FREQUENCY DOUBLERS
AN UNDERSTANDING AIDS IN EFFICIENT TUBE OPERATION

National Radio Institute No. 19C

A very high-powered oscillator/transmitter will not maintain its frequency at reasonably constant value. For this reason, high-power oscillators are seldom used. Instead, a master oscillator is designed to have the best possible frequency stability, and then a series of amplifying stages is used to get the required power. With this arrangement, it is possible to draw very little power from the oscillator, thus insuring its frequency stability.

Frequency Multiplication. It may happen that crystals cannot produce a frequency as high as the required output frequency. If so, it is possible to design an intermediate amplifier so that it has a strong harmonic output. The second or third harmonic of the crystal frequency may then be taken from this amplifier and amplified by the succeeding intermediate amplifier stages. This lets us get an output frequency that may be two or three times the master oscillator frequency. By using a chain of multipliers in this manner, we can get frequencies of four, six, or any other multiple of the master oscillator output.

The most practical form of oscillator possessing a high degree of frequency stability is one in which the frequency is determined by mechanical oscillation of a piezoelectric quartz crystal. Because of such desirable characteristics, almost all modern transmitters use some form of crystal-controlled master oscillator.

The natural mechanical resonance of a crystal is determined primarily by its thickness, and crystals are ground very carefully to a definite thickness to make them oscillate at some specific frequency. Unfortunately, as the thickness of a crystal is decreased in order to reach higher and higher frequencies, the plate becomes so thin that it is easily broken. Indeed, it becomes so fragile it can be used only in special circuits at greatly reduced power.

In practical instances, crystals are seldom used above a fundamental frequency of about 10 MHz. For crystal-controlling the output of an ultra-high-frequency transmitter, therefore, some indirect means of using a crystal master oscillator must be employed. This is usually accomplished by operating the crystal oscillator at some *sub-harmonic* frequency, say, 1/2, 1/3, 1/16, etc., of the desired output frequency and then employing one or more frequency multipliers to increase the crystal-controlled frequency to the desired point.

A frequency multiplier is an amplifier in which the output tank circuit is tuned to some harmonic instead of the true input frequency. Thus, if in the buffer circuit of Fig. 4, the output tank L_3-C_9 should be tuned to a frequency *twice* that of the crystal oscillator, the amplifier would not only continue to act as a buffer but also as a frequency *doubler* and give considerable power output at the second harmonic frequency instead of at the fundamental.

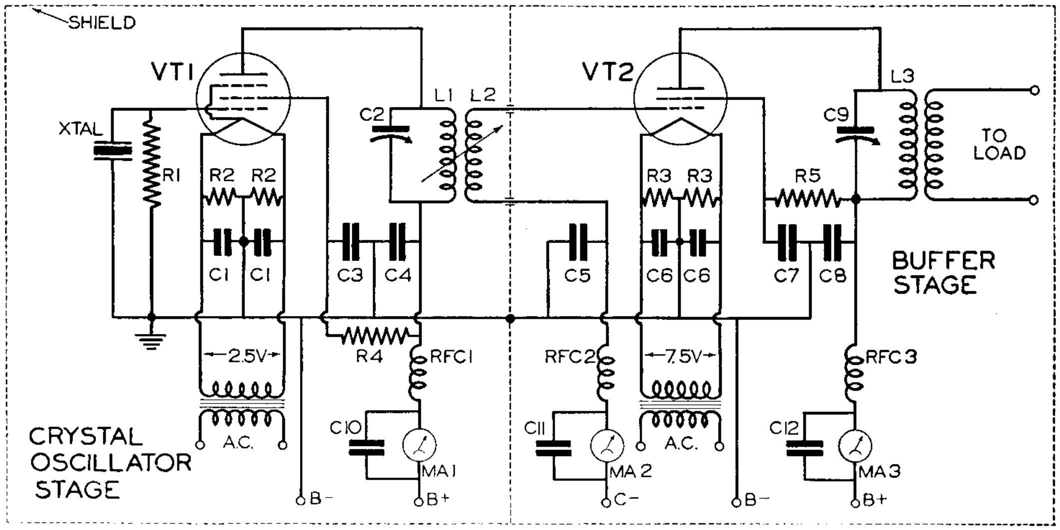


FIG. 4. A typical buffer stage using a screen grid tube. Screen grid tubes are desirable because they require no neutralizing.

In a similar manner, if the tank circuit L_3-C_9 should be tuned to a frequency *three times* that of the input, power will be delivered at the third-harmonic frequency; hence, the buffer behaves as a frequency tripler.

Several doubler or tripler stages can be used in cascade for even greater frequency multiplication. Two doublers in cascade, for instance, would multiply the crystal frequency by a factor of four, two triplers by a factor of nine, etc. Crystal control for almost any ultra-high frequency can be obtained. All that is necessary is that the quartz crystal be ground for the proper sub-harmonic frequency, and that the correct number of doubler or tripler stages be used.

HARMONIC GENERATION

Fig. 5 shows the basic circuit for an RF amplifier.

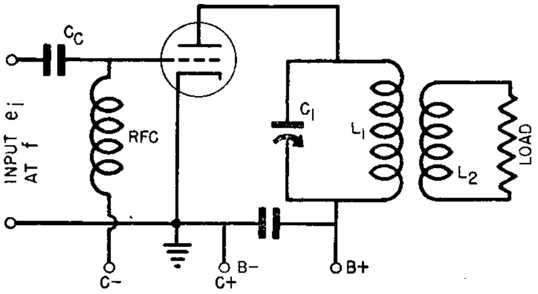


FIG. 5. When the output tank of an r.f. amplifier is tuned to some harmonic of the input frequency, such as the second, third, or fourth, it becomes a frequency multiplier.

For maximum efficiency, a multiplier amplifier is operated in class C by applying a grid bias greater than the plate current cut-off value, and then supplying sufficient grid excitation to drive the grid well into the positive region on positive signal peaks.

Under these circumstances, as illustrated in Fig. 6A, plate current pulses flow for only a short time (usually about 120°) during each positive half of the excitation cycle.

