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TELEVISION TRANSMITTER MODULATION SYSTEMS

INTRODUCTION

From the very earliest days of experimental television transmission, the electrical signals derived from the electro-optical pick-up system (e.g television camera) were amplitude modulated directly onto a carrier wave at radiated frequency. The first transmitter to be used for regular television broadcasts by the BBC, from Alexandra Palace in 1936, used this system of direct modulation, and in the immediate post-war years all television transmitters were of this design.

In 1956 The Marconi Company introduced the concept of intermediate-frequency modulation and produced a range of v.h.f television transmitters incorporating this principle. Intermediate-frequency modulation differs from direct modulation in that the video signal is amplitude modulated on to an intermediate-frequency carrier wave which is subsequently heterodyned to the required carrier frequency. These first i.f modulation transmitters were designed with a vision intermediate carrier frequency of 38·9MHz which has now become the frequency most commonly used for this application. A vestigial sideband shaping filter was included in the i.f chain enabling a common low-power filter to be used for all radiated frequencies in place of the more usual practice of designing high-power v.s.b filters for each television channel.

Broadcasting authorities, influenced by the well-established practices employed in amplitude modulated sound transmitters and to similar principles applied to vision transmitters, were reluctant to accept the additional circuitry required for the final mixer and did not look with favour upon the relatively large number of low-gain, broad-band thermionic valve linear amplifiers at both i.f and radiated frequency. For monochrome v.h.f television transmitters the advantages of i.f modulation-common frequency low-power generation and modulation circuitry, and the use of a common v.s.b filter, had to be weighed against the probable long-term drift of many cascaded thermionic valve linear amplifiers.

In recent years the introduction of transistors and other solid-state devices, and high-gain thermionic valves, has enabled i.f modulation to be compared more favourably with direct modulation.

GENERAL CONSIDERATIONS

Two of the basic requirements of a television transmitter can be summarized as, firstly, the ability to meet specification and, secondly, long-term stability of all parameters so that unattended operation may be employed, with infrequent maintenance visits. In general terms this means that the number of thermionic valves should be reduced to a minimum and types selected that combine high gain with extra long life expectancy. This also means that solid-state devices should be employed up to the highest attainable power levels consistent with reliable operation and sound economics.

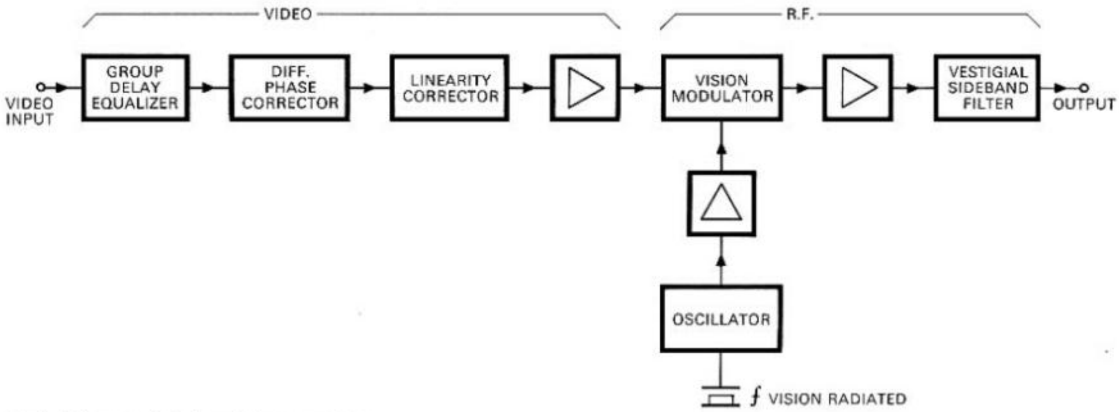

Fig.1 Direct modulation vision transmitter.

