# THE

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# A NEW HIGH-EFFICIENCY HIGH-POWER AMPLIFIER

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*A system is described whereby tuned radio-frequency power amplifiers may be designed with anode efficiencies in the range 90%-95% and with output powers 40%-200% higher than those obtainable with Class C amplifiers designed for optimum conditions. In addition the amplifiers are less sensitive to mistuning, lower in radio-frequency harmonic output, more linear in anode modulation and more amenable to calculation than comparable Class C amplifiers.*

## Class C Amplifier Efficiency

NO doubt has existed of the supremacy of the Class C amplifier for power generation since the inception of continuous-wave wireless transmission. It is therefore the proper standard by which to assess any alternative system, and an analysis of this familiar type of amplifier will first be made as an aid in understanding the new principles to be described.

In Fig. 1 are shown the waveforms normally associated with the Class C amplifier, where $V_{ai}$, $I_{ai}$, $P_{ai}$ and $\eta_{ai}$ are respectively the instantaneous values of voltage, current, power dissipation and efficiency at the anode.

At the instant of the infinitesimally small time interval $\delta t$, the instantaneous power drawn from the D.C. supply is $V_a . I_{ai}$ or ac.de. The average power drawn from the supply is $V_a . I_a$ where the area under the $I_{ai}$ curve is equal to that under $I_a$ per cycle.

Since the anode-cathode potential is bc, the instantaneous anode dissipation is:

$$P_{ai} = \mathrm{fg} = \mathrm{bc} \cdot \mathrm{de}$$

The energy dissipated at the anode during the period $\delta t$ is fg . $\delta t$, so that the total energy dissipated per cycle is given by the area under the curve $P_{ai}$. This is equal to the area (per cycle) under $P_a$.

Since the instantaneous tank potential is ab, the power to the tank is given by ab . de, and the instantaneous efficiency, neglecting tank losses, is:

$$\eta_{ai} = \mathrm{hk} = \frac{\mathrm{ab} \cdot \mathrm{de}}{\mathrm{ac} \cdot \mathrm{de}} = \frac{\mathrm{ab}}{\mathrm{ac}}$$

The average anode efficiency $\eta_a$ cannot be derived simply from the curve $\eta_{ai}$ since it depends upon the shape of the $I_{ai}$ curve. It is clear, however, that high average efficiency will be achieved if the majority of the anode current flows during the peak period of instantaneous efficiency, that is, if the current pulse $I_{ai}$ is narrow in width and if the tank circuit is properly tuned so that the negative peak of $V_{ai}$ occurs at the pulse centre. Broadening the current pulse increases the size of both " wings " on the $P_{ai}$ curve and mistuning increases one of them rapidly. In either case over-dissipation and inefficiency are the results.

The input power depends upon the area under the $I_{ai}$ curve and the output power is approximately proportional to it, assuming the efficiency to be fairly high in value.

Consequently narrowing the anode current pulse, in order to increase efficiency still further, implies reducing the output power, since the height of the pulse is normally limited by the peak emission rating of the valve. Power valves are therefore designed and used in such a way as to obtain an optimum compromise between power and efficiency. A Class C amplifier designed to operate simultaneously at the maximum ratings of all the valve electrodes usually gives out maximum possible power and develops an efficiency varying from about 70% for an H.F. valve to 60% for a V.H.F. valve or 50% for a U.H.F. valve. Under-running any valve by narrowing the current-pulse width will increase the anode efficiency up to a maximum of 100% at zero output, but the economic limit of under-running is, e.g., about 85% for an H.F. valve. Additional limitations encountered by the higher-frequency valves are anode-seal cooling and tank-circuit efficiency, both of which benefit from a lowering of $V_a$ and raising of $I_a$. This tends to shorten ab (Fig. 1) and to lengthen bc, which gives a lower optimum efficiency.