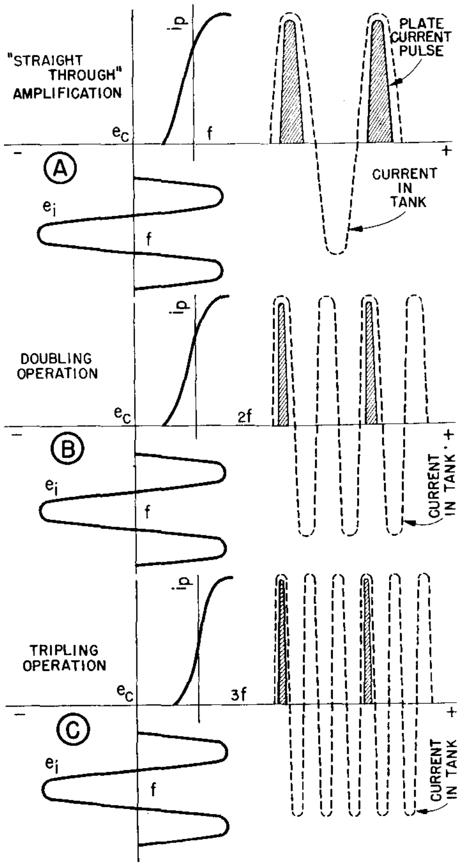


FIG. 6. In a straight-through amplifier, plate current pulses add energy to the tank circuit once each cycle, as at A. For a doubler, as at B, a plate current pulse flows every second cycle. Between pulses, the flywheel effect carries through for an extra cycle without additional energy. For a tripler, as at C, plate current flows only during every third cycle.

These plate current pulses, when flowing through the tank coil L_1 in Fig. 5, serve to charge the tank condenser C_1. After each plate current pulse passes, the tank circuit then oscillates because of its flywheel effect for the balance of the cycle. The total oscillating current flowing in the tank circuit L_1-C_1 then looks very much like the dashed curve shown in Fig. 6A.

This is the operation when the circuit is acting as a true amplifier and is giving "straight-through" operation resulting in the output frequency being exactly the same as that of the input. Note that a plate current pulse adds energy to the output tank circuit *once each cycle (similar to someone pushing on a swingset at the exact moment in time).*

Action as a Multiplier. For doubler operation the tank circuit L_1-C_1 in Fig. 5 is tuned to the second harmonic of the fundamental. In this case the oscillating current in the tank circuit follows the dashed curve shown in Fig. 6B.

After each plate-current pulse passes, the flywheel effect of the tank circuit carries through, not one, but *two* complete cycles before the next plate-current pulse flows. In other words, plate current furnishes energy to the output tank on *every other* cycle only, and in between, the tank circuit literally “coasts” along under its own power, derived from the inherent flywheel effect.

Since the plate current pulses feed energy to the tank circuit only half the time, it is reasonable to expect that the second harmonic output power will be lower than that possible at the fundamental frequency with this particular circuit adjustment. We find this to be true. In fact, the efficiency of such a doubler is just about one-half that obtainable from a straight-through amplifier and ordinarily is about 30-40%.

The action of the circuit for frequency tripling is quite similar. If the tank circuit in Fig. 5 is tuned to the third harmonic, then the oscillating current follows a dashed curve like Fig 6C. In this instance, plate current supplies energy to the tank on every third cycle, hence one-third of the time. In between, the flywheel effect carries through three complete cycles.

As you might expect, the efficiency of a tripler is even lower than that of a doubler. This is true because energy is supplied to the oscillating tank for such a small part of the time. Ordinarily, efficiencies between 20-30% can be obtained.

Even greater frequency multiplication can be obtained if the tank circuit in Fig. 5 is tuned to higher harmonics such as the 4th, 5th, etc. As the number of the harmonic is increased, however, the number of cycles the tank circuit flywheel effect must complete between plate current pulses, (without energy added to the circuit) also increases. The multiplier efficiency, therefore, rapidly decreases as higher orders of multiplication are attempted. Frequency multiplication greater than a factor of three usually is not worthwhile. In other words, to increase the input frequency four times, it is ordinarily better to use two doubler stages in cascade rather than a single quadrupler stage.

In spite of lowered efficiency, if the tank circuit of a doubler or tripler is not loaded too heavily, so that there is a high Q, and so that there will not be too much damping or “dying away" of the oscillation between plate current pulses, the wave form of the doubled or tripled frequency at the output can be surprisingly good.

Tank-Circuit Filter Effect. Another viewpoint regarding the action of a frequency multiplier is to consider the impedance of the parallel-resonant output tank when this effective tube load is tuned to different harmonic frequencies of the input stage.

A parallel tuned tank circuit like L_1-C_1 in Fig 5 has a high impedance only at the frequency for which it is resonant. For all other frequencies both higher and lower than resonance, the impedance falls to a very low value.

This change of impedance with frequency is illustrated by the dashed curve in Fig. 7.

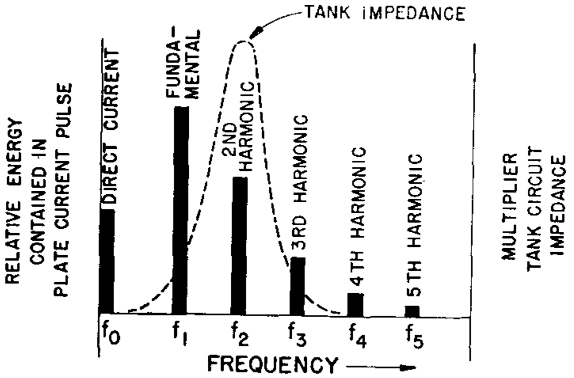


FIG. 7. A multiplier tank circuit acts as a filter because its impedance is highest, and hence, offers greatest tube load at the harmonic frequency for which it is tuned.

The short duration plate current pulses flowing through the tank circuit in Fig. 5 and illustrated more clearly in Fig 6, contain not just one frequency but also a great number of frequencies. Actually, plate current pulses such as these may contain some direct current energy, some energy at the fundamental frequency, a little less at the second harmonic frequency, still less at the third harmonic, and so on. The most important currents flowing, which when added together make up such a plate current pulse, may be scattered along the frequency spectrum like the heavy upright lines in Fig. 7.

If all these currents of different frequencies are flowing through the output tank circuit of the multiplier stage in Fig. 5, the only frequency amplified to any extent will be that one for which the tank circuit has the highest impedance and hence, presents the greatest tube load. Thus, if the output tank of a multiplier is tuned to the second harmonic of its input frequency, we have the situation illustrated in Fig. 7. The stage performs as a doubler simply because the tank circuit acting as tube load has its highest impedance at the second harmonic frequency. At all other frequencies the impedance of the tank circuit is very low. The undesired frequencies, therefore, are virtually shorted out.

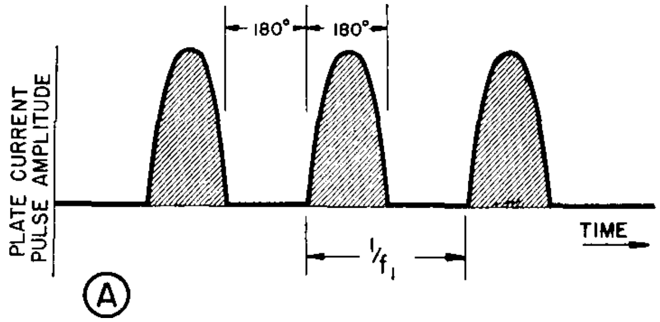
Because it has the ability to accept energy at one frequency only and reject energy at all other frequencies, the tank circuit of a frequency multiplier actually behaves as a filter.