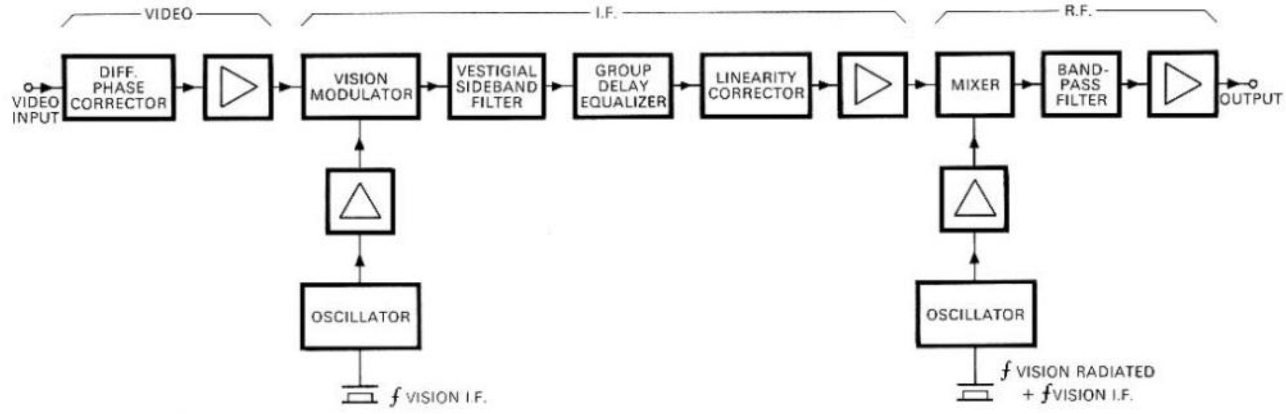

Fig.2 I.F modulation vision transmittter.

Either system of modulation can fulfil these requirements on both v.h.f and u.h.f television bands but, as both systems have advantages and disadvantages, it is necessary to make a careful assessment of the gains and losses to achieve an optimum system.

DIRECT MODULATION

v.h.f

In the earliest transmitters modulation was applied to the grid of the final r.f valve. Thus, for large output

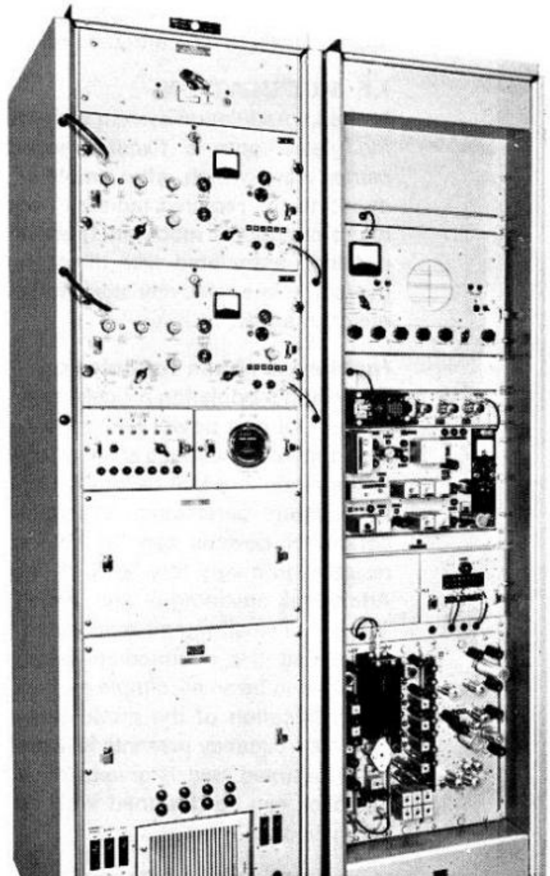

Fig.3 500W v.h.f television transmitter employing i.f modulation (68 thermionic valves, c.1958).

powers, the video modulation amplifier requirements were quite onerous. Video voltages in the 400V to 500V range, with reactive currents approaching 2A at 5MHz, were not uncommon.

General improvements in thermionic valves and, just as important, the introduction of swept-frequency techniques for adjustment permitted wideband r.f amplifiers to be designed and high-power transmitters made with one or more r.f linear amplifiers following the modulated stage. The reduction in size and capability of the video modulating amplifier was quite significant, although a large number of valves was still employed.

Improvements to thermionic valves have continued, and now long life valves for high-power r.f linear amplifier service are available with power gains exceeding 16dB. This makes possible a single or two-valve linear amplifier, depending upon power output level, driven from an all solid-state modulated r.f driver.

