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U.H.F TELEVISION TRANSMITTERS

INTRODUCTION

Television broadcasting in the u.h.f bands has been operating in the U.S.A for the last 10 years and more recently in Germany and Italy. Since the Stockholm Conference of 1961 on broadcasting in the v.h.f and u.h.f bands, at which some 4,500 channel allocations in the u.h.f bands were made for Europe, there has been an increasing interest in u.h.f. In many cases extension of television broadcasting will inevitably have to make use of u.h.f, and there will be an increasing demand for transmitting equipment. To meet this demand a new range of u.h.f television transmitters has been designed.

The transmitters will be suitable for standards G, H, I and K detailed in the Final Acts of the Stockholm Conference[1] and also for FCC standards. The main parameters of these standards are shown in Table 1.

The transmitters are designed from the outset to be suitable for colour, basically for the NTSC system with a video bandwidth up to 6 Mc/s and a colour sub-carrier frequency of 3·58 or 4·43 Mc/s. The colour system to be used in Europe has not yet been agreed, but whichever of the three systems being considered, NTSC, Secam, or PAL, is chosen, the transmitters will be suitable.

OUTPUT VALVES

One of the first tasks for the transmitter engineer in designing a television transmitter is to decide the valve he will use in the output stage. In Bands I and III there will be a choice between different makes or possibly between triode and tetrode. Usually it will not be a difficult choice, nor is it likely to be far reaching.

For u.h.f a much more interesting situation arises. By continuous development and the introduction of new techniques, high-power tetrodes capable of operating up to 1,000 Mc/s have become available. At about the same time and largely due to the impetus given by the introduction of tropospheric scatter communication systems, high-power c.w. klystrons suitable for television in the u.h.f band are also available. The transmitter engineer now has to choose between two very different devices, and, having chosen, there is no going back.

COMPARISON BETWEEN KLYSTRONS AND TETRODES

This comparison is made under the following main headings:

(a) Reliability
(b) Initial costs
(c) Ease of operation
(d) Running and maintenance costs.

Reliability

On this count, the klystron appears to score heavily.

TABLE 1

Standard	*Video Bandwidth Mc/s*	*Vision Sound Carrier Spacing Mc/s*	*Vestigial Sideband Mc/s*	*Vision Modulation*	*Sound Modulation*	*Frequency of Chrominance Sub-carrier Mc/s*	*Vision Sound Power Ratio*
G	5·0	5·5	0·75	Neg.	f.m.	4·43	5:1
H	5·0	5·5	1·25	Neg.	f.m.	4·43	5:1
I	5·5	6·0	1·25	Neg.	f.m.	4·43	5:1
K	6·0	6·5	0·75	Neg.	f.m.	4·43	5:1
FCC	4·18	4·5	0·75	Neg.	f.m.	3·58	2:1*

* A change to 10:1 is under consideration.

On a representative 10-kW tetrode, the cathode-to-grid spacing is less than 1 mm, and failures due to cathode/grid short circuit are by no means uncommon. No such small spacings occur in the klystron.

In addition, the various blocking condensers required in the tetrode amplifier are difficult to design because of the limited space, and this tends to increase their unreliability. No such condensers are required in the klystron amplifier. Again, although contact fingers are required for both klystrons and tetrodes, because of the greater robustness of the klystron, greater contact pressures can be used, and the contact fingers are therefore likely to be less troublesome.

A tetrode transmitter will include a larger number of tuned circuits, compared with a klystron transmitter, particularly at the higher output powers. For example, at an output power of 20 kW, a tetrode amplifier would have at least twelve tuned circuits in the vision chain, compared with four for a klystron. Moreover, it will probably be more difficult to cool the tuned circuits on the tetrode amplifier. This will tend to make the tetrode transmitter less stable with regard to maintenance of performance over long periods, which is important for unattended operation.

Initial Costs

Taking an output level of 10 kW as an example, using klystrons, a vision driving power of about 10 W peak would be required with 2 W for sound. Replacing the klystrons by tetrodes, would require three tetrodes stages in the vision chain, and two, possibly three in the sound chain.

The cost of power supplies will tend to be more expensive for the tetrodes; there are more of them and, for the vision amplifiers, will require to be built out to constant impedance, or stabilized, to deal with the video components in the valve currents. On the r.f side, we have to compare three klystron assemblies (one vision, one sound, one standby) with six tetrode stages.

Taking into account the much higher development costs on the tetrodes there would be very little difference in cost, and it is a reasonable conclusion that, with regard to initial cost, no particular advantage is shown by either klystron or tetrode. It is possible to make a tetrode design with the video modulation applied at a higher r.f level than considered above, and then using a smaller number of linear r.f amplifiers. Some consideration of this indicates that what is gained on the r.f side is offset by the increased cost of the bigger video modulator.

Ease of Operation

We are concerned here with setting up and maintaining the equipment to a given performance specification, and one of the main points is the maintenance of frequency response. In the case of tetrodes the valves would be operated under cathode-driven conditions, so that couplings would exist between the various broadband circuits and undoubtedly complicate the setting up and maintenance procedure.

With klystrons, virtually no couplings exist between the various cavities and each can be adjusted separately without reaction back to the others.

Running and Maintenance Costs

Comparison under this heading will depend mainly on power consumption and valve replacement costs. For a vision peak power of 10 kW, the power consumption for klystrons will be about 1·3 times that for tetrodes. The replacement cost for klystrons will be 2·3 times that for tetrodes. From this it can be deduced that the total cost will be the same if the klystron life is 2·5 times that of the tetrode. A reasonable expectation is at least 3, so the klystron will tend to be the cheaper.

For these reasons, the designs have been based on the use of klystrons, certainly for output powers of 5 kW and upwards.

METHOD OF VIDEO MODULATION

Two methods of video modulation are currently used:

(a) Grid modulation of triode or tetrode valve.

(b) Cathode or series modulation of triode or tetrode valve.

Both have proved adequate for monochrome operation, but have certain limitations for colour transmission.

Grid Modulation

For colour operation it is required to modulate down to 5% (sync. level = 100%) as compared with 10% for monochrome and it is in this region where the non-linearity rapidly increases. A typical tetrode under these modulating conditions could have a differential gain of 0·3 with perfect drive regulation. Imperfect drive regulation could make the situation considerably worse. At u.h.f, drive regulation could present a considerable problem.

The situation can be improved by adding to the output from the modulated stage an unmodulated signal in phase opposition to eliminate the lower part of the modulation characteristic where the main non-linearity occurs. Maintenance of the correct levels will then depend on the amplitude and phase stability of this anti-phase signal. With regard to differential phase, grid modulation is probably satisfactory.

Cathode Modulation

In a typical tetrode it is found that there is good linearity between output amplitude and anode current and if the series modulator I_a/V_g characteristic can be made linear, the overall linearity will be good. Normally this can be achieved at low modulation frequencies. However, two factors combine to spoil the linearity at higher modulation frequencies. The first is the fact that the video impedance of the r.f stage (i.e. the load seen by the modulator) varies with modulation level. The second is the inevitable capacity across the r.f stage, due to cathode circuit capacity, heater transformer capacity, etc, to earth. Typical figures indicate that an almost perfect differential gain at low frequency would be worsened to about 0·6 at sub-carrier. For the same reasons, the differential phase would be high, possibly 20°.

A New Method of Modulation

In view of these possible difficulties, a new method of modulation has been devised[2] basically operating on the absorption principle, which has the following advantages:

(a) Adjustment to the correct operating conditions is much simpler than for grid modulation.

(b) A high degree of linearity is obtained without critical balancing of r.f voltages in amplitude and phase.

(c) The load on the driver is constant over the modulation cycle, so that there is no drive regulation problem.

(Differential gain of 0·95 and differential phase of 1° have been measured.)