EFFECT OF SHAPING THE PLATE-CURRENT PULSE

If we continue to consider the output tank of a frequency multiplier as a filter absorbing energy at only one given frequency, then it is apparent that we can get a greater output if we increase the amount of energy in the plate current pulse *at that frequency.*

The energy contained in any given harmonic is determined entirely by *the shape and duration* of the plate current pulses. In other words, the strength of the second harmonic, and hence, the maximum output power we can hope to get from a frequency doubler, for example, can be controlled to some extent by changing the *shape* of the pulses of current the tube is allowed to pass.

A Half-Cycle Sine Wave. If we were to bias the multiplier in Fig. 5, not beyond plate current cut-off as is usually done for class C operation, but merely to cut-off so that we have class B operation instead, we would find that plate current pulses exactly equal to one-half a sine wave would flow in the plate circuit. The shape and duration of these pulses are illustrated in Fig 8A.



Frequency Doublers

By mathematical analysis, it is possible to determine the amplitude of the various frequencies contained in such plate current pulses. From this, we find that these amplitudes are distributed in the frequency spectrum about like the lines in Fig 8B.

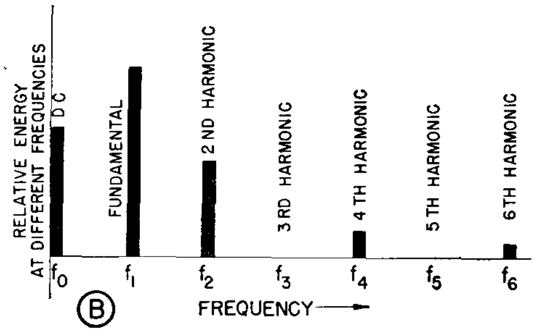


FIG. 8. Plate current pulses as at A, which are equal to one-half a sine wave, contain energy distributed as at B. Note that all ODD harmonics are zero.

First of all, there is some energy at a zero frequency f_0, which is simply direct current. (This is the plate current that would be read by a plate circuit milliammeter.)

Next, most of the energy is concentrated at the fundamental input frequency f_1. Note that the second harmonic frequency f_2 is not negligible by any means. Actually, energy at this frequency is very nearly 50% of that represented by the fundamental f_1. Plate current pulses of the shape indicated in Fig 8A, therefore, should make for very good *doubler* operation.

Higher order *even* harmonics such as the fourth f_4, and sixth f_6, etc., do exist. Their amplitudes, however, are very low as illustrated in the figure.

One interesting fact about Fig. 8B should not be overlooked. Note that all *odd* harmonics such as the third f_3, the fifth f_5, and so on, do not exist at all. In other words, the energy concentrated in *odd* harmonics is zero. Plate current pulses shaped like Fig. 8A would not give satisfactory *tripler* action.

A Half-Cycle Square Wave. If instead of a half-cycle sine wave, by some means we make the plate current pulses of a frequency multiplier resemble a half-cycle *square* wave as shown in Fig. 9A, we would find the harmonic content to be considerably different.

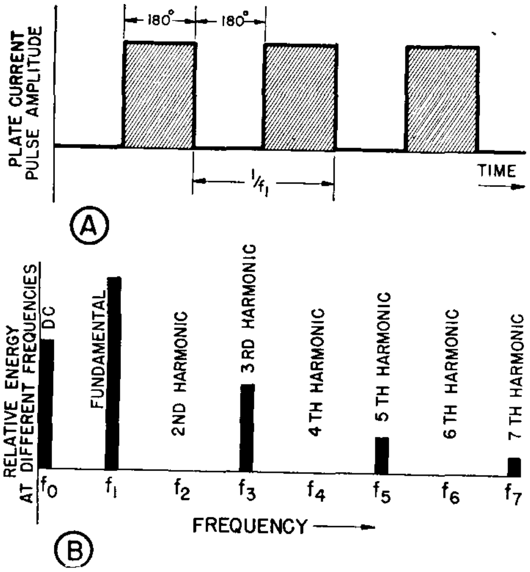


FIG. 9. Half-cycle square-wave pulses as at A contain energy at different frequencies as shown at B. Notice all EVEN harmonics have zero amplitude.

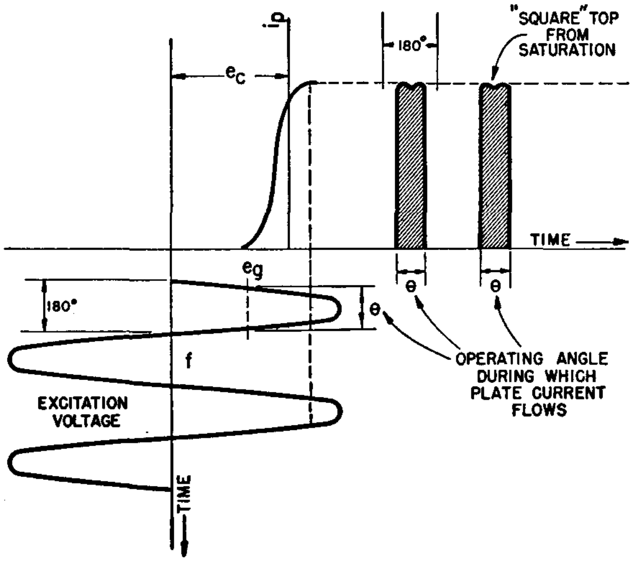
Mathematical analysis of such pulses indicates that the energy is distributed along the frequency spectrum like the lines in Fig. 9B.

As before, there is some direct current energy f_0. Also as before, most of the energy is concentrated in the fundamental frequency f_1. We next note, however, that the amplitude of the second harmonic f_2 is zero—and indeed, this is true for all *even* harmonics. It is evident then that pulses shaped like Fig. 9A contain no energy whatsoever at any *even* multiples of the fundamental frequency, and such pulses, therefore, could not be used in a frequency doubler.

On the other hand, looking at Fig. 9B once more, we see that all *odd* harmonics do exist. The third f_3, of course, contains more energy than those of higher order and actually approaches about 35% of that in the fundamental f_1. From this, we see that *square-wave* plate-current pulses will give good *tripler* action in a frequency multiplier.

Practical Multiplier Operation. In actual practice, neither of the plate-current pulse shapes shown in Figs. 8A and 9A are commonly used. This is true because plate current flowing half the time — and this really means class B operation - does not give as much efficiency as class C operation where plate-current pulses are shorter and last a period of time considerably less than a half-cycle. Hence, a compromise operation is used, with the result that the pulse has a shape that gives reasonable amounts of both even and odd harmonics.

Multipliers are usually operated under the conditions shown in Fig. 10.



θ DEGREES	OPTIMUM OUTPUT FREQUENCY
90-120	2f
80-120	3f
70-90	4f
60-70	5f

FIG. 10. In practical multipliers, the plate current pulses may be made "square-topped" by driving to saturation. The desired harmonic also is accentuated by adjusting the grid bias to obtain the optimum operating angle.

