LB-1067

A CONSTANT-INPUT-IMPEDANCE RF AMPLIFIER FOR VHF TELEVISION RECEIVERS

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Approved

Stuart Wm Seeley.

Most conventional television tuners exhibit undesirable variations of input impedance at different frequencies within the passbands and with varying bias voltages applied to the r-f amplifier tube. An analysis of the input characteristics of such tuners and commercial television-antenna systems including transmission lines shows the formation of selective mismatch under certain conditions which may form 'holes' within the passband of any television channel. Such holes degrade the picture quality, particularly for color reception when a deep hole falls upon the color sub-carrier. One solution to this problem is presented in this bulletin, using a constant-input-impedance r-f amplifier which consists of two stages of grounded-grid triodes in cascade with agc voltage being applied to the grid of the second stage. Other performance characteristics of this amplifier such as noise factor, gain, overloading capability, cross modulation, etc., as compared to those of a conventional cascode r-f amplifier are also described.

Introduction

A radio-frequency (r-f) amplifier is often used in very-high-frequency (vhf) television receivers primarily to reduce noise factor and to increase overall sensitivity. The conventional configurations for such r-f amplifiers are in the forms of (1) driven grounded grid using twin triodes, also known as 'cascode'; (2) grounded-cathode pentode; (3) grounded-grid triode; and (4) neutralized grounded-cathode triode. The relative merits of these connections are well known and it has been generally agreed that the cascode r-f amplifier exhibits the best overall performance characteristics. However, there is at least one major drawback common to all such conventional configurations, i.e., the variations of input impedances at different frequencies within the passband and and with changing automatic-gain-control (agc) voltages applied to the r-f amplifier tube.

$Z_o = 300\Omega$

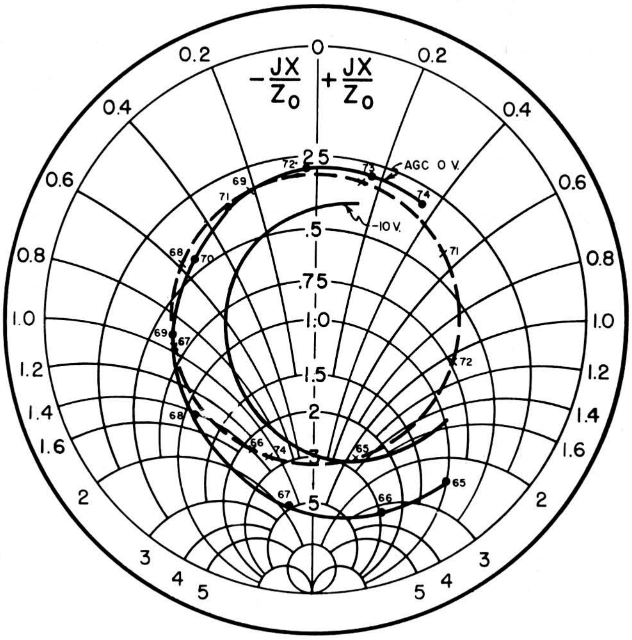

Fig. 1 – Input impedance characteristics of a typical antenna and VHF television tuner.

The input impedance characteristics of a cascode r-f amplifier such as that used in commercial vhf television tuners are shown by the solid lines in Fig. 1 for operation at channel 4. The deviations of the input impedances from 300 ohms introduce mismatch losses, and the variations of the input impedance with frequencies within the passband may produce 'holes' or 'suckouts' which degrade the picture quality.

Formation of 'Suck-Outs' and Mismatch Losses

Source or Antenna Impedance

The input-impedance characteristics of commercial vhf television antennas commonly used in the field during 1954-1955 are tabulated in Table I. In actual installation, the voltage-standing-wave-ratios (VSWR) of any antenna at different television channels are likely to be higher than the figures because of nearby objects and

