ENGINEERING TRAINING SUPPLEMENT

No. 1

Second Issue

SOME TRANSMITTER PROBLEMS

BY

A. N. THOMAS, A.M.I.E.E.

Edited and Issued by
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FOREWORD

This is the first of a series of Training Supplements on subjects of considerable technical importance to members of the Engineering Division. The material was originally presented in 1946 by the author, A. N. Thomas, in a lecture to the Engineering staff at the Brookman's Park Transmitting Station. The substance of the lecture was taken down in note form and subsequently re-written by a member of the Training Department, L. F. Ostler, who is also entirely responsible for the appendix. The Controller of Engineering considered the contents worthy of a wider circulation and the decision to publish the work in this form was therefore taken.

CONTENTS

SOME TRANSMITTER PROBLEMS

ANODE MODULATION.

The basic action of the modulator is to vary the H.T. on the anode of the modulated amplifier. For 100% modulation the modulator must raise the H.T. on the anode of the modulated amplifier up to twice its value in the unmodulated carrier condition, then reduce it down to zero, then up again to twice its value in the unmodulated carrier condition, and so on. This must be done at the modulation frequency and, of course, in linear relationship to the required modulation waveform.

As far as the modulated-amplifier valve is concerned, the basic modulating process is not affected by the type of modulator, whether it be Class A single-sided, Class A push-pull, or Class B push-pull.

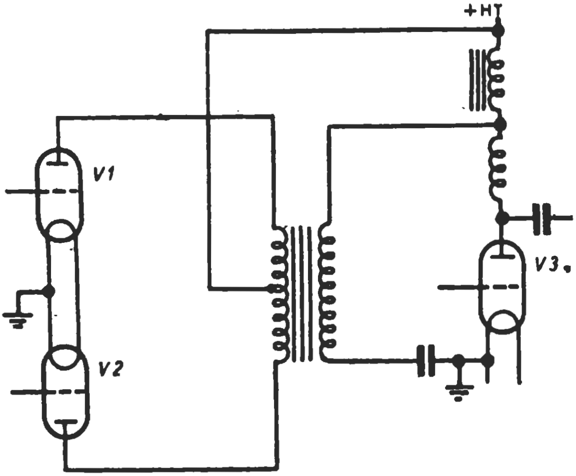


Fig. 1. Simplified Schematic of Circuit Providing Anode Modulation

Theoretically, the effect of modulation upon the modulated amplifier could be reproduced by dispensing with the modulator and by using a control rheostat to raise and lower the H.T. volts on the modulated amplifier. In practice it would not be possible to simulate normal modulation, even tone modulation, by means of the usual type of control rheostat because of the impossibility of operating it quickly enough and in a manner which would give the required waveform. Nevertheless, it is a clarifying thought to regard the modulator as doing a job equivalent to that of varying the H.T. control.

In Fig. 1, the valves V1 and V2 are connected in a push-pull modulator circuit to provide anode modulation of the modulated-amplifier valve V3.

Suppose the d.c. H.T. voltage on the anode of V3 were 10 kV. Then, to produce 100% tone modulation, the modulator must raise the H.T. to 20 kV., then reduce it to zero, then raise it to 20 kV., and so on, the H.T. following the sine law in its variations. The modulator would do this by producing across the secondary of the modulation transformer an alternating peak voltage of 10 kV., i.e., of a peak value equal to the d.c. H.T. on V3.

The modulation transformer has a certain turns ratio. Dependent upon this ratio there is a particular amplitude of voltage which must be produced across the primary of the transformer in order to provide the correct secondary voltage. In the circuit of Fig. 1 this primary voltage is the voltage which is frequently referred to as the 'anode-to-anode voltage' of the modulator stage.

The anode current pulses of the modulated amplifier occur at such a high repetition frequency in comparison with the L.F. modulating frequency that the modulated amplifier acts as though it were a pure resistive load on the modulation transformer, equal to the d.c. resistance of the valve and given by

$$\frac{\text{d.c. anode voltage of valve}}{\text{d.c. anode current of valve}}$$

Dependent upon the secondary load and upon the turns ratio of the modulation transformer, there is a 'referred resistance' which appears

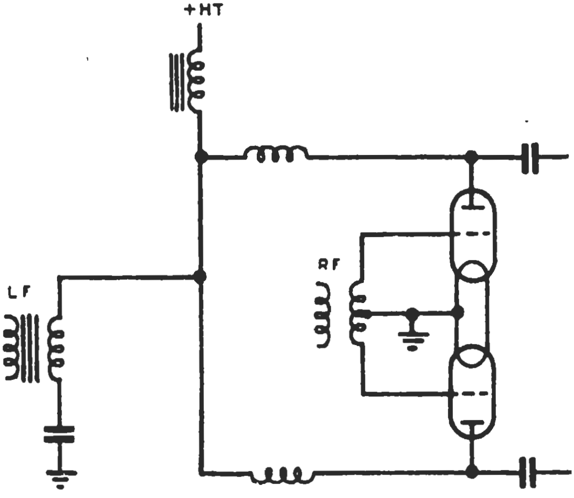


Fig. 2. Simplified Schematic of Anode-modulated Push-pull Modulated Amplifier

across the primary of the transformer and, which is the 'anode-to-anode load' into which the modulator valves work.

When the modulated amplifier contains two valves in push-pull, Fig. 2, the anode potentials rise and fall together at the modulation frequency. Thus, as far as the load on the modulation transformer is concerned, the two valves of the modulated amplifier must be regarded as being in parallel. Therefore, in calculating the load on the modulation transformer, the ratio of the mean H.T. to the *total* mean anode current, (i.e., sum of the two individual mean anode currents), must be taken.

If a carrier is amplitude modulated by sine wave up to 100%, half as much power again as that contained in the unmodulated carrier must be developed, i.e., the power in the 100% modulated carrier is 1.5 times the carrier power in the unmodulated condition. Thus, a transmitter producing 100 kW when unmodulated, produces 150 kW when the carrier is amplitude modulated by sine wave up to 100%. The extra power needed in the modulated condition is provided by the modulator. Thus, to modulate a carrier of 100 kW to 100%, the power output of the modulator must be $50/\eta$ kW., where η is the anode conversion efficiency of the modulated amplifier.