Sufficient grid excitation is supplied to drive the plate to full saturation so that the plate current pulses become fairly flat on top in a reasonable approach to a square wave. This pulse shape we have found increases the odd harmonic output energy.

For further increase in harmonic energy in the plate-current pulses, the *time duration* of these pulses, and hence, the operating angle θ *(theta)*, is controlled by adjusting the grid bias. The higher the grid bias, the smaller the operating angle θ *(theta)* will be; and the shorter the time duration of each pulse, the higher the harmonic frequency that will be accentuated.

In general, it has been found that for optimum *doubler* operation, the angle θ *(theta)* should be from 90° to 120°, meaning the plate current pulses should last about the time required for 1/4 to 1/3 cycle of the excitation frequency. For best *tripler* action, the grid bias should be increased until the operating angle is reduced even more. For higher order harmonics such as the 4th or 5th, the angle θ *(theta)* should be still smaller as indicated by the table in Fig. 10.

Frequency multiplication greater than 3-to-1, however, is seldom used because of the greatly reduced output power. Incidentally, reducing the operating angle as just described increases the *efficiency,* because we reduce the average plate current in such a way that there is less B+ power used, and a greater proportion of this power is at the required output frequency. However, this reduces the *amount* of output to such a low level that it is better to use multiple stages in cascade than it is to use a single high-order multiplier.

TYPICAL MULTIPLIERS

A frequency multiplier is an RF amplifier where the output tank is tuned to a harmonic instead of the fundamental input frequency itself, and the operating angle is adjusted by properly setting the grid bias and the excitation. Hence, a conventional screen-grid doubler stage would look very much like the buffer amplifier illustrated in Fig. 4.

In a similar manner, the triode buffer stage shown in Fig. 2 can be used as a frequency multiplier.

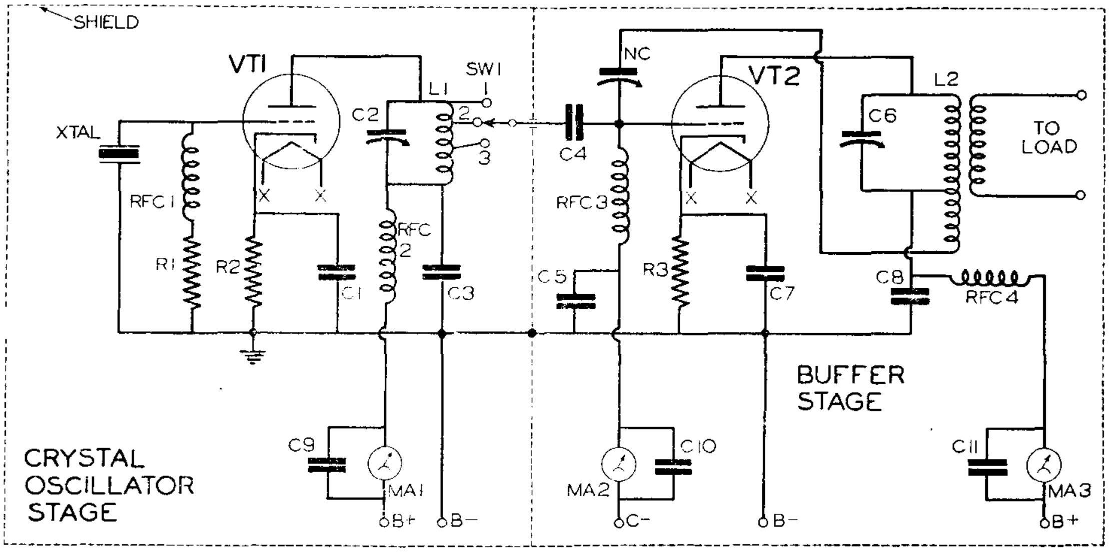


FIG. 2. A typical triode buffer amplifier following a crystal master oscillator. The buffer not only increases available power but isolates the oscillator from any changing load.

It is merely necessary to tune the output tank L_2-C_6 to the desired harmonic and increase the *C*- bias for optimum performance.

Neutralization Unnecessary. When a triode is used in a multiplier stage, the circuit can be simpler than that for straight buffer operation. Neutralization of a triode buffer is necessary to prevent self-oscillation. In a multiplier stage, however, the major voltage developed across the tank circuit does not have the same frequency as the excitation input power furnished to the stage. As a consequence, even though a considerable amount of plate circuit energy may flow back to the grid circuit through the plate-to-grid capacity, the feedback voltage can never be in phase with the input voltage because the frequencies of the two are not the same.

This means that a triode frequency multiplier cannot oscillate of its own accord and, therefore, does not require neutralization.

Accordingly, if the amplifier in Fig. 2 is to be used as a doubler or tripler instead of a straight-through buffer, the tank coil tap and the neutralizing condenser can be omitted.

To illustrate the simplicity of such a triode multiplier, let us look at Fig 11.

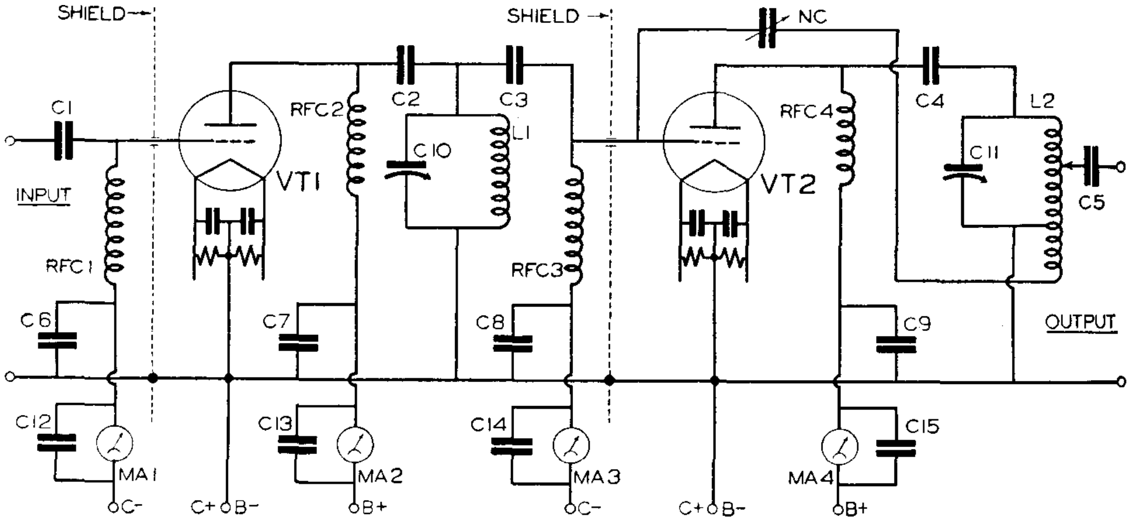


FIG. 11. A triode frequency multiplier driving a conventional "straight-through" triode amplifier. Since the plate and grid circuits of the multiplier operate at different frequencies, this stage requires no neutralization.

