RCA Engineering Note

"HIGH-EFFICIENCY" HARMONIC RESONATOR AMPLIFIERS

With Typical Values for RCA-5762/7C24

Summary

The use of power tubes in "High-Efficiency" Harmonic Resonator Amplifiers appears to offer significant advantages of improved efficiency with consequent lower cooling requirements, reduced harmonic output, and less critical tuning procedures. Since this class of service has not been well defined, appropriate tube ratings are not generally available. This *Note* reviews the rating principles involved and the relationships between "Harmonic Resonator" service and the more common class C operation.

Tube Capabilities

The principal factors that establish the power output capabilities of a grided electron tube are: the maximum voltages that can be applied, the current that can be drawn from the cathode, and the maximum power losses of the various electrodes. These values are established by the manufacturer for a particular class of service consistent with reasonable life expectancy. Class C telegraphy is normally used as the basis for ratings since tube operation in other classes of service can readily be related to it. See Ref. 1. Moreover, class C telegraphy or telephony operation of transmitting tubes is a well recognized approach to those services where maximum efficiency is desirable to minimize operating costs; hence, an ideal standard of comparison for other forms of high efficiency operation.

Class C Amplifier

Class C operation is efficient because the narrow plate conduction angle results in most of the plate current flowing during the period when the instantaneous plate voltage is relatively low. The relationships between the peak plate current, the dc plate current and the fundamental ac component of plate current at various conduction angles can be established on a theoretical basis; tables showing these relationships are available. See Ref.2. Power output, plate input (or DC plate current), peak plate current, plate dissipation, efficiency, and grid input can then be related to conduction angle as shown on the left of Fig.1. This graph illustrates that efficiency increases by narrowing the conduction angle; and the peak plate current and grid input requirement also increase rapidly. The design of the individual tube type will dictate the limiting parameter; however, maximum peak emission (peak plate current) will generally be reached first in conventional class C operation.

Adding Harmonic Resonators

The use of "High-Efficiency" Harmonic Resonator operation permits increased efficiency with lower peak plate current, lower plate dissipation, higher power output, and lower grid input requirements for a corresponding plate input (or DC plate current) as shown in transition from class C to "High Efficiency" service in Fig.1. This high-efficiency operation is achieved by the addition of low-loss third harmonic resonators in series with the rf plate and cathode circuits as shown in Fig.2. See Refs. 3 & 4. These resonators modify the plate and grid voltages seen by the tube as shown in Fig.3. The plate current waveform is essentially "squared" pulses of 120° duration which provide plate current flow during the longer period when the instantaneous plate voltage is at a minimum. Consequently, average plate dissipation is reduced and efficiency improved.

Performance of the "High-Efficiency" Circuit

A close approximation of tube performance in this class of operation can be made by assuming

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HYPOTHETICAL TUBE PERFORMANCE CLASS C AMPLIFIER AND HARMONIC RESONATOR AMPLIFIER SERVICE