The solid-state equipment may take one of two basic forms, either a low-level modulator followed by transistor linear amplifiers, or a higher level modulator at the power level necessary to drive a thermionic valve. An experimental variable capacitance diode modulator has been made with an output (sync tip power) of approximately 100W, and, by combining two or more such devices, even larger powers could probably be obtained. Investigations have also been made into the possible use of p.i.n diodes and r.f transistors for high-power modulators. The apparent simplicity of the circuitry is attractive, but there are disadvantages to such an arrangement. Firstly, the conversion efficiency (c.w to modulated r.f) is only 50% to 60%, and thus large c.w driving powers are necessary. Secondly, all semiconductors exhibit parametric capacitance and, with the large voltage excursions experienced in high-power modulators, considerable phase modulation is introduced into the output signal making pre- or post-modulation phase correction necessary.

Low-level modulation followed by transistor linear amplifiers is not an attractive solution for, while phase modulation may be reduced to acceptable proportions, the circuit complexity approaches that used for i.f modulation without the benefits provided by the i.f modulation system.

Low-level vestigial sideband shaping can be included almost anywhere in the linear r.f chain, but the filter must be adjustable for all channel frequencies. Group delay equalization of the vestigial sideband must be performed as a pre-distortion at video, as it is at present impossible to provide accurately adjustable group delay equalizers in the v.h.f bands. As is well known, group delay predistortion at video frequency cannot provide accurate equalization to the two differently shaped sidebands and a compromise adjustment must be adopted.

u.h.f

U.H.F transmitters invariably use output linear amplifiers employing multi-cavity klystrons, travelling-wave tubes or gridded valves. With the high gains provided by these devices modulated drive level requirements are quite modest, usually a few watts. This modulated drive level may readily be obtained from a solid-state modulator and the u.h.f variable capacitance diode modulator, pioneered by The Marconi Company, is the most used arrangement. Because of the low output power requirements the c.w drive level is acceptably small. Incidental phase modulation introduced by the modulator is of sufficient magnitude to require pre-phase modulation of the c.w drive signal to provide incidental phase modulation cancellation.

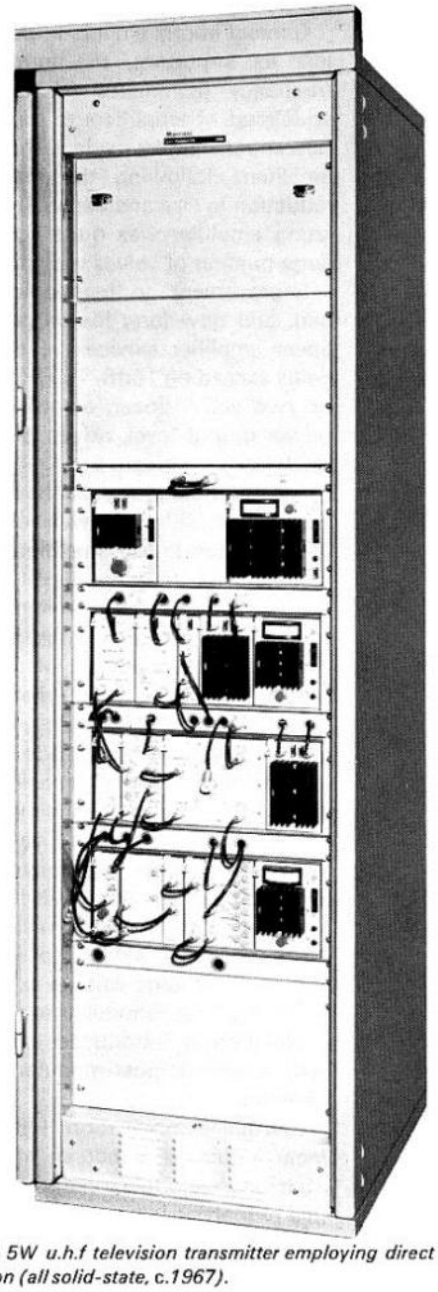

Fig.4 5W u.h.f television transmitter employing direct modulation (all solid-state, c.1967).