In this drawing we have VT_1 as a triode doubler (or tripler) driving a conventional triode amplifier VT_2. Since the frequency of the voltage developed in the tank circuit L_1—C_{10} is two or three times that of the input frequency, the triode multiplier VT_1 requires no neutralization.

On the other hand, since the output developed in the tank L_2—C_{11} has exactly the same frequency as the input to the grid of

VT_2, this triode stage must be neutralized to prevent self—oscillation.

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The phenomena of frequency multiplication is well known, even though it may not be as well understood by some Amateurs. It is safe to say that a Ham station without a doubler is as rare as a ham sandwich without mustard. But are these doublers being operated properly? Are they converting dc plate current into usable rf power, or are they dissipating it in the form of heat? The odds are that real improvements can be made. On this premise RCA engineers went about devising practical data for the guidance of Amateurs to help them select and operate tubes as frequency multipliers.

The Reason Why

Although the mechanics of handling doublers and triplers has now been reduced to a matter of simple arithmetic, an understanding of the basic engineering principles will assist in the solution of the formulas, and at the same time satisfy the Amateurs' natural curiosity and desire for "know-how."

Using a simple analogy, an electron tube frequency multiplier can be compared to a pendulum and its escapement (driving mechanism). The pendulum is the plate tank, and the escapement is the plate-current pulse. Now, if the escapement hits the pendulum once each cycle (360° excursion) the ratio is 1 to 1, and is equivalent to straight-through amplifier action. But if the escapement hits the pendulum once every two or every three cycles, the escapement frequency will be one-half or one-third the oscillation frequency of the pendulum, and the action will be equivalent to an electron tube operating as a doubler or tripler.

A moment of mental juggling with this analogy will make clear that for a given amount of driving force, the excursion of the pendulum will become smaller when the harmonic number is increased, simply because the escapement strikes the pendulum less often. Likewise, in an electron-tube circuit, as the harmonic number is increased, the plate-current pulse occurs less often. This means that the plate pulse power must be increased as the harmonic number is increased, if the dc plate input power is to remain unchanged.

Frequency Doubler Action

There are three main factors that limit the performance of frequency multipliers,

- maximum peak cathode current,
- maximum negative grid bias, and
- maximum rated plate dissipation.

Inasmuch as tubes are rated near their limits for amplifier service, and since the efficiency of frequency multipliers is generally less than that of amplifiers, multiplier applications will usually allow less plate power input. Otherwise, tube ratings will be exceeded.

Figure 1 shows graphically the action in a frequency doubler.

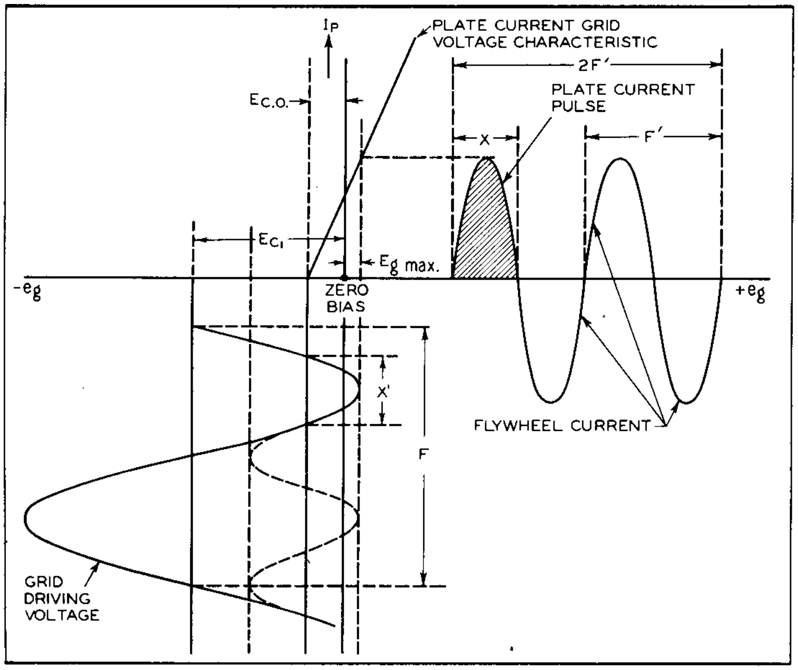
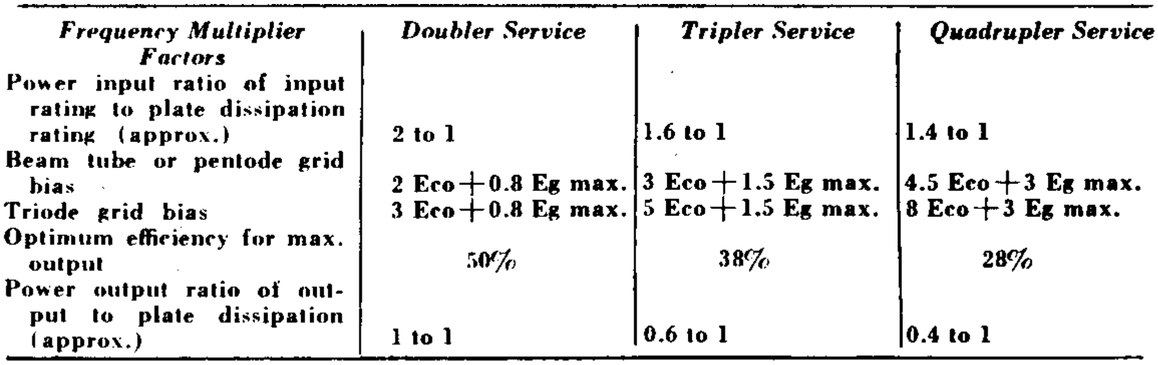


Figure 1. Graphic illustration of frequency doubler action.

The relationships illustrated are, of necessity, approximations, but they paint a representative picture of what occurs. For instance, it is shown that the plate current pulse occurs between the point of cutoff bias and the most positive excursion of the grid. This indicates that the correct bias voltage is not only a function of the mu-factor of the tube but that the combined effects of cutoff voltage and peak positive grid voltage determine it.

The function of high grid bias is to shape the plate-current pulse so that it approximates the shape of a half cycle of a wave of twice the grid-signal frequency. Note that the plate-current pulse (*X*) has the same width as the grid-voltage wave (*X′*) during the period of plate-current conduction. Note also that two complete oscillations occur in the plate circuit for each grid circuit cycle ($2F'=F$). It can be seen, therefore, that the grid circuit and plate circuit are synchronized. The lower-frequency grid voltage oscillates in perfect 1-to-2 timing in relation to the higher frequency ac plate voltage, and periodically produces pulses of plate current at exactly the right instant, every other plate-voltage cycle, to keep the plate circuit oscillating. For purposes of illustration, the drawing shows that plate current flows for exactly one-quarter of a grid-voltage cycle. Actually, this 90° conduction period may vary from 80° to 140° and still give excellent results. The grid-bias formulas given in Table 1 are based on a conduction angle of 120° for doubler operation.



