UL Output Transformers

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Stability of " Ultra Linear " Push-Pull Output Stages at High Frequencies

THE advantages afforded by the "ultra-linear" circuit for push-pull output stages have now been well established, but the necessary conditions to be met when designing the associated output transformer have not always been given the attention they deserve. This is especially true of the high-frequency performance, where one of the main troubles is the appearance of peaks in the frequency response, which in extreme cases lead to continuous oscillation. In this article it is hoped to explain the two main modes of possible oscillation and to show how, by suitable transformer design, and in extreme cases, with external components, these troubles can be minimized. Due to the distributed nature of the relevant components in a transformer (e.g., stray capacitance) any "lumped constant" explanation can at the best be only approximate, and the following arguments should not be taken

Fig. I. Basic circuit of a push-pull UL output stage.

as rigorous proofs, but only as simplified indications of the factors involved.

To conclude the article a transformer suitable for an N709 "ultra-linear" push-pull output stage, such as in the Osram "912" amplifier, is described.

The two main modes of oscillation in a push-pull UL stage can be classified as:—

(i) Oscillation involving cross-coupling between the valves in the output circuit.

(ii) Oscillation of one or both of the output stages, more or less independently.

Fig. 1 shows a typical basic circuit of a push-pull UL output stage. Unfortunately an equivalent circuit at high frequencies consisting of an array of leakage inductances cannot be drawn for such a circuit. Hence, to show the causes of the above modes of oscillation it is necessary to simplify the

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circuit. The maximum number of windings which can be dealt with if an equivalent high-frequency circuit is drawn is three, whereas in the above circuit there are effectively five windings. For a three-winding transformer the equivalent leakage inductance circuit can be drawn as three star-connected leakage inductances as illustrated in Fig. 2.

To consider the first cause of oscillation the original transformer winding arrangement must therefore be simplified as shown in Fig. 3.

Now, assuming this simplification is valid, it can be seen that if $L_{A1} >> L_{A2}$ then at high frequencies the screen of V1 becomes effectively coupled to A2 and not to A1. If, at the same time the screen of V2 becomes effectively coupled to A1, then a cross-coupled system similar to a multivibrator results. Besides this mode of cross-coupling it is also possible for one to be formed by stray capacitances.
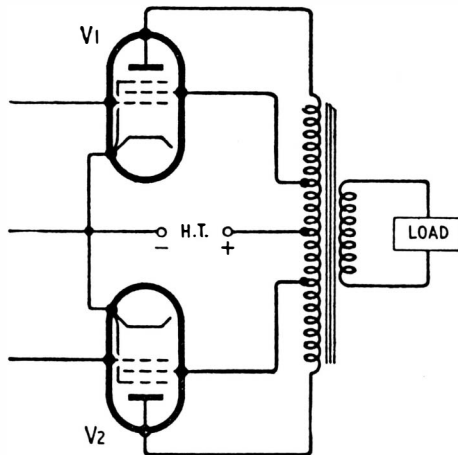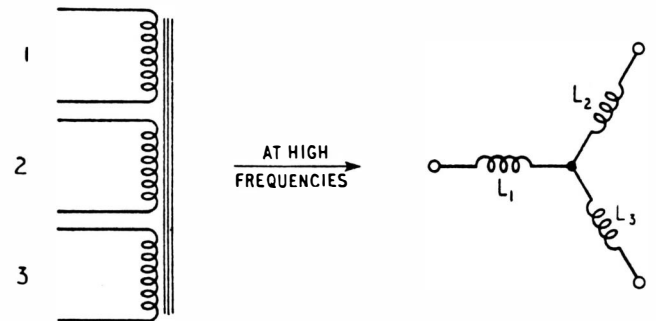