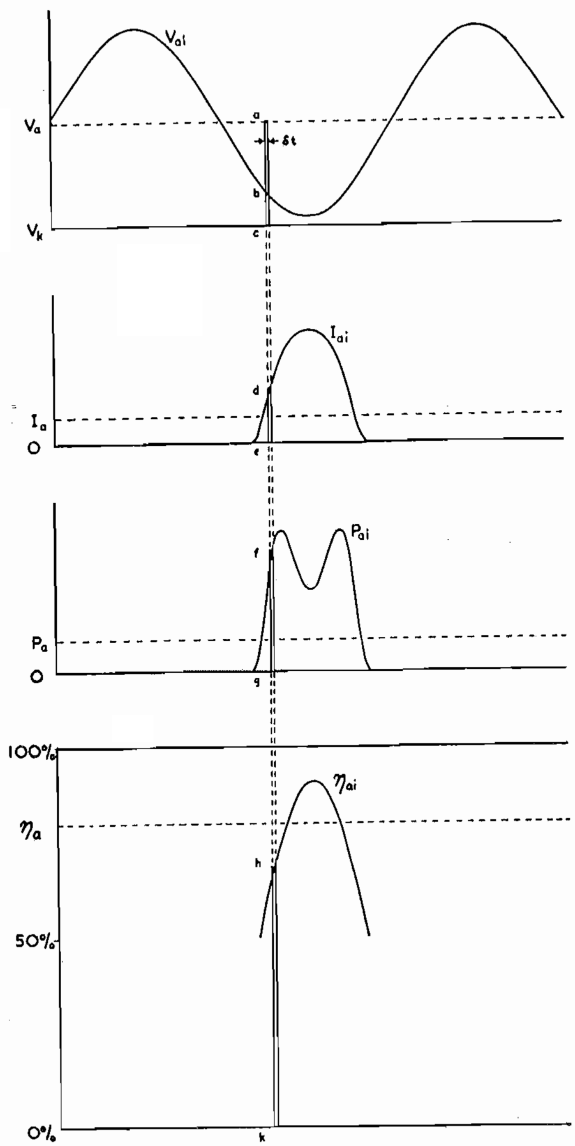


FIG. 1

## Early High-Efficiency Amplifiers

At the outset of C.W. transmission it was realized that if the anode voltage waveform were flattened at the negative peak a broad current pulse could be used without loss of efficiency. This involves harmonic tuning of the anode and a reasonable circuit for the purpose is one similar to that shown in Fig. 2, where $f$ is the fundamental tank frequency and $2f$ and $4f$ are harmonic frequencies. In principle, an infinite number of even-harmonic resonators can maintain an anode voltage waveform as in Fig. 3, while odd-harmonic resonators can maintain the waveform of Fig. 4.

Various patent specifications have been published on these lines, notably by G.D.T. (German 1917), Round (1919), Robinson (1922) and Royden (1945). In the first three of these it was held to be important that the grid voltage waveform should possess (more or less) the same harmonic components as the anode voltage waveform. The Royden patent made no exact statement of the impedances offered by the anode circuit to the harmonics in the drive waveform, beyond indicating that some lower harmonics encountered the load resistance, while all higher ones encountered the unspecified reactances in the stop-band of a low pass filter. The intended principle of operation of the circuit is obscure.

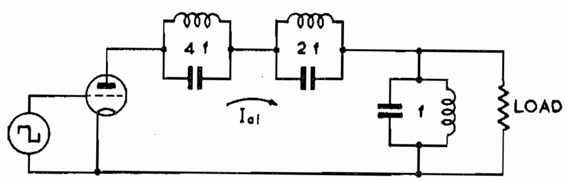


FIG. 2

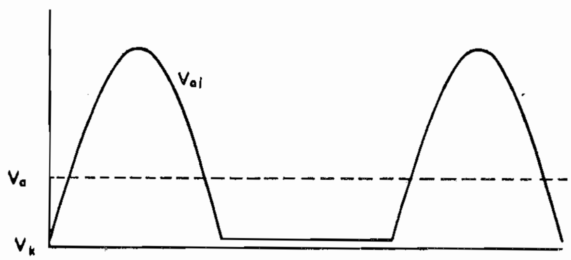


FIG. 3

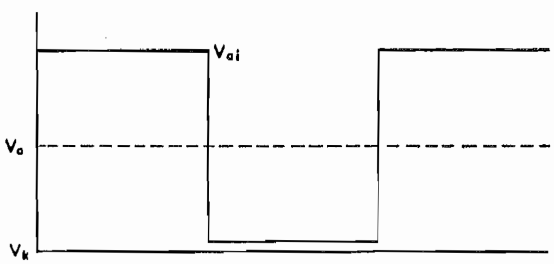


FIG. 4

In the G.D.T. and Round amplifiers, the harmonic resonators were made lossy or loaded with resistors in order that the anode circuit should present the same resistance to the harmonic as to the fundamental anode current. The anode voltage and current waveforms could then be replicas of the drive waveform. Unfortunately, the harmonic resistors dissipated power uselessly and the efficiencies were not high by modern standards. The circuits were justified, however, in that a larger input (and therefore a larger output) was possible for a given valve because a part of the inevitable loss was dissipated outside the valve envelope.

In the Robinson generator the resonators were unloaded and developed high impedances which opposed the flow of harmonic current. Where few harmonic resonators were used the current was of a spiky, complex waveform. Where many were used it tended towards a sine wave. In either case the ratio of power component to peak current was not high. The original device was driven by a mechanical interrupter; if a power valve were used it is probable that grid dissipation would limit the output to a relatively low level, since the amplifier would be heavily driven at frequencies for which high anode impedances existed.

## The High-Efficiency High-Power Amplifier

In its simplest form the new amplifier employs the circuit of Fig. 2, with loss-free harmonic resonators, and superficially resembles its predecessors. The important difference, which yields all the advantages of the system, is that the effective drive waveform is totally devoid of those harmonics for which anode resonators have been provided.

