IRE TRANSACTIONS

ON BROADCAST TRANSMISSION SYSTEMS

PGBTS-8 JUNE, 1957

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PUBLISHED BY THE

PROFESSIONAL GROUP ON BROADCAST TRANSMISSION SYSTEMS

IRE PROFESSIONAL GROUP ON BROADCAST TRANSMISSION SYSTEMS

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Annual Assessment: $2.00

IRE TRANSACTIONS®

on Broadcast Transmission Systems

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THE CORRECTION OF DIFFERENTIAL PHASE DISTORTION IN COLOUR TELEVISION TRANSMITTERS

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The variation of phase of small chrominance signals with luminance amplitude, commonly referred to as differential phase is one of the more difficult deficiencies to overcome in economic design. With the N.T.S.C. colour television system, change of phase with amplitude at the sub-carrier frequency causes a corresponding change of hue, and the N.T.S.C. specifications suggest that the phase error over the whole system should not exceed 10 degrees.

If this permitted tolerance is divided between cameras, distribution systems, transmitters, etc., the permissible tolerance in each individual piece of equipment is extremely difficult to achieve.

Normally for monochrome television the change of phase with amplitude is relatively unimportant and it is frequently found that equipment giving satisfactory performance on a monochrome system is well outside the permited differential phase tolerance for colour television. Fig. 1 shows the measured phase amplitude law of a satisfactory and typical design of monochrome television transmitter which is outside the permissible tolerance for colour television.

Attention to amplitude linearity by precorrecting the amplitude law gives some alleviation of the problem but does not seem to offer a complete solution as the amplitude correcting devices themselves are not usually equally effective over the whole video frequency bandwidth.

Over-all it is often found that when an economic design gives adequate amplitude linearity for colour television signals over the required bandwidth, there is still an unacceptable degree of differential phase distortion.

It seems logical, therefore, that a means for correcting the differential phase distortion, without affecting the amplitude linearity characteristic, is a worthwhile aim since it will permit existing monochrome designs to be corrected for colour operation with least modification.

Two distinct methods of correcting the phase amplitude law have been devised.

The first method consists, as shown in Fig.2 of a simple pentode or tetrode amplifier which has non-linear impedances in anode and cathode circuits so dimensioned that the phase changes with amplitude without significantly affecting the amplitude linearity.

Provided RL/RK is constant, the gain remains constant and amplitude linearity is unaffected at all frequencies at which amplitude linearity is significant.

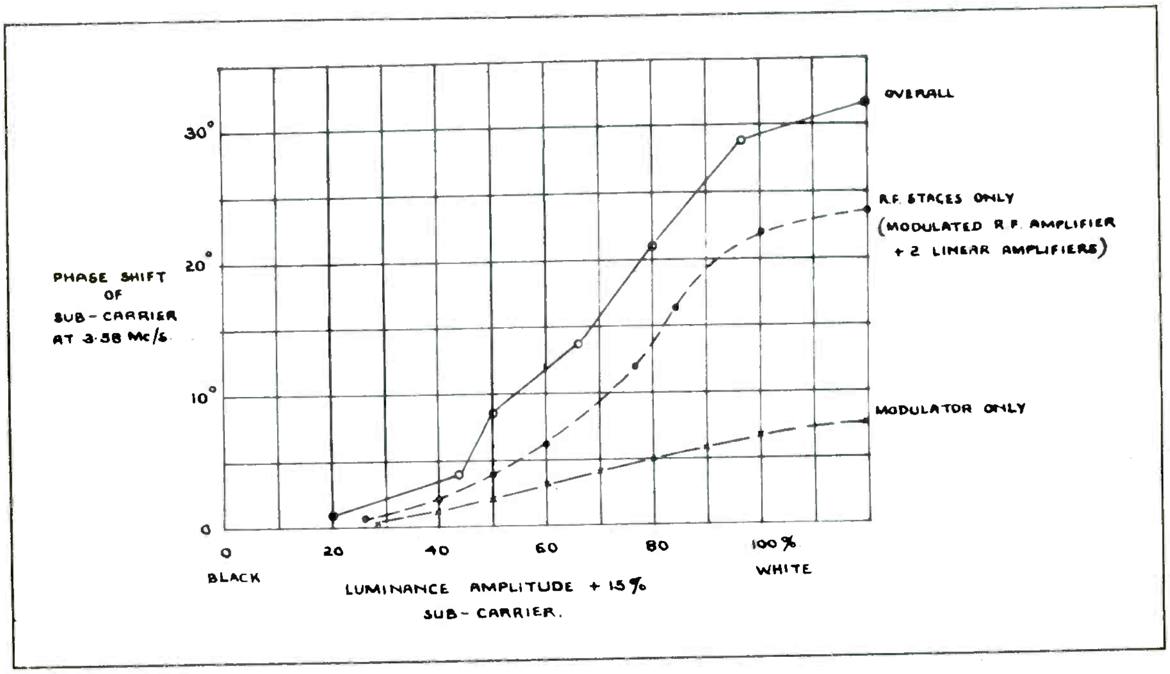

Fig. 1 - Typical phase/amplitude laws of an old type monochrome transmitter that is unsuitable for colour without modification.

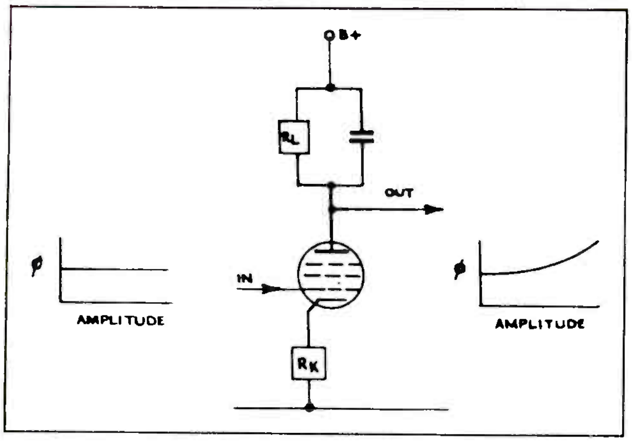

Fig. 2

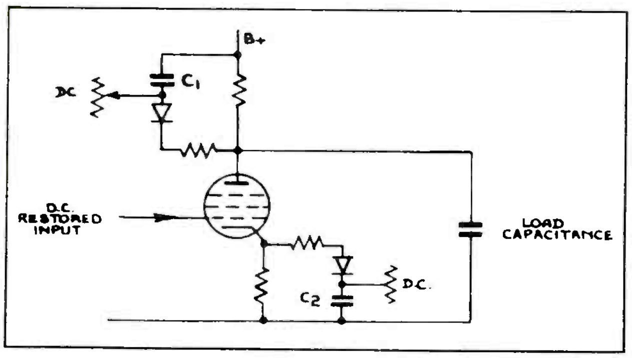

Fig. 3

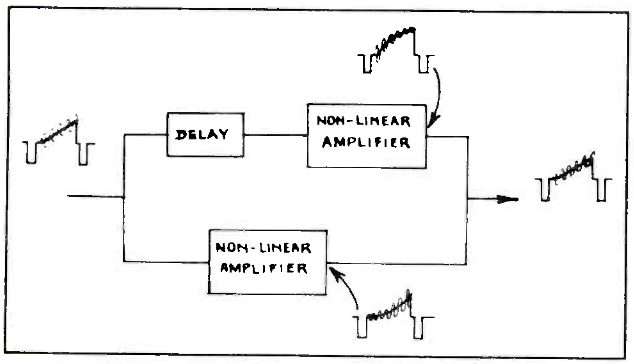

Fig. 4

If, however, RL and RK are non-linear with amplitude, while constant in ratio, the phase of the output signal will change with signal amplitude. In practice the phase changing circuit may be as Fig. 3.

In Fig. 3, for the simplest case, C1 and C2 are of negligible impedance and the diodes are made conductive or non-conductive by the signal; thea mplitude at which the phase correction starts to operate being determined by the signal amplitude and the diode bias, while the law of correction is determined by the ratio of the non-linear to linear resistance operative, and is made suitable by operating the stage at an appropriate signal excursion and by choice of diodes.

The second method, though more complicated gives a more flexible control of correction and is based on the fundamental scheme illustrated in Fig. 4.

The output is the sum of the outputs of the two independent channels and the over-all amplitude characteristic of the combined channels is linear. Each channel, however, has a complementary amplitude linearity law, one having gain which increases with amplitude and the other gain which decreases with amplitude. Since one channel has included in it a delay, the over-all delay/amplitude law is non-linear. For example, if the delayed channel contributes one half of the output signal at 'grey' less that one half at 'white' and more that a half at 'black', then the mean over-all delay of the two complementary channels will decrease as the over-all signal changes from 'black' to 'white'.

The crude theoretical correction possible by these means is permissible because of the relative delays which are significant in the luminance and chrominance channels. For example, a 20^{o} phase shift at 3.58 Mc/s corresponds to a delay of about 15 millimicroseconds which represents a negligible distortion of luminance transients yet is significant in obtaining constancy of hue.

One practical arrangement is illustrated in Fig. 5 and has been used to correct the phase/amplitude law of an old design of monochrome modulator to within about $\angle\frac{1}{2}^{o}$. The uncorrected and corrected phase amplitude law is shown in Fig. 6.

A more complicated corrector with greater flexibility of control is shown in Fig. 7.

In this form the polarity of the signals feeding each non-linear system is opposite (7b) in order to obtain the same polarity of operation in the diode system (7c) to avoid mismatching of the diode operation by D.C. current flow. The delay unit consists of switched lengths of coaxial cable, and a wide variety of correction magnitudes and laws is possible.

The frequency response and transient response of the corrector itself must not, of course, introduce significant deterioration, and this design requirement becomes more difficult as the flexibility of the correcting means is increased. However, the corrector shown in Fig. 7 meets this requirement and has the performance shown in Fig. 8.

The development of this type of corrector circuit is by no means complete. The extent to which over-all feed-back might be used to stabilize the over-all amplitude linearity of the corrector has not been explored, although there seems little doubt that it could be employed to simplify the setting up procedure at least for moderate amounts of phase/amplitude correction.

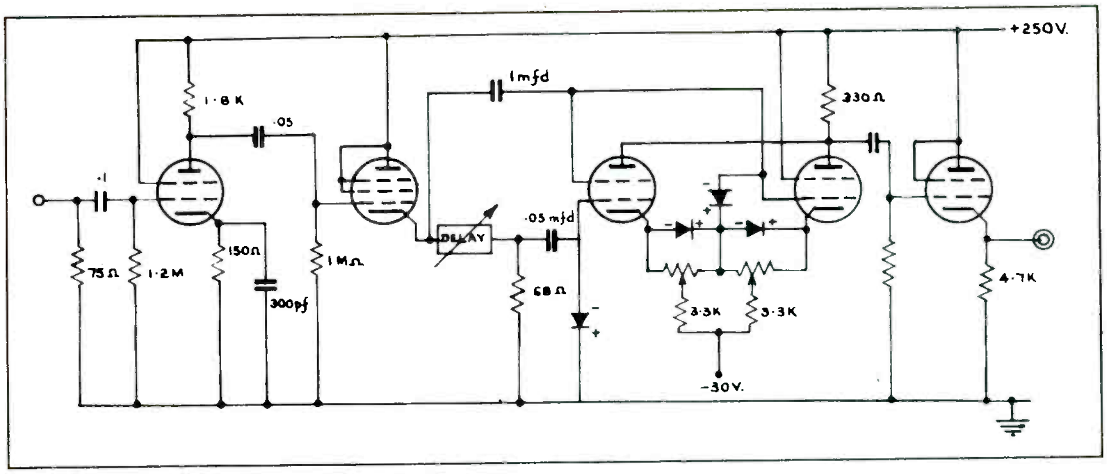

Fig. 5 - Pre-correcting circuit for differential phase errors.

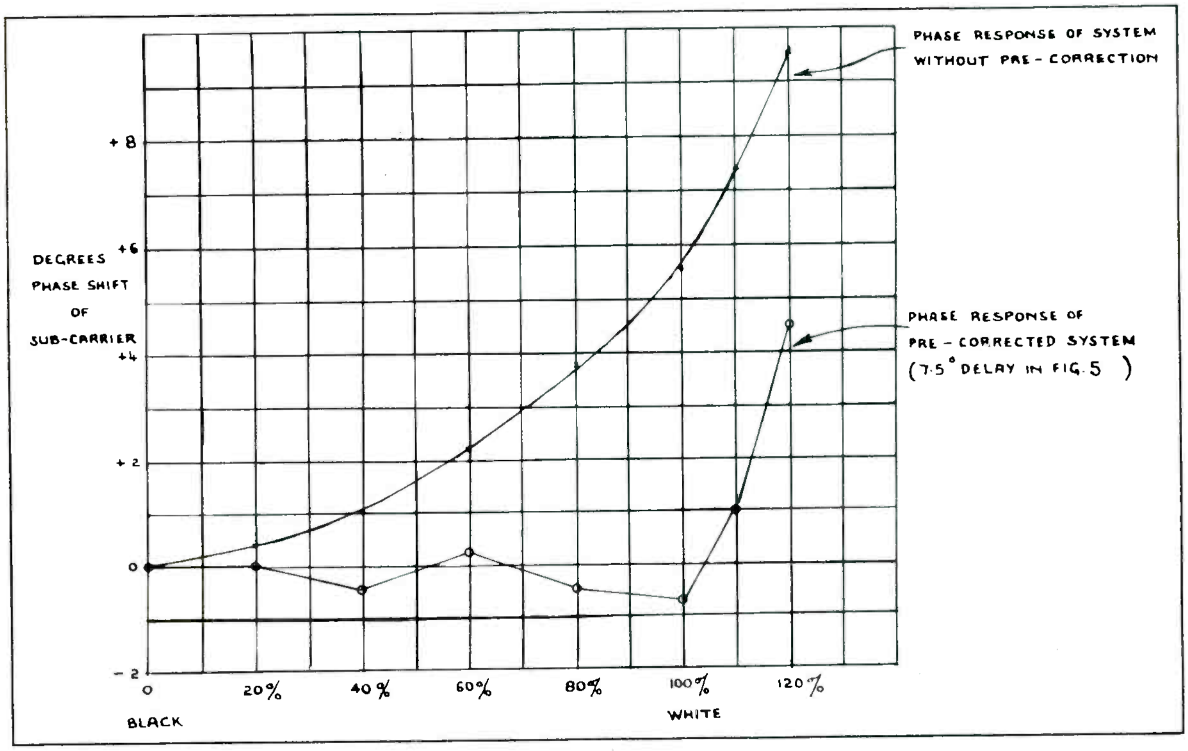

Fig. 6 - Luminance signal amplitude.

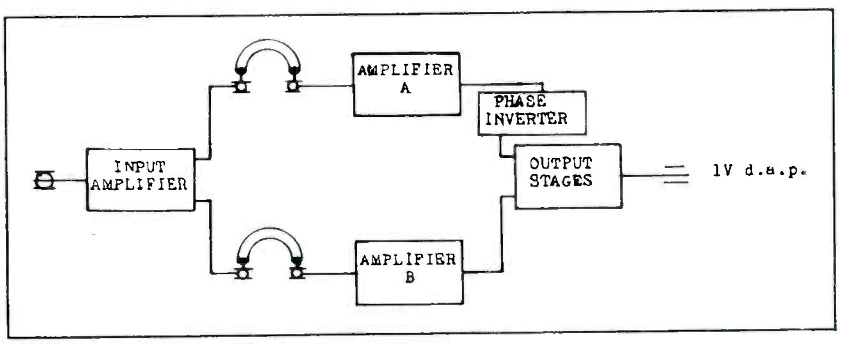

Fig. 7(a) - General arrangement of phase/amplitude corrector.