Frequency Multiplier Factors	*Doubler Service*	*Tripler Service*	*Quadrupler Service*
Power input ratio of input rating to plate dissipation rating (approx.)	2 to 1	1.6 to 1	1.4 to 1
Beam tube or pentode grid bias	2 Eco + 0.8 Eg max.	3 Eco + 1.5 Eg max.	4.5 Eco + 3 Eg max.
Triode grid bias	3 Eco + 0.8 Eg max.	5 Eco + 1.5 Eg max.	8 Eco + 3 Eg max.
Optimum efficiency for max. output	50%	38%	28%
Power output ratio of output to plate dissipation (approx.)	1 to 1	0.6 to 1	0.4 to 1

Table 1

For triplers, a 100° conduction angle was used and for quadruplers the angle chosen was 80°.

Performance Limitations and Efficiency

Optimum multiplier efficiency is a compromise. Although it is possible to obtain the same plate circuit efficiency in a multiplier stage as is attainable in a "straight through" amplifier stage, limitations in the peak cathode current available and in the maximum grid-bias ratings of the tube reduce the output power to a fraction of that attainable by operating the tube with less plate circuit efficiency.

Furthermore, high-efficiency multiplier operation requires increased driving power, which results in low power gain per stage. The efficiencies shown in Table 1 are therefore, compromise efficiencies. Even with recommended multiplier efficiency, the power gain is less than that of an amplifier, and the driving power requirements are considerably higher.

Preferred Tubes

The great number of limitations and compromise factors suggest that all tubes are not good frequency multipliers. A satisfactory triode type is one that has a combination of high *mu* and a high wattage filament. The 808, 826, 809, and 811 make an excellent group.

Beam tubes and pentodes, because of their extremely high grid-plate amplification factor, are naturally good multipliers, but some are better than others. High-wattage filaments (or heater cathodes) and high transconductance are two prime quality factors. In the transmitting power class, the 2E26 and 807 are preferred types, with the 815 and 829-B taking the lead for tripler service.

Application Considerations

Probably the best way to become acquainted with the use of Table 1 is to work out an illustrative example. Regular ICAS Class C telegraphy data is also needed, and inasmuch as the 2E26 is featured on page 4 of this issue of HAM Tips, it will serve as the number-one guinea pig. Using maximum ratings and typical operating conditions, take the following steps to determine optimum data for doubler service.

(1) To determine the *maximum power input*, multiply the *plate dissipation* by the *power input ratio*: as shown in Table 1.

13.5 watts plate dissipation X 2 = 27 watts = Power *in max*

(2) To determine the *maximum plate current*, divide the *power input* by the chosen plate voltage:

27watts power in / 600 volts plate = 45 mA = Ib max plate current

(3) To determine the *cutoff bias voltage*, divide the chosen screen voltage by the grid-to-screen *mu*-factor (6.5 for the 2E26):

185 screen volts / 6.5 = 28 volts = E*co*

(4) To determine the *peak positive grid voltage*, subtract the Class C telegraphy *DC peak Grid-No. 1 Voltage* (dc grid bias = -45 V) from the *Peak RF grid No. 1 voltage* (57 V):

57 - (- 45) = 12 volts = E*g* max

(5) To determine the *grid bias*, multiply the *cutoff bias* (E*co* = 28 V) by 2; then multiply the *peak positive grid voltage* (E*g* max = 12 V) by 0.8, and add their products:

(2 x 28V) + (0.8 x 12V) = -66V E*cl*

These multiplier values are given in the line labeled *Doubler Service* for pentodes or beam tubes in Table 1.

(6a) To determine the expected *power output*, multiply the *power input* by the *optimum efficiency* (50% for Doubler Service):

27 watts P*input* x 0.50 = 13.5 watts = P*output*

(6b) The *power output* can also be estimated by multiplying the *plate dissipation* (13.5 watts) by the *Power output ratio of output to plate dissipation* in Table 1:

13.5 watts x 1 = 13.5 watts = P*out*

The procedure is the same for triodes except that the grid-to-plate *mu* factor is used instead of the grid-to-screen *mu* factor. It will be seen that triodes require a larger cutoff voltage multiplier than screen-grid tubes. The reason is that the value of cut-off bias varies with the instantaneous plate voltage. For practical multiplier operation, the effect of this variation is to increase the required grid bias. In screen-grid tubes the cut-off bias is not a function of the plate voltage and, therefore, this effect is not present.

Parallel, Push-Pull, and Push-Push Operation

When more power is needed than a single tube will deliver, and a tube of the right size and proper characteristics is not available, two tubes may be used. If the tubes are connected in parallel, the operation will be essentially the same as for a single tube, except that the power output will be doubled, and the input and output capacitances *will be doubled*.

Push-pull operation is not so simple. It suppresses even-order harmonics and accentuates the odd ones; therefore, it is used in tripler and quintupler circuits. As compared with the parallel connection, the input and output capacitances are halved instead of doubled - an important advantage at very high frequencies.

Push-push (push-pull grids and parallel plates) is exactly the opposite of push-pull in that the even harmonics are accentuated and the odd multiples suppressed. It is used for doubler and quadrupler service, and can be expected to give somewhat higher power gain than parallel operation. Because the plate circuit receives twice as many pulses as a single-ended doubler, decrement losses are minimized; I^2R losses are reduced because some circuit components are required to carry only one-half the peak current normal to a regular doubler.

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USING THE RCA-5763 FOR FREQUENCY MULTIPLICATION

By ROBERT *M.* COHEN, W2LHP
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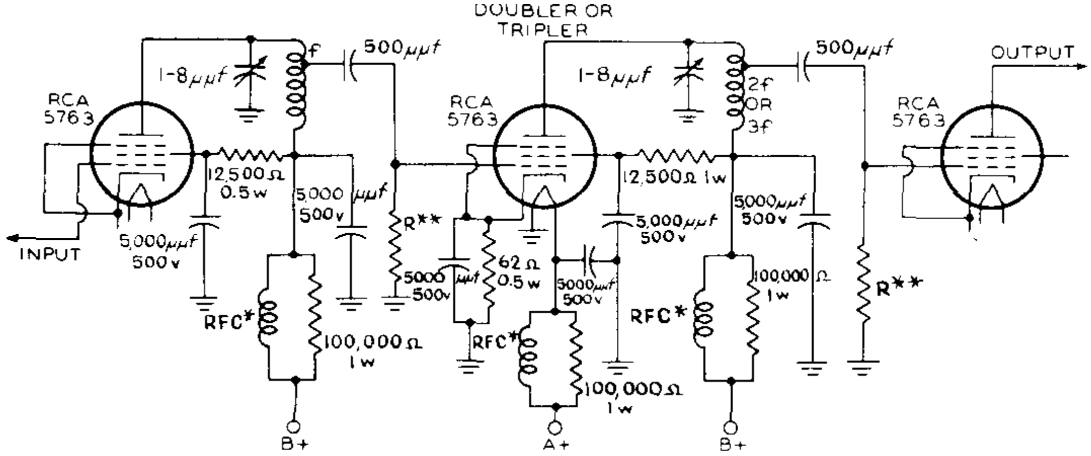
Amateurs will find many uses for the new miniature transmitting tube, RCA-5763, which operates very efficiently as a doubler, tripler, or quadrupler at frequencies up to 175 Mc. Although intended primarily for mobile service, its outstanding performance makes it deserving of a place in fixed station equipment where flexible all-band operation is desired.