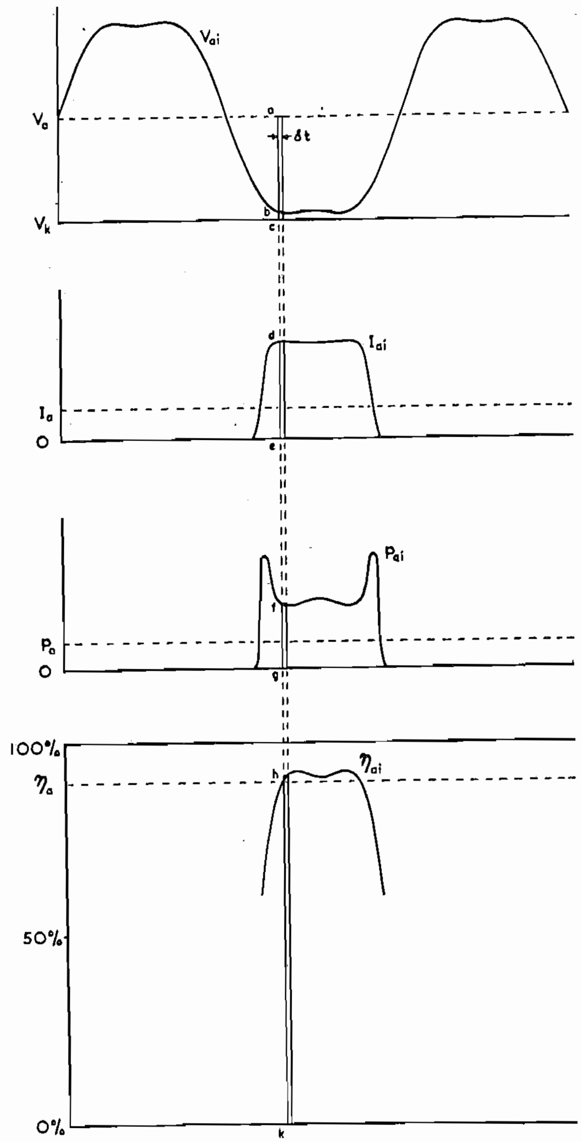


Fig. 5

For example, if the anode waveform is as in Fig. 3, and is maintained by even harmonic resonators, a simple square wave drive is used (i.e. the waveform of Fig. 4), giving 180° of valve conduction in each cycle. Such a waveform possesses only odd harmonics.

An acceptable approximation to the waveform of Fig. 4 is obtained by employing a single third harmonic resonator, which gives the $V_{ai}$ waveform of Fig. 5. An amplifier using this anode waveform can be driven by a rectangular pulse, 120° in length on the time scale, which will produce a similar pulse of anode current; $I_{ai}$ in Fig. 5 is an acceptable approximation to the required shape at high frequencies.

Comparing the corresponding waveforms (which are drawn to scale) in Figs. 1 and 5, it will be seen that the new amplifier tolerates a broad anode current pulse without loss of efficiency or excessive demands upon peak emission. Also, the instantaneous efficiency $\eta_{ai}$ is high and constant, so that the average efficiency $\eta_a$ is also high, notwithstanding that substantial values of

$I_{at}$ are drawn at parts of the cycle remote from the negative peak of tank voltage. These two considerations explain the high power output and high efficiency which are exemplified at two different power levels by the following results obtained with experimental amplifiers.

| | | |
|---|---|---|
| (*a*) | Type of transmission ... ... ... | Telegraphy |
| | Frequency ... ... ... ... | 1 Mc/s |
| | Valve ... ... ... ... ... | QY3-125 tetrode (equivs.: TT16D, 4-125A) |
| | Anode dissipation ... ... ... | 125 w. |
| | Output to load ... ... ... | 1,000 w. |
| | Output including tank loss ... ... | 1,175 w. (c.f. published max. Class C output: 375 w.) |
| | Anode efficiency ... ... ... | 90·4% |
| (*b*) | Type of transmission ... ... ... | Telephony (anode modulation) |
| | Frequency ... ... ... ... | 1 Mc/s |
| | Valve ... ... ... ... ... | BR189 triode |
| | Anode dissipation ... ... ... | 4·9 kW (rating: 27 kW max.) |
| | Output to load ... ... ... | 73·2 kW carrier (c.f. normal Class C: 50 kW) |
| | Output including tank loss ... ... | 74·5 kW carrier |
| | Modulation-crest output to load ... | 287 kW (N.B. $4 \times 73{\cdot}2 = 292{\cdot}8$ kW) |
| | Anode efficiency ... ... ... | 93·8% carrier (N.B. This changes very little at 100% modulation) |

This amplifier can operate indefinitely at 100% sinusoidal modulation without exceeding the rating limits of the valve.

## Principles of Energy Transfer

In the Class C amplifier, and in the earlier types of high-efficiency amplifier, the fundamental power developed in the useful load is given by the product of the fundamental components of current and voltage at the anode. In the new amplifier, however, a significant addition to this power comes from the interaction of the harmonic current and the fundamental voltage, as modified by the non-linear characteristics of a well-driven valve.