The increase of power due to modulating a carrier must necessarily lead to an increase in the aerial current as indicated on an R.F. ammeter connected in the aerial circuit. For constant resistance, power and current are related by the fact that the current is proportional to the square root of the power. Thus if the average power increases in the ratio 1 : 1.5 then the r.m.s. current increases in the ratio $1 : \sqrt{1.5} = 1 : 1.225$.

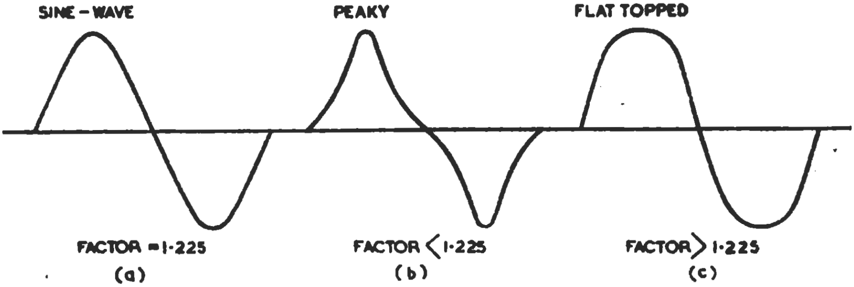


Fig. 3. The Aerial Current Multiplying Factor is Dependent upon the Modulation Waveform

In stating that the aerial ammeter reading for the 100% modulation condition is 1.225 times the reading for the unmodulated carrier condition, we are assuming sinusoidal modulation. If the modulation waveform is 'peaky,' Fig. 3(b), the factor is less than 1.225; if it is 'flat-topped,' Fig. 3(c), the factor is greater than 1.225. The factor will, in fact, be proportional to the area of one half cycle of the modulating voltage, Fig. 3. if the curve is symmetrical about the centre line. It therefore follows that the power in a 100% modulated carrier may be greater than or less than 1.5 times the power in the unmodulated carrier, according to the modulation waveform. One effect on the transmitter of distortion in the programme chain should now be obvious. For example, saturation caused by the overloading of an amplifier would produce flattening of the waveform and cause the power at 100% modulation to be greater than 1.5 times the unmodulated power with a sine-wave modulating input to the amplifier.

CLASS B AMPLIFIERS.

In a Class B system each valve functions as a half-wave rectifier with a pure resistive load.

A d.c. ammeter connected in such a circuit indicates neither peak current, nor r.m.s. current, but the *average* value of the current taken over the full-cycle period

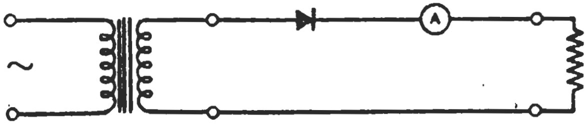


Fig. 4. Half-wave Rectifier

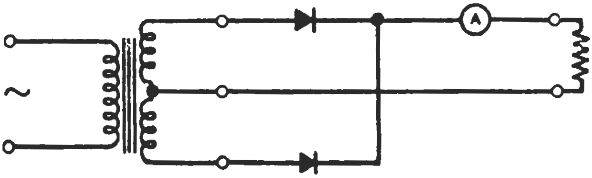


Fig. 5. Full-wave Rectifier

Suppose the meters in the circuits of Figs. 4 and 5 both indicated the same current value. This would show the average values of the current in the two circuits to be equal. It would also indicate that the peak current in the circuit of Fig. 4 is double that in the circuit of Fig. 5. The reasoning is as follows :—

Each pulse of rectified current gives the meter movement one impulse, but for half-wave rectification there is one pulse per alternating cycle, whereas there are two for full-wave rectification. To give the same d.c. reading the half-wave single pulse must have twice the amplitude of the two pulses of the full wave. (See Fig. 6.)

With sinusoidal waveform, the peak value of current in the circuit of Fig. 4 would be π, or 3.14 times the meter reading, while in the circuit of Fig. 5 it would be $\pi/2$, or 1.57 times the meter reading.

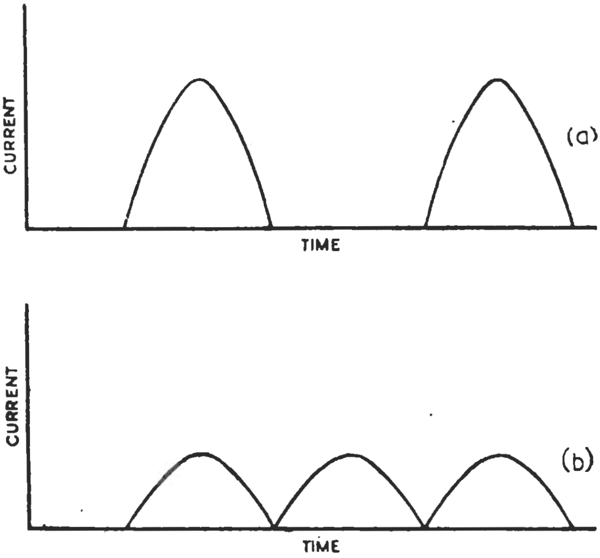


Fig. 6. Rectified Current of (a) Half-wave, (b) Full-wave Circuit when the Meter Readings are Equal

Symbols.

The following symbols are used in the ensuing sections :—

I_{max} = peak anode current.
I_{mean} = mean anode current.
$\hat{I}$ = peak value of fundamental a.c. component.
I' = swing of anode current above the standing-feed value.
I_f = standing feed.
E_{ht} = d.c. anode-to-cathode voltage.
$\hat{V}$ = peak value of fundamental frequency component of anode-to-cathode voltage.
$\hat{V}_t$ = peak value of fundamental frequency component of anode-to-anode voltage in a push-pull stage.
R = anode-to-cathode load resistance.
R_t = anode-to-anode load resistance in a push-pull stage.
$\eta \times 100$ = anode conversion efficiency, per cent.
W_{in} = anode power input of stage.
W = power output of stage.

In a Class B system each valve is a half-wave rectifier. If the anode-current pulses in the circuit of Fig. 7 were true half sine waves then the peak anode current of each valve would be equal to π times its anode-current meter reading. In practice, and to minimise distortion due to non-linearity of the valve characteristic, it is necessary to operate each valve with a small standing feed. As a result, the peak anode current of each valve will be slightly less than π times the meter reading.