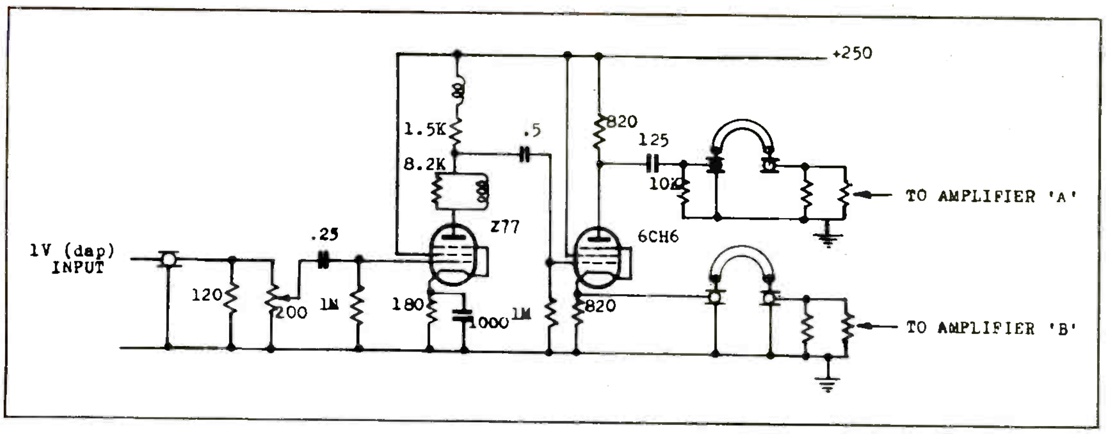

Fig. 7(b) - Input stages.

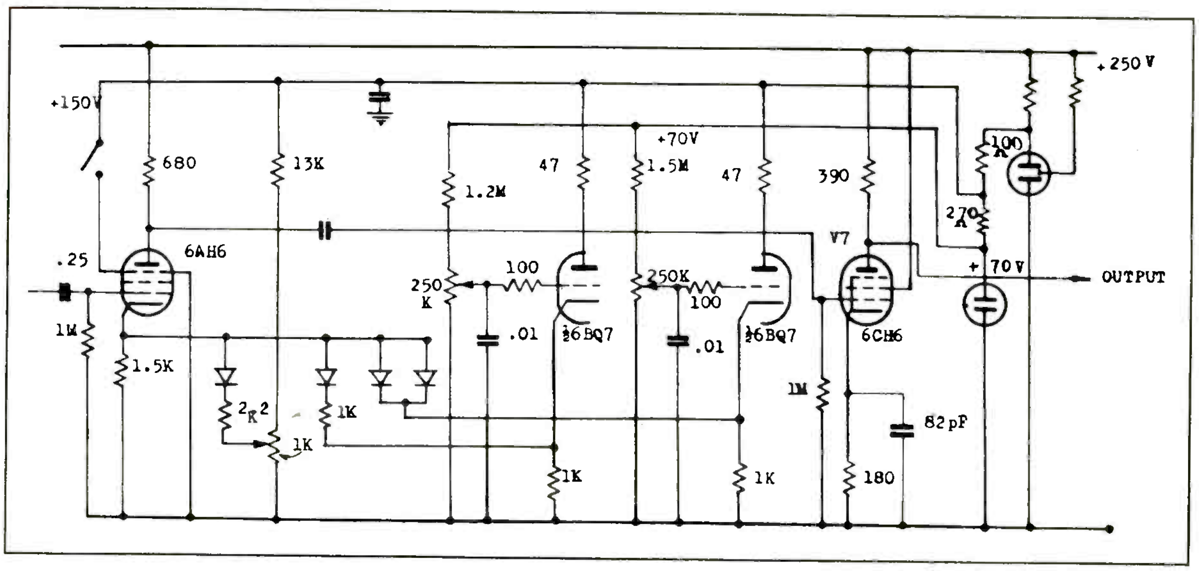

Fig. 7(c) - Amplifier 'A' & amplifier 'B'.

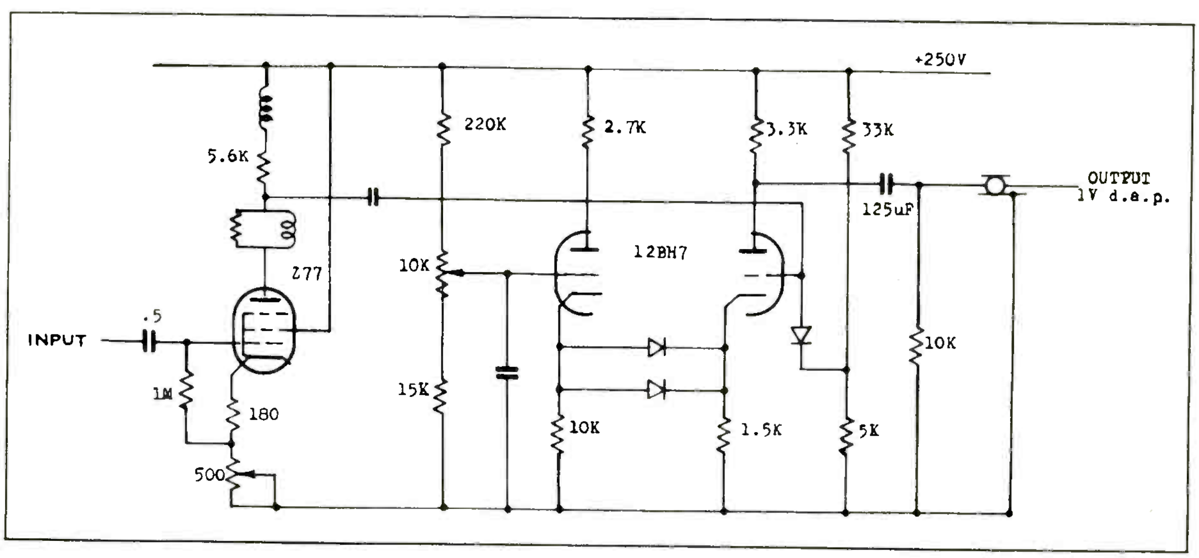

Fig. 7(d) Output stages.

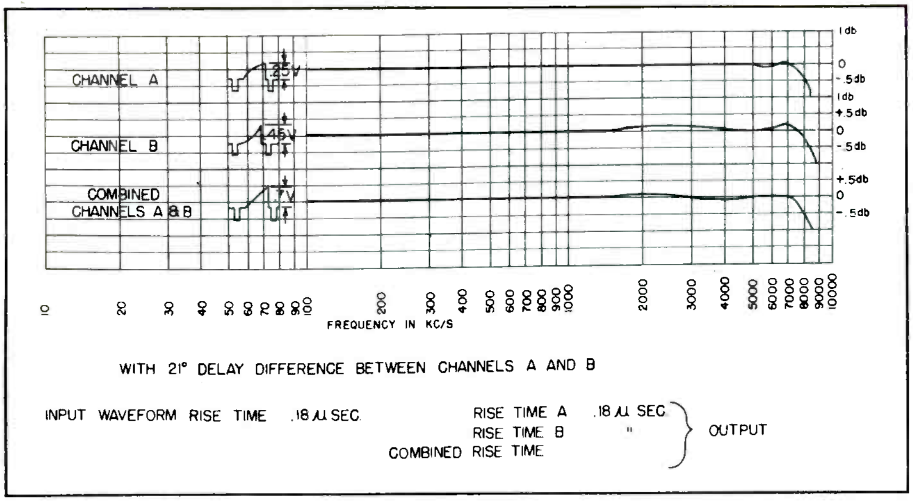

Fig. 8

Two types of test are used to measure the phase/amplitude law of a system. One uses an incremental method which comprises, say, a 10% amplitude sub-carrier sine wave super-imposed on a step sawtooth or, alternatively, a 10% sub-carrier sine wave swept over a linear sawtooth waveform.

Both these test waveforms lend themselves either to a swept display of error or for more accurate measurement to a point by point phase comparison technique which with care can give accuracy of measurement to less than $\angle \frac{1}{4}^{\circ}$.

The second type of test is used to appraise the overload capacity of a system and therefore its ability to handle saturated or near saturated colours. In this test a small sub-carrier signal is inserted at mid-grey in the picture signal region and increased in value until it corresponds to full modulation. The phase of the increasing amplitude signal is compared directly at all levels with the phase of the original small signal. This test tends to average the incremental errors but illustrates clearly the limit of modulation for acceptable phase shift.

Under these test conditions, any particular level of signal remains in constant relation to the valve characteristics. This, however, does not always apply in practice where A.C. couplings are used. Ideally for colour transmission in which phase amplitude law has to be corrected, this same constant relation condition should apply if the optimum results are to be obtained. This would, of course, imply a D.C. restoration process at each point in the chain where phase/amplitude errors are likely to be significant. There is, however, a degree of correction possible even when the signals are not all of D.C. type but the extent to which the system can be usefully employed under these conditions is not yet known.

AUTOMATIC GAIN CONTROL IN TV AUTOMATION

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Summary

An automatic programming device depends on automatic gain control in typical TV applications. An "All-Electronic" A.G.C. with sufficient operational range for use as an integral part of a monochrome vidicon film center is described and compared to other gain control methods.

An automatic programmer also lends itself to the switching functions of a color film center, using the flying spot scanner principle. The simplicity of the All-Electronic A.G.C. method described emphasizes the superiority of the flying spot scanner system for TV station operation.

The day of electronic equipment thinking for itself is upon us. In more and more broadcast and industrial applications electronics is taking the guesswork out of control systems, relieving the operator of tedious tasks, and increasing the thoroughness with which a complex job is done.

A recent development which has caused a great deal of interest is an automatic programming device. By simply punching out, on paper tape, the various operations necessary to switch from different picture sources, any portion of a schedule can be programmed automatically. This of course saves manpower and reduces the chance for "human error" which in turn eliminates many "lost commercials". To carry this automation a step further, it seemed desirable to have a means of automatically controlling the output level of the camera channels being used.

At this point a review of existing broadcast practice will bring out several pertinent points.

One of the major problems in television broadcasting has been the attention which has to be devoted to the slide and film equipments electronic controls. A master control operator has become a manpower fixture particularly in the smaller stations. Frequently he has been spread thinly, having to ride iconoscope gain and blanking, switch during breaks, and even be the projectionist between these tasks. Once in a while time gets the best of him -- he just doesn't have enough hands to do all of these things -- or he has to compromise here and there. The result is a lower quality picture, a missed commercial or just trouble. In today's highly competitive picture any of these troubles will reduce revenue to the station. Incidently, another factor that cannot be ignored is that good operators are hard to find and to keep.

Anything to reduce the need for close gain riding, to reduce switching level changes, and to reduce the complexity of station operation is a real advancement in the broadcasting business. A proven example of this is the audio-uni-level amplifier.

Let's examine more closely the first problem when operating a vidicon film chain. Practical level changes due to changes in highlight density of films and slides will cause video signal level changes of up to ten to one for monochrome. I am sure extreme examples can be found which will exceed this practical working value, but this figure was determined from (1) testing a wide range of agency supplied film and slide material (2) from surveying several stations in both large and small markets for samples of their thinnest and densest material, and (3) soliciting the opinions of as many chief engineers and operators as possible.

Switching between film, slide and Balop projectors has always caused some troubles. Rarely can you get a perfect match between light sources feeding your camera. Filters, Iris's, and polaroids have been used but why should you degrade your systems capabilities to your poorest source?

Another solution would be to place an automatically controlled variable density wedge between the projection lamp and the film or slide. Unfortunately this requires that all the wedges be controlled in parallel or the control be switched from projector to projector. If the latter method were used some form of pre-set manual control seems advisable to smooth out the transition since large differences would take many fields to accomplish the large mechanical correction. In addition to these problems it does not seem practical to limit the signal to noise ratio of the whole system to that of the dimmest source and the densest film or slide.

With the over-all problem of automatic vidicon monochrome gain control clearly defined a search for a practical solution devoid of servos was instigated.

A review of the vidicon tube characteristic shows that although there is a slight change in gamma the tube can handle a relatively wide range of input high light brightness. With normal camera control settings the target or signal electrode voltage is adjusted for the highest voltage possible with an acceptable "dark current" signal (short of edge flare). The beam can then be adjusted to discharge the highest "highlight" that will be encountered. A practical limit to this range was found to be 30 to 1.

An automatic gain control circuit which would maintain a constant to plus 10% output level with a varying input signal was found to be an ex cellent complement to this vidicon characteristic.

Here is an example of such a circuit which is being used to provide a constant level output from a monochrome vidicon camera channel. This circuit with the vidicon will operate over light level changes of 30 to 1. The stability is such that there is no noticeable bounce when the light level changes from minimum to maximum. The attack time is approximately one-field.

Referring to Fig. 1 you will see that V1 is the stage whose gain is to be automatically controlled. It is a pentode which has a regulated plate supply. This is done to minimize the D.C. change as the control voltage is rapidly changed from one extreme to the other. The output of V1 is coupled to V2 whose grid is clamped by a keyed clamp to remove the D. C. change which would cause an excessive bounce if it were allowed to be amplified with the rest of the signal. V3 is another amplifier. The bandwidths of these amplifiers are made narrow so that the fine white detail will not determine the peak voltage. It would not be desirable to have the level determined by extremely small detail whites. By various tests, a compromise bandwidth was found which satisfied this condition. The grid of V4 uses a D. C. insertion diode to establish a reference for the rectifier which is coupled to the cathode. The output of this rectifier is thus proportional to the peak to peak video signal. This voltage is D.C. coupled by V5 to the grid of V11, thus completing the A.G.C. loop.

A capacitor is in parallel with the rectifier load. The input time constant of the amplifier determines the attack time or the time that it takes the A.G.C. to readjust the level after a major change in input level. This attack time is made as rapid as possible without a resulting "bounce".

The threshold level at which the A.G.C. will take over is set by adjusting the input level control for the correct level into the A.G.C. loop. This is done while projecting a film or slide with the greatest density that will be encountered.

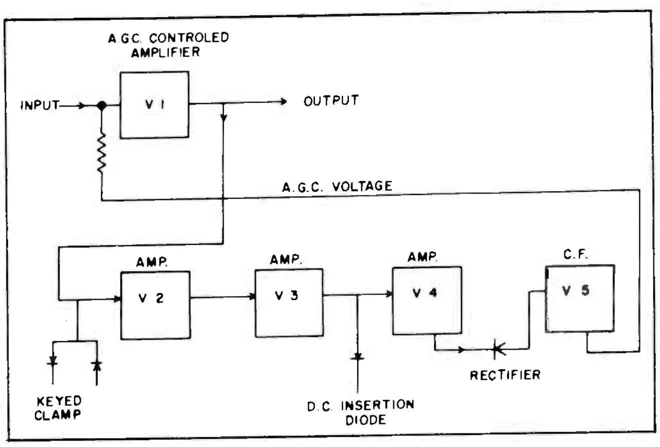

Fig. 1 - Block diagram of A.C.C. loop.

The automatic gain control circuit is an integral part of the automatic programming picture and will relieve the station personnel of another tedious task.

Switching to color film and slide programming it must be said that station operation has

PEAK RECTIFIED		
	EQUAL PARTS	1/3R+1/3B+1/3G
	"Y" DISTRIBUTION	.3R+.1B+.6G
	ONE COLOR	GREEN
AVERAGE SIGNAL		
	EQUAL PARTS	1/3R+1/3B+1/3G
COMMUTATED		
	V RATE	ALTERNATE FIELDS REPRESENTED
	H RATE	ALTERNATE LINES REPRESENTED

Fig. 2 - Methods of obtaining a gain control voltage.

become more complex. Here is where automatic programming can really help the broadcasters. Let the automatic programmer do the switching, let the automatic gain control hold the white level practically constant, and release the operator to the all important job of controlling picture quality in this high impact medium.

A quick review shows the monochrome arguments regarding variable density wedges still hold, but a new decision must be made for all control methods. From where will the error signal come? The following six signal sources were carefully analyzed and checked experimentally. They will now be evaluated relatively for three primary considerations: (1) Maintenance of a constant white level which in turn insures correct relative signal amplitudes into the individual gamma circuits, (2) Ease of obtaining the error signal, and (3) Simplicity of operation.

Peak signal rectification using a vertical sampling rate for equal parts of RGB maintained a close control over the three signals entering the gamma circuits and introduced no error when the peak signal is white or near white. It is obvious that a "one primary" color slide or strip of film will cause the A.G.C. circuit to call for excessive gain, but the equal parts matrix limits this error to a theoretical 200% which is greatly modified by gamma and finally limited by a white clip protective circuit, to a resultant maximum 50% error. A "Y" matrix was checked but the possibility of a 900% error practically eliminated that scheme. Another consideration minimizes this error problem. Rarely will the one color case occur in practice and may easily be avoided.

Peak rectification of either a "V" or an "H" rate commutated signal approaches the ideal solution from the error point of view. This way the peak signal of the brightest color component will be the controlling factor with no error introduced.