The vestigial sideband shaping filter can be placed between the modulator and the output linear amplifier but needs to be adjustable for all channel frequencies. If it is placed at the input to a klystron amplifier two undesirable effects are introduced. Firstly, intermodulation products generated in the klystron produce signals in the lower (suppressed) sideband region which, in effect, modifies the flank response of the over-all amplitude/frequency characteristic. The second effect is due to the level dependency of the klystron frequency response which introduces differential amplification of the sideband frequencies. As the sidebands are not of equal bandwidth the resulting distortion makes independent high and low-frequency (differential gain and line-time) correction necessary.

Earlier remarks concerning the group delay equalization of sideband frequencies near to carrier apply equally to v.h.f and u.h.f transmitters.

I.F MODULATION

In the i.f modulation system the video signal is first modulated onto a fixed intermediate-frequency carrier wave which, after amplification, is heterodyned to the required radiated frequency. This indirect method of modulation enables some of the problems associated with direct modulation to be overcome in a relatively straightforward and economical manner.

Incidental phase modulation

The vision modulation process can conveniently be carried out at a power level of a few milliwatts. If low-impedance circuits are used the signal voltages in the modulator will be small. Hence variations in the inherent parametric capacitance of the semiconductor devices can be held to small values resulting in a very low level of phase modulation. Additional advantages are immediately obvious. The use of small signals means that the video modulator and the intermediate-frequency c.w drive circuits can be small, simple and reliable.

Amplification of the modulated signal at intermediate frequency presents few problems as wideband untuned transistor amplifiers with negative feedback can be designed with excellent linearity and gain stability.

Vestigial sideband filter

The vestigial sideband filter may be included in the intermediate-frequency amplifier chain. In the thirteen major television systems only two different vestigial sideband amplitude/frequency characteristics are used. If the filter is designed with a low-

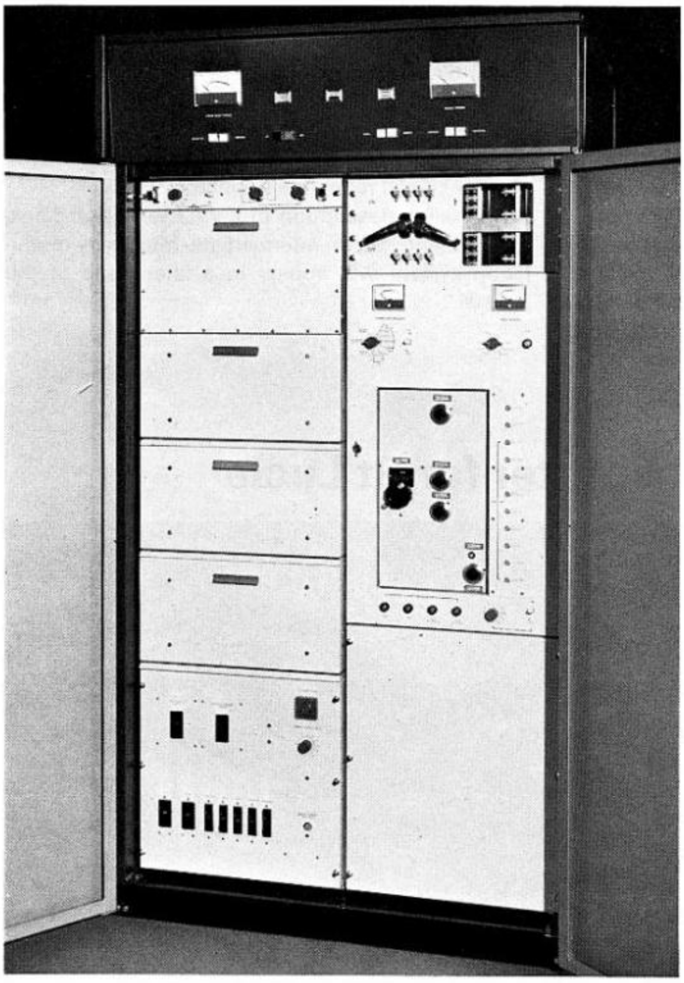

Fig.5 The latest Marconi 1kW v.h.f television transmitter employing i.f modulation (one thermionic valve otherwise all solid-state).

pass configuration (i.f modulation normally employs inverted sidebands), and the vision i.f carrier frequency is made the same for all systems, only two filter designs are necessary for all v.h.f and u.h.f television channels.