The basic principles of multiplier operation have already been discussed in some detail so we will limit our discussion to the particular operating condition~ and circuits specifically applicable to the 5763.

Fig. 1A shows the application of the 5763 as a frequency multiplier in the conventional manner.



R** 75,000 Ω, 1W FOR DOUBLER; 100,000 Ω, 1W FOR TRIPLER
RFC* RF CHOKE, #24 ENAMEL-COVERED WIRE CLOSE WOUND ON RESISTORS

Fig. 1A. Frequency multiplier circuit diagram using the RCA-5763.

The accompanying photograph (Fig. 1B) shows the lead arrangement and location of parts and is indicative of the generally accepted methods for obtaining short leads and proper circuit bypassing features necessary for good high-frequency performance.

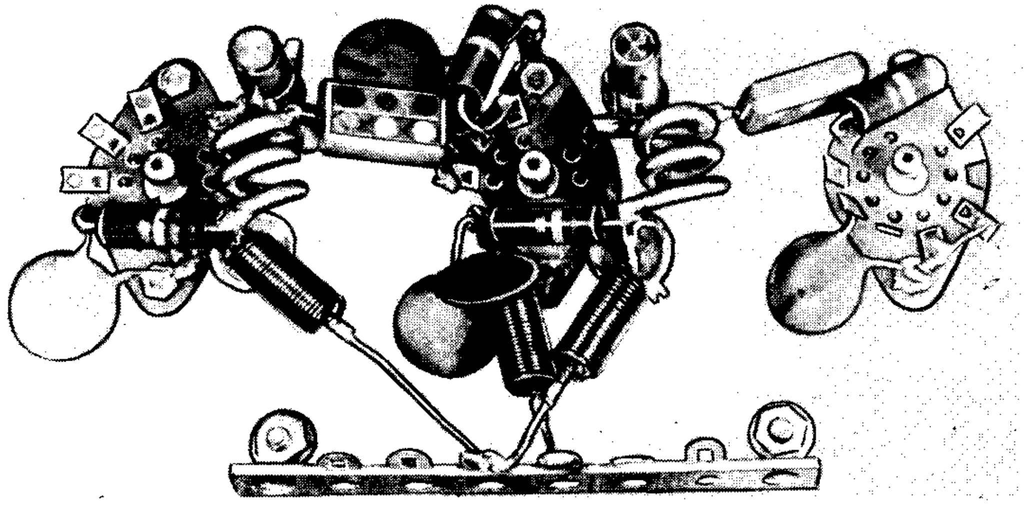


Fig. 1B. Photograph showing an actual model of a frequency multiplier constructed from the above diagram. Note that the placement of parts follows closely the position indicated in the diagram for the purpose of keeping leads as short as possible.

Fig. 2 is a family of curves of useful power output versus operating frequency made with this circuit. The term "Useful Power Output" refers to the power which is delivered to the grid of the following tube or the transmission line; it is equal to the total tube power output less circuit and radiation losses.

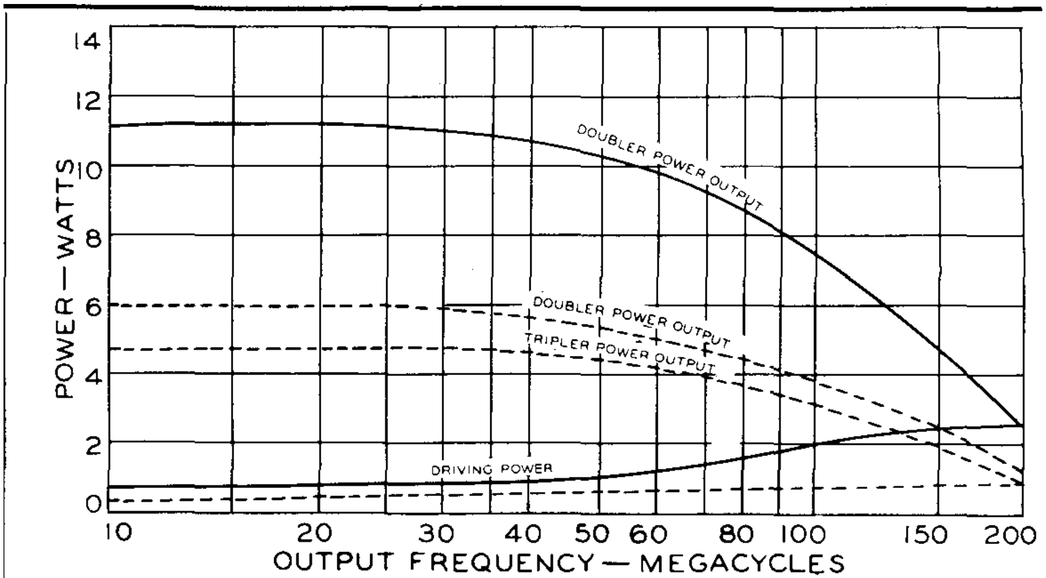


Figure 2. Useful power output of the RCA-5763 as a function of operating frequency in the circuit of Fig. 1A (dotted lines). The solid lines indicate the useful power output of RCA-5763's as a function of operating frequency in the push-push circuit of figure 3.