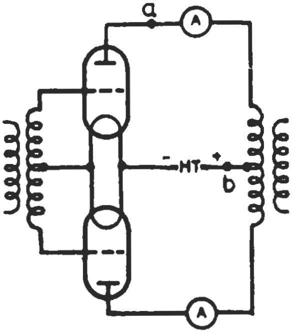


Fig. 7. Class B Push-pull Circuit

In dealing with the fundamental considerations of a Class B push-pull circuit it will be assumed that (i) the valves have a linear characteristic, (ii) they are operated without standing feed, and (iii) the grid input is sinusoidal. (Operation with a small standing feed is considered in the Appendix.)

With reference to Fig. 7, it will be assumed that each valve conducts for half-cycle periods only, and that during the period of conduction a half-sine-wave pulse of anode current, of peak value I_{max}, passes through the valve. It also passes through *one half* of the output transformer primary.

When one valve becomes non-conductive, the other comes into play, so each half-cycle of peak value I_{max} flowing through one of the halves of the transformer primary is followed by a half-cycle of peak value I_{max} which flows through the other half of the transformer primary.

An e.m.f. is induced into the transformer secondary. This e.m.f., produced by alternate half-cycles of peak value I_{max} in the halves of the primary, is identical with that which would be produced if there were an alternating current of amplitude $I_{max}/2$ flowing through the *whole* of the primary winding. In fact, it would not be possible, by any observations made in the secondary circuit, to distinguish between,

(a) Alternate half-cycles of peak value I_{max} in the two half-primary windings.

(b) An alternating current of peak value I_{max} in one half-primary winding only.

(c) An alternating current of peak value $I_{max}/2$ in the whole primary winding.

For the purposes of the calculations which maintenance engineers are expected to carry out, it is convenient to adopt the latter conception.

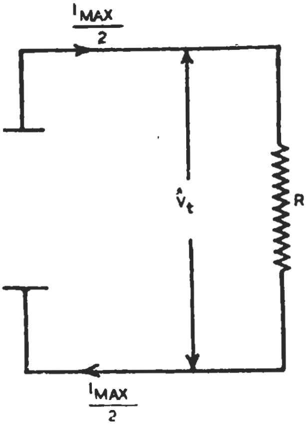


Fig. 8. Simplified Equivalent of Fig. 7, with Transformer and Secondary Load Replaced by the Anode-to-anode Load Resistance

Thus, when considering Fig. 7, the output transformer will be regarded as having, in its primary, an alternating current of amplitude $I_{max}/2$.

In working out the output conditions, it now becomes possible to use the simplified schematic of Fig. 8. Here the combination of output transformer and secondary load has been replaced by R_t, the anode-to-anode load imposed on the valves. R_t is regarded as a resistance through which is flowing an alternating current of amplitude $I_{max}/2$ and across which is operating an alternating voltage of amplitude $\hat{V}_t$.

Considerations based upon this type of equivalent circuit are applicable to any Class B push-pull stage, whether it be an audio-frequency or a radio-frequency stage. In the radio-frequency equivalent circuit, R_t would signify the anode-to-anode load represented by the tank circuit taken in conjunction with whatever is coupled to it.

By elementary principles,

$$\hat{V}_t = \hat{I} R_t$$

$$W = \frac{\hat{I}^2 R_t}{2}$$

(N.B.—The latter equation gives the *total* power output of the stage.)

From these two basic equations and noting that $\hat{V}_t = 2\hat{V}$ and $\hat{I} = \frac{I_{max}}{2}$, it is a simple matter to derive the expressions tabulated below :—

Ref.	1	2	3	4	5	6	7	8	Ref.
$\hat{V}_t =$	$2\hat{V}$	$\hat{I} R_t$	$\frac{I_{max} R_t}{2}$	$\frac{2W}{\hat{I}}$	$\frac{4W}{I_{max}}$	$\sqrt{2WR_t}$			a
$\hat{V} =$	$\frac{\hat{V}_t}{2}$	$\frac{\hat{I} R_t}{2}$	$\frac{I_{max} R_t}{4}$	$\frac{W}{\hat{I}}$	$\frac{2W}{I_{max}}$	$\sqrt{\frac{WR_t}{2}}$			b
$\hat{I} =$	$\frac{I_{max}}{2}$	$\frac{\hat{V}_t}{R_t}$	$\frac{2\hat{V}}{R_t}$	$\frac{2W}{\hat{V}_t}$	$\frac{W}{\hat{V}}$	$\sqrt{\frac{2W}{R_t}}$			c
$I_{max} =$	$2\hat{I}$	$\frac{2\hat{V}_t}{R_t}$	$\frac{4\hat{V}}{R_t}$	$\frac{4W}{\hat{V}_t}$	$\frac{2W}{V}$	$\sqrt{\frac{8W}{R_t}}$			d
$R_t =$	$\frac{\hat{V}_t}{\hat{I}}$	$\frac{2\hat{V}}{\hat{I}}$	$\frac{2\hat{V}_t}{I_{max}}$	$\frac{4\hat{V}}{I_{max}}$	$\frac{2W}{\hat{I}^2}$	$\frac{8W}{I^2_{max}}$	$\frac{\hat{V}_t^2}{2W}$	$\frac{2\hat{V}^2}{W}$	e
$W =$	$\frac{\hat{I}^2 R_t}{2}$	$\frac{I^2_{max} R_t}{8}$	$\frac{\hat{V}_t^2}{2R_t}$	$\frac{2\hat{V}^2}{R_t}$	$\frac{\hat{V}_t \hat{I}}{2}$	$\frac{\hat{V}_t I_{max}}{4}$	$\frac{\hat{V} I_{max}}{2}$	$\hat{V}\hat{I}$	f

The frequent appearance of the factor 2, or of powers of 2, in formulae associated with a Class B push-pull stage will be noted. It is not always due to the fact that there are two valves in the stage.

The peak voltage across the anode-to-anode load is twice the anode-to-cathode peak voltage. This arises from fundamental transformer theory and accounts for the factor 2 in such expressions as 1a, 1b, 3c and 2e.

The peak value of the anode current pulse is twice the peak value of the fundamental a.c. in the load, as previously explained. This brings the factor 2 into such expressions as 1c, 1d, 3a and 3e.

When power output is referred to, it is the power averaged over the full-cycle period, and current or voltage, when used in a power output expression, must be in terms of r.m.s. value. The r.m.s. value can be obtained by dividing the peak value by $\sqrt{2}$. The factor 2 appears when

$\sqrt{2}$ is squared, as will happen when the square of a current or voltage value, or the product of current and voltage, is used. See expressions 1f, 3f, 5f and 7e.