COLOUR OPERATION

The transmitters have been designed from the outset to be suitable for colour operation, using the NTSC system with video bandwidth up to 6 Mc/s, and a sub-carrier frequency of 3·58 or 4·43 Mc/s. It is considered that the design will also be suitable for the Secam and PAL systems, if one of these is eventually chosen as the system to be used in Europe.

The colour information is transmitted on a sub-carrier. The amplitude of the sub-carrier relative to the amplitude of the luminance signal determines the colour saturation, and the phase of the sub-carrier relative to that of the synchronizing burst determines the hue of the colour. Fig. 1 shows the transmitter spectrum for NTSC colour transmission with System I. Fig. 2 shows the waveform of one line for 95% saturated colours.[3]

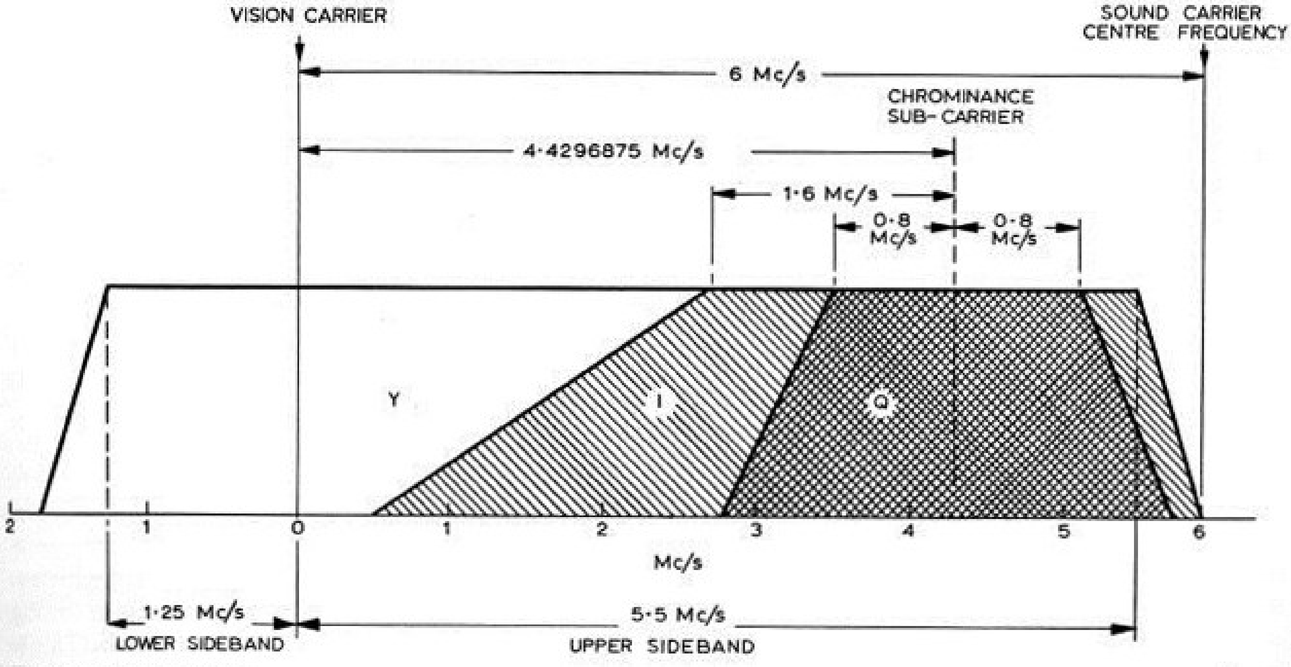

Fig. 1. Transmitter spectrum.

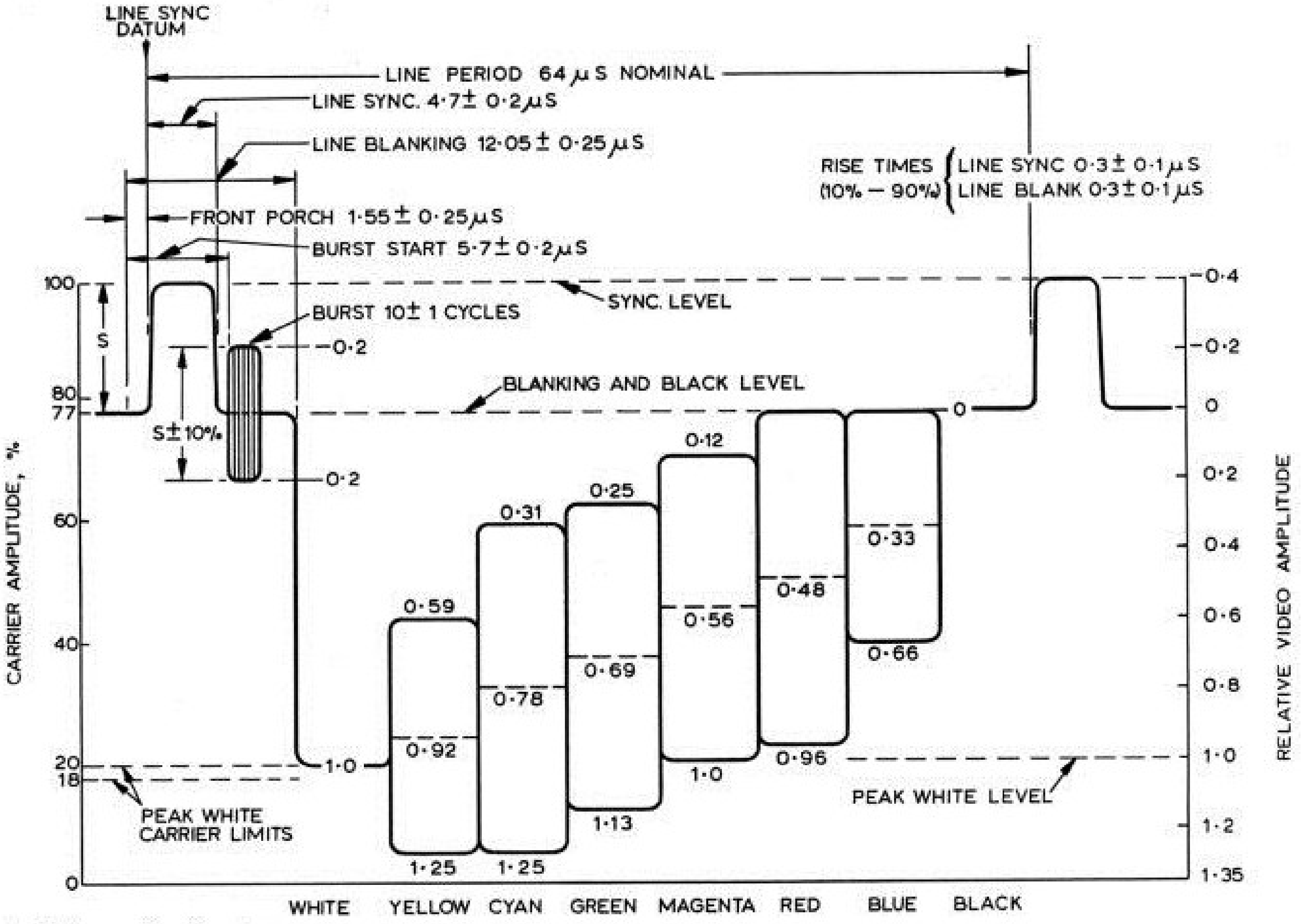

Fig. 2. Line waveform for colour.

The satisfactory transmission of colour signals requires the transmitter performance to be within closer limits as compared with performance required for monochrome transmission, plus additional requirements which do not apply in the monochrome case.

For monochrome operation a reasonable loss of high-frequency response can be tolerated. For colour, any loss at the sub-carrier frequency means a decrease in the saturation, which will degrade the performance to large colour areas. The response within the chrominance bandwidth must be maintained within close limits to give a good transient response to colour signals and thus maintain the quality of colour edges.

