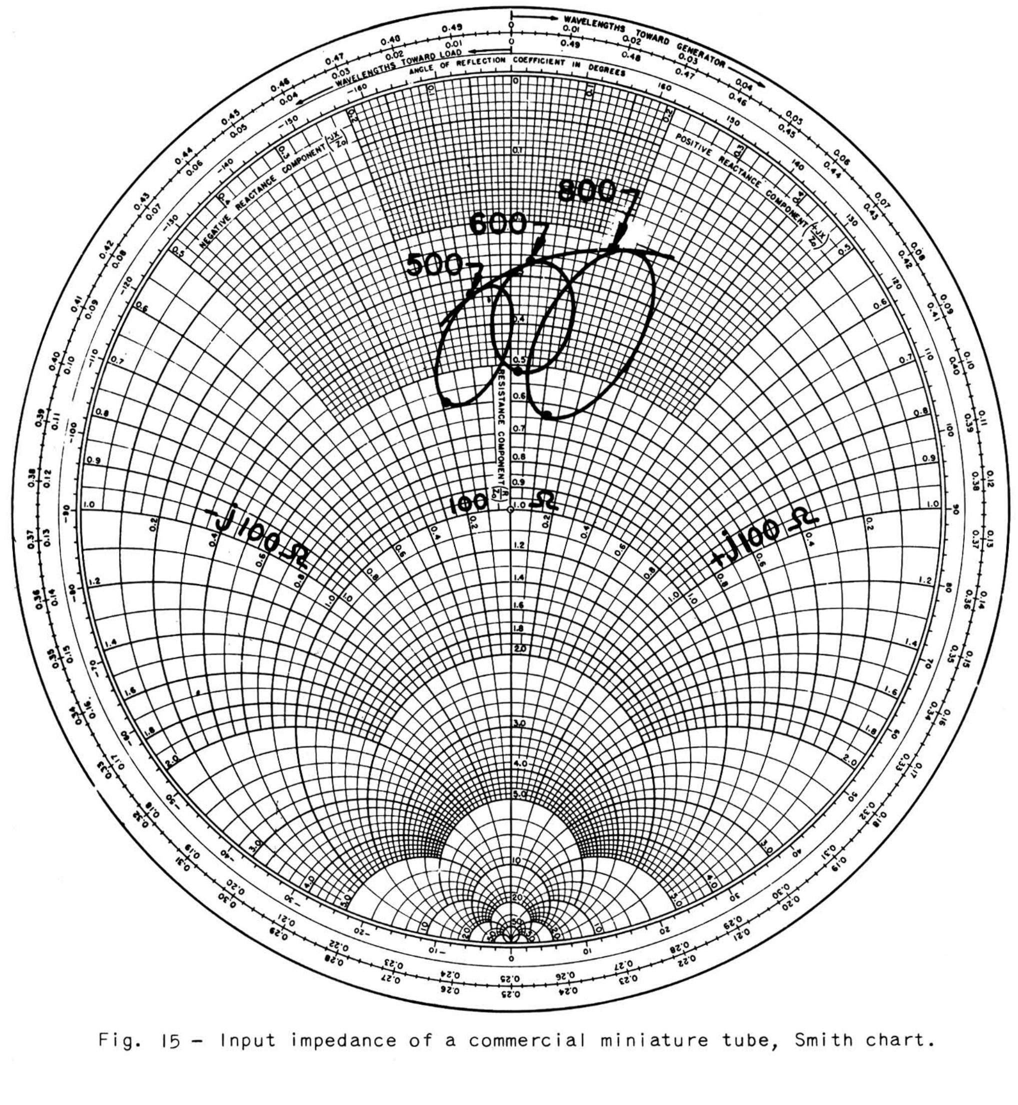

Fig. 15 – Input impedance of a commercial miniature tube, Smith chart.

pedance, including the cathode lead inductance, is measured directly by an admittance meter. The loops are above the curve, indicating no excessive negative resistance being reflected to the input circuit.

2. Miniature Tube Input Impedance

The input impedance of a typical miniature-type tube behaves quite differently, as presented in Fig. 15. The input impedance curve under the untuned plate condition is more inductive and its resistive component is greater than the corresponding pencil triode curve. Also, a tuned plate makes the input impedance more capacitive, and the resistive component greater. The size of the nearly-closed loops is larger, indicating greater variation in tube input impedance between tuned and untuned plate. Such loops are located below the untuned plate curve indicating negative resistance being reflected to the input circuit under these operating conditions.

The corresponding tube input resistance R_i and capacitance C_i shown in Fig. 16 reveal a clearer picture of what is taking place in the miniature-type tube. The input resistance with the plate circuit tuned at a certain frequency is almost equal to the input resistance with the plate circuit untuned. At that particular frequency, the amplifier is quite unstable, though it is still not oscillatory. The considerable variation in input capacitance is another sign of unstable operation. It makes

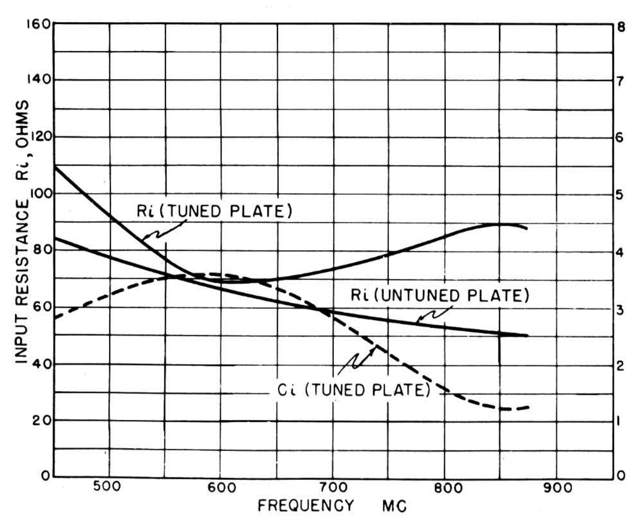

Fig. 16 - Input impedance of a commercial miniature tube.

the tracking of the input tuned circuit very difficult. The irregular magnitude of the input resistance R_i introduces mismatch between the receiving antenna and the r-f amplifier resulting in loss of signal power. If the same miniature tube is operated at reduced gain, then the input impedance variations would approach stable conditions. Insofar as stability is concerned, a reduction in amplifier gain makes the amplifier more stable.