Powers of 2, e.g., 4 and 8, appear as the result of multiplication. For example, it will be apparent why the factor 8 appears in expression 2f if $\hat{I} = I_{max}/2$ is substituted in expression 1f. Sometimes the numerical factor will disappear as the result of cancelling. For example, expression 8f will be obtained if $\hat{V}_t = 2\hat{V}$ is substituted in expression 5f.

Anode Conversion Efficiency of a Class B Push-pull Amplifier.

$$\eta\,\% = \frac{W}{W_{in}} \times 100 \tag{9}$$

Now, by expression 7f,

$$W = \frac{\hat{V}\,I_{max}}{2}$$

The power input, W_{in}, to the stage is given by the product of the mean anode-to-cathode voltage and the total mean feed current to the stage. This current is equal to twice the mean anode current of one valve, since there are two valves in the stage. Thus,

$$W_{in} = E_{kt}\,2\,I_{mean} \tag{10}$$

Since the peak-to-mean ratio of the anode current pulse is $\pi : 1$ it follows that $I_{mean} = I_{max}/\pi$.

Substituting $I_{mean} = I_{max}/\pi$ in equation (10),

$$W_{in} = \frac{2\,E_{kt}\,I_{max}}{\pi} \tag{11}$$

Substituting equations (7f) and (11) in equation (9),

$$\begin{aligned} \eta\,\% &= \frac{\pi\,I_{max}\,\hat{V}}{4\,I_{max}\,E_{kt}} \times 100 \\ &= 0.78 \times \frac{\hat{V}}{E_{kt}} \times 100 \\ &= \left(78 \times \frac{\hat{V}}{E_{kt}}\right)\% \end{aligned} \tag{12}$$

Anode-to-cathode Load of a Class B Push-pull Amplifier.

If a bridge measurement be made between points *a* and *b*, Fig. 7, the resistance value indicated will be found to be equal to one-quarter of the value of R_t, as calculated by equations (1e) to (8e). Apparently, $R = R_t/4$.

Over the full-cycle period, both sides of a push-pull amplifier contribute equally to the power output. Thus, if the amplifier provides a power output of 50 kW, then 25 kW is contributed by each side.

If the anode-to-cathode load is assumed to be one-quarter of the anode-to-anode load and a calculation of power output of one side of the amplifier is made on this basis the result will come out at 50 kW. In order to arrive at the correct figure of 25 kW. it is necessary to take the anode-to-cathode load as being one-half the anode-to-anode load, i.e., $R = R_t/2$.

There has been much loose thinking about this matter. Confusion can be avoided if the following be noted:—

(i) If the power output of a Class B amplifier, or of one side of it, is referred to without any reservation, it is implied that the reference is to the power *averaged over the full-cycle period*. On this basis the anode-to-cathode load must be taken as one-half the anode-to-anode load.

(ii) Since one side of a Class B amplifier is not continuously operative but is active for alternate half-cycle periods only, it follows that the power output averaged over the active half-cycle period is double the power output averaged over the full-cycle period. Thus, if the power output of a Class B amplifier is 50 kW., then the power output of each side *averaged over the active half-cycle period* is 50 kW. Considered over the full-cycle period, however, this amounts to a power output of 25 kW. for each side of the amplifier.

If the anode-to-cathode load is taken as one-quarter of the anode-to-anode load, then the calculated power is that appropriate to the active half-cycle period.

Since in calculations normally carried out by maintenance engineers the power required is that appropriate to the full-cycle period it should be assumed that $R = R_t/2$.

A bridge measurement made between anode and cathode should be taken as giving a value which is one-half the anode-to-cathode load and one-quarter of the anode-to-anode load.

No uneasiness should be felt on this score if it be remembered that the apparent anode-to-cathode load of $R_t/4$ indicated by the bridge is, if considered on the half-cycle basis, equivalent to $R_t/2$ considered on the full-cycle basis.

VOLTAGE DISTRIBUTION IN THE OUTPUT CIRCUITS OF CLASS C MODULATED AMPLIFIERS.

It is important that engineers, knowing the value of the d.c. H.T., should be able to work out the voltage distribution in the output circuit of a Class C modulated amplifier for the condition of 100% modulation. The practical importance of being able to do so will be appreciated if one considers the possibility of a capacitor breakdown occurring when there is no exact duplicate available for replacement. If an engineer has no idea of the peak volts which the replacement capacitor must withstand he is not in a very favourable position to make a suitable replacement.

Consideration is given below to various types of output circuit. In all the cases considered it is assumed that the d.c. H.T. is 10 kV., and that the circuit is being operated under conditions of 100% modulation.

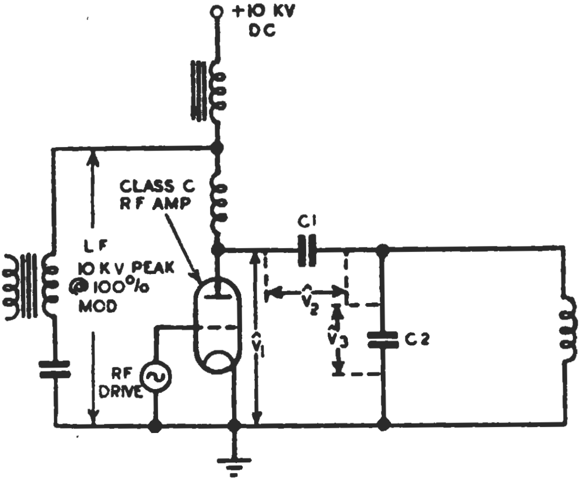


Fig. 9. Output Circuit (i)

The peak value of the modulating L.F. voltage in the circuit of Fig. 9 will be equal to the d.c. H.T. on the modulated amplifier, namely, 10 kV.

Under conditions of Class C operation the valve will be driven hard and it may be assumed that, for all conditions of loading, the peak R.F. anode-to-cathode voltage will approximate to 90% of the d.c. H.T., i.e., 9 kV., in the unmodulated condition. At 100% modulation this doubles to 18 kV.

The total peak voltage between anode and cathode will equal the sum of the H.T., the peak L.F. and the peak R.F. voltages.

$$\hat{V}_1 = \underset{\text{d.c.}}{10} + \underset{\text{L.F.}}{10} + \underset{\text{R.F.}}{18} = 38 \text{ kV.}$$

The tank coil presents no appreciable impedance at d.c. and L.F.; consequently the full d.c. and L.F. voltages appear across $C1$.