These requirements imply tighter limits in overall amplitude frequency response than required for monochrome. Additionally, to maintain the quality of colour edges, a good time match is required between the luminance and chrominance signals, and this again implies tighter limits in group delay characteristic than required for monochrome.

The linearity of a transmitter for monochrome is usually specified in terms of its response to a relatively low frequency signal, either a saw-tooth or a step waveform. For colour, the linearity to a signal at the sub-carrier frequency must also be included. This latter is usually referred to as the differential gain, meaning the change in gain of the system to an input signal at sub-carrier frequency with change in luminance. A higher degree of linearity will be required for colour, and a specification of 0·95 for differential gain is usual. Moreover, the transmitter is required to be linear over a greater amplitude range (5 to 88%), as compared with monochrome (10 to 75%).

Hue fidelity depends on the transmission of the sub-carrier signal, without change in phase relative to the synchronizing burst, for change of sub-carrier amplitude or luminance level. This is referred to as differential phase and for the transmitter the limit is ±2°. The video modulator must be capable of dealing with the large amplitude sub-carrier signals. This is not necessarily required for monochrome.

DESIGN

The design is based on a driving transmitter as a separate entity, which can be used with a series of amplifiers giving a range of output powers as required. In this way maximum flexibility is obtained.

THE DRIVING TRANSMITTER

The transmitter is housed in a cabinet 5 ft (1·5 m) wide, 2 ft 7 in. (0·75 m) deep and 7 ft (2·15 m) high, and contains all the equipment required to produce from standard video and audio inputs, vision and sound r.f outputs in the u.h.f band. The vision r.f output is fully corrected for driving klystron amplifiers for colour operation.

The vision r.f output power is about 10 W peak with the appropriate sound output power. Where additional output power is required, space is available, without modification, for fitting an amplifier to increase the vision output power to 75 W peak and correspondingly on the sound.

The cabinet also contains an envelope monitor and, when required, the additional units for parallel operation. All power supply units use silicon rectifiers. Fig. 3 shows the basic block diagram.

Vision R.F Circuit

The vision crystal oscillator is housed in a temperature-controlled oven to give a frequency stability of ±500 c/s at the output of the transmitter. This is followed by a transistor amplifier which is also used as a muting amplifier when parallel operation is used. This is described in more detail later.

The total multiplication is 32 and this is in two parts, one ×8, and the second ×4. For parallel operation the r.f phasing network is connected between these two units, i.e. the phase adjustment is carried out at ¼ output frequency.

At this point the output level is about 8 W. This passes to the absorption modulator. The modulated output from the absorption modulator is amplified in a linear broadband amplifier using one 4CX250K valve. This operates as a cathode-driven amplifier, with a strip line cathode circuit and resonant cavity anode circuit. For an output of 75 W peak, another identical amplifier is included.

Video Circuits

The video circuits amplify the incoming 1-V signal to the required output voltage of about 20 V, and include, among other things, all the correction circuits for full colour performance.

Differential Gain Amplifier

A higher degree of linearity or differential gain is required for colour as compared with monochrome, and the linearity must be maintained over a greater amplitude range. Linearity correction of this type is normally done in controlled steps. The overall differential gain of the transmitter is specified as 0·95% and this means that the correction due to each step must not exceed 0·5 dB.

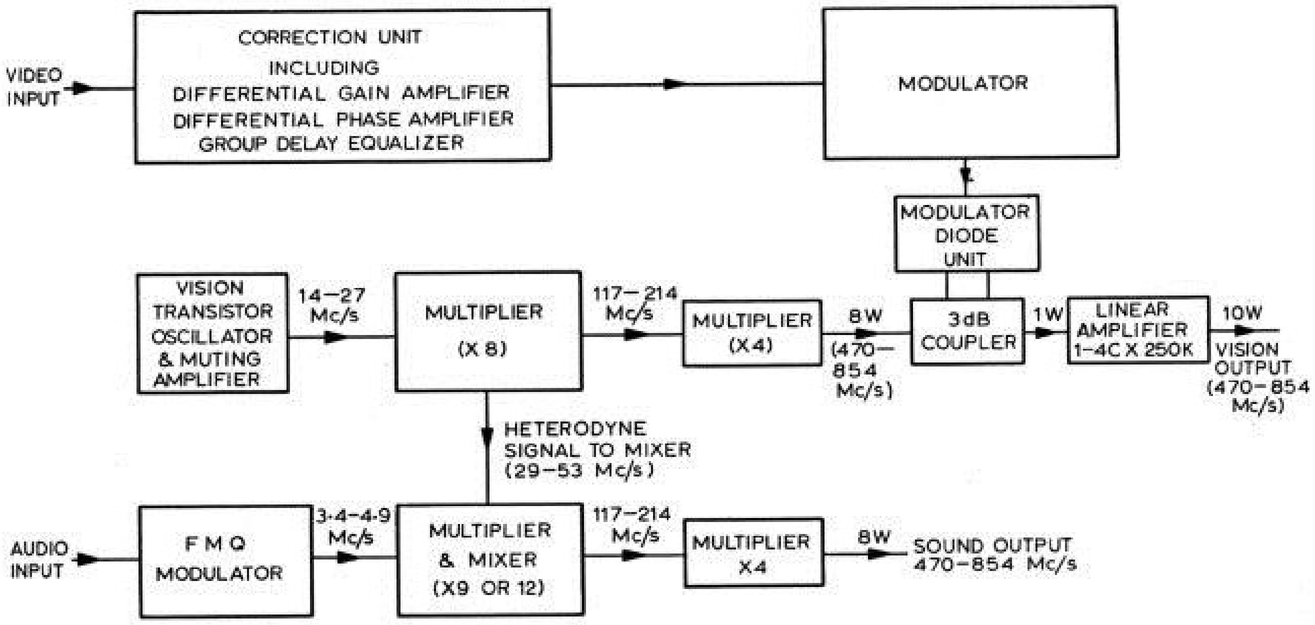

Fig. 3. Driving transmitter block diagram.