A commutated "V" rate signal is made from alternate fields of red, blue, green video and an "H" rate signal is from alternate lines of red, blue, and green video.

Other methods were considered but none apparently have comparable practical possibilities at this time.

How do these methods rate in ease of obtaining the error signal?

The equal parts peak rectification, the "Y" peaks rectification, and the average signal are obtained with similar ease from a common plate load of three cathode followers, one in each color channel.

The peak rectification signal of one color or the Y signal from the encoder may be obtained with similar ease and more cheaply than the former three.

The peak rectified commutated signal is the most difficult and most expensive to obtain. Of these the "V" rate is simpler particularly when vertical rate sampling is used for RGB presentation on the waveform monitor, but the attack time will be much slower than any other method mentioned. The "H" rate sampling requires the most extensive circuitry, but provides a signal which quickly follows video changes for a comparable attack time.

Simplicity of operation includes consideration of the set-up procedure and operating characteristics.

The one signal source methods require threshold and tracking adjustment. The resultant video will follow the single signal source whether or not it is representative of all three.

The tri-signal sources require a threshold and tracking adjustments. The resultant video depends on their being white in the picture for perfect operation but practically the equal parts RGB method does an excellent job.

The commutated signal sources require threshold and tracking controls, but the commutating circuitry is an additional requirement.

From this whole investigation it was determined that the equal parts RGB peak rectification method is superior. The H commutated method had a slight margin of superiority in operation but was significantly more complicated electronically. The following paragraphs will explain the method for automatic gain controlling a G.E. color film center -- a center which lends itself particularly well to this advancement in the broadcasting art.

Fig. 3 shows a simplified block diagram of a video A.G.C. system for color. For purposes of explanation only one of three channels will be referred to. The input video signal which normally is varying in level, is applied to the "gain controlled stage" V1. The gain of this stage is varied by application of a D.C. control voltage. V1 is followed by several stages of video amplification, a keyed-clamp, and an output stage.

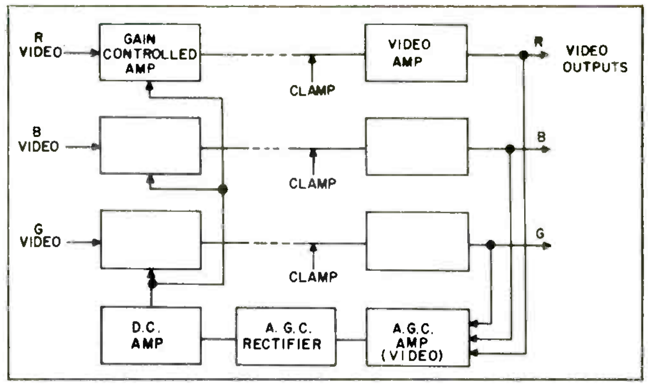

Fig. 3

Some of the output video is taken off and amplified in V6, a relatively narrow band video amplifier, and D. C. restored to establish black level. This is followed by a cathode-follower which drives the A.G.C. rectifier. The rectifier develops a D. C. voltage proportional to the white peaks which are negative-going at this point. The D.C. is filtered, amplified and used to control the gain of V1.

An important requirement of any A.G.C. system is in fact "attack time" so that a minimum amount of disturbance will be observed at the output during transition from one input level to another. For the most part, the attack time is limited by the time-constant of the RC filter (or filters) following the rectifier. If this time constant is made short to speed up the attack, a 60-cycle component due to imperfect filtering of the rectified video signal is fed back and adds to the video. So long as this component is not too large compared to the video, the keyed clamp will remove it. In practice the attack time can be made to be less than 1/10 of a second. This automatic correction is made significantly faster than one made by even a well trained operator. This of course is one of the primary advantages of an all-electronic level control system.

The over-shoot or "hunting" of the A.G.C. system is also a function of the filtering following the A.G.C. rectifier. For best results the minimum number of RC filters which should be used in a practical circuit is about two. One of these should have a time constant of at least 10 times that of the other. Since the A.G.C. rectifier and its driver must charge up the first filter capacitor on very short white peaks it is desirable to make the first RC the short one.

During the attack time of the A.G.C. circuit, the output video may rise to many times the nominal value. To prevent overloading subsequent amplifiers (causing them to draw grid current, etc.) a white clipper should follow the A.G.C. amplifier to clip off the high amplitude, short duration peaks. Such a combination of fast attack A.G.C. and white clipper will give excellent results.

When used with a film and slide pickup which has a linear transfer characteristic, the A.G.C. amplifier will have to handle video level variations of 10:1 or so as mentioned before. This puts a stringent requirement on the gain-controlling tube since it must remain linear over wide variations of D.C. plate current. A circuit which works very well in this respect is shown in Fig. 4. It is the well-known cathode-coupled amplifier. In this application, however, the D.C. control voltage is applied to both grids so that the plate current and Gm's rise and fall together. Even at low plate currents (and therefore low gain) the

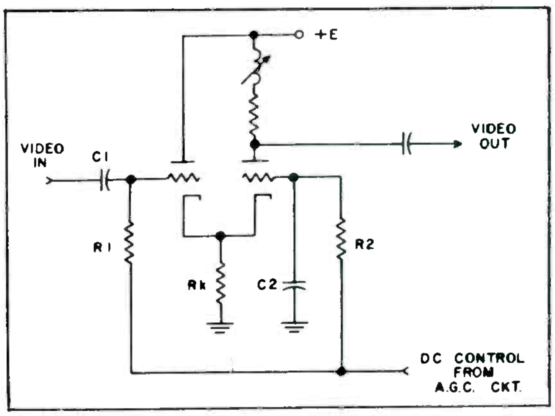

Fig. 4

stage is very linear because of the push-pull type of operation where the instantaneous plate currents due to the video signal are 180° out of phase.

In color channels another problem exists which we call "tracking". This is the ability of the three separate gain-controlled stages (red, blue and green) to change in gain by equal increments for given changes in control voltage. The cathode coupled stage has an advantage here too since it is very degenerative to the D.C. control voltage (due to a large cathode resistor) and one simple tracking adjustment is all that is required.

The upper limit of input level is more-or-less set by the linearity of the gain-controlled stage. The lower limit is determined by the tolerable noise and maximum gain of the A.G.C. amplifier. Due in part to these factors, the input-output characteristic is designed to have a "threshold" as shown in Fig. 5. Below this point the rectifier is biased so that it does not conduct and there is no A.G.C. action. The gain-controlled stages are then at full gain. When the video level increases to the point where the rectifier conducts, increasingly negative D.C. voltage is applied to these stages. If the "loop gain" is high, this D.C. change will be large for a very small change in output level. The input-output curve will then be very flat above the threshold.

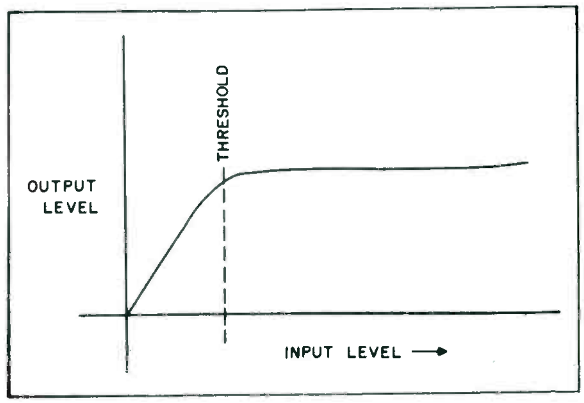

Fig. 5 - A.G.C. characteristics.

In a typical case the output may rise less than 10% for an input level increase of 1,000%.

In this color A.G.C. system the sensing signal is derived from equal amounts of red, blue and green. Ideally there should then be some white in all scenes when using this method. However, if there is not, the only error is a slight shift in output level. As long as the three gain stages are adjusted to track, as mentioned before, the color balance will not be affected.

Checking the A.G.C. (or gamma) tracking is very simple if a 20-cycle monitor switcher unit is available. By observing the 20 cps sequential output of red, blue and green at H rate the three traces are superimposed on the waveform monitor screen. If an H rate sawtooth is observed in this manner, it is very easy to check tracking errors if they exist. Color A.G.C. tracking to within one or two per cent can be achieved without tube selection.

It seems natural that automation will soon become a much used tool of the broadcaster. A.G.C. is an integral part of this system and is now available for both monochrome and color film systems.

Yes -- our electronic equipment is relieving us of tedious, time consuming control functions and these two circuits are major steps forward in the art.

A 50 WATT AMPLIFIER FOR MICROWAVE RELAYS

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Summary

The significant problems encountered in the engineering development of a klystron amplifier system for 6000 megacycle microwave television relays are discussed and the final results and limitations of the system are set forth. All data submitted herewith is on the basis of laboratory results.

Introduction

During the past few years of microwave relay development, we have seen the 100 milliwatt microwave relay give way to the 1 watt microwave relay because of the considerable added advantages of greater distance and greater propagation reliability and this in turn has led to the demand for and the eventual production of a power amplifier capable of a nominal 50 watt power output, which in turn further increases propagation reliability and gives the possibility of using microwave relays over distances which are now considered prohibitive. The development of a 50 watt amplifier became possible recently with the announcement by Eitel-McCullough of the development of their type X563E tube. This is a four cavity klystron amplifier of conventional design which was specifically designed by Eimac for use in this field. A principal advantage to be gained by the use of such a power amplifier is the increase in path reliability by the addition of some 17 db of fade margin. There are many existing paths of 40 to 50 miles now in use wherein such a fade margin could spell the difference between complete path reliability and sometimes complete fadeouts. Also, due to the nature of microwave propagation wherein the distance is a logarithmic factor of power, the use of such a 50 watt amplifier in certain areas, particularly mountainous country where adequate terrain clearance is readily available, should probably result in reliable microwave relay operation over paths of 100 to 200 miles. Actually, the propagation charts would indicate possibilities far in excess of this, but other conditions of propagation would appear to limit the use of such equipment to probably a maximum of 200 miles and possibly less.

Tube Characteristics

The X563E, as developed by Eimac Company, is in general an extremely rugged reliable type tube of conventional design, utilizing a coaxial type input and waveguide output for RF energy. It requires some 2500 to 3000 volts for the beam voltage and draws approximately 115 milliamps of beam current. Focusing of the beam is achieved by two separate electromagnets which must be controlled both as to location and as to current. Frequency of the klystron amplifier is adjusted by means of Allen wrenches on each of the four cavities. Frequency adjustment is quite simple, the input and output cavities being loaded with their respective coupling arrangements are somewhat broad in tuning; the two intermediate cavities not being loaded are considerably sharper, but there is no difficulty in making the adjustment. Of course, the tube must be adequately air-cooled. The collector, in particular, must be air-cooled because of the heat dissipation and the body of the tube in turn must be air-cooled because of the heat provided by the electromagnet system.

In general, this tube is designed with long-life components. The cathode structure is of the conventional long-life type oxide coated, and it is reasonably expected that when operated in accordance with specified limitations that the tube will have a life expectancy of approximately 10,000 hours. Eimac has run some life tests on these units, which would indicate that this life could easily be expected. It must be remembered that this tube is still considered a developmental tube by Eimac and there is some possibility of changes in the tube itself. However, we feel that the results so far experienced will indicate a minimum of changes in subsequent production units.

Mounting Arrangement

It is felt that the mounting of this particular tube, because of the magnetic structure and the inflexibility of input and output couplings, is probably one of the most severe problems encountered in the use of this equipment. The tube is supplied with a mounting bracket which holds both electromagnets as well as the tube itself. and clamps in place the waveguide output. However, due to the extremely careful tuning adjustments required of the magnetic assembly in order to get proper efficiency and to hold down body current which could damage the klystron, it is somewhat difficult to make a mounting arrangement which will satisfactorily hold the tube in place and at the same time allow sufficient access to make the necessary adjustments for proper tuning of the tube. We have used the Eimac supplied mounting arrangement with some additions in the way of mounting and stiffening screws, as well as springs, which load the electromagnets to the point where they do not shift position rapidly and there is constant pressure on all adjusting screws during the entire line-up procedure. Because of the fact that this amplifier is mounted inside an enclosed housing, it was necessary to provide somewhat larger blowers than would ordinarily be necessary were the equipment mounted in an exposed position. The blower supplying the cooling for the collector is approximately 25 CFM and the blower supplying the cooling for the body and electromagnet structure is also

25 CFM. Even so, the entire assembly runs quite warm, however, not to the point of causing short life or other deterioration.

The tube must be mounted vertically, and therefore, there is some problem of using it at a portable installation where there might be possibility of having to elevate or depress the equipment to some difficult angle. It is hoped that in the near future some further refinements of the mounting arrangement can be made which will allow the equipment to be mounted in other than a vertical position.

Power Supplies

The power supplies for this amplifier assembly are generally conventional except for the fact that heavy filtering has been employed because of the fact that any AC voltage appearing on the power supplies will generally be amplified, so ripple must be held to a very low limit. In general, the high voltage beam supply is a conventional full wave rectifier with adequate filtering and with a variac control which allows setting the voltage at the optimum value. This variac control is fairly necessary because all adjustments of the magnetic system must be done with relatively low beam voltage. The power supplies for the magnet assembly are derived from germanium rectifiers because of their relatively small size. Filtering is employed to provide 1% or less ripple on the magnets as this again will modulate the beam and provide AC ripple on the output. The only other supply necessary outside of the filament is the focusing voltage which, because of the fact that it does not draw any current, has been supplied by means of a fixed battery with a high resistance potentiometer for adjustment. This, in effect, results in approximately shelf life for the battery and it is felt that it is probably the most satisfactory solution for providing such a voltage, particularly in view of the insulation requirements for this supply.

Protective Equipment

Because of the characteristics of amplifier klystrons and the fact that certain operating conditions could give rise to extremely short life of the tube, it has been considered necessary to add certain protective features to the equipment. The most necessary protective feature is the addition of a relay in the body current return from the klystron. This relay is so set that it will open whenever the body current exceeds 25 milliamperes, which is the maximum that can be safely allowed on the tube without damage. Body current will exceed this amount in the event of failure of either electromagnet or serious misalignment of the electromagnets or of possible excess beam current or beam voltage. A second protective feature is the addition of a thermostat on the body of the klystron, which operates in such a fashion that the beam supply and magnet supply are both opened if the temperature of the body of the klystron becomes excessively high. These two protective features, in general, cover the necessary requirement for this amplifier. There is the possibility, in addition, of including a relay on the output circuit of the klystron amplifier excited from a crystal or other rectifier which would automatically remove the voltage from the klystron in the event that output should fail as evidenced by lack of crystal current. This feature is considered to be an alternative measure and not completely necessary, but one which could be added without great difficulty.

Tuning And Alignment Procedures

The proper sequence of procedures for alignment of the equipment is to apply approximately 1000 to 1500 volts of beam voltage together with the normal focusing and filament voltage. Focusing voltage is approximately 80 to 90 volts negative. With these voltages applied, the magnet supplies should be adjusted for minimum body current. A selector switch is available on the metering circuit to measure body current, collector current, focusing voltage, and beam voltage. With the meter in the body current position, the magnets should be adjusted first as to current for minimum body current, and then the position of the magnets should be adjusted for minimum body current. The position of the magnet is controlled by three adjusting screws on each magnet. The lower, or collector magnet, is much less effective; the upper, or focusing magnet, is very effective and adjustment must be very carefully made. Body current at low beam voltage should be 5 milliamperes or less. After the magnets have been adjusted at low beam voltage, the beam voltage should be increased to approximately 2000 to 2200 volts, where sufficient beam current exists to start making tuning adjustments on the various cavities. With a power indicating meter or other device connected to the output of the klystron and with the klystron being excited from a microwave source with approximately 20 to 50 milliwatts input, the cavities should be adjusted in order, starting with the input cavity. Usually, adjustment of the first cavity will provide some indication on the power meter. There should be a means of adjusting the power meter for approximately a 20 to 30 db range; all tuning should start with the lower range. Then adjust the cavities in succession, No. 2, No. 3, and finally the output cavity. After these adjustments have been made, the voltage should be increased gradually to approximately 2500 volts, at which time, it is advisable to again check adjustment for the higher voltage, but there is always some significant difference. All adjustments of the magnetic circuit are preferably made by observing body current and adjusting for a minimum value of body current. As is common with power amplifiers, it is usually advisable to go through the tuning adjustment two or three times in order to insure that all tuning is peaked to the right value. After the circuit has again been checked for magnetic focusing, the cavity tuning should again be checked and then the output of the klystron should be adjusted with the two tuning screws available on the waveguide output section to match the klystron to the available load. This klystron is fairly well matched, but some very significant improvements amounting to as much as 3 to 5 db can often be accomplished by matching of the tuning screws in the output of the waveguide. This has the twofold effect of providing less power dissipation in the klystron and of providing a better matched load, which in turn will give better modulation results. The tuning adjustments as outlined before are rather straightforward. There is some value in detuning the second and third cavities of the klystron to provide for a wider band operation. These cavities when tuned to peak are quite sharp and the result is that the overall bandpass of the klystron amplifier will be of the order of 6 to 8 megacycles, whereas, frequently the modulation swing of the driving klystron is approximately 6 to 8 megacycles and therefore there is very little leeway for drift of either tube. However, by adjusting in opposite directions, the second and third cavities of the klystron amplifier for approximately 1 to 2 db of loss in power output, it is quite possible to achieve 14 to 16 megacycles of bandpass and still maintain the required 50 watt power output. It will, of course, be necessary to drive the klystron with 40 to 50 milliwatts in order to get this output. However, this should normally be the driving power for a modulated klystron amplifier. It would be well to note that because of the fact that there is a requirement for 40 to 50 milliwatts of driving power for optimum results and there is also a requirement for some 5 to 10 db of isolation between the klystron amplifier and its oscillator driver, it is probably not possible to utilize a 100 milliwatt driver to the optimum advantage as use of such a driver will limit power output to approximately 20 watts or possibly less.