The R.F. peak voltage of 18 kV. appears across the series combination of $C1$, and the tuned impedance of the tank circuit. In practice, the impedance of the latter will be so high compared with the reactance of $C1$ that only a small fraction of the R.F. voltage will appear across $C1$.

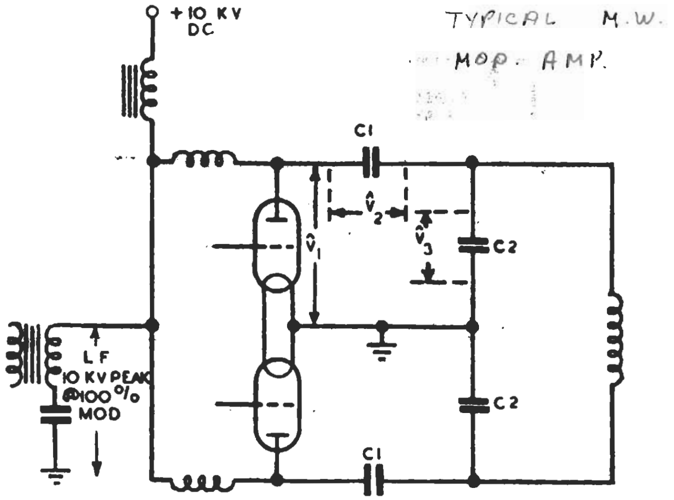
Neglecting the small R.F. voltage across $C1$, the peak voltage across $C1$ equals the sum of the d.c. and L.F. components, i.e.,

$$\hat{V}_2 \simeq 10 + 10 \simeq 20\,\text{kV}.$$

The tank coil is a short circuit on $C2$, as far as d.c. and L.F. voltages are concerned; consequently, only an R.F. voltage appears across $C2$, and this is equal to the anode-to-cathode R.F. voltage, less the small drop across $C1$.

Neglecting the small R.F. voltage across $C1$,

$$\hat{V}_3 \simeq 18\,\text{kV}.$$



TYPICAL M.W.
MOD. AMP.

Fig. 10. *Output Circuit (ii)*

The peak anode-to-cathode voltage in Fig. 10 is the same as that in Fig. 9.

$$\hat{V}_1 = 38\,\text{kV}.$$

The d.c. and L.F. anode-to-cathode voltages are distributed between $C1$ and $C2$ in inverse proportion to their capacitances.

The R.F. anode-to-cathode voltage appears across the series combination of $C1$ and a portion of the impedance of the tuned tank circuit. In practice the fraction of the R.F. voltage appearing across $C1$ will be small.

Neglecting the R.F. voltage component,

$$\hat{V}_2 \simeq \underset{\text{d.c.}}{10\,\frac{C_2}{C_1 + C_2}} \underset{+}{+} \underset{\text{L.F.}}{10\,\frac{C_2}{C_1 + C_2}}$$

$$\simeq 20\,\frac{C_2}{C_1 + C_2}\,\text{kV}.$$

The total peak voltage across $C2$ will be the sum of the d.c., peak L.F. and peak R.F. components. Neglecting the small R.F. drop across $C1$, the R.F. voltage component across $C2$ is equal approximately to the anode-cathode R.F. voltage, i.e., 18 kV.

$$\hat{V}_2 \simeq \underset{\text{d.c.}}{10\frac{C_1}{C_1+C_2}} \underset{+}{+} \underset{\text{L.F.}}{10\frac{C_1}{C_1+C_2}} \underset{+}{+} \underset{\text{R.F.}}{18}$$

$$\simeq 20\frac{C_1}{C_1+C_2} + 18 \text{ kV.}$$

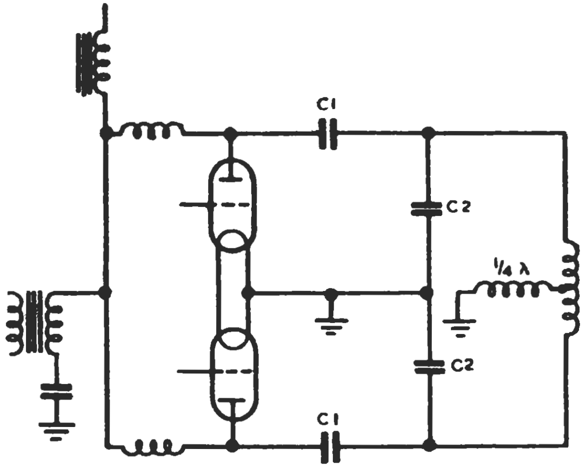


Fig. 11. Output Circuit (iii)

The tank capacitors $C2$ of Fig. 10 could be relieved of the d.c. and L.F. voltage components by connecting a quarter-wave choke between the centre of the tank coil and earth, as shown in Fig. 11, but this will increase the peak voltage which $C1$ has to withstand by $\frac{20C_1}{C_1+C_2}$.

The peak voltage across $C2$ in Fig. 11 $\simeq$ 18 kV.

The use of a choke introduces complications in connection with the transmission of the upper audio-frequencies, due to the variation, with frequency, of the effective impedance between anode and cathode.

A method (as employed at Start Point), of minimising the peak voltage on the tank capacitors of Fig. 10 is to insert a capacitor $C3$, as shown in Fig. 12.

The d.c. and L.F. voltages are now distributed between $C1$, $C2$ and $C3$ in series, in inverse proportion to the capacitances $2 \times C1$, $2 \times C2$ and $C3$. By making the capacitance of $C3$ small in comparison with that of $C2$ the greater part of the d.c. and L.F. voltages appear across $C3$, with consequent reduction of strain on the $C2$ capacitors. The voltage rating of $C3$ must. naturally, be made high enough for it to fulfil its purpose without breakdown,

S.P MOD. AMP

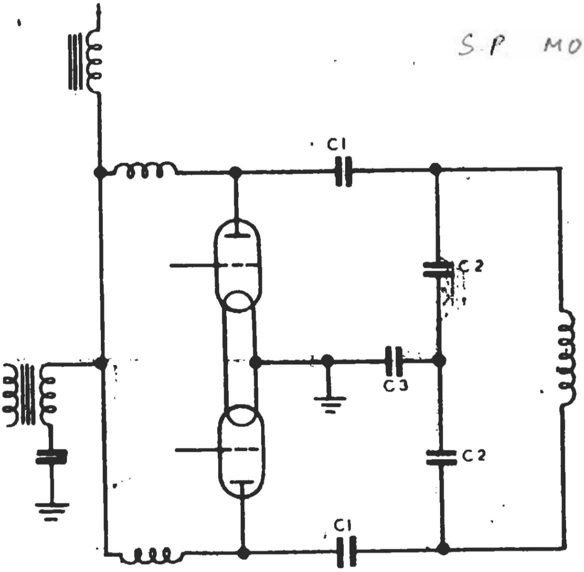


Fig. 12. Output Circuit (iv)