In a linear circuit with complex voltage and current waveforms, no nett energy is developed by a given current in association with a voltage component at any but its own frequency. This is demonstrated mathematically by integrating between limits the product of two simple periodic functions of differing frequency. The value of such an integral is itself periodic with variation of the limits of integration, tending towards an arithmetic average of zero over long periods. However it can have non-zero average values between chosen limits especially over periods shorter than one cycle. This means that if, in the circuit of Fig. 2, the valve is made to conduct only during the periods when energy is being transferred from the D.C. supply to the energy-tank, then the positive part of this periodic energy-transfer can be fixed, as it were. The negative energy-transfer which would normally occur in a linear circuit is, of course, inhibited during the cut-off period of the valve.

The mechanism of this energy-transfer is shown more clearly for a particular case in Fig. 6, where an anode circuit with one second-harmonic resonator produces the $V_{ai}$ waveform shown. The dotted sine wave is the fundamental component, i.e. the tank output circuit voltage. Two separate instants of time are indicated by the vertical strips a-e and p-u.

During the first instant the D.C. supply voltage $V_a$ (= ac) is shared between the three circuit elements so that ax appears across the tank, xb across the harmonic

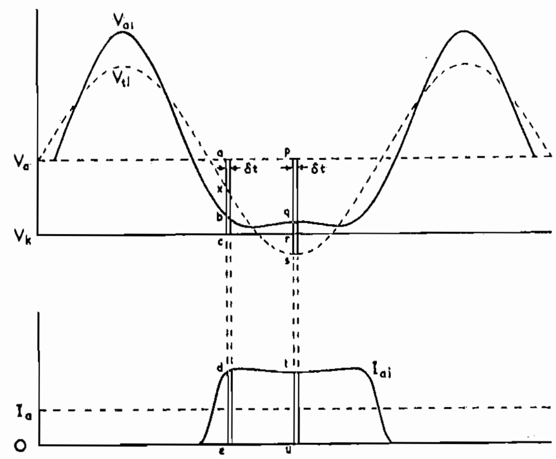


FIG. 6

resonator and bc across the valve. Since the current *de* is common to all three, the respective energy increments received by the three elements are:

Tank: + ax . *de* . $\delta t$ Resonator: + xb . *de* . $\delta t$ Valve: + bc . *de* . $\delta t$

During the second instant the potential difference across the resonator has reversed in sign, so that $V_a$ (= pr) can be considered as the sum:

$$\text{pr} = \text{ps} - \text{sq} + \text{qr} \quad (\text{c.f.: ac} = \text{ax} + \text{xb} + \text{bc})$$

The corresponding energy increments now become:

Tank: + ps . tu. $\delta t$ Resonator: − sq. tu . $\delta t$ Valve: + qr . tu . $\delta t$

In other words, at this instant, the energy flowing into the tank and valve-anode is provided partly from the D.C. supply and partly by the resonator giving up energy acquired during the earlier instant. With any suitable waveform of $I_{ai}$, the nett energy per cycle received by the resonator need be no more than that required to make good its unavoidable loss, whereas the energy throughput can be a substantial amount contributing towards the tank energy, and therefore towards the useful fundamental-frequency.

Clearly, the ideal $I_{ai}$ waveform in Fig. 6 is a rectangle 180° long, since such a waveform gives or takes no energy from the second-harmonic resonator through which it passes, and yet it provides the maximum possible area under $I_{ai}$ (and hence the maximum $I_a$ and maximum output) compatible with a given permissible peak emission. Less sharp waveforms with fewer harmonics are used at high frequencies, but give substantially the performance calculated for the ideal case.

## Drive Waveform

The effective drive waveform may differ from the actual drive waveform applied to the grid, since the valve is cut off for the greater part of each cycle. For example considering an amplifier with a third-harmonic resonator, the drive waveforms of Figs. 7 and 8 are equivalent, since the period and amplitude of conduction (shown shaded) are identical in the two cases. The effective waveform has the same harmonic analysis as the actual waveform of Fig. 7; in both cases the third harmonic and all its multiples are absent, while all other harmonics are present, including the second. But in the actual waveform of Fig. 8 the third harmonic is present while the second harmonic and all its multiples are absent. A further difference is that the grid bias voltage, and hence the drive power, is larger for the drive waveform of Fig. 7.

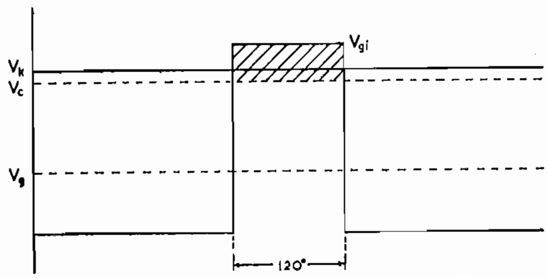


Fig. 7

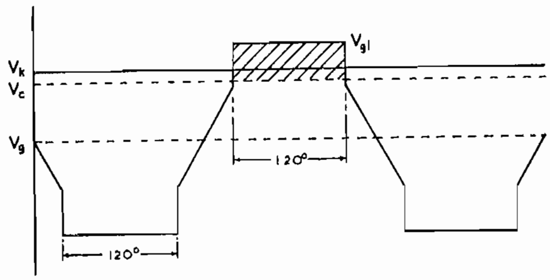


Fig. 8

In practice a drive waveform such as that in Fig. 9 can be employed. It can be shown, for instance, that there is no third harmonic in the top-cap of a waveform containing 15% third harmonic if it is cut off at a level of 0·46 of the peak value of the complex wave. Hence the paradoxical situation that a very good way of ensuring second but no third harmonic in the anode current is to provide a grid voltage waveform containing third but no second harmonic!