V.S.B filter group delay equalization

Group delay pre-distortion at video frequencies must apply equal correction to the upper and lower sidebands of the modulated signal and, as the group delay errors of the two sidebands are different, only an average value of correction can be applied. Thus neither sideband is correctly equalized. The characteristic dip in the amplitude/frequency response near to carrier frequency also results from this compromise adjustment.

However, when group delay equalization is applied at the intermediate frequency after modulation, each sideband can be independently corrected. Not only does this reduce the transmitter group delay errors, but the amplitude/frequency response remains unaffected.

The v.s.b filter and group delay equalizer can be designed as an entity to provide the correctly shaped vestigial sideband amplitude response with a linear phase characteristic.

Differential gain correction

Differential gain correction may be achieved by pre-distortion of either the video signal or the modulated i.f carrier. If the video signal is pre-distorted and a v.s.b filter is included before, for example, a klystron amplifier, additional circuits for the correction of line-time non-linearity are also required.

When pre-distortion is applied to the modulated i.f carrier after bandwidth limiting by the v.s.b filter, wideband aperiodic circuits, embracing low and high sideband frequencies can be employed to apply equal correction to colour subcarrier and line-time frequencies. For this technique to be successful it is necessary that all i.f and r.f circuits following the linearity correction circuits should have wide-band amplitude responses extending well into the lower (vestigial) sideband region.

COMPARISONS

Circuit complexity

The circuitry required for the vision chain of a transmitter employing i.f modulation is more complex than that necessary for direct modulation. With i.f modulation two highly-stable oscillators, one at vision i.f carrier frequency and the other at (normally) vision radiated carrier plus vision i.f carrier frequency are required. The heterodyne oscillator chain and the vision mixer have to be provided for translating the vision i.f signal to radiated frequency and solid-state linear amplifiers are necessary to raise the power from the mixer to a level sufficient to drive a thermionic valve amplifier. For v.h.f signals up to 230MHz, linear solid-state amplifiers providing 60W (sync level) output power have been developed by The Marconi Company and, by the application of new techniques, problems of dynamic and thermal stability have been successfully solved. For u.h.f transmitters, only 2W or 3W of output power is required to drive t.w.t or klystron amplifiers, and this level can readily be obtained from u.h.f transistor circuits.

For direct modulation transmitters employing high-power solid-state vision modulators, the c.w drive level is, of necessity, large and pre- or post-phase modulation must be applied to ensure acceptable levels of incidental phase modulation.

V.S.B filter

Two low-power fixed-frequency filters provide vestigial side-band shaping for all of the television channels in the major world systems in Bands I, III, IV and V when i.f modulation is employed. With the direct modulation system the v.s.b filter has to be tuned to the required channel frequency.

Group delay equalization of sidebands near to carrier frequency

Pre-equalization at video frequency of the group delay errors introduced by the v.s.b filter entails compromise adjustment which is just adequate for most purposes. Modulation at i.f enables independent group delay equalization of the two sidebands without compromise, leading to smaller transmitted group delay errors.

Differential gain correction

The ability to provide differential gain pre-correction at intermediate frequency can lead to the elimination of the additional line-time linearity correcting circuits that are sometimes necessary when video frequency pre-distortion is used.

TELEVISION SOUND TRANSMITTER

Most television sound systems employ frequency modulation of the sound carrier and normally a combination of frequency multiplications and mixing to raise the basic frequency of the frequency modulator to radiated frequency. The techniques employed are similar for intermediate frequency and non-intermediate frequency systems, but the i.f system enables the frequency modulator to operate on a fixed frequency per system, with the attendant advantages of common spares and common frequency crystal reference oscillators.

A detailed description of a v.h.f television transmitter employing an intermediate-frequency modulation system will appear in a later issue of this journal.