By the introduction of $C3$, the total of the d.c. and L.F. voltage components across $C2$ is reduced to

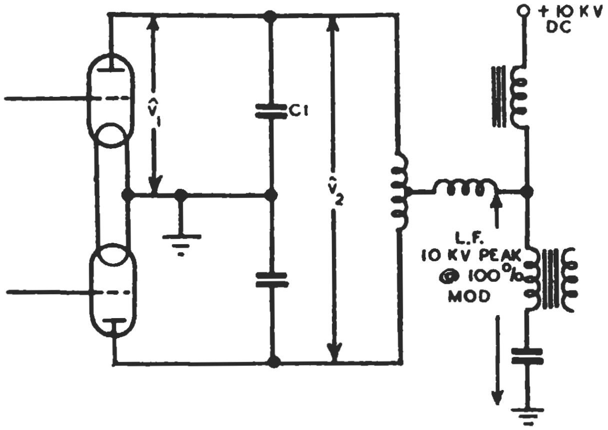
$$20\,\frac{2C_1C_3}{2C_1C_3 + 4C_1C_2 + 2C_2C_3}$$

$$= 20\,\frac{C_1C_3}{C_1C_3 + 2C_1C_2 + C_2C_3}\ \text{kV}$$

The R.F. voltage component across $C2$ will be reduced somewhat by $C3$, but not to any very appreciable extent, owing to the high impedance of the tank circuit at R.F. For practical purposes the R.F. voltage component across $C2$ can be taken as 18 kV., as before.

In the circuit of Fig. 13 the peak anode-cathode voltage and the peak voltage across $C1$ are the same. By the same reasoning as before, $\hat{V}_1 =$ 38 kV.

It is of some interest to consider the peak voltage across the tank coil. The two ends of this coil are equi-potential points at d.c. and L.F. : consequently, the potential difference between the ends of the coil is purely R.F. and is equal to the sum of the R.F. components of the anode-cathode voltages of the two valves. $V_2 = 18 + 18 = 36$ kV.



S.W. MO
AMP.

Fig. 13. *Output Circuit (v)*

APPENDIX.

Class B R.F. Amplifier.

Relations between Anode-current Meter Reading and (i) Peak Anode Current, (ii) Peak Value of Fundamental a.c. Component, (iii) Swing of Anode Current above Standing Feed Value.

If the valve characteristic were linear and the grid input sinusoidal, the anode-current pulses of a valve biased to the exact point of cut-off would be half sine-wave pulses. The peak-to-mean current ratio, considered over the full-cycle period, would be $\pi : 1$.

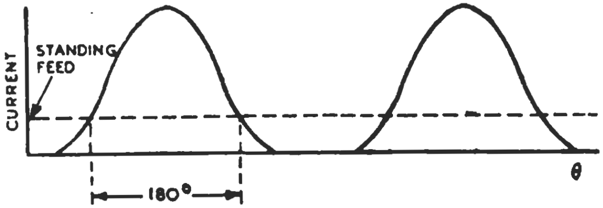


Fig. 14. Waveform of Anode Current of Class B Valve having a Standing Feed

When, as in practice, the valve characteristic is not linear and the valve is biased to a point slightly above cut-off, giving rise to a small standing feed, the anode-current pulses are no longer half sine-wave pulses and the peak-to-mean current ratio is less than $\pi : 1$.

Each current pulse has a duration which is slightly greater than a half-cycle period and has a waveform which is dependent upon the valve characteristic. In general, the current pulses will be of the nature indicated graphically in Fig. 14.

The curvature of the valve characteristic makes an accurate determination of the relation between the peak and mean current values a matter which is quite complicated. By adopting a simplifying assumption, however, it is possible to obtain a close approximation which is quite accurate enough for normal engineering purposes and is generally applicable to all Class B operated valves.

The assumption is made that the valve characteristic is linear but that on this characteristic the valve is biased to a point which gives the same standing-feed value as that obtained in practice.

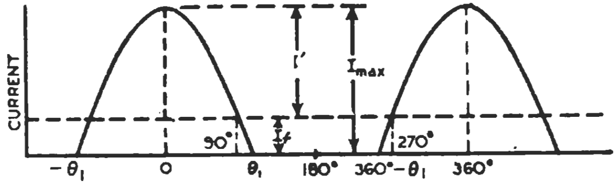


Fig. 15. Waveform of Anode Current of Class B Valve having Standing Feed and Linear Ia-Eg Characteristic

On this assumption the graphical representation of the anode current simplifies to Fig. 15.

I' = swing of anode current above the standing-feed value.
I_f = standing feed.
$I_{max} = I' + I_f$ = peak value of anode current pulse.

The anode current can now be represented by the equations,

$$i = I' \cos\theta + I_f \quad (\text{from } \theta = -\theta_1 \text{ to } \theta = +\theta_1) \qquad (13)$$

$$i = 0 \quad (\text{from } \theta = +\theta_1 \text{ to } \theta = 360^\circ - \theta_1)$$

Since $i = 0$ when $\theta = \theta_1$, then, from (13),

$$I_f = -I' \cos\theta_1 \qquad (14)$$

Substituting $I_f = -I' \cos\theta_1$ in equation (13),

$$i = I' \cos\theta - I' \cos\theta_1 \qquad (15)$$

Analysis of current of the form under consideration is given in Technical Instruction TT.8, page 40. In that Instruction the numerical values derived by analysis are restricted to angles of conduction of 180° or less, but the formulae given are of general application and are valid when the angle of conduction exceeds 180°.