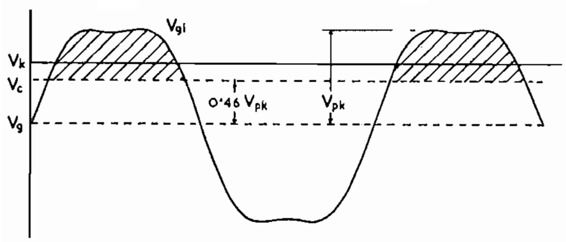


Fig. 9

## Stability of Anode Waveform

A harmonic resonator is of the highest possible "Q" and is not externally loaded. The component of anode current necessary to maintain it in oscillation at the desired amplitude and in the correct phase is therefore negligibly small compared with the power-producing harmonic and fundamental currents passing through it. It would therefore require an impossible precision of drive waveform to ensure the presence, in its correct proportions, of this very small current, were it not for the stabilizing effect of saturation in a well-driven amplifier.

In the waveforms of Fig. 6, bx and qs approximate to the negative and positive peaks of the second-harmonic voltage and are of the order of 35% of $V_a$. The anode-cathode voltages bc and qr are of the order of 10% of $V_a$. If we assume a decrease of peak harmonic making it 30% of $V_a$, then bc increases to 15% and qr decreases to 5%. Assuming sharp saturation and a linear diode line, de must therefore increase by half and tu must decrease by half. This means that a large second-harmonic current component is excited in $I_{ai}$, and it is in such a sense as to oppose the original change in harmonic amplitude. This large current, passing through the high resonator impedance, would produce such a large opposing voltage if it were allowed to develop, that the feedback factor (" Aβ ") of the negative-feedback loop so formed can be shown to be upwards of 30 db. in a typical case.

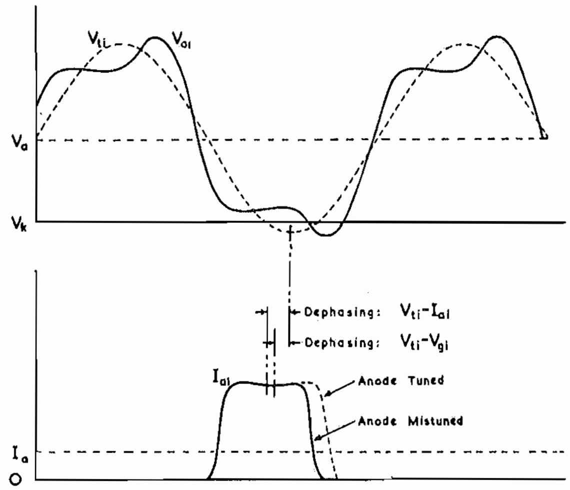


FIG. 10

A similar mechanism stabilizes the amplitude of the fundamental component of the anode voltage, so that, for a given waveform, there is a rigid proportionality between the output voltage and the D.C. supply voltage.

Further mechanisms stabilize the phases of both fundamental and harmonic anode voltages, so that moderate divergencies from the ideal grid waveform are accommodated by changes in the current waveform. The amplifier automatically seeks the best possible compromise in any given situation, provided that full saturation drive is available.

## Auxiliary Advantages

The high stability of anode waveform yields two advantages as compared with Class C operation.

Firstly, the self-accommodation acts to prevent any sharp rise of anode dissipation when either the tank or the resonator is mis-tuned. The normal tuning-dip is observed in the anode feed, but this is an indication of academic operation, not of increased losses. Ideally, even a Class C amplifier, if properly saturated, should show an increase of output power when it is slightly mis-tuned. The corresponding increase of feed which, in the new amplifier, is not accompanied by any great increase of dissipation, serves as a tuning indicator in the orthodox manner. Fig. 10 shows a typical anode voltage waveform which may develop in a mis-tuned third-harmonic amplifier. It will be seen that the anode-cathode potential contrives to remain at a low value during conduction, although the negative peak of the tank voltage ($V_{t1}$) no longer coincides with the centre of the drive pulse.

Secondly, the rigid proportionality between the output voltage and the supply voltage makes the amplifier exceptionally linear with anode-modulation. It is usual to find that the limit of output from a given valve is set by the grid dissipation. If the available dissipation is to be made full use of, while saturation is to be maintained at all times, it is necessary to modulate the drive in an anode modulated amplifier.

Analysis of the $I_{a1}$ pulses of Class C and of high-efficiency amplifiers (Figs. 1 and 5) observed experimentally show that the Class C pulses are richer in lower harmonic frequencies and no less rich in higher ones. This is not surprising, since at least one major low harmonic is carefully removed for high-efficiency working, and the optimum current-pulse is broad and flat rather than narrow and peaked. The result is a rather purer waveform at the output, although high-order low-level harmonics may not be significantly different in the two cases. The tank circuits are similar for the two amplifiers, and may be taken to filter out similar harmonics to a similar degree.