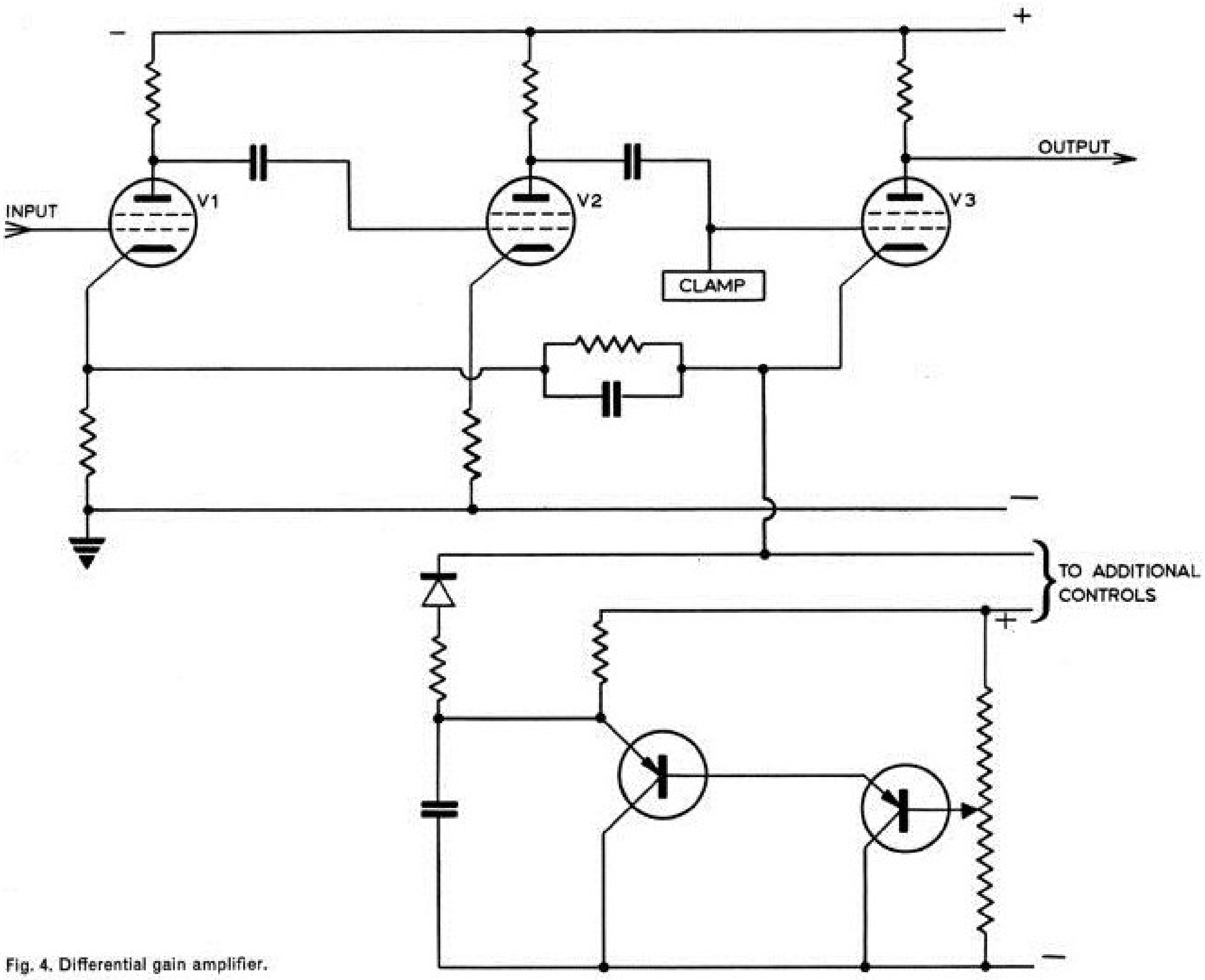

Fig. 4. Differential gain amplifier.

This is achieved by using a three-stage feedback amplifier, as shown in Fig. 4. The feedback, and hence the gain, is modified by progressively switching, by means of diodes, resistors from cathode of V3 to earth. The switching point of each diode is controlled by a two-stage transistor stabilizer in conjunction with a potentiometer. Only one switching circuit is shown in Fig. 4. The actual number required will depend on the degree of non-linearity to be corrected.

Differential Phase Amplifier[4]

Correction of differential phase errors is achieved by adding to the main signal, two further signals, derived from the main signal, but suitably delayed or advanced. Adjustment of the amplitude of the correcting signals then changes the phase of the output signal relative to the input signal.

Fig. 5 shows the vector diagrams at sub-carrier frequency. In (a) AB is the input signal vector, and BC and CD the correction signal vectors, which gives an output signal vector AD, providing a negative phase correction of ϕ_1. By reducing the amplitude of the correcting vectors to BE and EF, and negative phase correction of ϕ_2 is provided. Fig. 5(b) shows the correcting vectors changed in phase by 180°, giving positive correction of phase.

A total correction of about 16° is available and the relative amplitude and phase of the correcting signals is such that with any correction, the frequency response is changed by less than 0·5 dB at 5·5 Mc/s.

Fig. 6 shows the schematic diagram. V1, V2 and V3 have a common anode load, V1 and V2 being a cathode-coupled pair. The input signal goes to the grid of V3 through a delay line, to give the output signal produced by V3 the correct phase relation with the

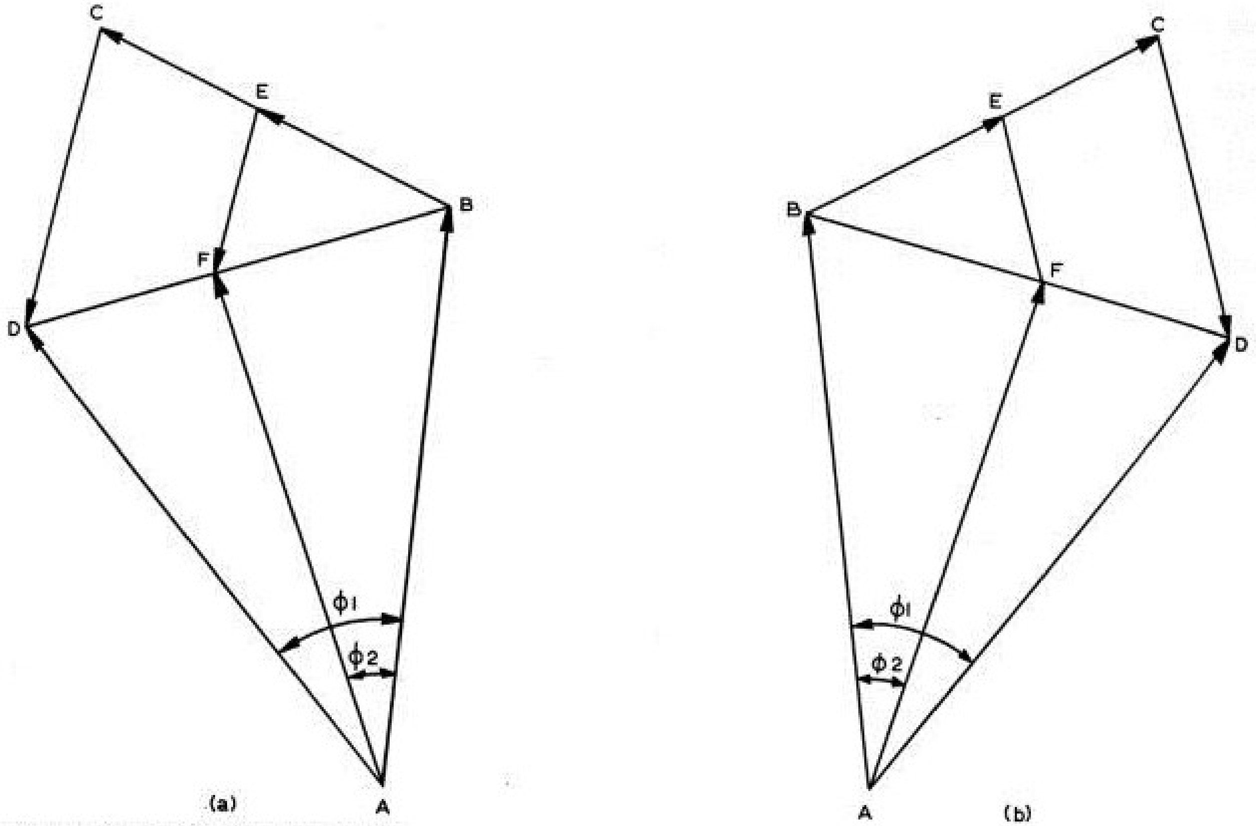

Fig. 5. Vector diagram-differential phase amplifier.