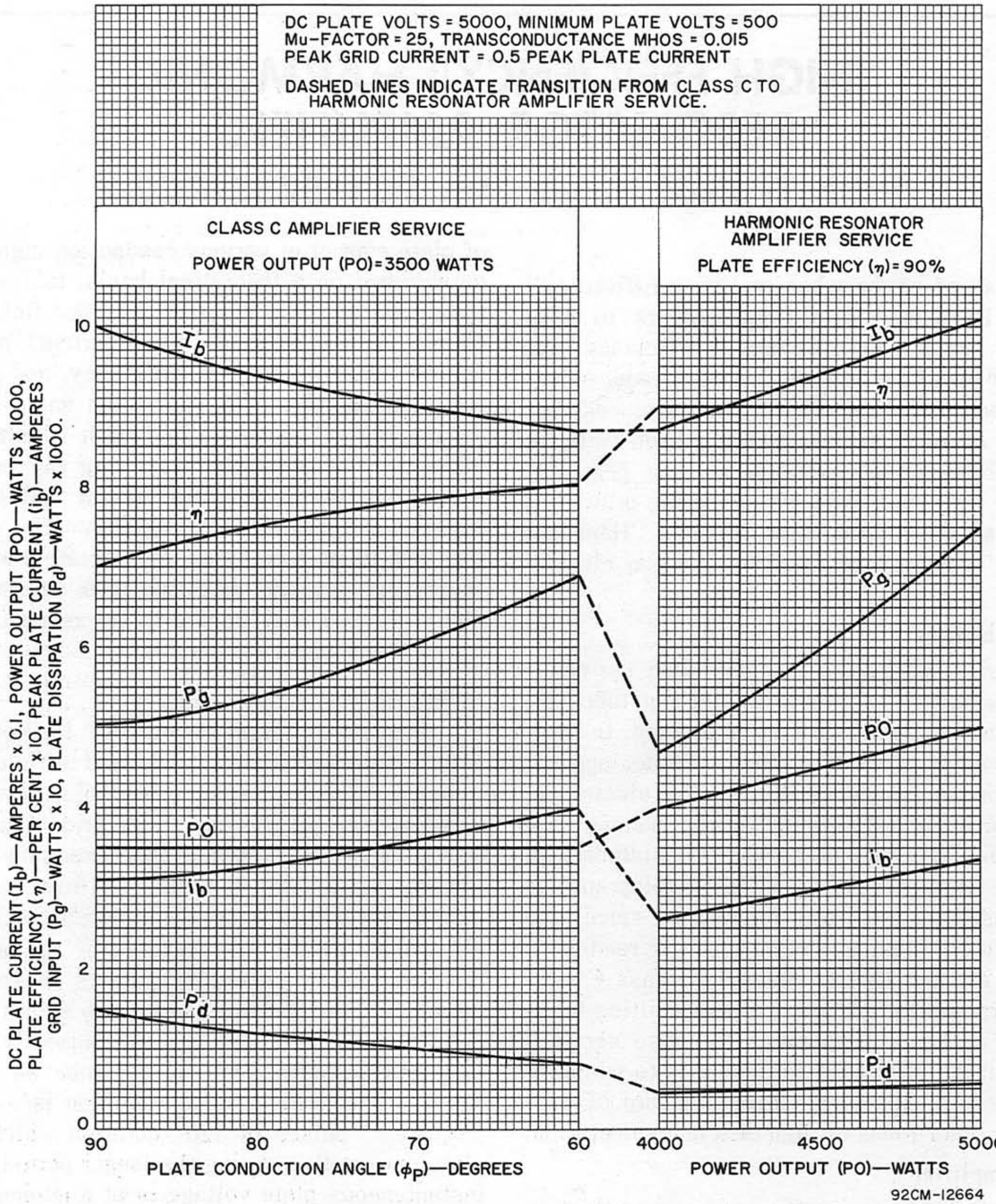

Fig.1

ideal "square-wave" pulse shapes and a 120° plate conduction angle. The following relationships are then established:

DC Plate Current = $I_b = i_b/3$, where i_b is the peak plate current

Power Input = PI = $E_b I_b$, where E_b is the DC plate voltage

Plate Dissipation = $P_d = eb_{min} I_b$, where eb_{min} is the minimum instantaneous plate voltage

Power Output = PO = PI - P_d

On this basis, the ratio of peak-to-average grid current is also 3 and the grid input is the product of maximum instantaneous grid voltage and DC grid current ($e_{c_{max}} \times I_c$). However, in actual practice,

SIMPLIFIED DIAGRAM OF "HARMONIC RESONATOR" AMPLIFIER

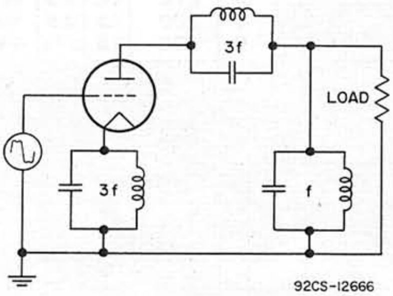

Fig.2

the finite slope of the voltage waveform reduces the effective grid-conduction angle by 30 to 40°. Therefore, the DC grid current and grid input are correspondingly less.

By using the relationship in the previous paragraph and setting the maximum performance obtainable within the peak current limitations of the example of Fig.1 as a base, increased performance capability is shown on the right of Fig.1. Again, the design of the individual tube type will dictate the limiting parameter; however, maximum grid input will generally be reached first in "Harmonic Resonator" operation for present tube designs. Hence, unless actual measurements can be made, the more conservative 3:1 peak-to-average grid current ratio should be used in predicting tube performance.