TABLE I

Impedance Characteristics Of Commercial VHF TV Antennas

	VSWR – Nominal Impedance 300 Ohms						
Channel	2	4	6	7	9	11	13
1. Folded dipole (Ch 2)	2.0	6.0	13.0	poor at all upper vhf TV channels			
2. Folded dipole (Ch 4)	3.0	2.0	6.0				
3. Folded dipole (Ch 6)	11.0	3.0	2.0				
4. Folded dipole (Ch 10)	poor at all lower vhf TV Channels			1.2	1.8	2.3	4.0
5. Conical	4.0	2.4	2.0	2.3	1.9	1.2	1.4
6. All-channel Yagi (1-bay)	2.5	1.6	4.0	2.0	1.7	1.7	2.4
7. All-channel Yagi (2-bay)	1.3	2.2	2.6	2.4	1.2	1.2	1.8
8. Mallet #225	3.8	1.6	2.7	2.0	1.2	1.6	2.5
9. Mallet #225B	6.0	1.8	2.4	3.4	3.7	4.0	4.2
10. In line high-low array	20.0	1.5	2.4	1.6	1.5	2.2	2.8

other imperfections in the region surrounding the antenna and transmission line installation. An analysis has been made on the assumption that the average vhf television antenna exhibits a VSWR of 4 to 1. Let Z_a (antenna impedance) = 1200 ohms for this case. Then the impedance looking into the transmission line at the far end (Z_S) is given by[1]

$$Z_S = Z_o \frac{Z_a/Z_o + \tanh al + j\,[1 + Z_a/Z_o \tanh al]\tan \beta l}{1 + (Z_a/Z_o)\tanh al + j\,[\tanh al + Z_a/Z_o]\tan \beta l} \tag{1}$$

where

Z_o = characteristic impedance of the transmission line

a = attenuation constant of the transmission line (0.95 db/100 ft. at 70 mc)

β = propagation constant of the transmission line

l = length of transmission line

The relationship showing Z_S as a function of frequency for a transmission line of 60 ft. (average installation), assuming a uniform a value for the frequencies within the passband of a television channel, is indicated by the dotted line in Fig. 1 at channel 4. It is noticed that the attenuation of the transmission line reduces the VSWR of the antenna at the receiver end.

Mismatch Loss

A close inspection of the dotted and solid curves of Fig. 1 reveals the fact that the mismatch loss between the receiver and the antenna system (antenna and transmission line) is highly selective at frequencies within the passband of channel 4. This selective mismatch loss can be obtained by the aid of the circuit shown in Fig. 2.

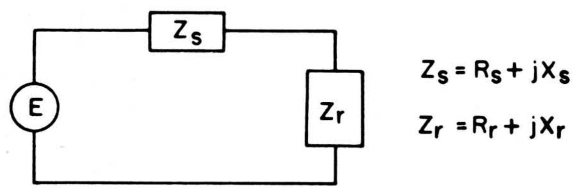

Fig. 2 – Equivalent circuit of a receiver system.

The maximum power (P_m) delivered to Z_r is,

$$P_m = \frac{E_S^2}{2(Z_S + Z_S^*)} \tag{2}$$

but the actual power (P_L) delivered to Z_r is,

$$P_L = \left(\frac{Z_r + Z_r^*}{2}\right)\left(\frac{E_S}{Z_S + Z_r}\right)^2 \tag{3}$$

where Z_S^* and Z_r^* are the conjugate of Z_S and Z_r, respectively. Then the mismatch loss of A in db is

$$A = 10 \log \frac{4R_r R_S}{(R_r + R_S)^2 + (X_r + X_S)^2} \tag{4}$$

The absolute values of A as a function of frequency are indicated in Fig. 3 again at channel 4 with an average

[1] F. E. Terman, RADIO ENGINEERS' HANDBOOK, p. 183, McGraw-Hill Book Co., N. Y.