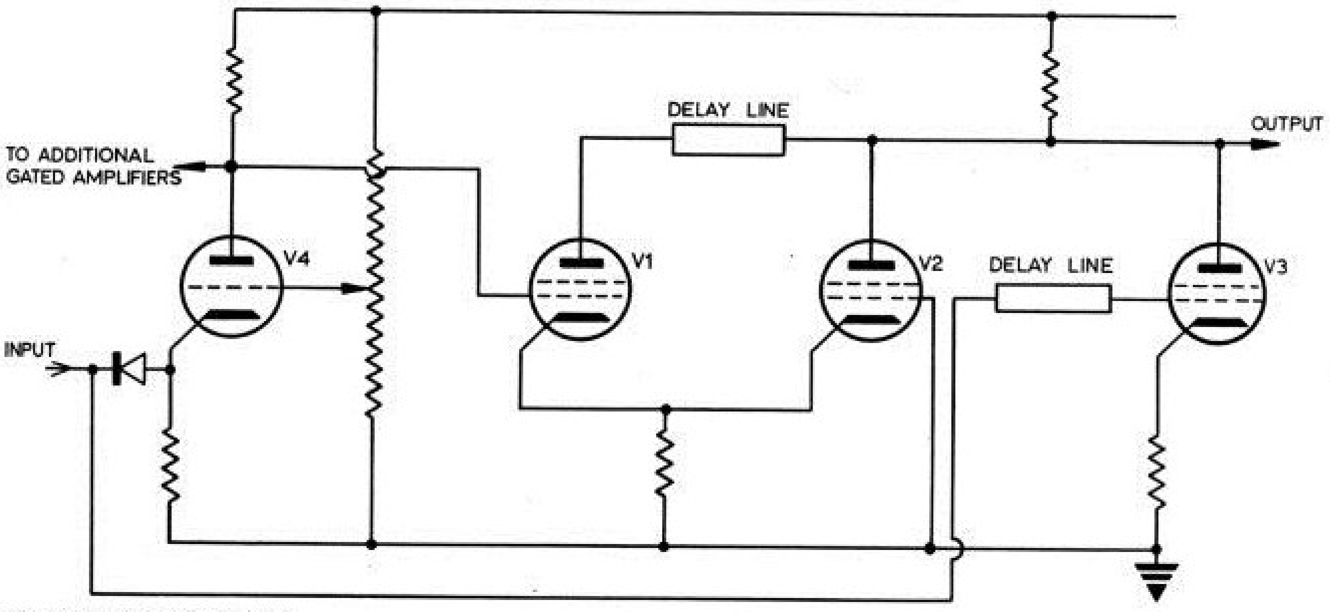

Fig. 6. Differential phase amplifier.

correcting signals. The correcting signals are produced by V2 and V3 in conjunction with the gated amplifier V4, which can be adjusted such that correcting signals are available over any given part of the waveform. Eight gating amplifiers are used, with a common anode load, but with separate onset adjust, such that a total correction of 16° can be obtained with any required law. Reversal of the phase of the output from the gating amplifiers reverses the phase of the correction.

Group Delay Correction

Fig. 7 shows the group delay characteristic without correction over the pass-band of the transmitter from $fv - 1{\cdot}25$ to $fv + 5{\cdot}5$ Mc/s for standard I. This is largely determined by the filterplexer. Correction at the high-frequency end of the band is readily obtainable with video frequency circuits.

Due to the asymmetric characteristic around vision carrier, full correction here would require the correction to be done at r.f which could be exceedingly complex and expensive. It has been stated that, in terms of adjacent channel interference, there is evidence to show that the usual sharp vestigial response is unnecessary, and that a less sharp cut will be adequate. This will give a less asymmetric group delay around vision carrier, and allow correction to be carried out at video frequencies. As far as is known, no decisions or agreements have been reached regarding a modified vestigial response.

However, with the group delay characteristic shown in Fig. 7, due to the rapidly decreasing contribution of the lower sidebands, when the receiver amplitude/frequency characteristic is included, calculations indicate that a compromise correction for group delay errors around vision carrier is feasible with video frequency circuits, and these have been used in the corrector described below.

Six all-pass networks are used, three of the type shown in Fig. 8(a) and three of the type shown in Fig. 8(b). These are tuned to different parts of the video spectrum. Various combinations are selected to give the correction curves shown in Fig. 9. Each of the two low-frequency corrections can be combined with any one of the high-frequency corrections, to give six correction curves in all. For any correction curve, the amplitude/frequency characteristic is flat within $\pm\frac{1}{8}$ dB from 0 to 5·5 Mc/s. An additional three-section corrector is also included to pre-correct for high-frequency group delay errors in the average receiver.

Clamp Circuits

The clamp pulse generator is so designed that it continues to give clamp pulses of the correct amplitude, duration and timing in the presence of noise pulses of duration up to 1·5 μsec and amplitude up to synchronizing pulse amplitude and of positive or negative polarity. The clamps are designed to give effective clamping without distorting the synchronizing burst.

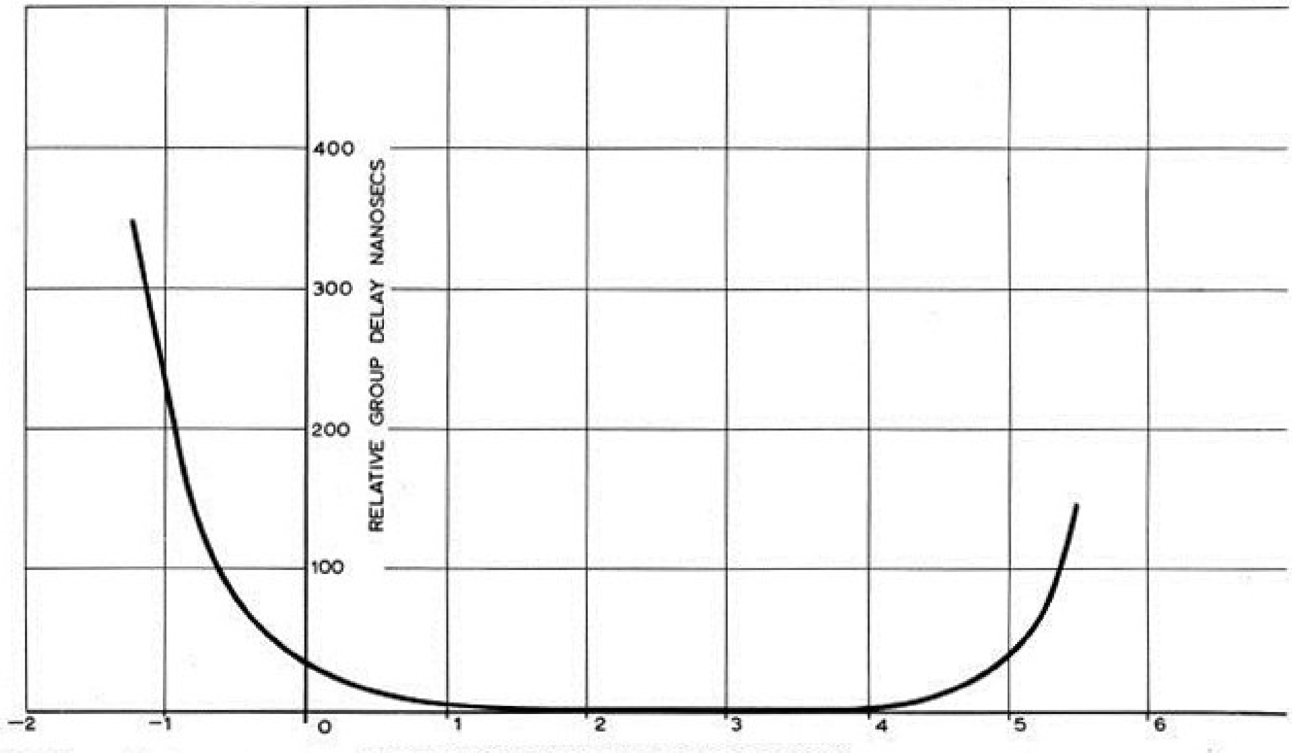

Fig. 7. Group delay characteristic.