The RCA-5762/7C24 Power Triode in a "High-Efficiency" Circuit

TYPICAL PLATE AND GRID VOLTAGE WAVEFORMS

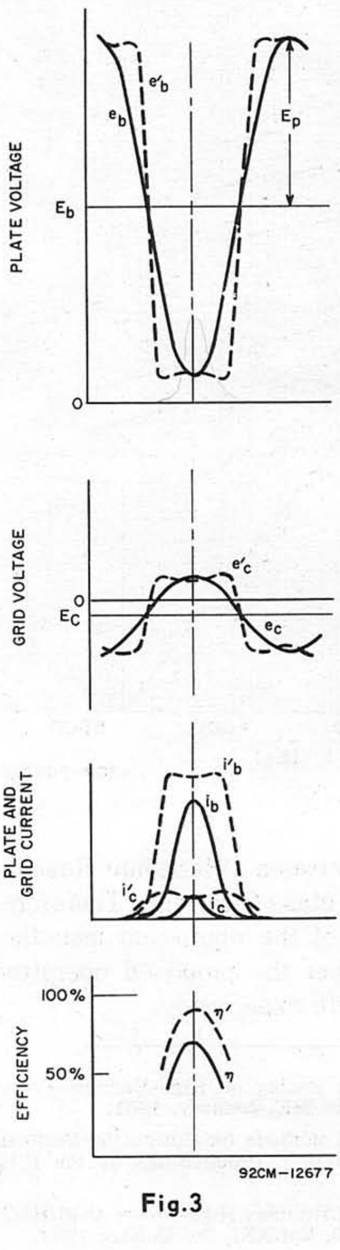

Fig.3

Comparative typical performance of a transmitting tube is given below to demonstrate the parameters discussed above. The RCA-5762/7C24 is selected for its low cost and reliability in a wide range of broadcast and communications applications. In addition, the tube is used in a "high-efficiency" circuit in the RCA BTA-5U/10U transmitter.

In the chart shown in Fig.4, column I specifies the tube performance at carrier level as published in the technical bulletin for the RCA-5762/7C24 dated 4-64 under Plate Modulated RF Power Amplifier, Class C Telephony, Typical Operation in Grid-Drive Circuit at a DC Plate Voltage of 4700 volts. Fig.5 shows the same performance plotted on the typical constant-current characteristics graph from the technical bulletin as operating path "AD" with point "A" at optimum conditions. The peak plate current (i_b) of 4.5 amperes will double at the crest of modulation to 9 amperes, the limiting value for reasonable tube life expectancy in this service.

Column II of the chart shows the tube performance at the same plate

CHART OF TYPICAL OPERATION FOR RCA-5762/7C24

		I	II	III
DC Plate Voltage	E_b	4700v	4700v	4700v
DC Grid Voltage	E_c	-400v	-400v	-400v
Min. Instantaneous Plate Voltage	$e_{b_{min}}$	460v	300v	440v
Max. Instantaneous Grid Voltage	$e_{c_{max}}$	+275v	+200v	+235v
Plate Voltage Swing	$E_p = E_b - e_{b_{min}}$	4240v	4400v	4260v
Plate Conduction Angle	ϕ_p	60°	120°	120°
Ratio: Peak Value/DC Current	i_b/I_b	4.7	3	3
Ratio: Peak Value/Fund. AC Current	i_b/I_p	1.8	-	-
Peak Plate Current	i_b	4.5a	2.9a	3.75a
DC Plate Current	I_b	.96a	.96a	1.25a
Fundamental AC Plate Current	I_p	1.73a	-	-
Grid Conduction Angle	ϕ_g	43°	120° (80°)*	120° (80°)*
Max. Instantaneous Grid Current	i_c	1.8a	1.5a	1.6a
DC Grid Current	I_c	0.28a	.5a(0.33a)*	0.533a(.355a)*
Grid Input	$P_g = e_{c_{max}} \times I_c$	77w	100w (67w)*	125w (83w)*
Power Input	$PI = E_b I_b$	4500w	4500w	5900w
Power Output	PO	3700w	4200w	5350w
Plate Dissipation	PD = PI-PO	800w	300w	550w
Plate Circuit Efficiency	Eff = PO/PI	82%	94%	91%

* Empirical value in parentheses represents the reduced grid conduction angle discussed in the text and the corresponding factor of $i_c/I_c = 360°/80° = 4.5$.

Fig.4

input and at point "B" in Fig.5, but in a "High-Efficiency" circuit. (A straight line representing the path of operation is not applicable because the tube is either conducting at point "B", or it is completely cut off.) Note that although plate input remains the same, power output is higher and grid input, peak plate current, and plate dissipation are now much lower than the values in column I.

Column III of the chart shows the tube performance in a "High-Efficiency" circuit at point "C" in Fig.5 to achieve higher power output. Plate input and efficiency are higher than the values for the class C in column I and plate dissipation and peak emission requirements are lower.

The grid input in column III is still slightly higher than for the typical class C in column I case and theoretically life expectancy must be reduced. However, actual measurements in the RCA BTA-5U/10U transmitter confirm that the more conservative empirical figures shown in parentheses have some safety factor.

Grid and Plate Current Ratings for the RCA-5762/7C24 in the RCA BTA-5U/10U

A maximum grid current limit of 0.380 ampere has been established for these transmitters and operating experience shows a favorable watt-hour/dollar relationship. Because the peak cathode current demands in this service are considerably reduced, the permissible DC Plate Current per tube in these transmitters has also been increased from 1.0 ampere maximum to 1.4 amperes maximum; typical operation is at 1.25 amperes.