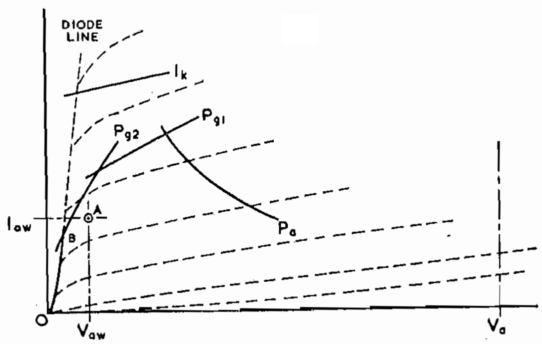


FIG. 11

## Calculated Ideal Performance

If the performance of a given valve is analysed by assuming idealized anode waveforms, such as those in Figs. 3 and 4, the calculation process is so simple that it can be reduced to filling up a form (and, in fact, the author uses such forms for the purpose). Moreover, it is found that experimental amplifiers with far from ideal waveforms diverge from the calculated ideal performance only by small amounts which are easily estimated.

With ideal waveforms the valve is either conducting at constant voltage and current values for all electrodes, or else it is totally cut-off. Instead of having to decide upon an optimum load-line and to check it by point-to-point integrations, the designer has only to decide upon an optimum working point.

This choice is made upon a set of $V_g$-$V_a$-$I_a$ curves (constant voltage or constant current) as shown in Fig. 11. A permissible area for the working point is bounded by lines showing the limits of dissipation, etc., of the various valve electrodes. For example, if the current pulse is 120° wide the valve conducts only for one-third of each cycle and the line $P_a$ is drawn for an anode dissipation of three times the normal maximum. The same factor applies to $P_{g1}$ and $P_{g2}$, but not to $I_k$ which shows the limit of peak cathode emission. $P_{g1}$ and $P_{g2}$ are normally plotted on their own curves and then transferred to the anode curve.

Any working point such as A (Fig. 11) is then chosen within the delimited area, suitably spaced from the boundaries to give reasonable design factors of safety.

Remembering that the valve only conducts for one-third of each cycle, it can now be seen that:

| | |
|---|---|
| Power drawn from D.C. supply ... | $0{\cdot}33\ I_{aw}\ V_a$ |
| Power dissipated at anode ... ... | $0{\cdot}33\ I_{aw}\ V_{aw}$ |
| Power to tank circuit ... ... ... | $0{\cdot}33\ I_{aw}\ (V_a - V_{aw})$ |
| $\eta_a\ (= \eta_{ai})$ ... ... ... ... | $\dfrac{V_a - V_{aw}}{V_a}$ |

The choice of the working point requires experience based upon the actual handling of the circuits but, once it is chosen, the rest of the design follows automatically. Given a valve true to its published characteristics, an amplifier designed in this way displays the predicted meter readings with an accuracy which shows that it has a natural tendency to seek the chosen working point.

For the objective comparison of different valves, the intersection of the grid dissipation line with the diode line (e.g. B in Fig. 11) gives a convenient " ideal optimum " working point. The corresponding optimum amplifier is usually realizable experimentally, but is not safe for production, being without safety-factors.

The tank circuit and resonators are both designed as tanks according to personal ideas of good engineering practice. The essential characteristic of a tank is that the energy stored in free oscillation at the rated voltage shall be many times larger than the throughput of energy per cycle under working conditions. All the necessary information regarding energy-throughput can be deduced after the choice of working point and anode voltage has been made. The KVA and hence, usually, the bulk of, e.g., a third harmonic resonator is about one-fifteenth that of the tank circuit, although its energy-contribution may be as high as one-tenth.

General docility of behaviour is exemplified by the 70kW BR189, experimental amplifier already mentioned. After performance checks, this amplifier has been in use for fifteen months up to the time of writing, as a hack apparatus for testing high-power components. Various random impedances have been connected to the output end of the tank circuit and the circuit tuned by engineers who had no previous experience with this type of amplifier. The original valve is still giving substantially the original meter readings.

## Drive Amplifiers and Complex Tank Circuits

At frequencies up to about 1 Mc/s, aperiodic drive amplifiers can be designed giving good approximations to ideal rectangular waveforms.

Above this frequency, tuned drive amplifiers become necessary, the target being one- or two-harmonic complex grid waveforms (e.g. Fig. 9) with suitable bias arrangements. The waveform of Fig. 9 can obviously be obtained direct from the anode of a smaller high-efficiency amplifier but in general this source will not be properly matched in impedance to the input of the driven stage.

Matching of impedance without distortion of waveform is possible by using complex tank circuits which are electrical equivalents of the series arrangements of resonators hitherto discussed.