Fig. 2. Three-winding transformer and its equivalent circuit at high frequencies. L_1, L_2 and L_3 are leakage inductance components associated with each winding. An " ideal " transformer should be inserted in two of the limbs to allow for differences in impedance level, but these will be omitted.
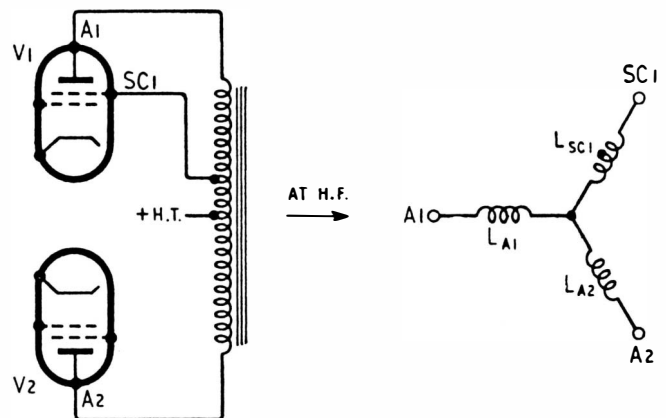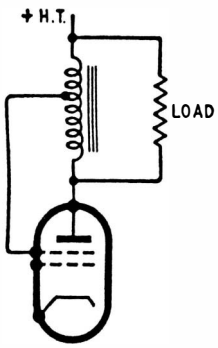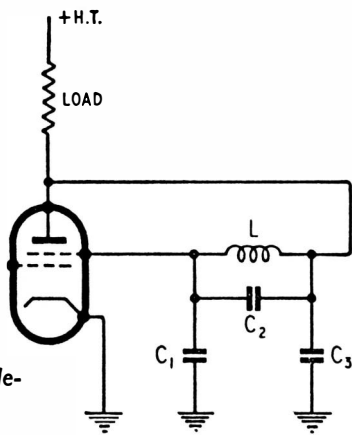

Fig. 3. Illustrating the origin of cross-coupling between opposite halves of a push-pull stage.
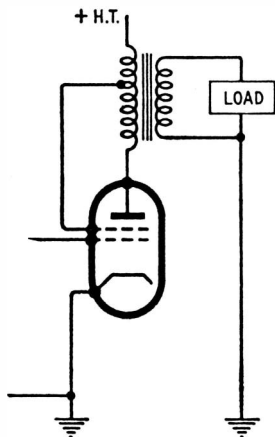
Above : Fig. 4. Simple single-ended UL output stage.

Above Right : Fig. 5. Equivalent circuit of Fig. 4. L is leakage inductance and C_1, C_2, C_3 are stray capacitances.
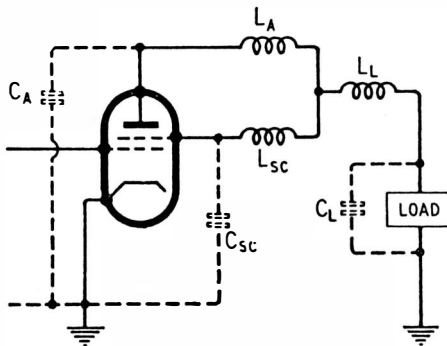

Fig. 6. The addition of a secondary winding modifies the conditions shown in Figs. 4 and 5. L_A, L_{SC} and L_L are leakage inductances and C_A, C_{SC}, C_L stray capacitances associated with the three elements of the transformer (and load).

Hence for stable operation both of the above faults must be avoided. If a transformer happens to violate the above conditions, matters can often be improved by connecting small capacitors between anodes and their respective screens.

The second cause of oscillation can best be dealt with by consideration of a single-ended output stage. Fig. 4 shows the simplest of output stages with a tapped choke and the load connected directly to the anode.

Assuming that the choke can be represented as a two-winding transformer, an equivalent circuit as shown in Fig. 5 can be drawn.

This is the Colpitts oscillator circuit, and if the damping is sufficiently small and the ratio of the stray capacitances correct then oscillation can result. If this trouble occurs it can usually be cured by artificially increasing C_2 or better by increasing the damping at high frequencies only, by connecting a series resistor and condenser combination across C_2. The condenser is necessary to avoid loss of power within the working range.

The inclusion of a secondary winding on the simple tapped choke circuit of Fig. 4 produces an additional complication. Fig. 6 illustrates such a circuit with the equivalent high-frequency circuit.

By suitable winding arrangements it is possible to reduce either L_A, L_{SC} or L_L effectively to zero. Fig. 7 illustrates this point.

The first and second of these possibilities can be used, but in general the third should be avoided unless the load is purely resistive. If the load has a shunt capacitive component (as in Fig. 6) then a capacitance exists directly between the junction of L_A and L_{SC} and earth. A two-section L-C ladder filter type of network is then produced which causes considerable phase shift with little attenuation, so increasing the possibility of oscillation.

From the foregoing brief discussion the relevant conditions to be observed can be summarized as : —

(i) The inductive coupling between a screen and its associated anode must be kept tighter than with the other anode or the load.

(ii) Stray capacitive coupling between a screen and the opposite anode must be kept small.

(iii) The magnitude of the leakage inductances, anode (1) to screen (1) and anode (2) to screen (2), and the anode and screen capacitances to earth should be kept as low as possible since the higher the frequency at which "single-sided" oscillations are liable to occur the more easily they will be effectively damped.