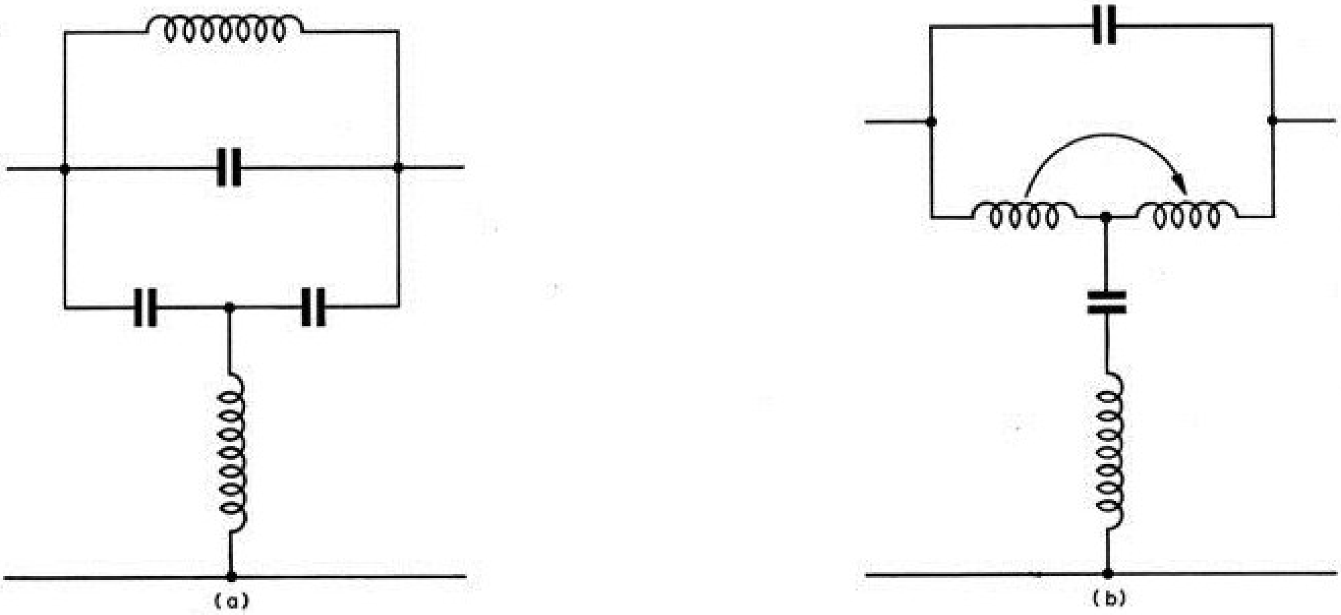

Fig. 8. Group delay corrector.

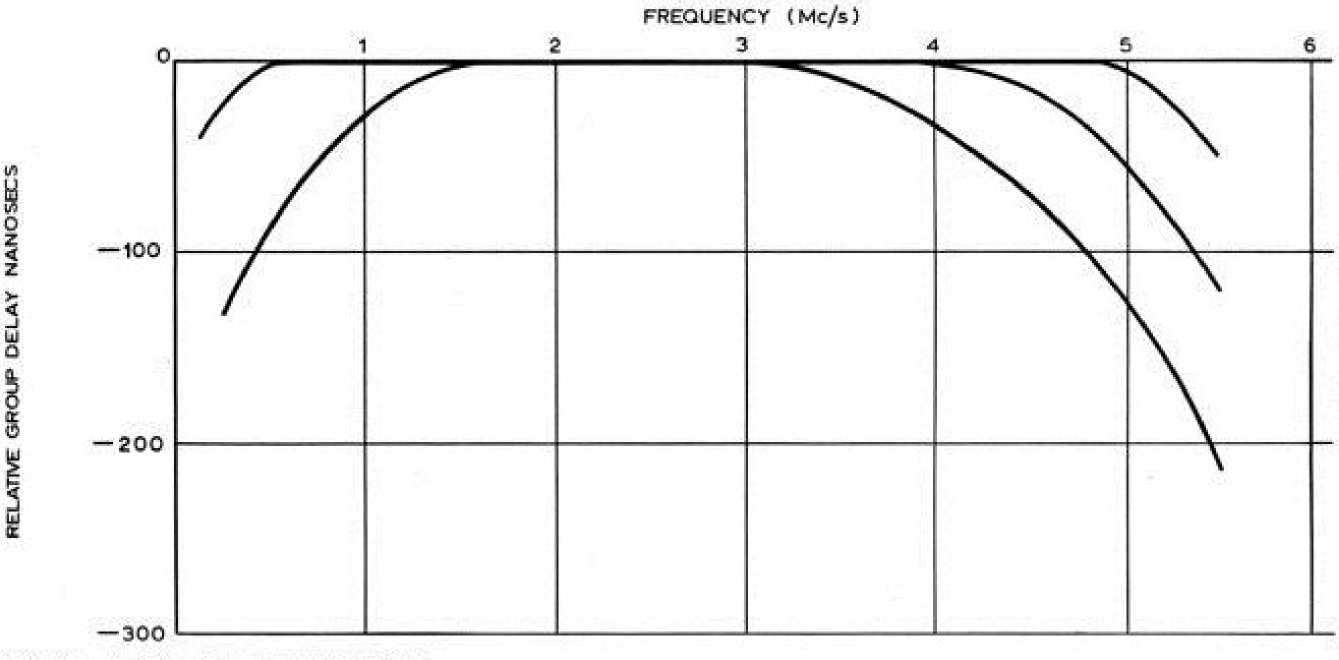

Fig. 9. Characteristics of group delay corrector.

Level Stabilization

Feedback systems are included to stabilize blanking and synchronizing levels, the feedback signals being derived from detectors on the output feeder.

Sound Circuits

The frequency-modulated drive is derived from the Marconi f.m.q drive.[5] The output frequency is produced partly by multiplication and partly by mixing with a signal derived from the vision multiplier chain. This allows the required stability on vision sound-frequency spacing to be maintained without imposing too severe a restriction on the centre frequency stability of the f.m.q drive. Fig. 10 shows a front view of the driving transmitter.

25-kW AMPLIFIER

The amplifier uses the same type klystron (Eimac 4KM100L) for both the sound and vision amplifiers. It would be possible to use a smaller klystron for the

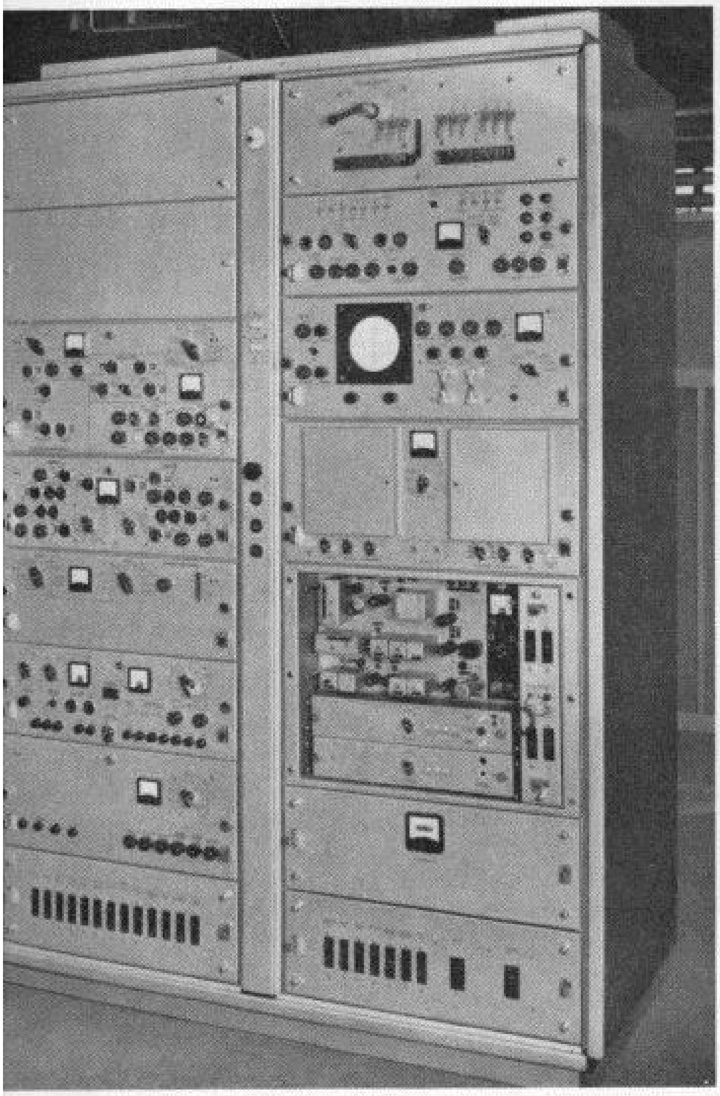

Fig. 10. Front view of driving transmitter.