The classical " Reactance Theorem " of R. M. Foster (Bell System Technical Journal, Vol. 3, p. 259, April 1924) shows that any possible arrangement of poles and zeros in a two-terminal reactive network can be realized either by series arrangements of parallel resonators and reactances (e.g. Fig. 12) or by parallel arrangements of series resonators and reactances (e.g. Fig. 13) or by hybrid arrangements of both (e.g. Fig. 14). Formulae are given whereby equivalent circuit values can be calculated.

Although the poles and zeros of equivalent circuits obtained in this way are identical, the ratios of the energies stored at different polar resonances are not identical, so that they are not equivalents when considered as resonator-tank combinations. Fortunately it is of no importance in such applications where the zeros may lie between the chosen poles, so that satisfactory tank equivalents can be calculated for any given case by moving the zeros. The circuit of Fig. 14 yields best results in single-harmonic applications.

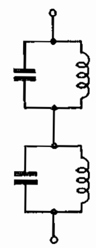

FIG. 12

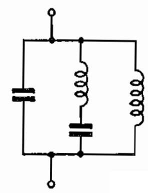

FIG. 13

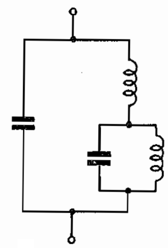

FIG. 14

The parallel-capacitor complex tank (e.g. Fig. 13 or 14) has two advantages. Firstly, at very high frequencies the capacitor may be largely or wholly the internal valve capacity. Where this principle is applied to a final stage amplifier the output is coupled through a frequency-selective network to that element of the tank which has the highest KVA of fundamental energy-storage. Obviously, calculated precautions against harmonic output are needed. Secondly, the capacitor can be split to give voltage division, and hence impedance matching, between the anode and the load. The anode voltage is faithfully reproduced in the load if the circulating current through the capacitor greatly exceeds that drawn by the load.

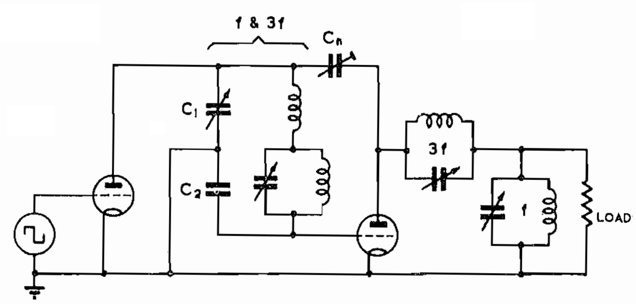


FIG. 15

A typical application of a complex tank is shown in Fig. 15. The ratio of $C_1 : C_2$ determines the degree of impedance transformation. The tap in the split capacitor is earthed so that the anode voltage is in antiphase with the output. This makes it possible to neutralize the driven stage with a very small capacitor ($C_n$) connected between the two anodes.

In general, the complex tank exhibits interaction between the tuning controls.

However, if care is taken to make variable only those circuit elements with a preponderance of energy at one frequency, and if only one control is provided for each frequency present, then tuning can usually be accomplished without difficulty, e.g. in about three adjustments of each of the two controls in the case of the third harmonic complex tank shown in Fig. 15.

### Transmission-Line Tanks and Resonators

At very high frequencies, transmission-line analogues can be made of the lumped-constant circuits already discussed. The multiple-resonance characteristics of a mis-terminated line should be of use if care is taken over stray reactances. Examples of such use are suggested in Figs. 16 and 17 which respectively relate to a third-harmonic and to a multiple even-harmonic amplifier.

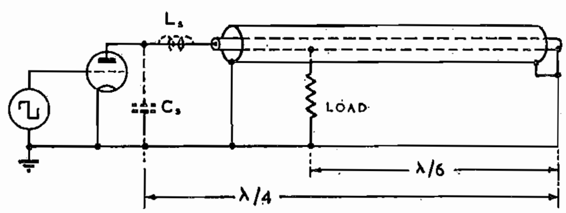


FIG. 16

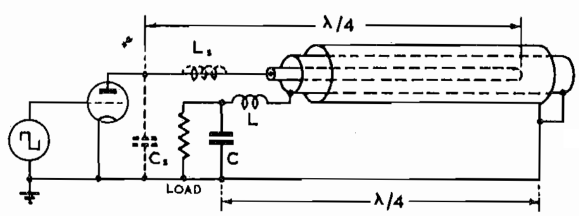


FIG. 17

The short-circuit quarter-wave line of Fig. 16 develops high impedances at the fundamental and at all odd harmonics simultaneously. The high impedances are developed at exact multiples of the fundamental only if the line is terminated non-reactively at both ends. The stray anode capacity $C_s$ must therefore be compensated, e.g. by $L_s$ so that the combination represents an artificial extension of the real line. This extension involves a finite upper cut-off frequency above which clean resonances cannot be obtained. This is not inconvenient since the only harmonic pole required is the third. The load is connected to the inner conductor at a point two-thirds of the electrical line length from the short-circuit. This point is a voltage-node for the third harmonic resonance, which is therefore loss-free.

The open-circuit inner line of Fig. 17 produces poles at every even-harmonic frequency up to the cut-off frequency of $L_sC_s$. The short-circuit outer line, electrically in series with the inner line, produces one significant pole which is at the fundamental frequency. All the other poles are lossy and off-tune relatively to the harmonic spectrum, since the cut-off frequency of LC is only just above the fundamental frequency.