To satisfy these requirements there is one main condition to be observed: —

"Each half-primary should, if possible, be wound without being sectionalized with the other half-primary or the secondary. If it is necessary to sectionalize each half-primary, then the sections must contain screen and anode subsections in the same propor-
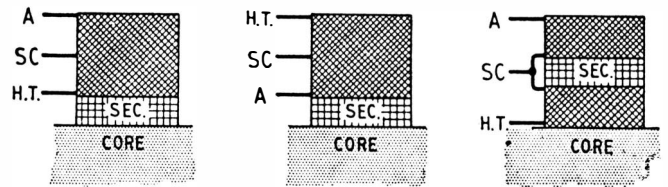
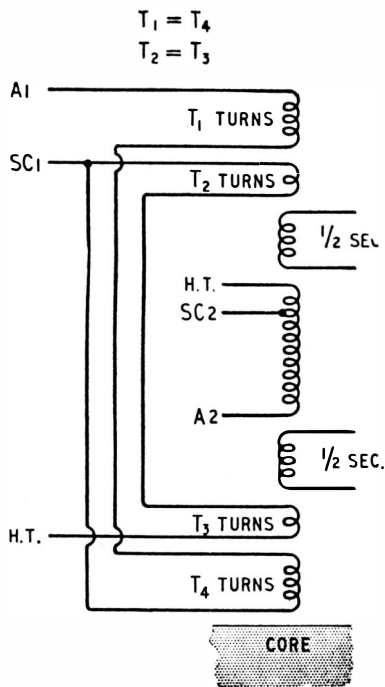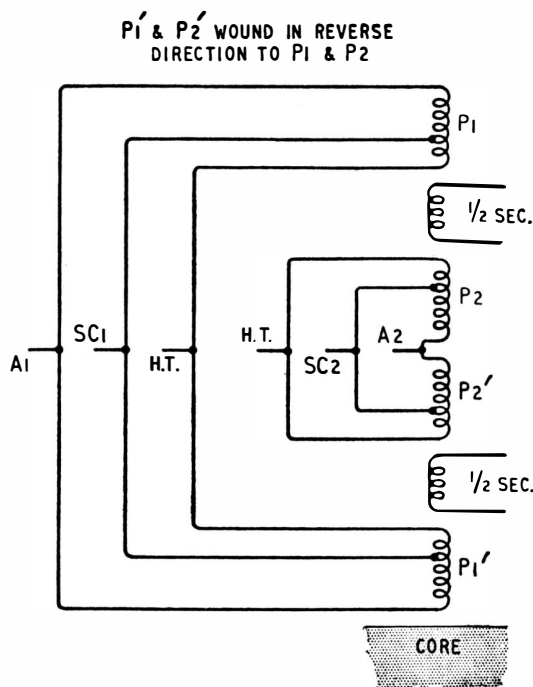Fig. 7. Winding arrangements required to reduce any one of the three principal leakage inductances to a minimum.
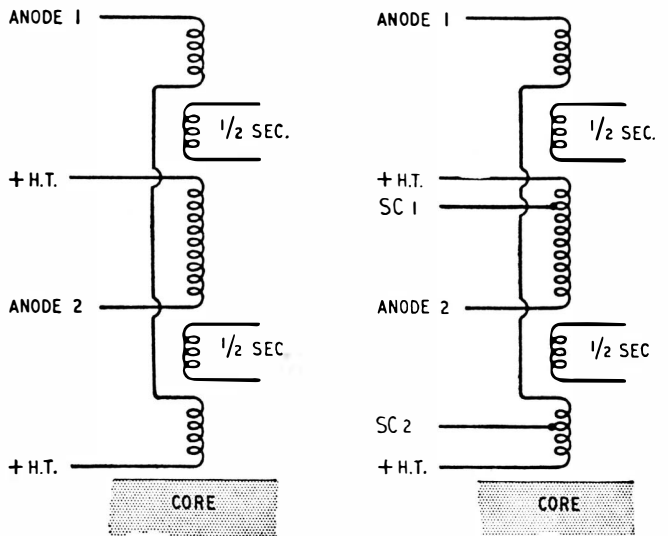
Figs. 8 and 9. Typical sectionalization of output transformer for normal operation with triodes or tetrodes. If tapped for UL operation in this manner, instability is likely.

T₁ = T₄
$T_1 = T_4$
$T_2 = T_3$

P1' & P2' WOUND IN REVERSE
DIRECTION TO P1 & P2

SERIES WOUND SECTIONS

PARALLEL WOUND SECTIONS

Fig. 10. Alternative ideal winding arrangements conforming to the criteria for stable operation in the UL circuit.

Fig. 11. Simplified winding arrangement for UL operation which gives good results in practice.