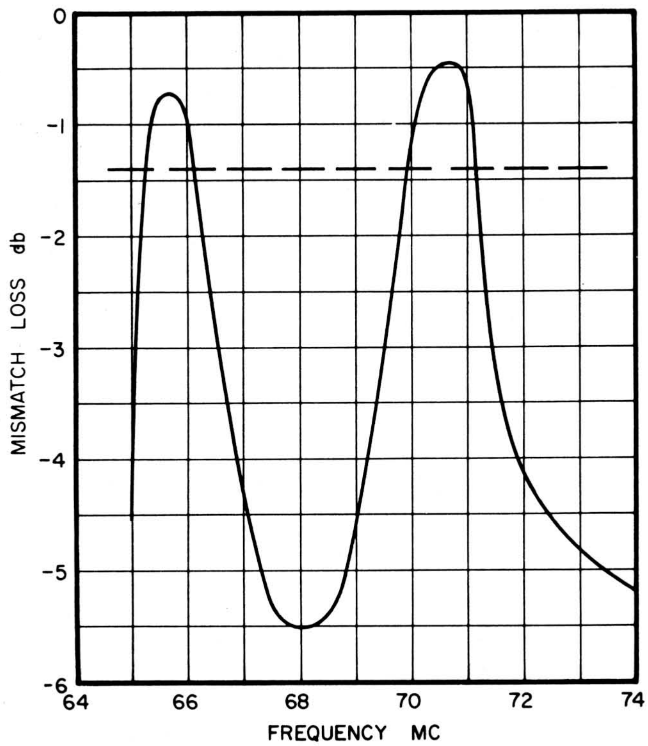

Fig. 3 – Selective mismatch loss of a VHF television tuner using cascode RF amplifier with an antenna of $Z_a = 1200\Omega$ and 60-foot transmission line.

television antenna and vhf television tuner using a cascode r-f amplifier. It is noted that under these conditions the mismatch loss is 5.5 db at 68 mc. A 'hole' or 'suck-out' thus results at that frequency. Incidentally, the location and the depth of the suck-out depends upon the exact length of the transmission line, the impedance of the antenna, and the input impedance of the receiver.

Effect on Picture Quality

The foregoing analysis is based on a purely resistive mismatch between the antenna and the transmission line. If the mismatch is other than purely resistive, the locus of Z_S will lie on the same circle as shown in Fig. 1 but with different frequency distributions around the circle.

A deep suck-out existing in the passband because of selective mismatch is objectionable in television reception, particularly for color receivers, because when it falls upon the frequency of the color sub-carrier, the color quality may be degraded.

If the receiver is so designed that its input impedance is constant at all frequencies within the passband and with any signal level, the mismatch loss will not be selective as shown by the dotted line in Fig. 3. Conversely, when the antenna impedance is held constant at Z_O (characteristic impedance of transmission line) at all frequencies within the passband, the mismatch loss is again not selective even if the input impedance of the receiver may vary. However, the development of a constant impedance antenna is beyond the scope of this investigation.

Input-Impedance Characteristics of Cascode Amplifiers

At vhf the input impedance of any vacuum-tube amplifier is affected by the presence of (1) couplings between the grid and other electrodes, (2) cathode impedance, and (3) the transit time effects. To improve the input impedance of an r-f amplifier for use in television receivers, a knowledge of such characteristics of the cascode-amplifier circuit is required.

A cascode-amplifier circuit consisting of a grounded-cathode triode followed by a grounded-grid triode is shown in Fig. 4. The variations in input capacitance of

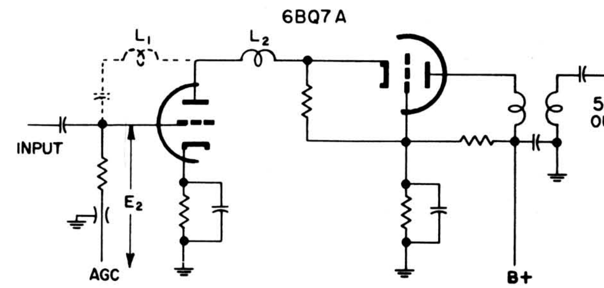

Fig. 4 – A cascode amplifier circuit.

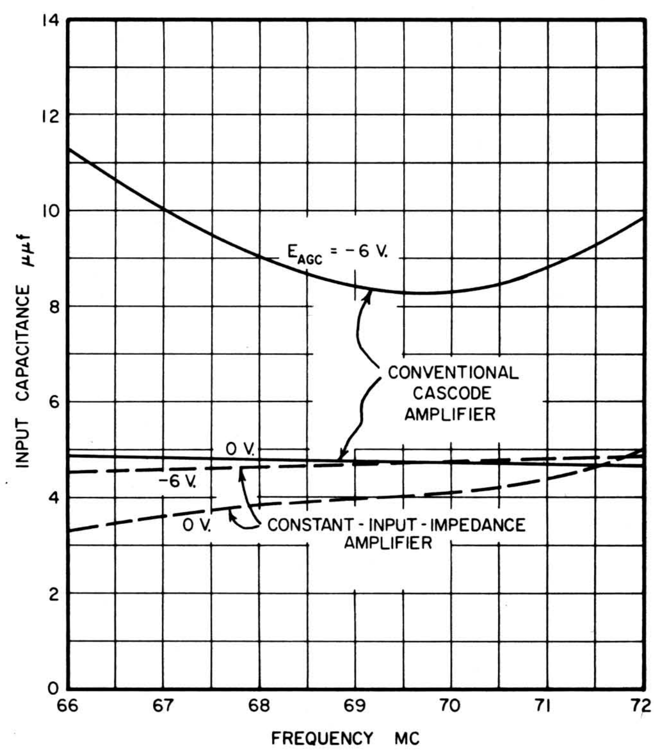

Fig. 5 – Input capacitance change with AGC voltage at channel 4.