"Cut-off" frequency in connection with transmission-line resonators refers to "phase" cut-off, not to "amplitude" cut-off. Clearly, sharper cut-offs can be obtained with more subtle LC circuits, notably with "*m*-derived" sections based upon an "*m*" of 1·4.

### Driving from a Sine-Wave Generator

Since a master-oscillator normally produces a sine-wave output voltage, it is necessary at some stage in a cascade of amplifiers to effect the conversion from sine-wave to complex-wave operation. This can conveniently be done by the circuit of Fig. 18, in which a resonator of low reactance compared with the anode resonator but tuned to the same frequency is inserted in the cathode circuit. The high degree of negative feedback developed makes it impossible for any significant third-harmonic current to develop, no matter what grid-voltage waveform is employed. In practice, with a sine wave input, correctly related in amplitude with the grid bias, the relative voltages developed between grid and cathode are self-adjusting to the waveform shown in Fig. 9. The exact levels of bias and input and of cathode-resonator tuning are not critical.

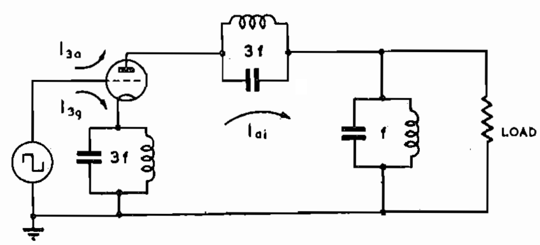


FIG. 18

Unfortunately, it is not always possible to realize the circuit of Fig. 18 because of the finite losses associated with the two resonators. The small third-harmonic currents necessary to make good their losses are in antiphase with each other if considered as circulating in the anode current loop. Both of these currents ($I_{3a}$ and $I_{3g}$ in Fig. 18) must therefore be supplied in the grid current waveform. A valve with a large, stable value of grid current will operate with a comparatively lossy cathode circuit, whereas a "better" valve, operating with a smaller drive power, requires a specially built high-Q resonator. Certain valves with variable, weak, or negative grid current characteristics cannot be used in this circuit. Examples of the various types are the BR191 which tolerates a cathode Q of 100, the BR189 which requires a Q of over 400, and the BR1122 which cannot be used at all.

### Special Valves for High Efficiency Operation

In Fig. 1, let it be assumed that $V_a$ is increased by a given amount and that $V_{ai}$ is increased so that the minimum anode-cathode voltage remains unaltered. The off-centre anode-cathode voltage bc will be increased, de will therefore be increased in a low-$\mu$ triode, or remain the same in a pentode or tetrode. The instantaneous dissipation fg will be increased in either case and the "wings" on $P_{ai}$ will grow to give a substantial increase in average anode dissipation. This cannot be offset by narrowing the anode pulse without losing more than the power gained, assuming optimum working as the starting point.

These considerations indicate that there is no point in designing a Class C valve to withstand more anode voltage than is implicit in the dissipation and emission ratings.

On the other hand, in Fig. 5, the value of bc does not necessarily rise with increase of $V_a$. Apart from an increase in the degree of " dimpling," the sizes and shapes of $I_{ai}$, $P_{ai}$ and $\eta_{ai}$ remain substantially the same for quite large variations of $V_a$. If it is assumed, for example, that $V_a$ is doubled, the output power is also doubled and the efficiency moves halfway towards 100%, while the anode dissipation, peak emission and all feed currents remain constant.

A case therefore exists for designing valves for high-efficiency operation by modifying existing Class C valves in the direction of higher anode voltage ratings, at least for frequencies or designs where adequate margin exists in the cooling of glass-metal seals.

To verify this hypothesis, experimental amplifiers were made with KT45 valves. These valves were originally designed for line-scan use in television receivers, and had a pulse rating of 8 KV on the anode, while possessing a dissipation of 21 watts and other characteristics similar to those of a type of power valve which in normal Class C practice operates at about 600 v. DC. Careful " spot-knocking " of selected valves up to 10 KV gave them a safe D.C. or peak A.C. rating of 6 KV, and they were then operated as high efficiency amplifiers at 2 KV D.C. anode voltage.

Outputs of over 200 watts at 93% efficiency were recorded without overloading, which was compared with the normal Class C output from the same valves at 600 v. D.C. of 38 watts average. With special valves, therefore, an advantage in output power of over 400% relative to Class C was obtained at this dissipation level.

In designing high-efficiency amplifiers with Class C valves it is usual to find that the grid dissipation limits the output power obtainable before other capabilities of the valve are fully utilized. For a given cathode structure, therefore, a valve designed for high-efficiency operation rather than Class C operation should have a heavier grid dissipation, a lighter anode dissipation, and a higher anode voltage rating. Where possible, the excess anode dissipation required for Class C should be exchanged for better anode-seal cooling so that the higher anode voltage rating may not constitute a limit at very high frequencies by reason of the increased seal current.

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