It can be seen from the preceding that the tune up procedure for this particular type of klystron amplifier is not difficult, and can easily be accomplished in the field by adequately trained personnel who will normally operate this type equipment. Frequency is, of course, determined by the frequency of the driving oscillator and the frequency can be checked at that point as the klystron amplifier is a completely passive device and transmits nothing but the signal which is fed into it.

Final Equipment Arrangement

The equipment is all housed in one so-called carrying case which is probably not as neat an arrangement as could be hoped for, but accomplishes two objectives. One, the equipment is in a sense portable, that is, it is transportable and can be used as a field instrument, and two, all of the equipment is housed in a single package, which is a definite advantage from the standpoint that power supplies of the 3000 volt type and magnetic supplies, supplying several amperes of current need not be transmitted through connectors and cables which might make the arrangement somewhat difficult. All power is supplied from a single transformer, and the arrangement is such that the equipment is fairly easily accessible for adjustment and tune up or servicing as required. The klystron tube has been mounted in such a way that it is quite possible to get to all of the tuning adjustments for ease of line up. The entire assembly is housed in a weatherproof box which is accessible, as mentioned before, and at the same time can be mounted directly on an antenna system much the same as the present microwave transmitter assemblies are mounted on antennas and directly connected into the waveguide feed. However, this box is considerably larger and heavier, but still it is possible to be mounted in such an arrangement. The configuration of the assembly is such that the klystron feeds into a directional coupler which is provided with a power monitoring device and also a double-stub tuner for matching. The power supply is variously located around the case in such a manner as to try to equalize the weight of the assembly. In all, the assembly weighs some 120 lbs., principally because of the weight of the power supply components, although the klystron with its magnets and associated devices weighs 27 lbs. It is hoped that in the near future a relay-rack type mounting for this equipment can be devised which will be considerably more accessible and of somewhat more compact design because of the relaxation of limitations due to the housing arrangement necessary here. All power supply requirements are from a single 60 cycle, 115 volts AC supply cord and the only other input requirement is the coax cable from the microwave transmitter which supplies RF power. This cable is so designed that it supplies the isolation attenuation between units, and therefore, the driving transmitter should be located so that no additional cable is required.

Conclusion

The design of this amplifier is not considered to be the ultimate that might be achieved, but is merely the first step in the design of what we consider will be a series of medium power amplifiers, which will probably be of considerable value to the microwave relay industry in that they will provide additional gain through additional power and will probably result in more reliable propagation. They may also result in being able to economically transmit programs over distances which were hitherto considered impractical. This might be particularly useful in the pickup of off-the-air programs for remote areas where there is considerable height available, but the distances are prohibitive. It is hoped that because of the long life components and the relatively conservative design of the parts used in this equipment, that once the unit has been installed and placed in operation that the maintenance will be reduced to a minimum and that the equipment will function for a long period of time comparable to the regular relay equipment which supplies the driving power. Since reliability is one of the prime prerequisites of any such system, we feel that the design of this equipment in making it suitable for long life operation is one of the most important features. Because of the very significant changes in focus during initial warmup, it will be necessary to operate the amplifier continuously, leave the magnet supply on continuously, or provide a time delay of some 15 minutes before applying beam voltage. We also believe that continued efforts to obtain a more suitable mounting arrangement, which will be less critical of adjustment, will also yield large benefits, and we feel that use of this type equipment will give us the necessary experience to be able to build a better mounting arrangement.

There is considerable conjecture as to the ultimate advantages to be achieved from a 50 watt unit and many of these will be proved by coming installations. It is hoped by those of us who have had experience with various fading difficulties that the use of higher power will overcome many of these difficulties, and it is hoped that in the near future, possibly at the next meeting of this group, that we will be able to present a paper showing the results of such endeavors.

VIDEO TRANSMISSION TESTING TECHNIQUES FOR MONOCHROME AND COLOR

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The growth of television has been accompanied by an even faster development of instrumentation which was required to meet the increased complexities associated with the broadcasting of high fidelity television pictures.

In the early days, the same kind of techniques that had been used for measuring the performance of radio and wire circuits were used for television. The simplest equipment was an R. F. source which generated frequencies up to 5 mc together with a suitable indicator which showed how these frequencies were being transmitted. As less and less time for point by point measurements was available, with the ever increasing duties for technicians and engineers, more sophisticated techniques were worked out for measuring signal levels, resolution, rise time of pulses, frequency response, pulse widths and so forth. These practices are now well established and fairly standard throughout the industry and just as we think all is well, along comes COLOR!

Standard Test Signals

At the start of color television, the same chaotic conditions prevailed as in the early days of monochrome. For example: When a synthetic source for the generation of color bars was required, each engineer designed his own. There were as many types of color generators as there were engineers, until a situation was reached whereby a color bar generator was designed which made over 100,000 color combinations! The NTSC finally standardized many methods which were used for the field testing of the then proposed color TV signals. From this work, and as a result of the operating experience of NBC, CBS, ABC, the A T & T and the CBC, a series of standard signals were evolved for color which are now also being used for monochrome transmission, (since color signals had greater precision requirements). If the facility will pass these standard test signals, it is in good shape for color and in excellent shape for monochrome. These standard test signals have now been adopted by all the U.S. television networks, and are also used by the A T & T, CBC, The Bell Telephone Company of Canada, Canadian National and Canadian Pacific Railways. They are:

1. The Window Signal

2. The Multifrequency Burst or Multiburst Signal.

3. The Modulated Stairstep Signal with 50% APL (Average picture level) (Alternate signals 10 and 90% APL).

A standard color bar signal is used by NBC and CBS for checking local facilities and network operations. The above signals are sent or used during station breaks and other non-program times. The signal generating equipment occupies two standard racks. Recently, however, these same signals have been repackaged for portability into one or two suitcase size packages (Figs. 1 through 5).

Auxiliary standard equipment used in conjunction with these signals included a high quality oscilloscope and a 60 second picture oscilloscope camera for recording the above signal waveforms.

Other Test Signals

Among other signals being used, is the color stripe signal, which is sent during monochrome programs and consists of a burst of color subcarrier immediately following and preceding blanking. This signal is primarily used for checking color receiver performance.

Another interesting signal is the sine squared wave which is used widely in Europe, the Soviet Union, Australia and to a limited extent in Canada. This signal gives an evaluation of amplitude vs frequency response, transient response, envelope delay and phase in one signal. However, it is somewhat more complex to interpret than the standard signals.

Various types of signals to be sent out continuously along with monochrome or color programming during the last four lines in the vertical blanking interval have been suggested by NBC and others and are contained in proposals presently before the FCC. The NBC signal contains sufficient information to establish sync, burst, chroma and white level as well as to provide for measurement of differential gain and differential phase. Proposals before the FCC envisage sequential gating of multiburst, chroma, modulated stairstep, sine squared square wave, and color bars for each of four lines during the vertical blanking interval or alternatively each type of signal is allowed to occupy four lines for a stated number of minutes, to be followed by another signal on the same four lines for the next interval.

Measurement of Smears, Streaking, Snickets, Glitches, Ghosts, Echoes, Ringing and Low Frequency Phase Shift

Smears can be generally considered to be deficiencies occurring at high frequencies and low frequencies, Snickets are synchronous impulses occurring during horizontal time which may appear anywhere in the vertical field.

Glitches are impulses occurring during vertical time and may be either stationery or slowly moving through the picture in a vertical direction.

Ghosts indicate the whole frequency band to be affected and can be often due to unterminated lines or improper stubs hung across a circuit causing reflections.

Echoes on the other hand, indicate deficiencies in only part of the transmission characteristic.

The early signal used for measuring many of these characteristics was from a square wave generator. Interpretation of the square wave was quite difficult. Not only were several square wave frequencies required, at both low and high repetition rates, but there was no sync pulse and the square wave had a 50% duty cycle. The sine squared square wave is a better signal but it requires a calibration overlay on the oscilloscope. If a facility has been initially checked with the sine square signal then it is excellent for routine video testing. A disadvantage is the lack of a low frequency component.

The Window Signal has both low and high frequency components as well as sync and setup. Here are some examples of the window signal and the deficiencies it shows after being transmitted through a facility. (Figs. 6 through 16).

Measurement of Amplitude vs Frequency

Early sine wave testing was soon supplemented by video sweepers or wobbulators, which is simply a variable frequency sine wave generator in a hurry. Both the sine wave and video sweepers have no sync pulse, making them difficult to transmit through black level clamping circuits and the video sweeper does not always readily indicate the frequency of the trouble, even with the markers. Also the non-synchronism of sine waves with sync and blanking gives wrong information. The degradation of square waves through a facility is equally difficult to measure, since an absolute knowledge of the rise time of the original square waves and their duration is necessary, plus required calculations to determine the amplitude vs frequency response. The multiburst signal on the other hand, with its series of strategically chosen spot sinusoidal frequencies, gives a very satisfactory quick evaluation of the amplitude vs frequency response. Here are some examples of a multiburst signal sent through a facility under typical conditions. (Figs 17 through 23)

Measurement of Differential or Incremental Gain

The measurement of incremental gain is useful in monochrome transmission because it shows the condition of grey scale linearity. In addition, for color television, this measurement becomes important because the luminance component plus the proper chrominance determines the color. For example: An orange color with improper brightness or luminance could be received as brown. The measurement for differential gain is quite similar to intermodulation distortion measurement at audio frequencies. The generated signal in its simplest form consists of the addition of low and high frequency sinusoids plus a sync pulse. In one type of generator, the Kelly Test set used by the Telephone Company, a 15750 cycle sine wave with a sync pulse superimposed is the low frequency and 3.58 mc color subcarrier frequency is the high frequency. However, with sine waves, it is difficult to determine during what portion of the sinusoid distortion is taking place. A more common arrangement is that of a stairstep signal with chroma (3.58 mc) superimposed. After passing through the facility being tested, a High-Low Cross Filter acts as an intermodulation component separator. (Fig. 24) A differential phase-gain receiver of Kelly Test Receiver may be used to make this measurement as well. Here is an example of a modulated stairstep signal and the indication of differential gain as seen through the high pass position of a cross filter on an oscilloscope. (Figs. 25 through 29)

Measurement of Differential or Incremental Phase

In this measurement the stairstep signal is again used. The signal may be examined by means of a high pass filter. The resultant phase is determined by adding a source of variable phase and amplitude of 3.58 mc to the signal and nulling both phase and amplitude. The Chromascope or (vectorscope) (Fig. 30) with a phase magnifier may also be used for this measurement, as can the Kelly Test Set, or a transmission test differential phase-gain receiver. With the latter two units, a wideband oscilloscope is not required. Fig. 31 shows the signal through the differential phase gain receiver. (Also Figs. 32 through 34)

Color Signal Measurements

Since color bars are unvarying in their characteristics and generally represent the limits which the color system is capable of reproducing, they provide a powerful check of the ability of the facility to pass color. Some examples of what happens to a color bar signal when transmitted over facilities with varying characteristics are shown in the following slides. (Figs. 35 through 45) The generation of color bar signals is complex, and the equipment occupies a full rack of space. For special uses, a number of portable color bar generators have been developed. A typical example and block diagram of such a generator is shown in Figs 46 and 47.

Measurement of Group Velocity, Phase Slope or Envelope Delay

The measurement of envelope delay is indispensable for proper color video transmission since it determines the arrival time of the lower frequency components of a video signal. Poor envelope delay can give rise to what is known as the "funny paper effect" in a color picture. It appears as misregistration of colors in broad areas lying outside the outlines of the pictures being sent. In monochrome transmission this distortion may show up as peculiar edge effects. A number of methods have been developed for making this measurement. One consists of measuring point by point, the absolute phase and then obtaining the graphical derivation of the phase slope -- hardly a procedure for routine testing. The sine squared wave can indicate phase relations but requires considerable training, the use of charts, and an overlay on the oscilloscope. Figs. 48 and 49 show sine square wave signals.

The best method that has been developed to date is the envelope delay curve tracer. This device sweeps the entire video spectrum with a pair of frequencies, precisely spaced with respect to each other. The phase of the two signals transmitted are compared at the receiving end to determine the relative phase or envelope delay as a function of frequency. Refer to block diagrams -- Figs. 50 and 51. The spacing of the two frequencies determines the amount of resolution that can be obtained. At low frequencies, this spacing can become such a large part of the frequency being measured that some difficulty may be encountered. In this case another technique of measuring the absolute phase of low and high frequencies may be employed. Fig. 52 shows the envelope delay of an NTSC Phase Equalizer.

Necessity for High Quality Instrumentation

Of utmost importance in performing most of the measurements which have been discussed, is the use of high quality oscilloscopes and picture monitors. Unless the observing devices are free from phase and amplitude distortion, and possess good transfer characteristics in themselves, it is not possible to maintain uniform video transmission signals. The oscilloscope should be free of any phase or amplitude error for at least 35% higher than the highest frequency of interest. As the above standard test signals and methods of measurements become more generally used, we can look forward to further improvements in transmission standards which will result in the highest quality television pictures of which the system is capable.

Fig. 1 - Portable video transmission test signal generator (1003).

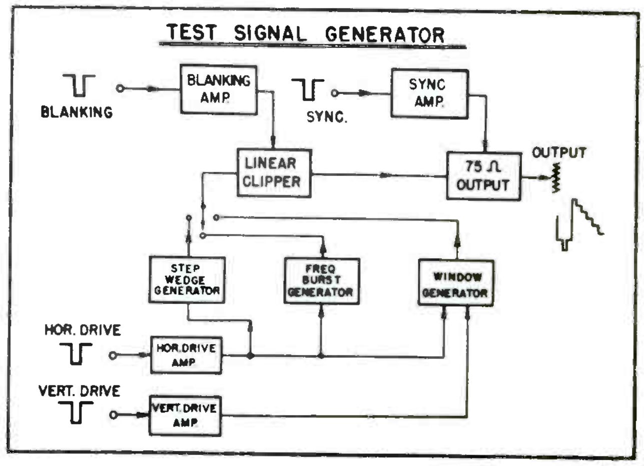

Fig. 2 - Block diagram of internal arrangement of 1003 and sync generator.