the cascode circuit at channel 4 as functions of frequency and agc voltage are illustrated by the solid curves in Fig. 5. Similarly, the corresponding variations in input resistance are shown by the solid curves in Fig. 6. The input-impedance characteristics at channel 10 are similar to those at channel 4, except that the input loading at higher frequencies is more severe because of more pronounced transit time effects. The big change of input impedance within the passband at a given bias voltage results in selective mismatch as explained, and the large fluctuation of both input capacitance and resistance with bias voltage detunes the input circuit and hence the passband characteristics. Furthermore, such selective mismatch and detuning effect also exist in practically all conventional r-f amplifiers, including the the grounded-cathode pentode and triode configurations to which the agc voltage is applied. To overcome these inherent disadvantages of the conventional r-f amplifiers for use in television receivers, a constant-input-impedance amplifier circuit has been developed.

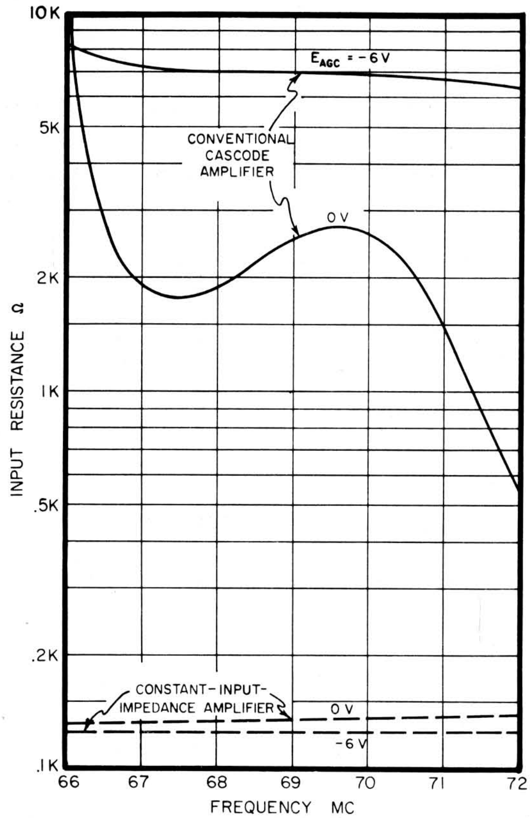

Fig. 6 – Input loading change with AGC voltage at Channel 4.

Constant-Input-Impedance RF Amplifier Circuit

General Considerations

The selective mismatch can be minimized by employing an amplifier configuration so that the amplifier input impedance is constant and nearly equal to the source impedance. For television application, the source impedance is in the order of 300 ohms. Therefore, a grounded-grid triode amplifier where no agc voltage is applied is more desirable and may fulfill this requirement. Under matched conditions, the input impedance of a grounded-grid triode connection ($Z_{in} \cong 2/G_m$) approaches 300 ohms with most miniature-type tubes such as the 6BQ7A.

To avoid overloading and cross-modulation difficulties, a second stage, again a grounded-grid triode, is used. AGC voltage is applied only to the second stage. The complete schematic diagram is shown in Fig. 7.

Characteristics of Input Capacitance and Resistance

The variation of input capacitance and resistance as functions of frequency and agc voltages are shown by the dotted curves in Figs. 5 and 6 respectively, for the