APPENDIX

By the analysis given in Technical Instruction TT.8, the following ratios are obtained :—

Ratio of Mean Current to Standing Feed.

$$\frac{I_{mean}}{I_f} = -\frac{\sin\theta_1 - \theta_1\cos\theta_1}{\pi\cos\theta_1} \qquad (16)$$

Ratio of Peak Pulse Current to Mean Current.

$$\frac{I_{max}}{I_{mean}} = \frac{\pi\,(1 - \cos\theta_1)}{\sin\theta_1 - \theta_1\cos\theta_1} \qquad (17)$$

Ratio of Peak Fundamental A.C. to Mean Current.

$$\frac{\hat{I}}{I_{mean}} = \frac{\theta_1 - \cos\theta_1\sin\theta_1}{\sin\theta_1 - \theta_1\cos\theta_1} \qquad (18)$$

Ratio of Swing of Current above Standing Feed to Mean Current.

$$\frac{I'}{I_{mean}} = \frac{\pi}{\sin\theta_1 - \theta_1\cos\theta_1} \qquad (19)$$

Since all the above ratios are expressed in terms of θ_1 it is possible to plot curves relating the ratio of mean current to standing feed to the other ratios.

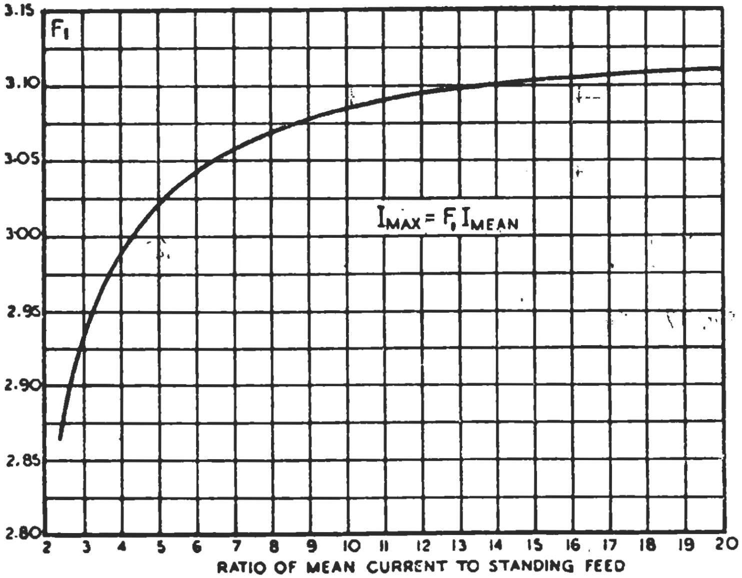


Fig. 16. Curve for Factor F_1 (I_{max}/I_{mean}) in terms of the ratio I_{mean}/I_f

$$\text{Let } \frac{I_{max}}{I_{mean}} = F_1$$

$$\text{Then, } I_{max} = F_1 I_{mean} \qquad (20)$$

With no modulation, i.e., under carrier transmission conditions, I_{mean} can be taken as given to close approximation by a d.c. anode-current meter. Strictly, the mean current indicated by the meter is the mean of current pulses of the form indicated in Fig. 14 and not of the form indicated in Fig. 15, upon which equations (16) to (19) are based. The difference between the mean values corresponding to Figs. 14 and 15, respectively, is very small and the matter becomes of even less importance when, as in practice, the existence of small meter errors must be accepted.

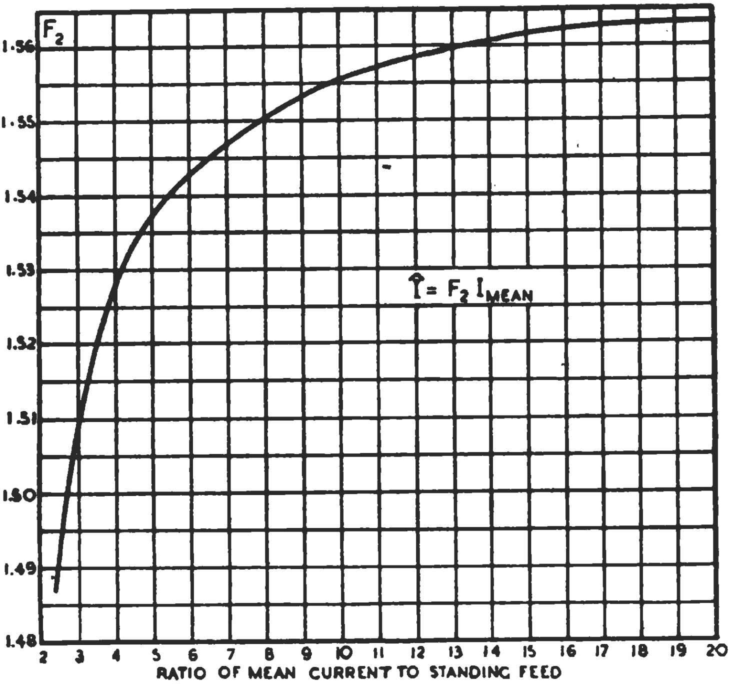


Fig. 17. Curve for Factor F_2 ($\hat{I}/I_{mean}$) in terms of the ratio I_{mean}/I_f

When the ratio I_{mean}/I_f is known, the appropriate value of F_1 can be read directly on Fig. 16.

$$\text{Let } \frac{\hat{I}}{I_{mean}} = F_2$$

$$\text{Then, } \hat{I} = F_2 I_{mean} \qquad (21)$$

Given the ratio I_{mean}/I_f, the factor F_2 can be obtained from Fig. 19.

$$\text{Let } \frac{I'}{I_{mean}} = F_3$$

$$\text{Then, } I' = F_3 \, I_{mean} \tag{22}$$

Given the ratio I_{mean}/I_f, the factor F_3 can be obtained from Fig. 18.