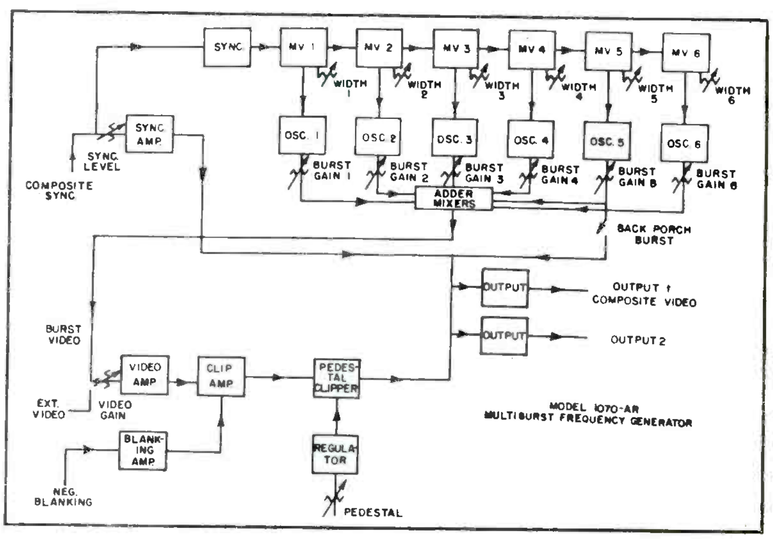

Fig. 3 - Block diagram of multiburst.

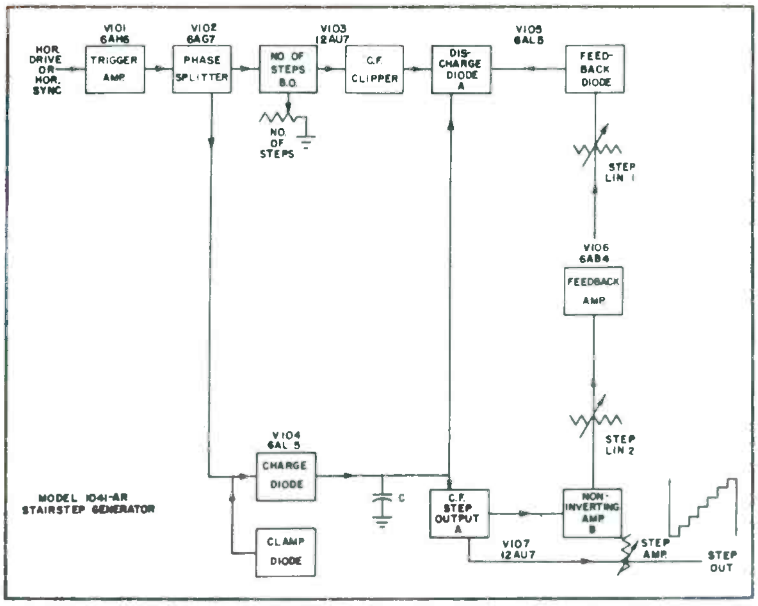

Fig. 4 - Block diagram of stairstep signal.

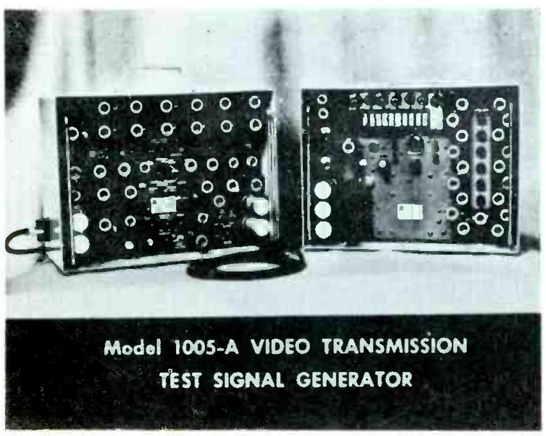

Fig. 5 - Portable video transmission test signal generator (1005).

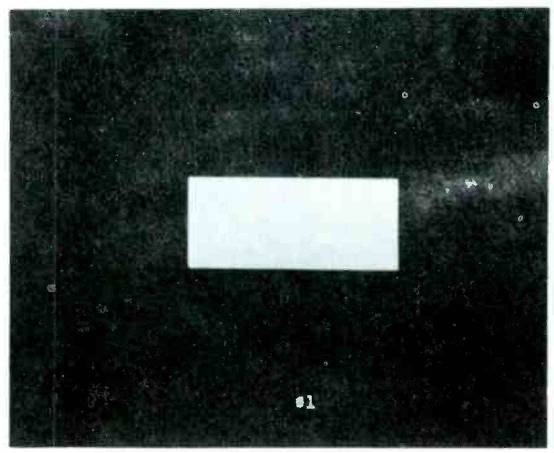

Fig. 6 - Window picture - as generated.

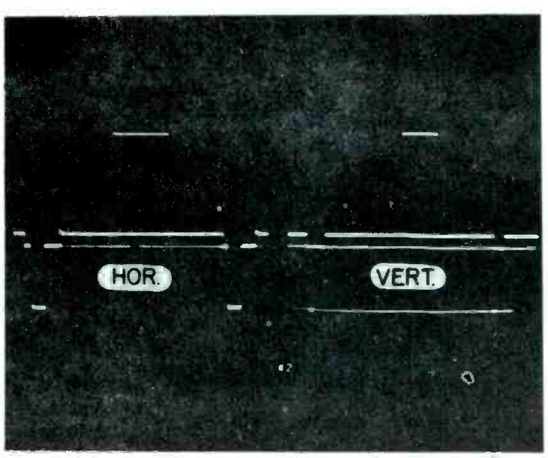

Fig. 7 - Window signal - as generated.

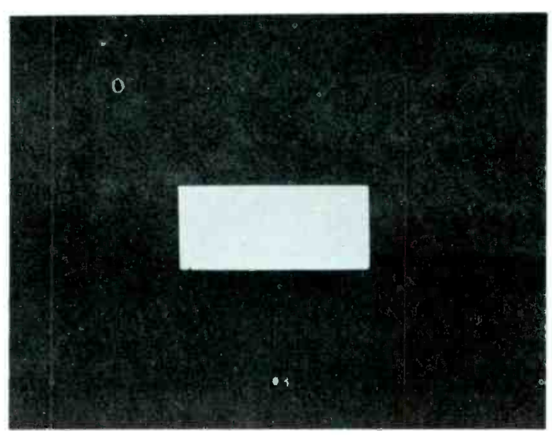

Fig. 8 - Window picture negative streaking (black after white).

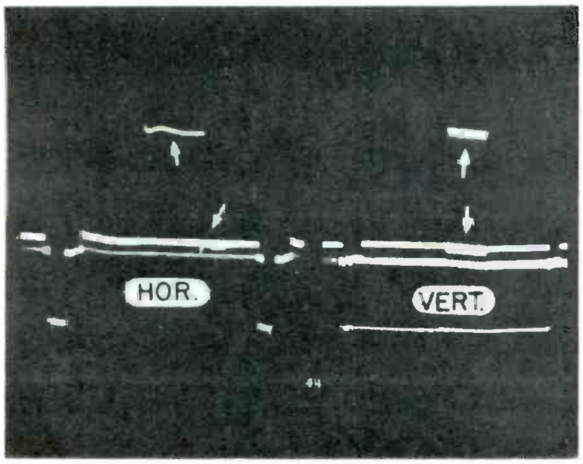

Fig. 9 - Window signal negative streaking (black after white).

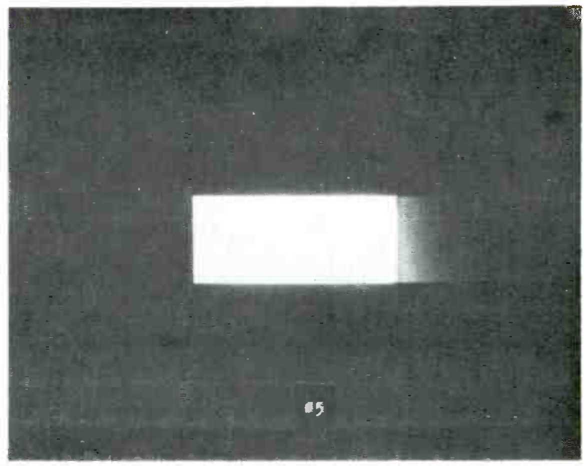

Fig. 10 - Window picture positive streaking (white after white).

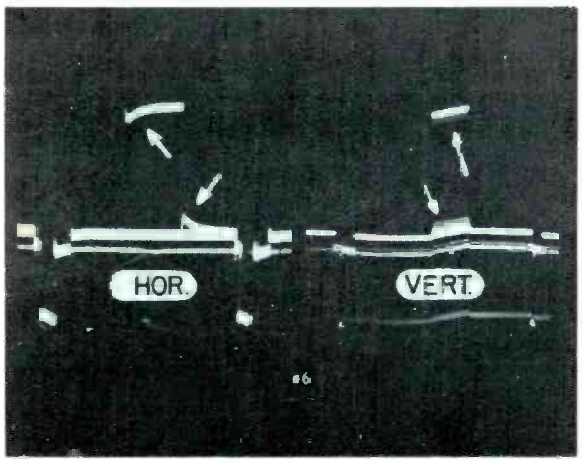

Fig. 11 - Window signal positive streaking (white after white).

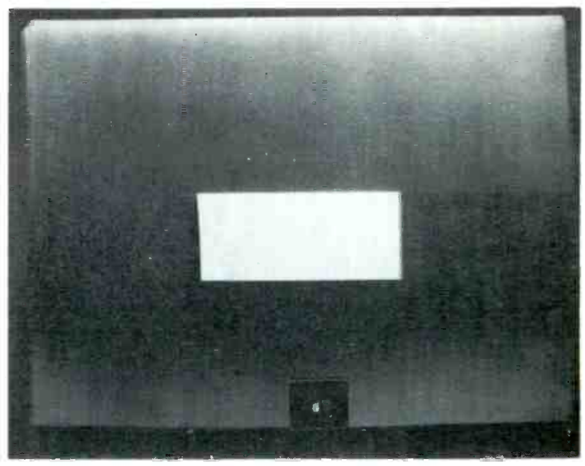

Fig. 12 - Window picture bad low frequency distortion.

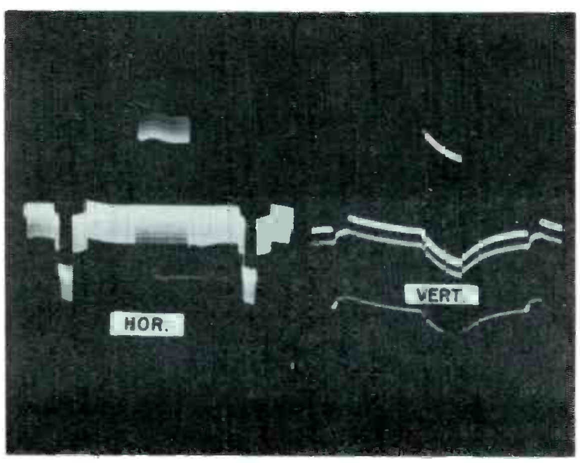

Fig. 13 - Window signal bad low frequency distortion.

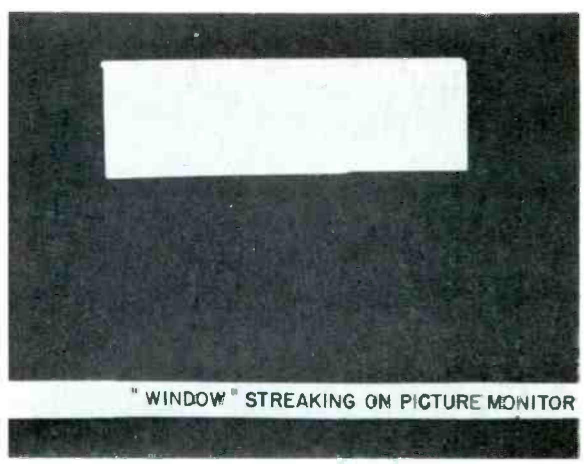

Fig. 14 - Window picture system normal - monitor overloaded.

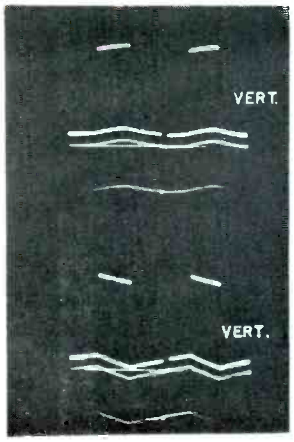

Fig. 15 - Window signal low frequency distortion.

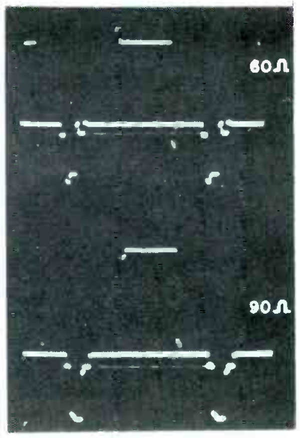

Fig. 16 - Window signal mismatch termination.

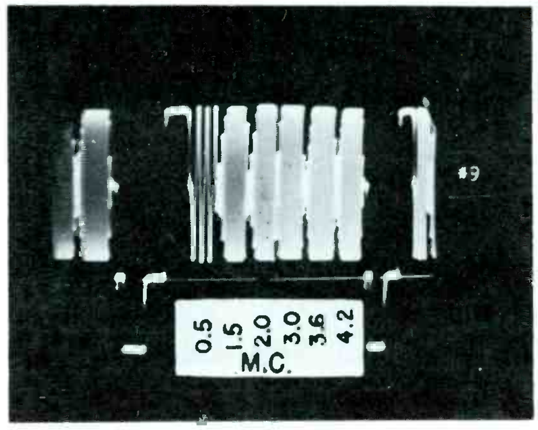

Fig. 17 - Burst signal - as generated.

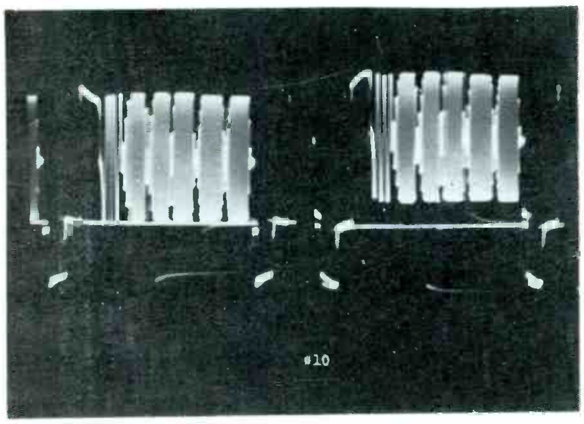

Fig. 18 - Burst signal
Left - loss of lows and no setup
Right - gain of lows and increase setup.

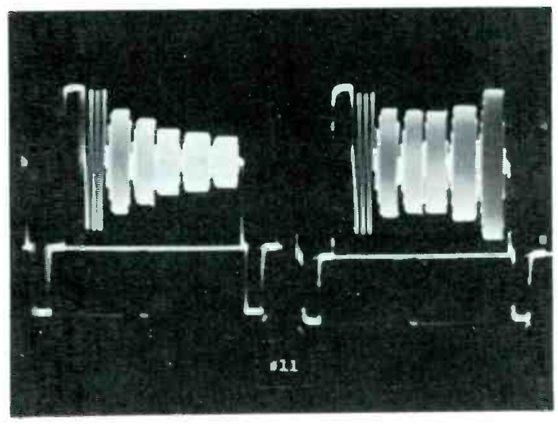

Fig. 19 - Burst signal
Left - with roll off - poor frequency response
Right - equalize - set improperly.

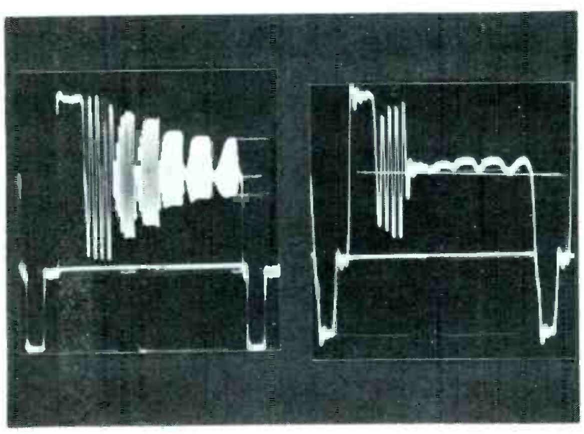

Fig. 20 - Burst signal
Left - bad black compression and frequency selective
Right - lows increased and selective black compression.