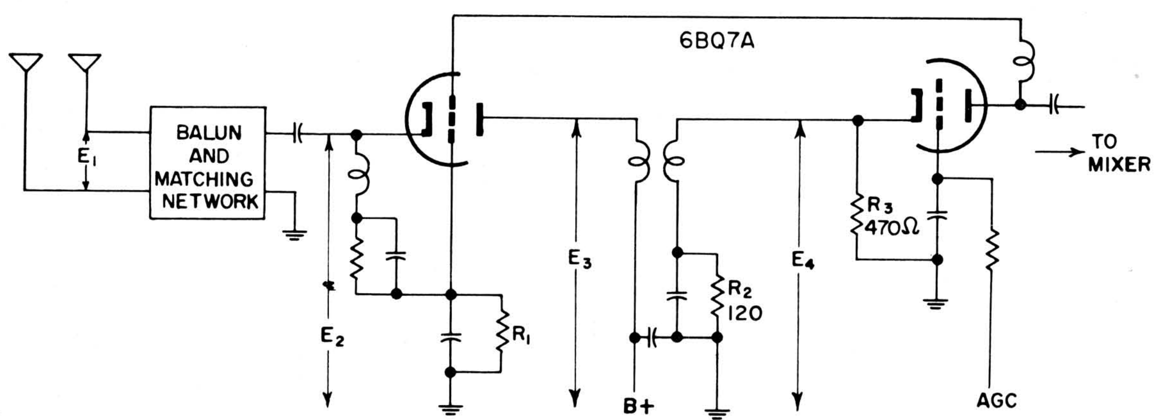

Fig. 7 – Schematic diagram of the constant-input-impedance VHF television amplifier.

convenience of direct comparison. The differences between the solid and dotted curves represent the improvement in input impedance variation with this circuit over the conventional cascode-amplifier circuit.

Operating Principle

If agc is applied to the first stage, the input impedance of the amplifier will vary with the agc voltage. For this reason, the agc voltage was applied to the second stage. Even though the input impedance of the amplifier will still be affected by the variation of the input impedance of the second stage, the large value of the plate resistance of the first stage prevents all but a minimum change of the input impedance of the amplifier. Both the input capacitance and resistance, according to Figs. 5 and 6, are practically independent of frequency and agc voltage.

Because of the high input conductance of the grounded-grid amplifier, the voltage E_2 shown by Fig. 7 at the cathode of the first grounded-grid stage is approximately equal to E_1 across the terminals of the transmission line. The voltage E_4 at the cathode of the second stage is greater than E_2 by a factor which is equal to the gain of the first stage if the input conductances of these two stages are the same. In a cascode r-f amplifier, E_2 is usually stepped up because of its high input impedance by a factor which may be greater than or nearly equal to the gain of a grounded-grid amplifier. For this reason, E_4 of Fig. 7 will be somewhat less than E_2 of a cascode amplifier such as shown in Fig. 4 for an equal input signal strength, E_1. This reduction in voltage swing at the input of an r-f amplifier improves the amplifier performance insofar as overloading capability and cross-modulation difficulty are concerned.

The operation of the amplifier circuit of Fig. 7 is complicated by the fact that the input conductance of the second grounded grid stage decreases with increasing agc voltage. Under this condition the voltage E_4 becomes greater which may cause excessive overloading and cross modulation. To overcome this difficulty, a voltage-limiting resistor R_3 is connected at the input of the second stage. A resistance value of 470 ohms was found to be an optimum compromise between the power gain of the amplifier and voltage-limiting action. The input impedance of the second stage, therefore, will be kept at 470 ohms under severe agc voltage conditions.

The use of a bleeder resistance R_1 (15K ohms) obtains the voltage stabilization of the first stage for d-c stacking operation. When the agc voltage is less negative the bleeder carries a relatively small amount of current. When the agc voltage is high, the second stage amplifier will stop conducting and the necessary current for the first stage will be passed by the bleeder. Therefore, the d-c voltage upon the plate of the first stage amplifier will vary only a small percentage.

Comparative Performance Characteristics

The constant input impedance r-f amplifier has been constructed with an approximately matched input and using an RCA elevator balun. Its other performance characteristics are to be compared to those of a cascode amplifier for operation at channels 4 and 10.

Input Impedance

The input impedance characteristics of the amplifier circuit shown by Fig. 7 at channel 4 with 0 and -6 volts agc voltage are shown by the solid curves, and those at channel 10 by the dotted curves in Fig. 8. These curves are to be compared with those on Fig. 1 for a cascode amplifier. The small variation of the input impedance with frequencies and agc voltages eliminates suck-outs and minimizes mismatch loss when it is used in conjunction with an average television antenna and transmission line. The desired signal may be attenuated about 1.5 db due to the VSWR of 4 to 1 of an average antenna system, but the picture quality will not be discernibly degraded.