SEC. 1 & 2 IN SERIES — 15 Ω
— · · — · · PARALLEL — 3·7 Ω

Fig. 12. Practical winding sequence equivalent to the circuit of Fig. 11. Details of a transformer for use with N709 valves in UL push-pull are given in tabular form below.

tion as the complete half-primary. Alternatively the sectionalizing can be done by connecting complete half-primary sections in parallel."

To clarify this statement the following case can be considered. Fig. 8 shows a typical winding arrangement for use with triodes or tetrodes. To convert this to "ultra-linear" operation the simple arrangement of Fig. 9 should not be used, since it violates the design condition and is liable to be unstable. Instead the arrangements shown in Fig. 10 can be used, both of which conform to the design condition. The first employs series-connected sections and the latter parallel-connected sections. Unfortunately both are rather complicated and if a very low half-primary to half-primary leakage inductance is not of prime importance, then, by reversing the positions of the primary and secondary windings, a much simpler but nevertheless very satisfactory winding arrangement results. Fig. 11 illustrates this winding arrangement which is suitable for most "ultra-linear" output stages up to the 30-watt class.

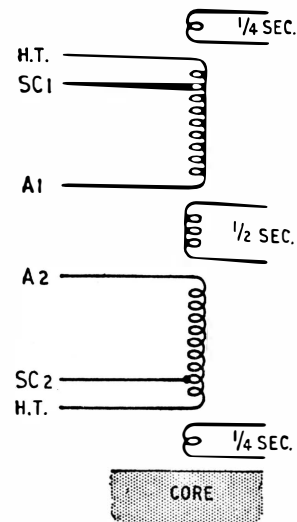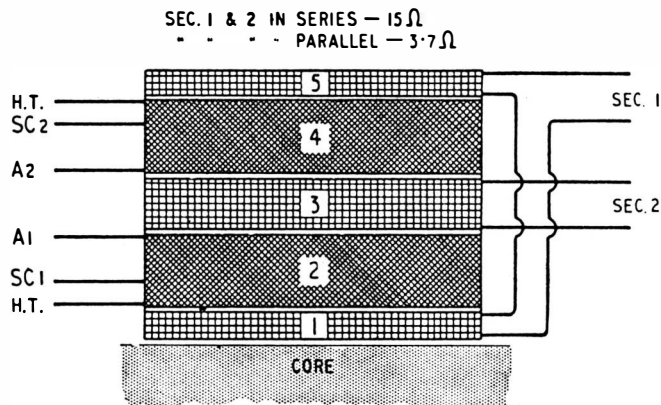As a rider to this section it must be said that transformers not designed to the above principles are not necessarily unstable but in general require external stabilization, whereas the above designs in general do not.

Before specifying the design of the output transformer, which as far as low and middle frequencies are concerned can be designed along conventional lines, one factor which is often questioned should

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Design for UL Output Transformer for N709 Valves in Push-pull.

Core: 1¼-in stack of No. 29a, 0.014-in thick Stalloy laminations.

Windings (from core)—See Fig 12:
(1) 45 turns of 22 s.w.g. enamelled copper wire, wound in one layer.
    2 turns of 5-mil. Empire cloth.
(2) 1,940 turns, tapped at 390 turns, of 38 s.w.g. enamelled, 178 turns per layer, 3-mil. paper interleaving each layer.
    3 turns of 5-mil. Empire cloth.
(3) 90 turns of 22 s.w.g. enamelled in two layers.
    3 turns of 5-mil. Empire cloth.
(4) 1,940 turns, tapped at 1,550, 38 s.w.g. enamelled.

178 turns per layer, 3-mil. paper interleaving.
3 turns of 5-mil. Empire cloth.
(5) 45 turns of 22 s.w.g. in one layer.
1 turn of 5-mil. Empire cloth.

Test Specification:
Primary d.c. resistance 520 ohms, anode-to-anode.
Secondary d.c. resistance (on "15 ohms") 1.2 ohms.
Primary inductance at 5V, 50c/s   75 H
Leakage inductance, primary—secondary, referred to primary   28—30 mH
Leakage inductance A1–SC1   10 mH
Leakage inductance A2—SC2   9 mH
Leakage inductance ½ primary to ½ primary 24 mH

be explained. It is often asked how such small "ultra-linear" transformers (e.g., Gilson W0710) can possibly have the low-frequency performance specified. This can be explained as follows. Distortion at low frequencies for a given transformer is approximately proportional to $\dfrac{r_a \times R_L}{r_a + R_L}$, where $r_a =$ effective a.c. anode resistance and $R_L =$ effective load resistance; and hence the lower the effective r_a the lower will be the distortion. Tetrodes have a high effective r_a, and triodes a low effective r_a but also, unfortunately, a low power efficiency. Transformer dimensions increase as the standing anode current increases owing to the greater space required for the primary winding which carries the sum of the standing valve current plus the current due to the power absorbed in the load. Now the "ultra-linear" circuit combines a low effective r_a with a high efficiency and hence the transformer need not have an excessively large primary inductance and can be wound with relatively thin wire. This produces a transformer whose dimensions are therefore smaller than those of a similar component for either a triode or a tetrode output stage.