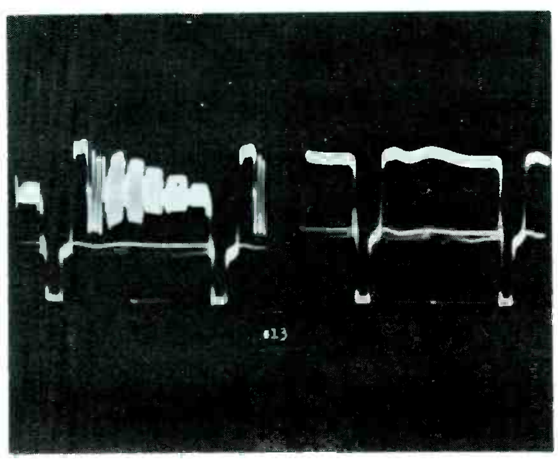

Fig. 21 - Left - hi-frequency attenuation and black compression
Right - Pedestal of above shows low frequency distortion.

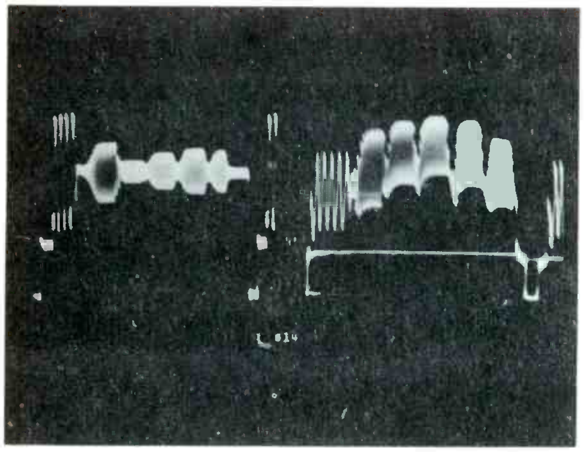

Fig. 22 - Burst signal Left - selective hi-frequency attenuation. Right - black compression a-c axis shift.

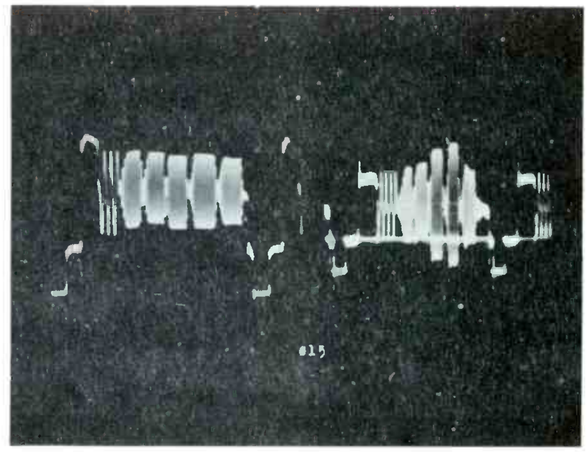

Fig. 23 - Burst signal Left - fair trans. some loss of low frequency Right - bad. trans. (overpeaked.)

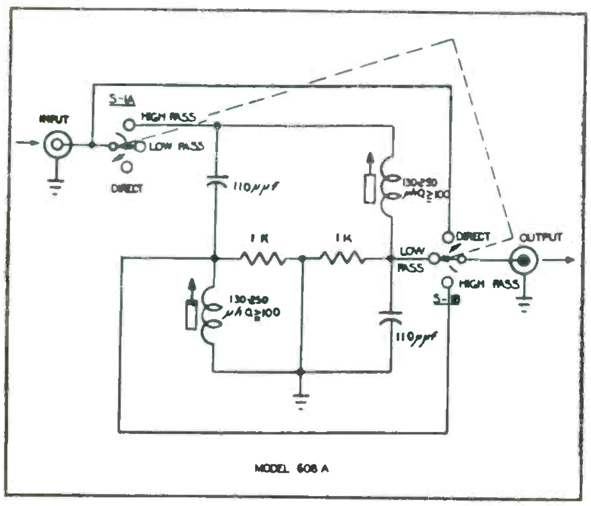

Fig. 24 - Hi-low cross filter.

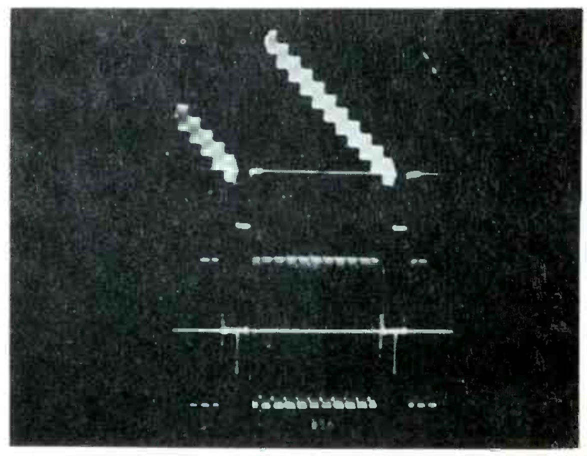

Fig. 25 - Stair-step signal Top - As generated. Bottom - Using cross filter in hf position.

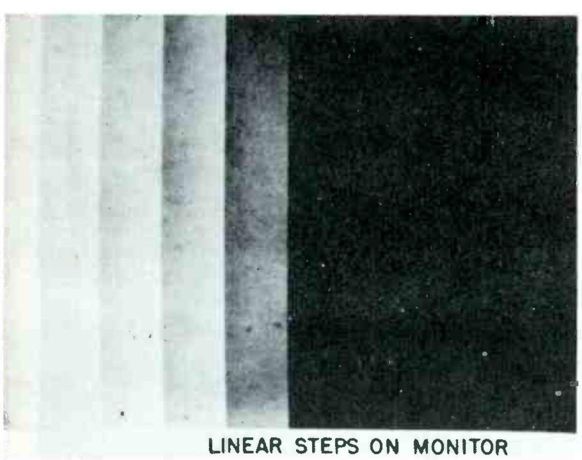

Fig. 26 - Stair-step picture Spikes show relative position of steps in relation to original signal.

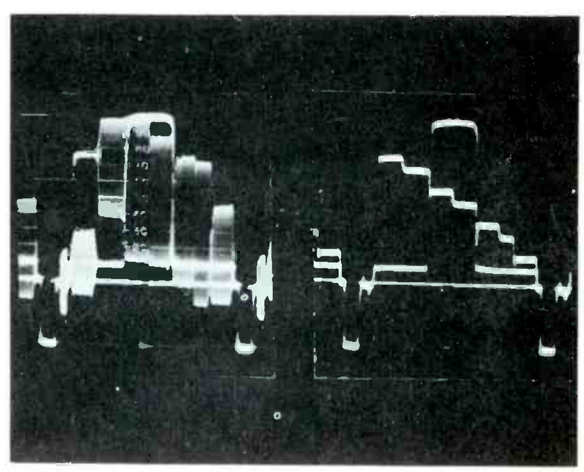

Fig. 27 - Color bar Left - Complete signal. Right - Luminance only thru low pass hi-lo cross filter.

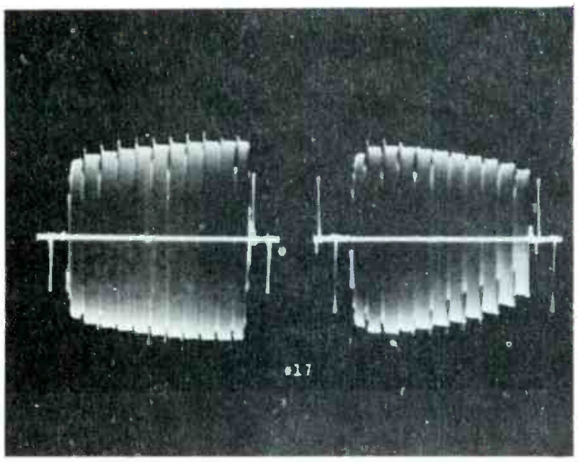

Fig. 28 - Stair-step signal Left - 20% white comp. Right - 10% white, 20% black.

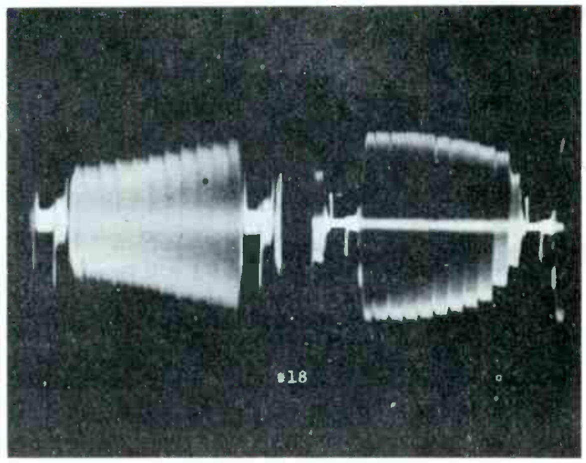

Fig. 29 - Stair-step signal Left - white comp (from white to black) Right - black comp.

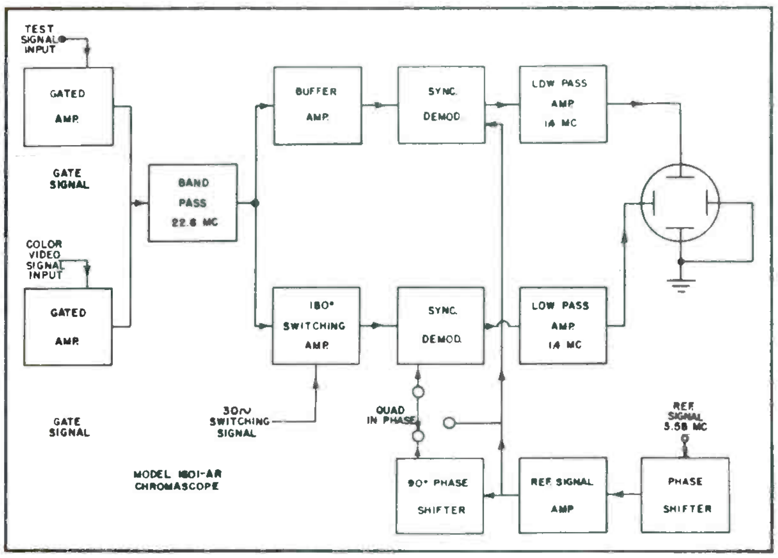

Fig. 30 - Block diagram chromascope or vectorscope.

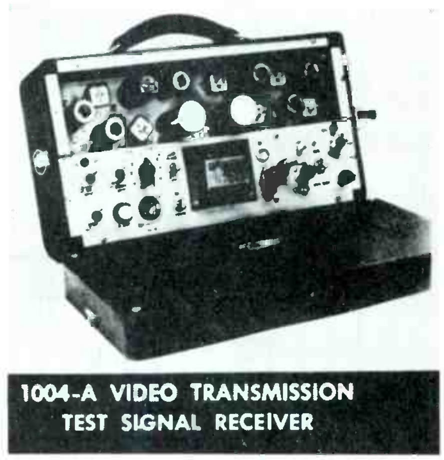

Fig. 31 - Differential gain phase test receiver.

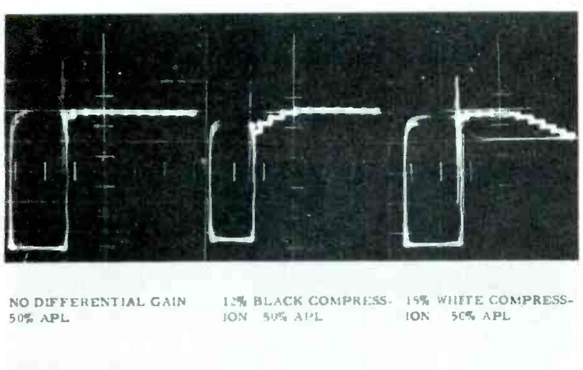

Fig. 32 - Stair-step signal differential gain as seen thru differential phase-gain test receiver.

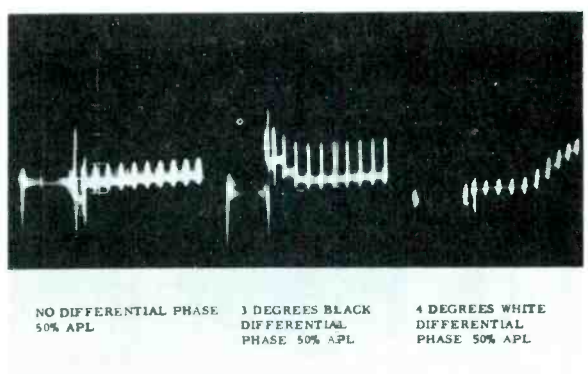

Fig. 33 - Stair-step signal differential phase as seen thru differential phase-gain test receiver.

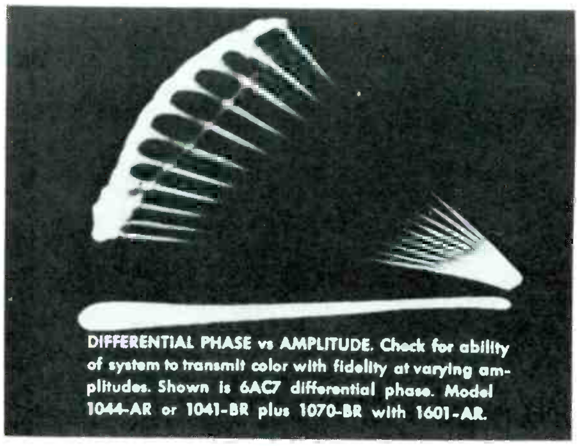

Fig. 34 - Stair-step signal on chromascope with phase magnifier.

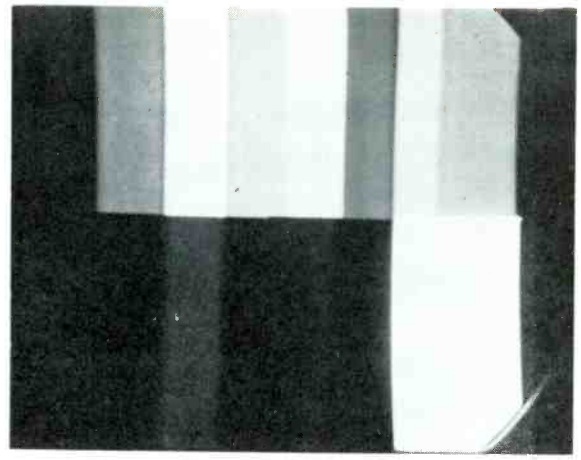

Fig. 35 - Color bar signal.

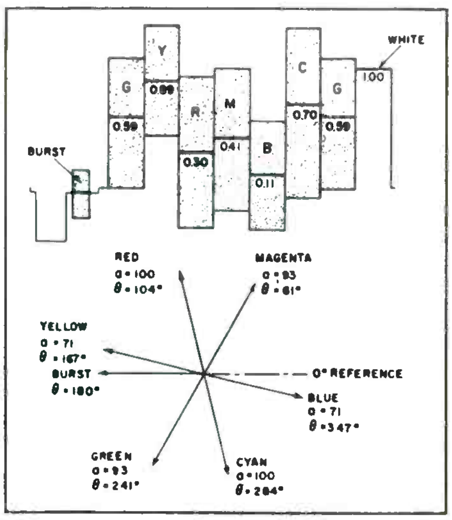

Fig. 36 - Color bar signal Top - idealized color bar signal. Bottom - idealized chromascope position of color bar vectors.

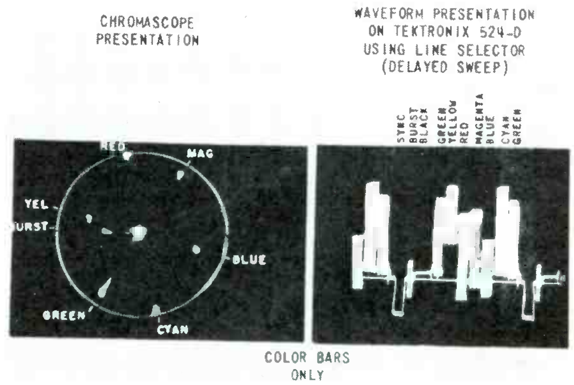

Fig. 37 - Color bar signal - Left - chromascope presentation. Right - actual color bar signal.