These data, presented in terms of useful power output, are of considerable value to the designer of a transmitter but are not necessarily indicative of tube efficiency, especially at high frequencies where the radiated energy and circuit losses consume a substantial part of the tube output. By way of illustration, the tank circuit power loss including tank circuit radiation is calculated approximately from the unloaded tank-circuit parameters by means of the following relation:

$$Total\ \ Tank\ \ Circuit\ \ Loss = \frac{E^2 2\pi f C}{Q}$$

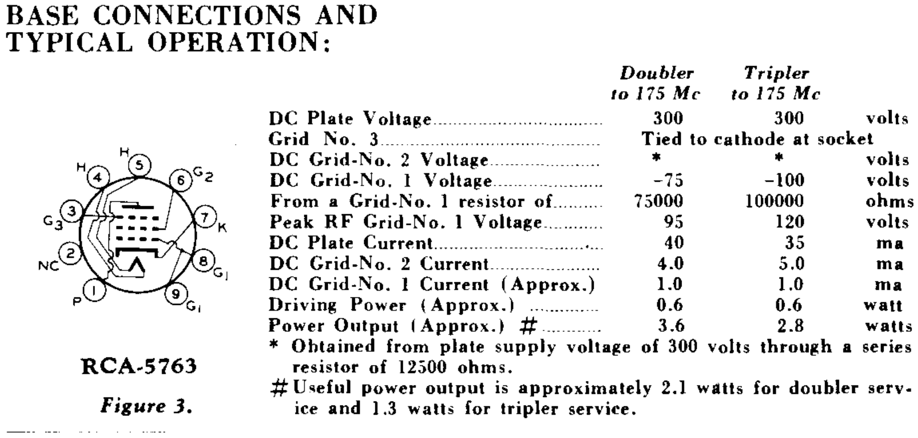
f = frequency
Q = Q of unloaded tank circuit with tube out and circuit restored to resonance
E = RMS value of tank circuit voltage in volts with tank circuit unloaded
C = Total value of tank circuit capacitance including tube, wiring, etc. in picofarads

For the doubler circuit given in Fig. 1 when used in a typical compact mobile transmitter, the total tank circuit loss at 150 MHz is:

$$Total\ \ Tank\ \ Circuit\ \ Loss = \frac{(150\,Volts)^2 \times 2\pi \times (150 \times 10^6\ \ Hz) \times (15 \times 10^{-12}\ \ F)}{110} = 2.86\,Watts$$

This value, approximately equal to the useful power output, is large but is typical of the normal condition in the 150-MHz region when "lumped circuits" are employed. The tank circuit *Q* of 110 is reasonably good and the total capacitance of 15 pF is difficult to reduce.

Fig. 3 is a chart giving the recommended operating conditions for the multiplier circuit.



BASE CONNECTIONS AND TYPICAL OPERATION:

	Doubler to 175 Mc	*Tripler to 175 Mc*	
DC Plate Voltage	300	300	volts
Grid No. 3	Tied to cathode at socket		
DC Grid-No. 2 Voltage	*	*	volts
DC Grid-No. 1 Voltage	−75	−100	volts
From a Grid-No. 1 resistor of	75000	100000	ohms
Peak RF Grid-No. 1 Voltage	95	120	volts
DC Plate Current	40	35	ma
DC Grid-No. 2 Current	4.0	5.0	ma
DC Grid-No. 1 Current (Approx.)	1.0	1.0	ma
Driving Power (Approx.)	0.6	0.6	watt
Power Output (Approx.) #	3.6	2.8	watts

* Obtained from plate supply voltage of 300 volts through a series resistor of 12500 ohms.

\# Useful power output is approximately 2.1 watts for doubler service and 1.3 watts for tripler service.

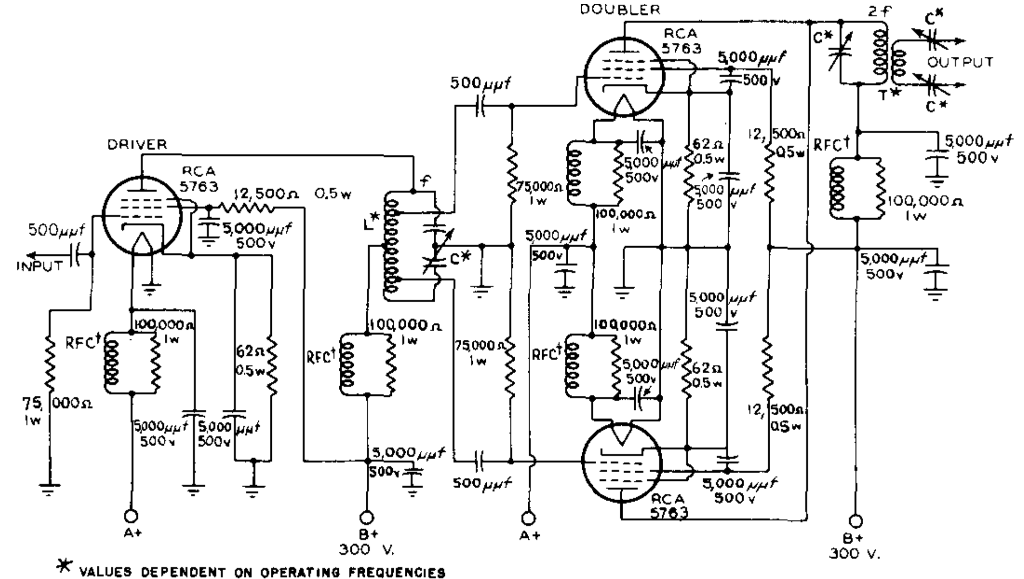
RCA-5763

Figure 3.

Both doubler and tripler operating conditions are given, since the same circuit is used with a change in *grid-No. 1 resistance*. It is well to remember that when the tube is operated at lower *B+* supply voltage than indicated, best multiplier operation occurs, in general, with high driving voltage, high developed bias, and with tank circuits having very low capacitance. In order to obtain maximum power output at high frequencies, the value of the *grid-No. 2* resistor should be adjusted so that the full rated value of 250 volts is applied to grid No. 2.

The plate circuit efficiency of this tube is sufficiently good to allow application of full power input at frequencies up to 175 MHz. It is important to note that above 125 MHz, greater power gain is obtained when the tube is used as a doubler than as a straight-through neutralized amplifier because loading of the driving stage due to the input resistance of the 5763 is less severe at the lower frequency.

Because of its low value of output capacitance, two 5763's may be used to advantage in the "push-push" doubler circuit shown in Fig. 4.



* VALUES DEPENDENT ON OPERATING FREQUENCIES

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Figure 4. Circuit diagram of the Push-Push Doubler using a pair of RCA-5763's.

A single 5763 used as a tripler will provide more than adequate driving power, making a combination which is especially suitable for a low-power transmitter.

Fig. 2 also shows a chart of measured power output as a function of operating frequency (solid lines) similar to that shown for the single multiplier (dotted lines).

Because the grid-No. 2 dissipation of this beam pentode will increase rapidly when the excitation is increased, especially with an unloaded amplifier, the maximum allowable grid No. 2 input of 2.0 watts must not be exceeded. Tubes can be quickly ruined if this rating is not adhered to.

Because of the high amplification factor of the 5763, a small cathode resistance of 62 ohms can furnish sufficient voltage to protect the tube in the event of temporary excitation failure and resultant loss in bias developed across the grid resistor. The cathode bias of 5.0 volts required for protection is sufficiently small to make the loss in de plate voltage negligible.