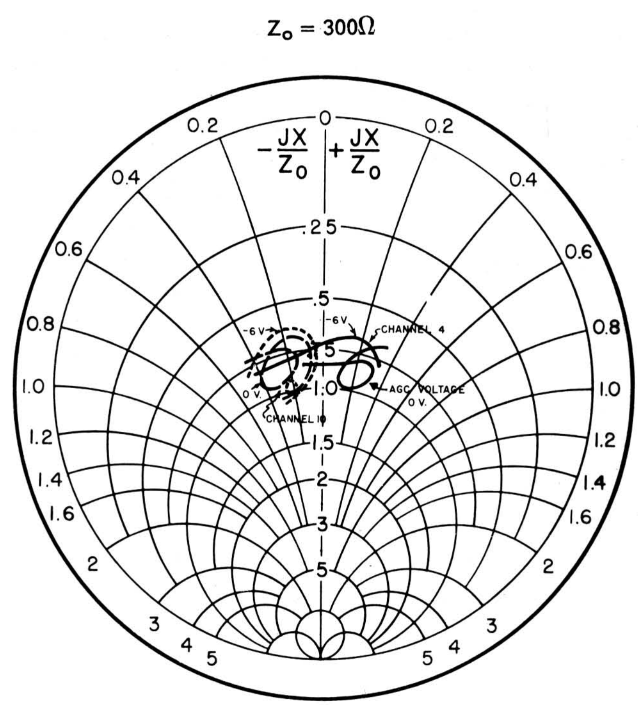

Fig. 8 – Input impedance of the constant-input-impedance amplifier.

Noise Factor

The noise factor of a cascode r-f amplifier and the constant input impedance amplifier are as follows:

	Ch. 4	Ch. 10
Cascode Amplifier (Fig. 4)	4 db	8 db
Constant Input Impedance Amplifier (Fig. 7)	5	8.5

The noise factors of these two types of r-f amplifiers are comparable. Only at the lower vhf television channels the cascode amplifier definitely exhibits a somewhat lower noise factor. In the field, however, this difference is mostly masked by the galactic noise.[2] It has been shown that the system (antenna, transmission line, and receiver included) noise factor, f, is modified by the presence of the galactic noise, f_a, and is given by

$$f = f_a - 1 + f_c f_t f_r \qquad (5)$$

where

f_c = noise of antenna circuit
f_t = noise of transmission line
f_r = noise of receiver

f decreases at a rate of 7 db/octave. At channel 4, f_a is in the order of 10 db. Thus, the overall system noise factor is governed by f_a rather than the receiver noise factor. Heretofore, television receivers have been deliberately mismatched in the input circuit at low channels to secure slightly lower noise figures. The effort, however, is not worthwhile because of the existence of f_a. Instead, it may be more significant to have the input circuit matched for maximum power transfer. Therefore the increase of the receiver noise factor at channel 4 from 4 to 5 db may amount only to a net degradation of less than 0.25 db.

Cross Modulation

Cross-modulation characteristics of a cascode and constant-input-impedance amplifier are compared directly in Fig. 9 under identical operating conditions. With 1

[2] W. Chrichlow, D. Smith, R. Morton and W. Corliss, 'World-wide Radio Noise Levels Expected in the Frequency Band 10KC to 100MC' NBS CIRCULAR 557, August 25, 1955.