An important advantage of this is that in a practical case the leakage inductances can be kept small without complicated sectionalization, such as would be found necessary for a transformer in a triode output stage.

TECHNICAL MAN-POWER

Education, Recruitment and Training of Engineers and Technicians

"WE are acutely aware that the demand for highly trained technologists is going to grow and at an ever-increasing rate as fields like electronics and nuclear energy are exploited and as more and more established fields of industry apply modern techniques. Only the strongest measures will prevent the present gap between supply and demand becoming greater than it is already." So concludes the report on the recruitment of scientists and engineers by the engineering industry, recently issued by the Government's Advisory Council on Scientific Policy*.

This is but one of the many warnings on the deficiency of technical man-power during the past few weeks. Whilst it is true that there is an increasing shortage in industry generally, it is particularly true of the radio industry.

Speaking recently at a luncheon of the Radio Industries Club, Ian Orr-Ewing, M.P., who in addition to being a director of Cossor's is also a governor of Imperial College, reviewed the technical man-power position of the nation generally and the needs of the radio industry in particular and went on to outline steps that could be taken to meet this need. That there is a shortage is undeniable. Of 206 situations vacant in a recent issue of the *Daily Telegraph*, 142 were for technical personnel; unfilled vacancies on the Technical and Scientific Register of the Ministry of Labour on November 14th totalled 5,090. Not only is there a shortage in industry and in the technical branches of the Government services, but, by comparison with the U.S.A. and the U.S.S.R., we have—per head of population—less than one-half the number of technical and scientific staff in our technical schools, colleges and universities.

Increased Government Help

Much is, of course, already being done by the Government to increase the facilities for technological studies. In London £15M is being spent on expanding Imperial College and, as Mr. Orr-Ewing pointed out, the Government is stepping up construction of new buildings in other parts of the country, in fact the expenditure in 1956/57 will be double that of 1954. On the question of the expansion of university facilities for technological studies, opinions differ. One firm in the light engineering industry submitting evidence to the Committee on Scientific Man-power (set up by the Government's Advisory Council on Scientific Policy) stated:— "We believe that any large expansion of university facilities for technological students may well have an adverse effect on the quality of the boys entering industry as student apprentices."

To help independent and direct-grant schools where facilities for teaching science subjects are seriously inadequate through lack of capital resources an "industrial fund for the advancement of science education in schools" has been set up by seventeen major industrial organizations. Among the sponsors are Associated Electrical Industries (which includes B.T-H., Metrovick and Siemens), B.I. Callender's Cables, English Electric (which includes the Marconi companies) and G.E.C.

What can the radio industry do to meet its annual need of one thousand professional electronic engineers of graduate standard and several thousand technicians and technologists with National and Higher National Certificates? In addition, according to the Radio and Television Retailers' Association, there is at present an estimated shortage of some 5,000 trained service technicians in retail shops. On this point, Mr. Orr-Ewing said that if and when colour television arrives we shall need science graduates as service technicians!

Many firms have apprentice schemes which, having been approved by the Ministry of Labour, provide for deferment of National Service until the completion of the apprenticeship. But, as Mr. Orr-Ewing pointed out, more than half the people in the radio industry are employed by firms with no such apprenticeship scheme. The growing tendency towards the introduction of sandwich courses for trainees (alternately six months in the works and six months at college) is a good thing but all too often boys having received their basic technical training in the radio industry leave to join other industries, many of which (although using electronics) have no such training scheme as that sponsored by the Radio Industry Council.

Among the many suggestions made by Mr. Orr-Ewing to "sell radio and electronics to the schools" was the fostering of friendly relationships between science and maths. masters and local firms. He pointed out that many of these masters could undertake consulting and laboratory work, technical writing and holiday jobs and thereby promote a two-way flow of ideas between the academic staff and industry. He also suggested that, in reverse, more part-time teachers could be lent by the industry to local schools.

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* "*Report on the Recruitment of Scientists and Engineers by the Engineering Industry*," H.M.S.O.