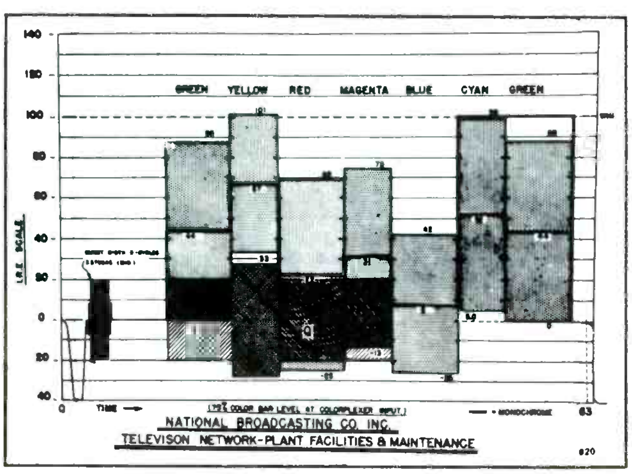

Fig. 38 - Color bar signal

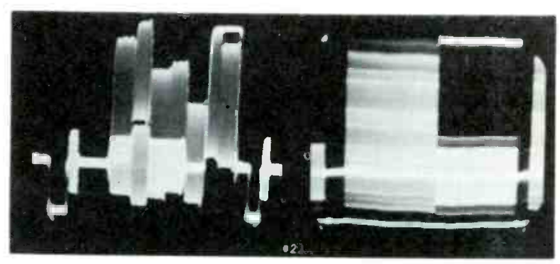

Fig. 39 - Color bar signal - as generated Left - horizontal. Right - vertical.

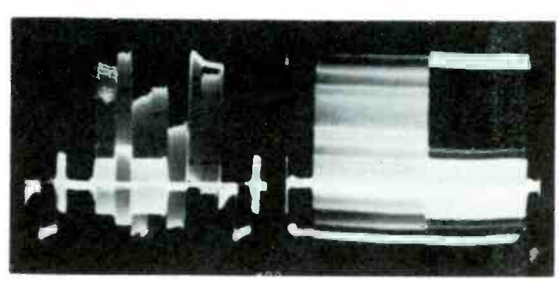

Fig. 40 - Color bar signal loss of low frequency.

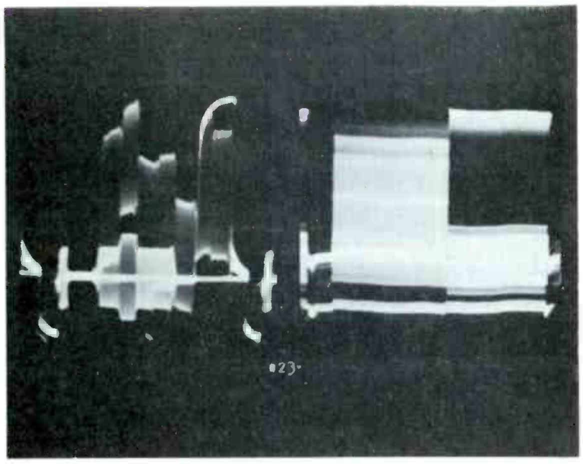

Fig. 41 - Color bar signal gain of low frequency.

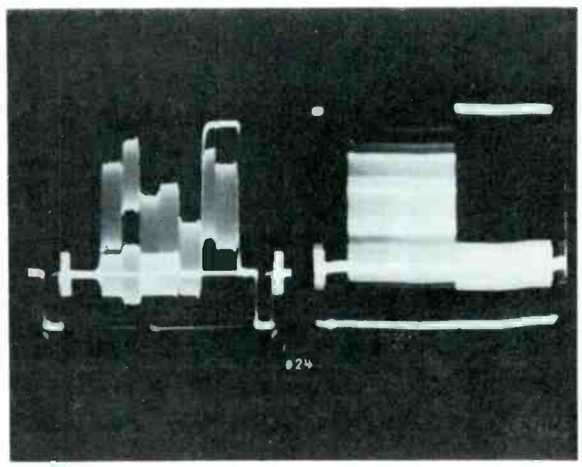

Fig. 42 - Color bar signal loss of chroma.

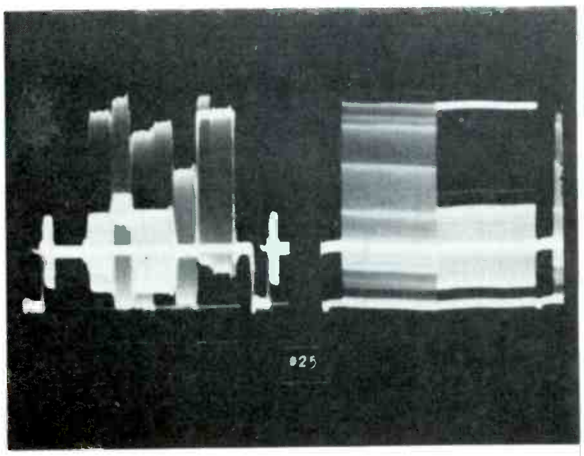

Fig. 43 - Color bar signal gain or excess of chroma.

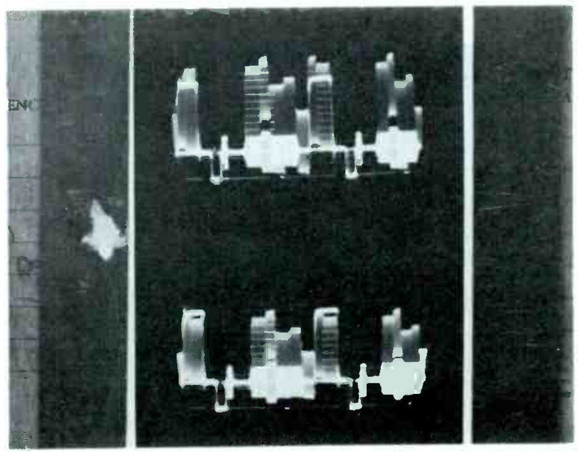

Fig. 44 - Color bar signal Top - with 33% overswing of chroma. Bottom - with chroma reduced to 75%.

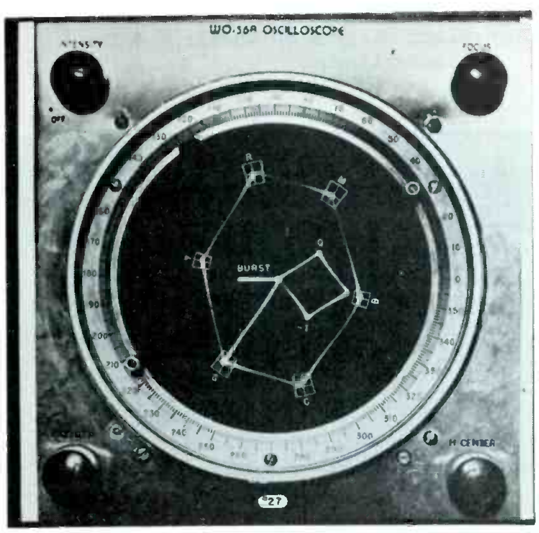

Fig. 45 - Vectorscope or chromascope of color bars in descending luminance.

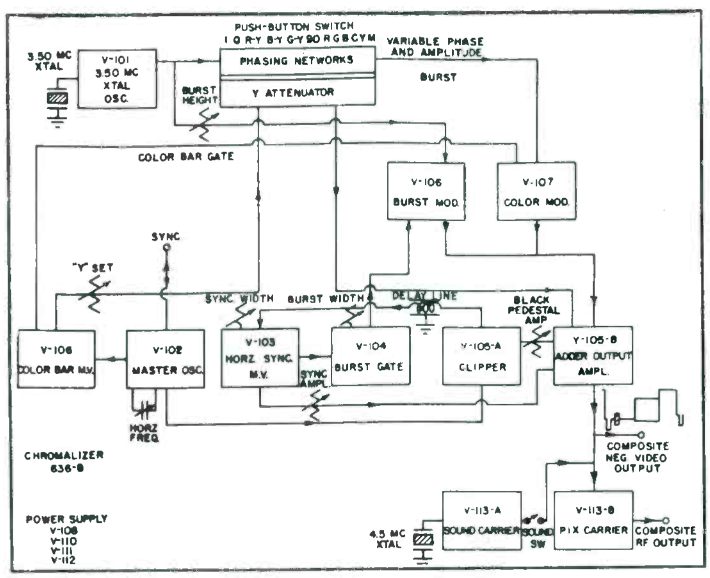

Fig. 46 - Block diagram of portable precision color bar generator.

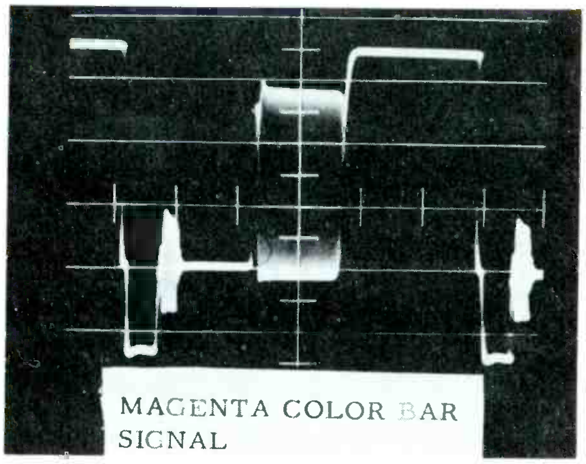

Fig. 47 - Waveform of portable precision color bar generator.

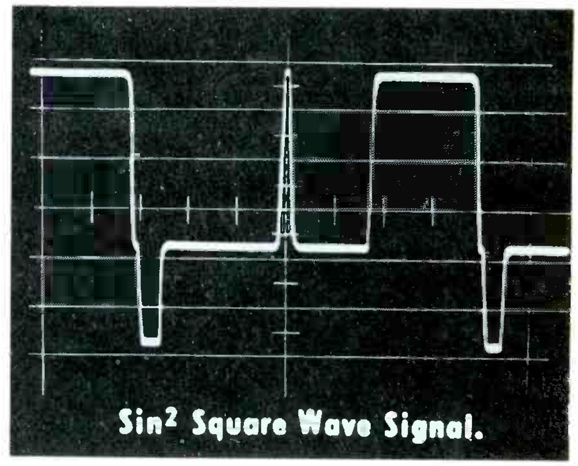

Fig. 48 - Sine square square wave signal.

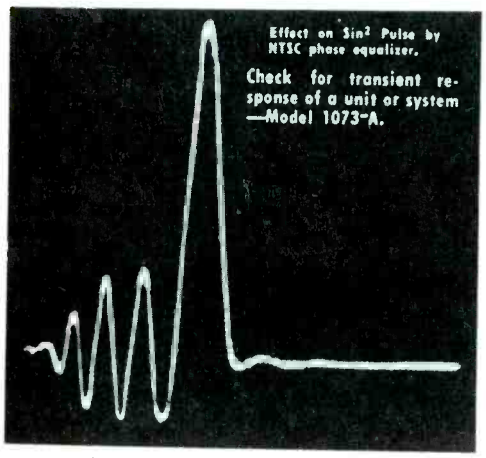

Fig. 49 - Detail of sine square square wave signal.

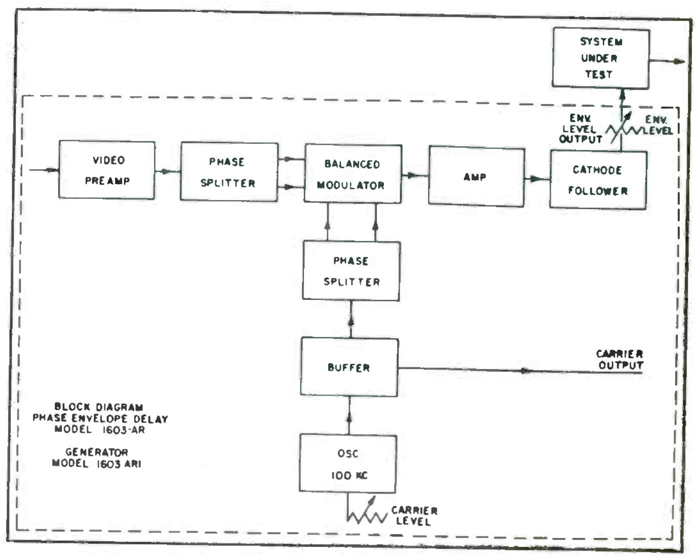

Fig. 50 - Block diagram of envelope delay transmitter.

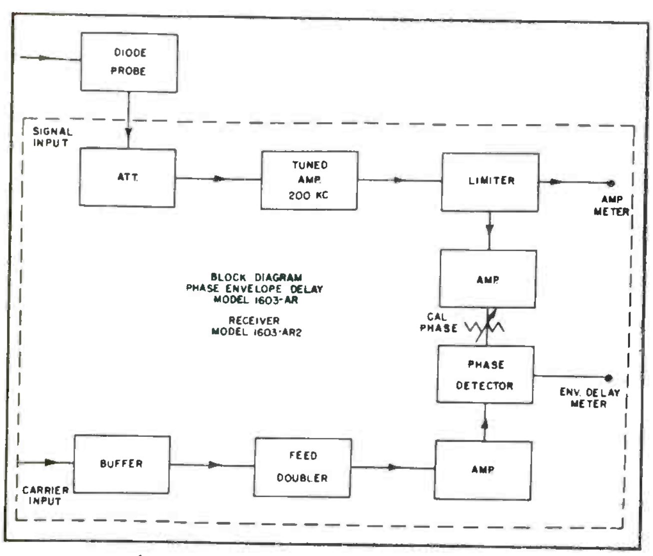

Fig. 51 - Block diagram of envelope delay receiver.

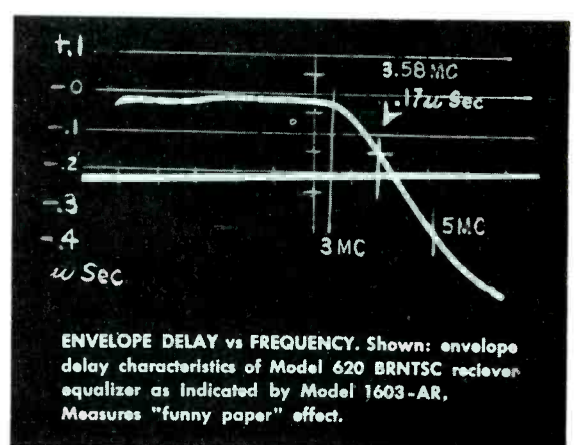

Fig. 52 - Envelope delay test signal thru NTSC phase equalizer.

ACHIEVEMENT OF PRACTICAL TAPE SPEED FOR RECORDING VIDEO SIGNALS

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Ampex Corporation
Redwood City, California

Introduction

A few years ago, commercial television made its appearance as a dominant economic and cultural force on the American scene. At about the same time, tape recorders emerged as the unparalleled medium for the reproduction of sound. Commencing with this loosely defined milestone, engineers, production people, station owners, and sponsors looked forward to the use of tape for the recording of television programs.

Prior to 1956, television tape recording systems had been demonstrated, for monochrome and for color, in various stages of refinement, and using somewhat differing techniques.

In April of 1956 at the NARTB Convention in Chicago, Ampex Corporation demonstrated for the industry an engineering model of a tape recorder for black and white television use, designed and developed along lines radically different from anything seen previously. The overwhelming acceptance of this video tape recorder by the industry exceeded even the expectations of those who developed it.

Nature of the Problem

The purpose of this paper is to indicate some of the general technical aspects of the Ampex rotary head approach.

The foremost problem to be solved in devising a system for recording television signals on magnetic tape is that of reproducing high frequencies. In a practical system, it is necessary that the width of the magnetic gap of the playback head be smaller than the shortest recorded wavelength. This is the consideration that makes it necessary to use a tape speed of at least 7 1/2 ips, and preferably 15 ips, to obtain the highest quality in audio recordings. This does not imply that the amplitude of a 15 kc signal has "bottomed out" completely, but rather that signal-to-noise considerations in the particular application have limited the frequency response. A .00025" playback gap might result in an effective gap of about 1/3 mil, and thus a null frequency of 45 kc at 15 ips, or 22.5 kc at 7 1/2 ips.

Thus, it can be seen that for truly professional audio recording useable information should not be packed more closely than 2 kc per inch of tape speed. Other applications of magnetic tape recording might permit utilization of a greater density of information. Also as a function of the application involved, the weighing of such factors as manufacturing techniques and tolerances, component life, and reliability might in some cases permit a decrease in gap width of the playback head, with a resultant allowable increase in information packing.