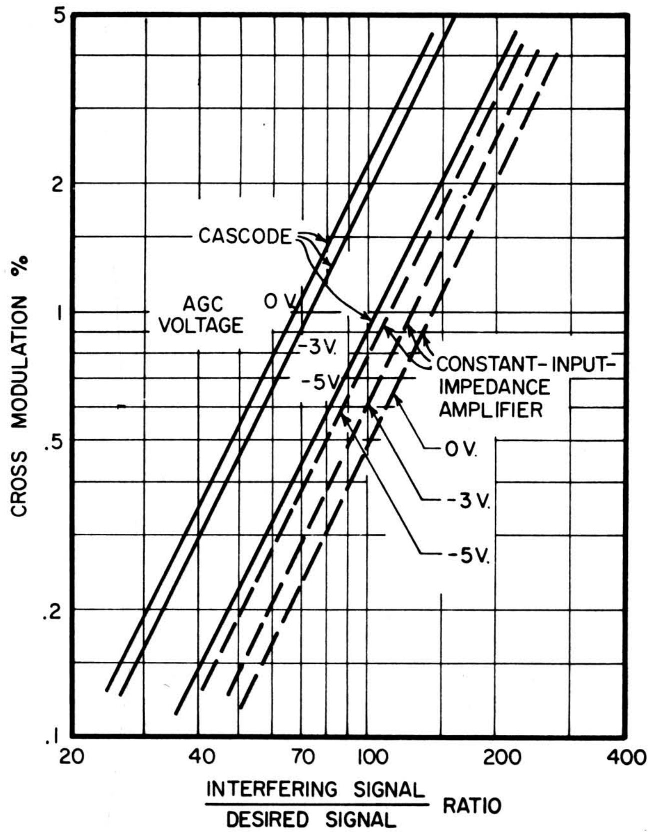

Fig. 9 – Cross modulation characteristics using a 6BQ7A vacuum tube. (Signal 1 mv. Channel 10).

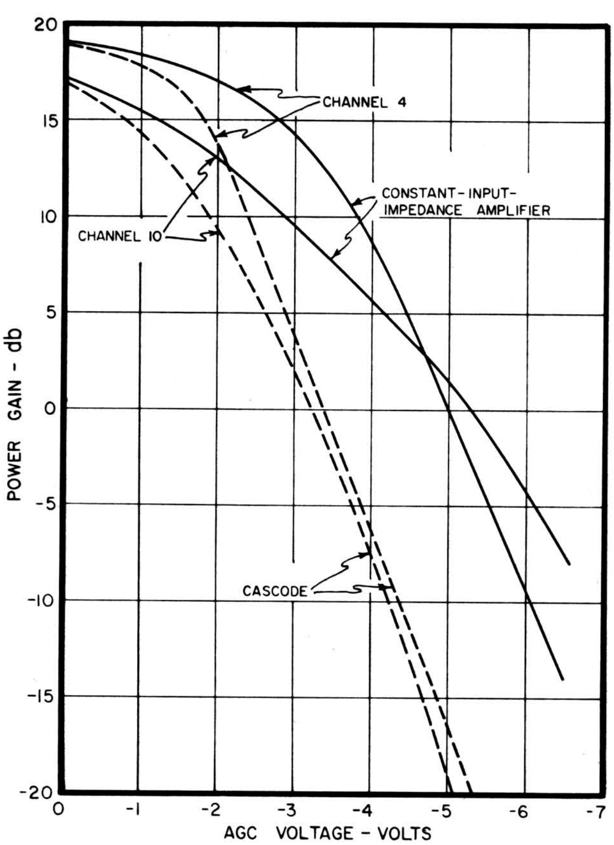

Fig. 10 – AGC characteristics.

percent cross modulation, for instance, the constant-input-impedance amplifier can stand an interfering signal which is 140 times stronger than the desired signal when the agc voltage is zero. Under the same condition, the cascode amplifier permits a ratio of 70 times. However, the difference between these ratios diminishes as the agc voltage is increased. Generally, the cross-modulation characteristics of these two amplifier circuits are again comparable.

It is noted that the cross-modulation percentage reduces with increasing agc voltage for the cascode amplifier, but conversely for the constant-input-impedance amplifier. The input conductance of the second grounded-grid stage of the constant-input-impedance amplifier decreases with increasing bias voltage until it reaches a certain value determined by the voltage-limiting resistance, R_3.This reduction of input conductance increases the voltage, E_4 and hence the cross modulation. Consequently, a smaller value for R_3 will further cut down the cross-modulation percentages.

AGC and Gain Characteristics

The gain of both amplifiers, shown in Fig. 10, is about 19 db at channel 4 and 17 db at channel 10. However, the gain of the constant-input-impedance amplifier can be increased by raising the value of the voltage-limiting resistance, R_3. It is noted that the slope around the cascode amplifier, as compared to about 9.5 db/volt for the constant-input-impedance amplifier.

Passband Characteristics

With a wide-band input circuit, the passband characteristics of a cascode r-f amplifier are generally acceptable for the transmission of color television signals under various bias conditions. Such characteristics of the constant-input-impedance amplifier are again comparable to those of the cascode r-f amplifier.

Conclusions

It has been observed that the input-impedance characteristics of this newly-developed r-f amplifier are superior to those of a conventional cascode amplifier. The other performance characteristics such as gain, noise factor, cross modulation and agc characteristics are comparable to those of a cascode amplifier.

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