RF Amplifier Affecting other Tuner Performance

Because of relatively unstable operation, a u-h-f amplifier using a miniature-type tube is usually operated at reduced gain, thus degrading its noise factor to some extent. The overall tuner noise factor under these conditions is not substantially improved over the good commercial television receivers on the market. The planar-type tubes do better, but they may not be good enough to justify their high cost. The present cylindrical-type tubes are less expensive, but they are not quite as good. Television designers may question the advisability of using an r-f stage, unless new tubes are developed, or unless there are other advantages for the use of a u-h-f amplifier in a television receiver.

1. AGC possibility

The operating point of a crystal diode mixer is usually determined by the amount of excitation supplied by the local oscillator. In extremely strong signal areas, the mixer might be overloaded, which would degrade the picture quality in many ways. By applying AGC to the u-h-f amplifier stage the overloading effect might be reduced.

When both the heater and plate power supplies are cut off, the u-h-f amplifier stage has a loss of 10 to 20 db, measured from the cathode to the plate circuit. Since the frequency is high, the forward isolation is rather poor due to coupling through the tube. The use of an a-g-c controlled r-f amplifier stage extends the overloading level about 3 to 1 in signal field strength at the expense of some complications to the amplifier operation, because any circuit component inserted in the grid of the amplifier tube may lead to undesired effects on amplifier stability. The question remains how serious the overloading problem is in the present u-h-f commercial receivers.

The fields near u-h-f television transmitters have been calculated. According to FCC ruling, the effective radiated power is to be measured in the horizontal plane which permits greater beam power in tilted beam antennas. Thus antennas such as the RCA tilted beam antenna would permit 2000 kw e.r.p. on the main lobe. Some receivers may be located on hills or buildings, such that there is little difference in elevation between the receiver and the transmitting antennas. The free-space line-of-sight fields shown in Fig. 17, were calculated for differences in elevation of 100 and 1000 feet for the RCA tilted beam antenna at short distances. Ground reflection may double the field strengths shown. Examination of the curves reveals the fact that fields higher than 10 volts per meter will practically never be encountered; fields up to 1.0 volt per meter can be expected as far as 5 miles from the transmitter; and also higher transmitting antennas are desirable to keep down overload and interference on nearby receivers.

With a field of 1.0 volt per meter, the signal voltage developed across the tuner input impedance is about 0.5 volt or may be less, which would not badly overload the present commercial receivers using a crystal diode mixer. Therefore, the overloading problem does not seem to be serious at u-h-f unless the receiving antenna gain be increased, or the FCC should decide that the maximum e.r.p. limit be extended.

2. Oscillator Radiation

The RETMA recommended that receiver oscillator radiation be limited to 500 μv/m at 100 feet on all u-h-f channels, to be effective in July, 1954. Most u-h-f receivers on

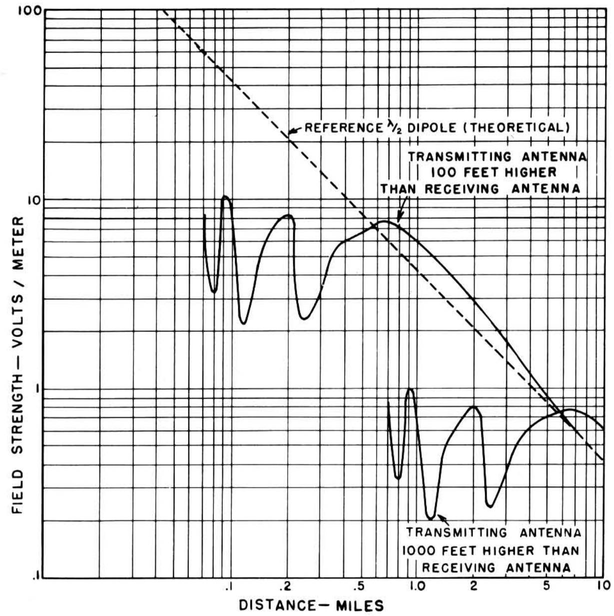

Fig. 17 - Field strength from UHF TV transmitter 1000 kw in horizontal plane, with RCA tilted beam antenna.

the market today fail to fulfill this requirement. Oscillator radiation consists of two major components--(a) radiation directly from the receiver or tuner chassis, and (b) radiation through the signal frequency circuits and the receiving antenna. At the present time each component of the radiation generally exceeds the 500 μv/m limit. The use of an r-f amplifier stage preceding the mixer helps reduce the oscillator radiation through the signal frequency circuit and the receiving antenna. With the anticipated improvement in receiver noise factor and future lowering of the u-h-f oscillator radiation limit, additional isolation between oscillator and antenna may become essential. While the backward attenuation of a grounded-grid amplifier, from the plate to the cathode circuit, varies with the type of tube, with the type of circuitry, and with frequency, an attenuation of 20 db is readily obtainable.

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