TYPICAL CONSTANT-CURRENT CHARACTERISTICS

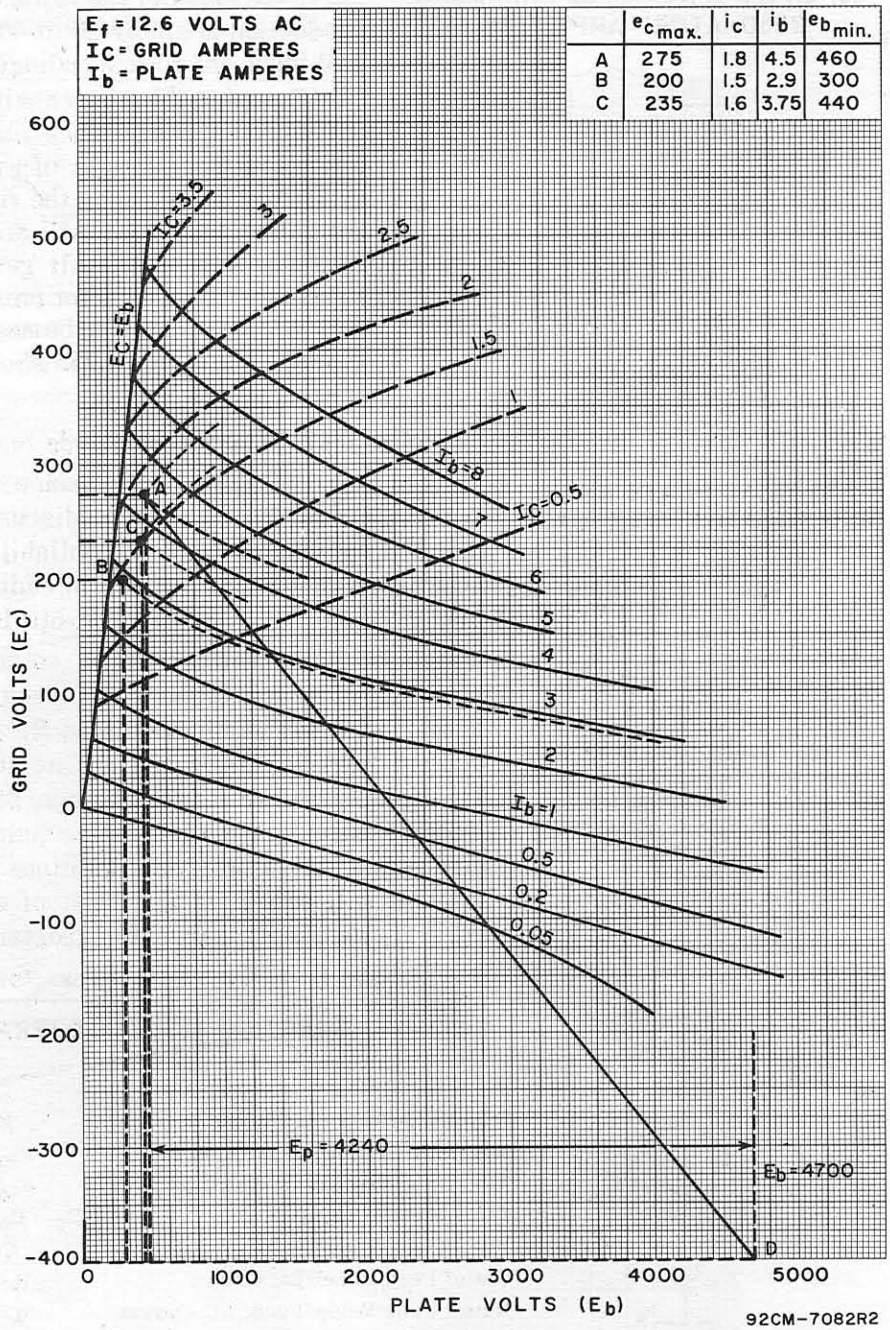

Fig.5

Conclusion

The use of power tubes in High-Efficiency Harmonic Resonator Amplifiers appears to offer significant advantages of improved efficiency, reduced harmonic output, and less critical tuning procedures. Significantly more power output can frequently be obtained provided adequate grid dissipation capability is available. However, individual tube-circuit design complexities do not permit the derivation of a general relationship between "Harmonic Resonator" service and present class C ratings. Therefore, it is the responsibility of the equipment manufacturer to determine whether the proposed operation will result in adequate life expectancy.

1. E. E. Spitzer, "Electrical Rating of High-Vacuum Power Tubes," Proceedings of the IRE, January, 1951.
2. W. G. Wagener, "Simplified Methods for Computing Performance of Transmitting Tubes," Proceedings of the IRE, January, 1937.
3. V.J. Tyler, "A New High-Efficiency High-Power Amplifier," the Marconi Review No.130, Vol.XXI, 3rd Quarter 1958.
4. Broadcast News, March 1960.