A magnetic tape recorder for television use has the mutually conflicting requirements of high-frequency response and sufficient recording time. As a corollary of the latter requirement, it is necessary that reels of one-half to one hour program time be handled and shipped easily. Even with a 10 kc per inch response, a system for recording a 4 mc television picture by means of conventional techniques would require a tape speed of 400 ips, and would impose extremely great problems in the handling of tape, by both the top plate and the operator, even in the case of a 15 minute recording. Considerable work has been done by some investigators along the lines of time-division multiplexing systems, with tape speeds of the order of 100 ips. Difficulties encountered have centered in large part around means required to compensate for the channel-to-channel effects of tape skewing, the resulting complexity of such compensating means, and the consequent unsuitability of such systems for use in the television broadcasting field.

Ampex Solves Tape Speed Problem

The Ampex approach to the conflicting requirements of frequency response and tape storage consists of writing across a relatively slow-moving two inch wide tape by means of four magnetic heads carried on a drum which rotates at a rate sufficiently high so that the head-to-tape speed is adequate for the frequency response required. "Adequacy", in this case, signifies that the wavelength of the highest frequency component to be picked up by the playback heads is compatible with present-day techniques in the art of manufacturing tapes, and with reasonable manufacturing tolerances in the tape recorder itself.

The surprisingly low tape speed of 15 ips has been made possible by the use of very narrow information tracks, in combination with the particular method used for achieving relative control of drum rotation and longitudinal tape position. The ability to use such narrow tracks is the result of the unique modulation system employed as well as a departure from conventional techniques in the design of the individual magnetic heads.

The 15 ips speed represents not the lowest possible speed using a rotary head system, but what we consider the best compromise between the considerations of program storage on the one hand, and design and tolerance factors on the other. In deciding on this particular tape speed, we have in turn weighed all factors against the very important requirements of reliability of operation and performance in the field.

Basic Mechanical Design

Figure 1 shows the layout of the top plate. The tape is threaded from the supply reel around the supply idler, between the rotary drum and a concave guide, past the stationary erase head assembly and combination record-reproduce audio and control track head assembly, between the capstan and the capstan idler, around the take-up idler, and thence to the takeup reel. The drum carrying the four video heads is approximately two inches in diameter, and rotates at 240 rps, giving a head-to-tape speed of about 1500 ips. The concave guide has a curvature which roughly corresponds to the radius of the periphery of the drum, and intimate and precise contact between rotating heads and tape is ensured by mechanical design details of the head and guide assembly. Considerably more than 90° of arc is described by each video head as it sweeps across the two inch wide tape, which is cupped to conform to the curvature of the drum. The same heads are used for recording and for playback.

The Magnetic Pattern

Figure 2 shows the magnetic pattern on the tape. In the recording process, each video head writes completely across the tape. As the tape passes by the stationary erase head assembly the edges are erased, leaving suitable portions for the recording of the program audio track at the top of the tape and the system control track at the bottom, and at the same time leaving a video track which represents slightly more than 90° of arc of recorded information in order to allow for a continuous flow of information during playback. With the drum rotating at 240 rps and the tape moving at 15 ips, center-to-center track spacing is approximately 15 mils. Tracks are approximately .010" wide which allows about .005" between the edges of adjacent tracks. This track width is sufficient to give the required video signal-to-noise ratio and at the same time the spacing is great enough so that the machine is essentially self-operating during playback without any difficulties caused by cross-talk.

Quality of Reproduced Picture

One of the greatest technical advantages of the video tape recorder over kinescope recording is the lack of gray-scale distortion. This advantage lies not in the use of tape, but rather in the particular modulation system employed. There is no fundamental source of distortion in the brightness transfer characteristic, and there are no operating controls whose settings have any influence on the gray-scale characteristic of the machine.

Horizontal resolution obtained with the VTR is 320 lines. This figure is not inflexible. All that is necessary to obtain a greater resolution is to turn one knob and replace one filter, the entire procedure taking a few

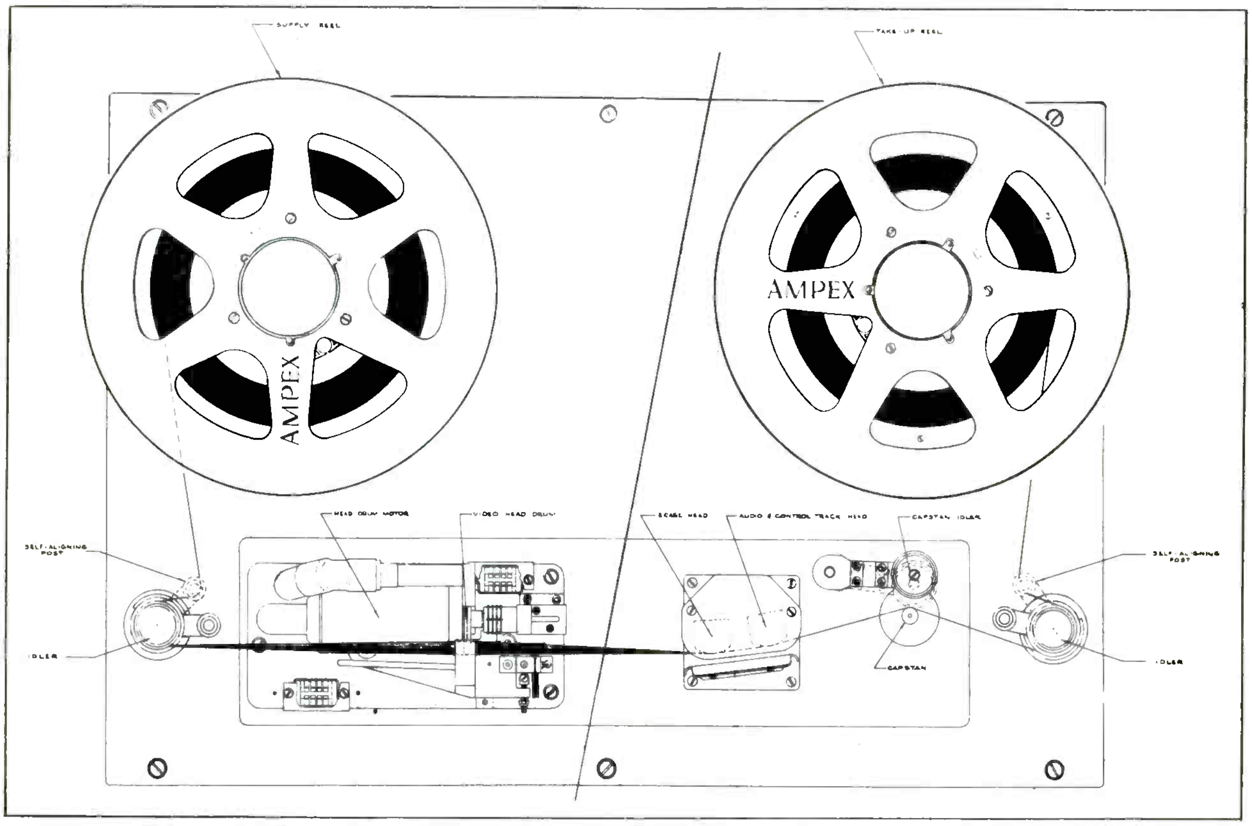

Fig. 1 - Top-plate layout.

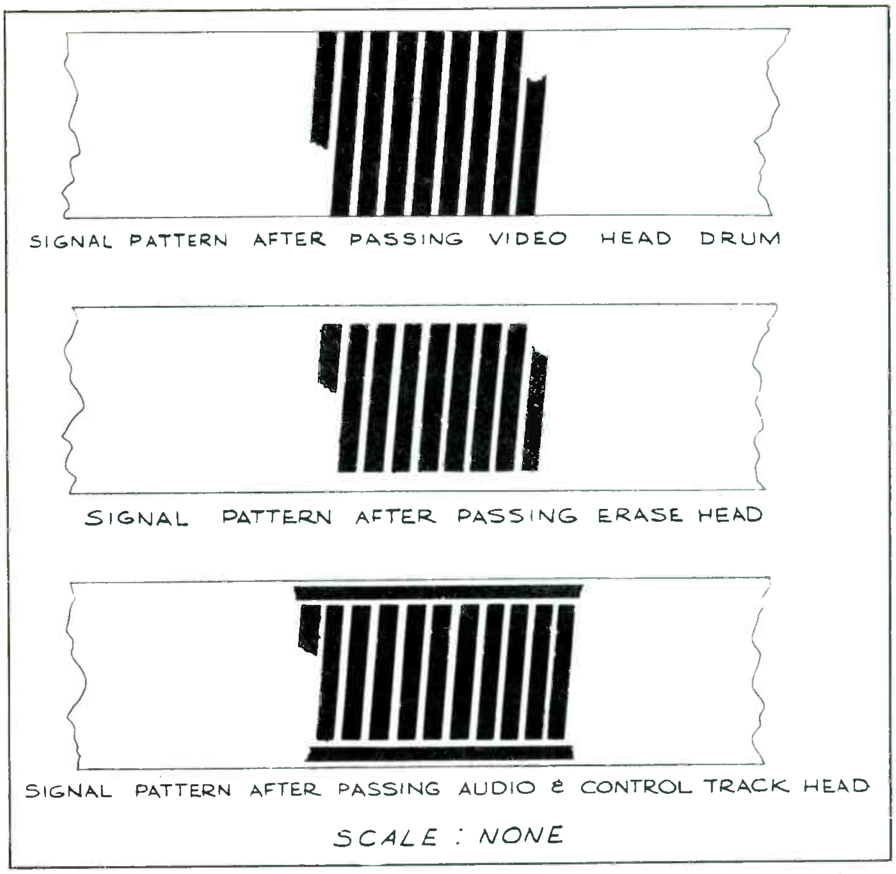

Fig. 2 - Magnetic pattern in sequential steps through head assembly.

seconds. The specification of 320 lines is one which allows a sufficiently safe margin in terms of signal-to-noise ratio, and at the same time is far more than adequate in terms of the final product -- the picture which is viewed on the home receiver. In the demonstrations presented in 1956, and especially those given at CBS Television City in June, the crispness and the tone of tape playbacks of a live camera pickup were essentially those of the live pickup itself.

Operational Simplicity Using Ampex VR-1000 Video Tape Recorder

Recording is a pushbutton procedure consisting of the sequential operation of the "start" and "record" buttons. Monitoring provisions are as follows: a 3-inch C-R oscilloscope mounted on the front panel indicates, by the lock-in of a Lissajous figure, that the synchronizing system is operating properly; a meter on the console indicates that r-f current is being fed to the rotating heads; and observation of a standard t-v monitor to which the output of the machine may be fed shows that the current in the heads is properly modulated. With observation of these monitoring facilities having been made, the probability of failure to make a good recording is very close to zero.

Playback operation consists of cuing up the tape in a fashion similar to that applying to audio recorders, pushing a start button at the proper time, and adjusting a vernier tracking control whose function is indicated on the cathode ray monitor mentioned previously. This tracking control may be adjusted either prior to cuing up the tape before program playback, or after playback has started. The adjustment of the control is a simpler and quicker operation than is the adjustment of an audio level in standard broadcast practice.

The Tape Itself

The machine will handle 4800 feet of 1 mil Mylar base tape on a 12 1/2 inch reel. At a tape speed of 15 ips, this gives 64 minutes of playing time.

Expected life of the tape is 100 passes, with the strong probability of considerable extension of this figure as a result of efforts by the tape manufacturers to produce a tape most suitable for the television application. Predicted life of the heads is about 100 hours for the first machines. Replacement of the head drum assembly will be an operation performed in the field by the user of the equipment.

Deterioration of the tape with usage is manifested by an increase in noise in a gradual fashion, but has no effect on gray-scale or resolution. Head wear, on the other hand, is not accompanied by any degradation of the reproduced picture, but is safely indicated by certain provisions in the system itself.

The Next Objective: Recording The NTSC Color Signal

A great deal of curiosity has been expressed in regard to the present and ultimate band width of the system, and the possibility of a simple extension of this band width if necessary in order to be able to record the NTSC color signal. What tends to be overlooked is that the realization of a system band width meeting NTSC color requirements as stated in terms of amplitude and phase response would not be sufficient by itself to permit the recording and reproduction of commercially acceptable color television programs. Of equally great importance are the factors of phase and frequency stability. Some difficulties might well be expected in trying to achieve the precision required for proper timing in a television signal, whether monochrome or color, when the reproduction of such a signal occurs through the medium of a tape recorder. Such difficulties would arise because of the obvious impossibility of maintaining an absolutely constant peripheral velocity with a rotating device, whether the device be a capstan as in a conventional top plate, or a drum as in the case under discussion. Therefore, in the rotating head approach the variations from average velocity are of great interest.

Let h be the instantaneous positional error of the drum due to a non-constant velocity. That is, if the peripheral velocity of the drum were absolutely constant, then h would always be zero. For the sake of illustration let us assume that hunting occurs in a sinusoidal fashion. We can now set

$$h(t) = A \sin 2\pi ft$$

where A equals peak amplitude of the positional error stated in rotational degrees or in equivalent microseconds.

This equivalence is a parameter of the system and in the case of the recorder under discussion the dimensions are such that one degree of drum rotation is approximately equivalent to 11.5 microseconds of information. Let us now consider a case in which A is equal to 1° and f is equal to 1 cycle/second. Then,

$$h(t) = 1^\circ \sin 2\pi t$$

and the first derivative with respect to time is

$$h' \cong 6.3^\circ \cos 2\pi t/\text{second}$$

and the second derivative with respect to time is

$$|h''| \cong 40^\circ \sin 2\pi t/\text{second}$$

Then the maximum value of h" is 40° per second squared. Therefore the percentage of velocity change per second at the maximum would be h" divided by the average number of degrees per second described by the drum, or $40/86{,}400^\circ \cong .47 \times 10^{-3}$ or a velocity change per second of .047%.

For a case in which at a given information point on the tape the drum during record had been in an accelerated condition with respect to the average velocity while on playback the drum were in a decelerated condition, this error would be additive and the total percentage rate of change of frequency would be .094%/second. For monochrome transmission the FCC requirement is that the maximum rate of change of the horizontal sync pulse repetition rate must not exceed .15%/second. Therefore, the quantities given in the example for amplitude and frequency of hunding would allow a recording and reproduction to be effected without objectionable disturbances in the reproduced raster.

The requirements for stability in the NTSC color signal are considerably more stringent than in the case of a monochrome signal. For color it is required that the frequency of the subcarrier be maintained at the nominal value within ± .0003% with a maximum rate of change not to exceed .1 cycle/second squared. Also, although this might be open to some discussion, let us say that it is necessary to hold the phase of the subcarrier to no more than a 5 degree shift from the beginning of one picture line to the beginning of the next.

Let us now consider the effect of hunting on the phase of the reference burst in the NTSC color signal. The quantities given in the example for amplitude and frequency of hunting gave us a maximum rate of change of 40° second squared, where the degrees referred to error in rotational position of the drum. This is equivalent, therefore, to about 40 x 115 or approximately 460 microseconds/second squared. Therefore, for one picture line the error would amount to 460 microseconds divided by 15,750 or approximately .029 microseconds. Since the period at 3.58 megacycles is equal to .28 microseconds, then .028 microseconds is equivalent to about 1/10 of a cycle, or 36° phase change at burst frequency. As was already noted, in the worst case this error could be doubled due to the coincidence of recording acceleration and playback deceleration, or vice versa, and thus the total phase error in a 63.5 microsecond period would amount to about 72° at 3.58 megacycles.

Thus, it would be necessary to reduce the product of hunting frequency times hunting amplitude by a factor of approximately 14 in order to maintain burst phase from line to line within 5°. The final choice of the most suitable system for a color recorder will certainly be based on the comparative merits of various approaches, considering technical feasibility, complexity, reliability, compatibility with other models of the VTR, and cost.

Additional Refinements in Development

Because of the importance of the operational features of any device to be used in television broadcasting, as many questions have been asked about splicing and editing techniques as about any other aspect of the entire VTR program. It is desirable that there be no loss of stability in the reproduced picture due to mechanical disturbances when a splice passes by the rotary heads, that the transition from one tape segment to another through a splice generate no picture roll-over, that picture tearing at the incidence of a splice due to a change in the source of the recorded material be held to a minimum, that the techniques for making adequate cuts and splices for editing purposes be simple and fast, and that it be possible to switch to or from the recorder in the playback mode with a minimum tendency toward roll-over. Although we will not be in a position to discuss details of the splicing, editing and switching technique until later, I believe that the method which has been developed for accomplishing these objectives will be completely satisfactory to the industry.