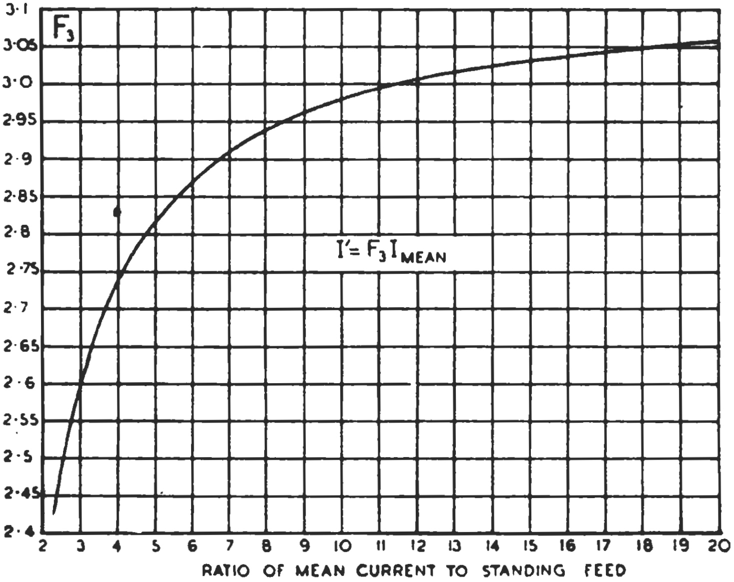


Fig. 18. Curve for Factor F_3 (I'/I_{mean}) in terms of the ratio I_{mean}/I_f

Anode Conversion Efficiency.

$$\eta \% = \frac{W}{W_{in}} \times 100 \tag{23}$$

$$W = \frac{\hat{I} \; \hat{V}}{2}$$

$$= \frac{F_2 \; I_{mean} \; \hat{V}}{2} \tag{24}$$

$$W_{in} = I_{mean} \, E_{ht} \tag{25}$$

Substituting equations (24) and (25) in equation (23),

$$\eta \% = \frac{F_2 \; I_{mean} \; \hat{V}}{2 \; I_{mean} \; E_{ht}} \times 100$$

$$= \frac{F_2}{2} \times \frac{\hat{V}}{E_{ht}} \times 100 \tag{26}$$

Example :—

The final amplifier of one of the 50 kW. transmitters at Brookman's Park is of the push-pull type with seven valves per side operating in Class B. Given that under carrier conditions,

Anode-to-cathode H.T. $= E_{ht}$ = 11.5 kV.

Peak anode-to-cathode a.c. volts $= \hat{V}$ = 4.75 kV.

Total anode d.c. feed to amplifier $= I_{mean(t)}$ = 14 amps.

Total standing feed $= I_{ft}$ = 2.8 amps.

calculate :—

(a) Anode conversion efficiency.
(b) Power input.
(c) Power output.
(d) Anode-to-anode load.
(e) Peak anode current per valve under carrier conditions.
(f) Peak anode current per valve at 100% modulation.

Answer :—

$$\frac{I_{mean(t)}}{I_f} = \frac{14}{2.8} = 5.$$

From Figs. 16, 17 and 18,

$F_1 = 3.024$
$F_2 = 1.537$
$F_3 = 2.820$

(a) Anode conversion efficiency.

$$\begin{aligned}\eta\,\% &= \frac{F_2}{2} \times \frac{\hat{V}}{E_{ht}} \times 100 \\ &= \frac{1.537}{2} \times \frac{4.75}{11.5} \times 100 \\ &= 31.8\%\end{aligned}$$

(b) Power input.

$$\begin{aligned}W_{t\ in} &= E_{ht}\, I_{mean(t)} \\ &= 11.5 \times 14 \text{ kW.} \\ &= 161 \text{ kW.}\end{aligned}$$

(c) Power output.

$$W_t = W_{t\ in} \times \eta\ \%/100.$$
$$= 161 \times 0.318 \text{ kW}.$$
$$= 51.2 \text{ kW}.$$

(d) Anode-to-anode load.

The value of the anode-to-anode load is given by the ratio of the fundamental peak a.c. voltage across the load to the peak a.c. component of fundamental current in the load.

In the example the peak anode-to-cathode voltage is given as 4.75 kV. This value is that indicated on a peak voltmeter connected between anode and cathode, but to a close approximation it is reasonable to regard the indicated voltage as the peak voltage at the fundamental frequency. Actually, the meter reading is affected by the presence of harmonics. The valves are operated under a condition which causes the current in the tank circuit to have a harmonic content, even though the system is push-pull. Since the tank circuit is tuned to the fundamental frequency, the load on the valves at a harmonic frequency will be low and the harmonic content of the voltage across the peak voltmeter will therefore be negligible.

The peak value of the current at fundamental frequency in the load will be the peak value of the fundamental frequency component of the total anode current of one side of the amplifier. This can be calculated by taking one-half the total feed to the two sides of the amplifier and multiplying by the factor F_2. Thus, in the anode-to-anode load the peak value of current at fundamental frequency = 7 × 1.537 = 10.76 amps.

N.B.—The peak a.c. in the load must not be confused with the pulse current peak of one side of the amplifier.

The peak voltage across the anode-to-anode load will be twice the anode-to-cathode voltage, = 9.5 kV. = 9,500 V.

Thus,

$$R_t = \frac{9{,}500}{10.76} = 880\ \Omega$$

(e) Peak anode current per valve under carrier conditions.

$$I_{max} \text{ per side} = F_1 \times I_{mean} \text{ per side}$$
$$= 3.024 \times 7 \text{ amps}.$$
$$= 21.2 \text{ amps}.$$
$$I_{max} \text{ per valve} = \frac{21.2}{7}$$
$$= 3.0 \text{ amps}.$$

(f) Peak anode current per valve at 100% modulation.

Under conditions of 100% modulation, the maximum swing of the anode current above the standing-feed value is $2\,I'$, see Fig. 15.

$$
\begin{aligned}
I' \text{ per side} &= F_3 \times I_{mean} \text{ per side} \times 2 \\
&= 2.820 \times 14 \text{ amps.} \\
&= 39.5 \text{ amps.}
\end{aligned}
$$

$$
\begin{aligned}
I_{max} \text{ per side} &= I' \text{ per side} + I_f \text{ per side.} \\
&= 39.5 + 1.4 \text{ amps.} \\
&= 40.9 \text{ amps.}
\end{aligned}
$$

$$
\begin{aligned}
I_{max} \text{ per valve} &= \frac{40.9}{7} \\
&= 5.8 \text{ amps.}
\end{aligned}
$$

Note.—I_{max} can be calculated to a good degree of approximation when $I_{max} \gg I_f$ by the following quick method, which does not involve reference to graphs :—

$$
\begin{aligned}
I' &\bumpeq \pi\left(I_{mean} - \tfrac{1}{2} I_f\right) \\
I_{max} &\bumpeq I' + I_f
\end{aligned}
$$

Applying this method to part (e) of the above example,

$$
\begin{aligned}
I' &\bumpeq \pi(7 - 0.7) \bumpeq 19.8 \text{ amps.} \\
I_{max} &\bumpeq 19.8 + 1.4 \bumpeq 21.2 \text{ amps.}
\end{aligned}
$$