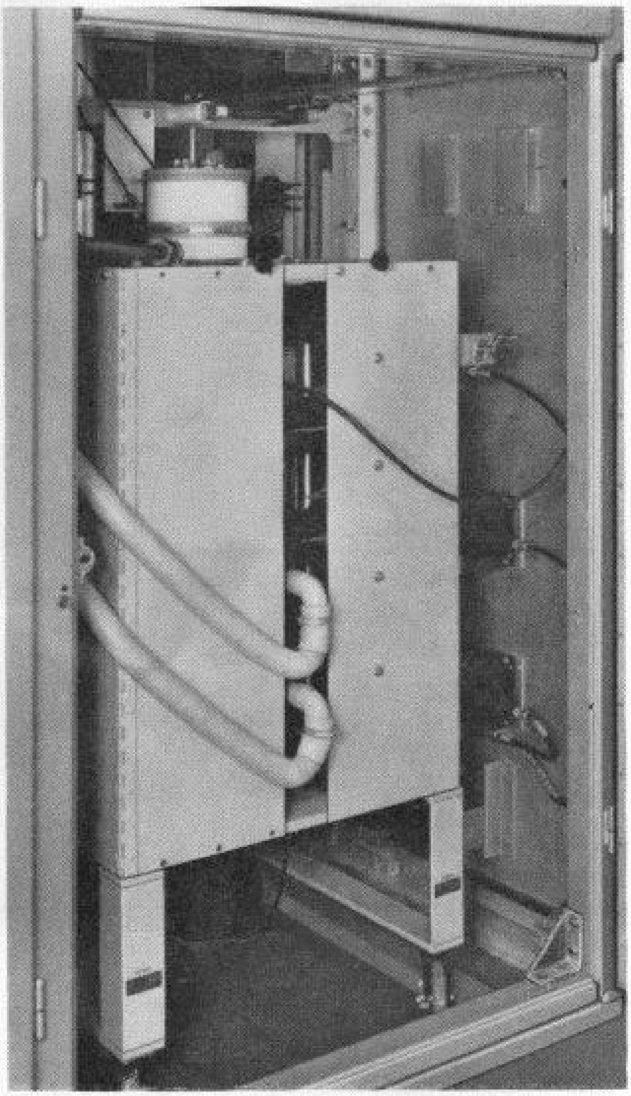

Fig. 11. The 4KM100LA Klystron mounted in transmitter.

sound amplifier, but no particular advantage would be gained and it would have the disadvantage that two spare assemblies and tubes would be required instead of one in the present case. This spare assembly and tube will normally be adjusted for the vision channel, but can equally well be used for the sound channel.

The 4KM100L is a four-cavity, electromagnetically focused tube, with a perveance of 2. The collector and drift tubes are water cooled, and the cavities air cooled. A modulating anode is fitted, which is used for the automatic suppression of internal arcs and also for adjusting the beam current. This latter facility is used for the sound klystron as described later. The five focusing coils are series connected, so that only one supply per tube is required.

Three tubes are required to cover the u.h.f Band:
4KM100LA 470–610 Mc/s
4KM100LF 580–720 Mc/s
4KM100LH 720–890 Mc/s

Fig. 11 shows the tube in its assembly mounted in the transmitter.

The required output from the sound amplifier could be obtained with a lower beam voltage than that used for the vision amplifier, but this would result in a lower efficiency. By using the same beam voltage and reducing the sound klystron beam current, by biasing the modulating anode, optimum efficiency is maintained. This leads to using the same h.t supply for sound and vision klystrons, with considerable saving in components, and the design is based on this.

The complete amplifier, with the exception of the filterplexer and the water-cooling equipment, is housed in an enclosure 23 ft 6 in. (7·2 m) long, 5 ft 6 in. (1·7 m) deep and 7 ft (2 m) high. Access to the front and right-hand side only is required, so that the enclosure can be installed close up against a wall of the transmitter hall.

The two heater supplies, the two focus coil supplies and the beam supply all use silicon rectifiers, which are fully protected against switching surges and also against mains supply surges. The beam supply consists of two separate rectifiers, each with an output voltage of 9 kV with their outputs series connected into a common smoothing circuit. Both rectifiers are powered through an automatic voltage regulator, controlled from the beam voltage itself, so that the voltage can be adjusted and maintained within ±1%. The focus coil supplies are stabilized to maintain constant output current, to reduce the warming-up time.

An electro-mechanical interlock system is provided for personnel safety, and comprehensive interlock and overload trip circuits protect the equipment. These circuits are designed on the fail–safe principle.

The modulated drive to the vision klystron is connected via a three-port circulator. This ensures that the impedance seen by the driving transmitter is 50 Ω irrespective of the klystron input impedance, the adjustment of the latter being thereby much less critical.

The r.f input level to the vision klystron is controlled by a continuously variable attenuator of new design.[6]

The water-cooling equipment is in two units, the heat exchanger and the pump unit. The latter includes the pump, water-flow meters and trips etc for the two klystrons, and the water-cooled test load. A 70% water–30% glycol mixture is used in the cooling system. This will allow operation down to −15°C. An inhibitor is used and the water system is zinc-free. Fig. 12 shows a front view of the amplifier.

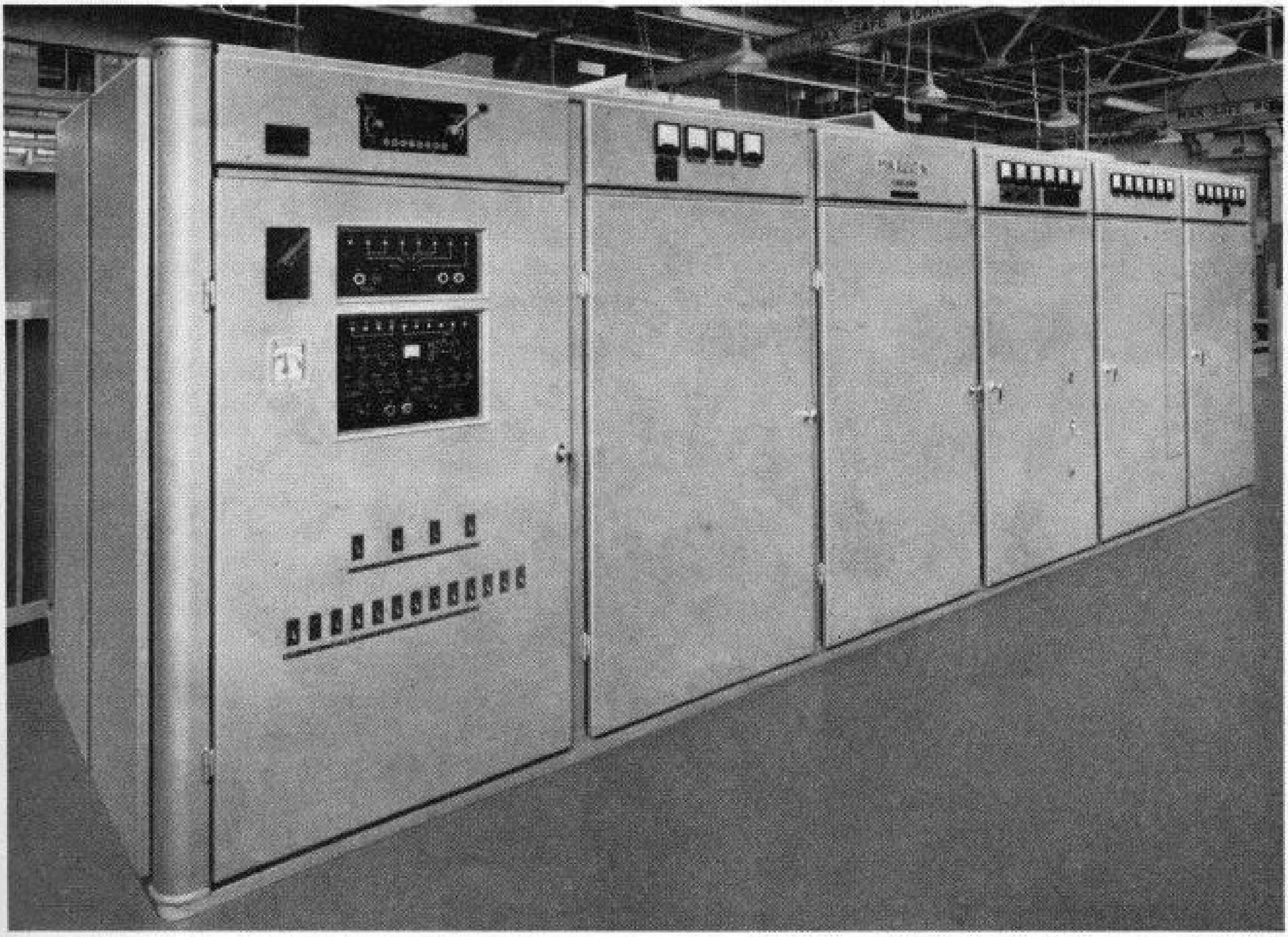

Fig. 12. Front view of the 25-kW amplifier.

PARALLEL OPERATION

The Marconi Company has extensive experience in the design of television transmitters for operation in parallel to increase reliability.

It is contended[7] that the method employed with two complete chains, both in operation, gives maximum reliability, and this has been borne out by experience. Only the drives are required to operate on a working/standby basis.

For parallel operation, means must be provided for:

(1) Automatic changeover from working drive to standby under fault conditions.

(2) Maintenance of correct phase between the two r.f outputs.

The drive changeover for the vision chain is shown in Fig. 13 and is effected without the use of relays. The crystal oscillators of each transmitter is followed by a transistorized muting amplifier.[8] The output of both muting amplifiers pass to a hybrid, the two outputs of which drive the two transmitter chains. Both oscillators are working continuously. The muting amplifiers are cross-connected and a preference switch allows either A or B drive to be selected as the working drive. If A is selected as the working drive, output from A is normal, while output from B is attenuated by at least 70 dB. If the output from A decreases by 2 dB, changeover to B takes place and output from A is effectively muted. Similarly for B as the working drive.

A similar arrangement is used for the sound chains, with the vision oscillators replaced by the two f.m.q drives. In this case, however, loss of deviation can take place without loss of r.f output, due to a fault in the audio-frequency circuits. Additional circuits are included to give automatic changeover for such faults.

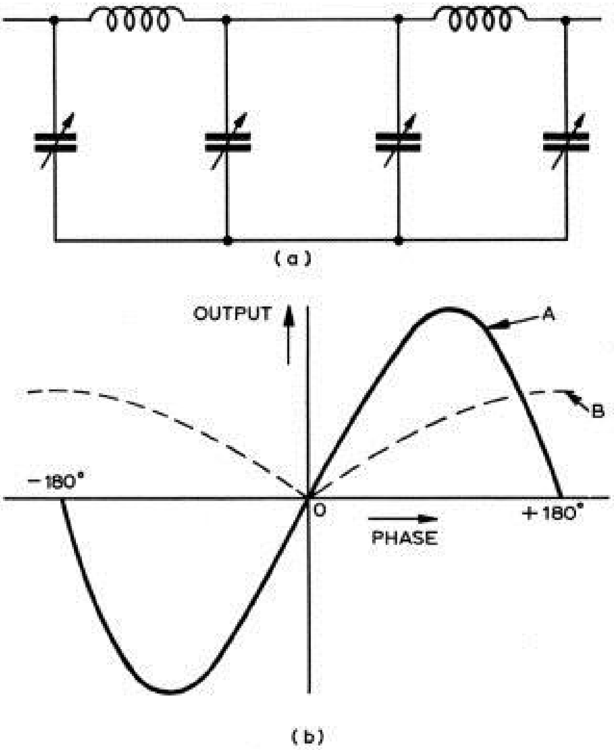

Fig. 14. Parallel operation—r.f phasing.

This is on a comparative basis so that changeover does not take place during periods of no modulation.

R.F Phasing

In the vision chains a multiplication of 32 takes place after the drive split at the hybrid. A similar condition occurs on the sound chains. This means that a considerable phase difference is possible at the r.f outputs of the two driving transmitters, particularly during the warming-up period.

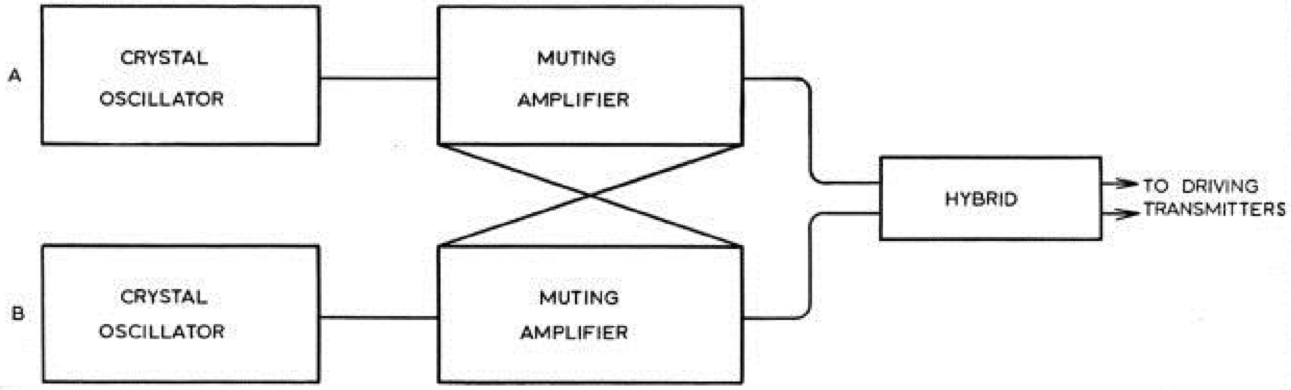

Fig. 13. Parallel operation—drive changeover.

In addition, there can occur considerable difference in phase shift through the two klystrons. The overall phase shift through the klystron is of the order of 2,000°, and a differential of 2% on the two beam voltages will produce a phase difference of about 20° between the two r.f outputs. For these reasons an automatic phasing system is employed, separate identical equipments being used for sound and vision. The phase correction is carried out at quarter of the output frequency with the circuit shown in Fig. 14(a). This gives an adjustment of ±45° at quarter output frequency, i.e. ±180° at output frequency with minimum attenuation.

The capacitors are ganged and operated by a servomotor via a servo-amplifier. Control is effected by one of two phase discriminators connected to the two relevant output feeders. The characteristics of these discriminators are shown in Fig. 14(b). Discriminator A has the correct characteristic around zero phase difference for proper control, but has an inherent ambiguity between the in-phase and the anti-phase conditions. The characteristic of B is incorrect around zero-phase, but has no ambiguity. It is, therefore, arranged that over a pre-determined range, say ±50°, discriminator A is in operation, while outside these limits an automatic changeover to B takes place. The phase having been brought into the range of A, automatic changeover to A takes place, and the correction is completed by A.

CONCLUSION

These transmitters will meet the needs of television services now expanding into the u.h.f bands, and also the growing demand for colour. Their inherent reliability and ease of operation will be of great benefit in the dilution of skilled technical manpower that this expansion will cause.

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