TECHNICAL MANUAL

HARRIS
COMMUNICATIONS AND INFORMATION HANDLING

HARRIS

PDM BROADCAST EQUIPMENT TRAINING

I. GENERAL

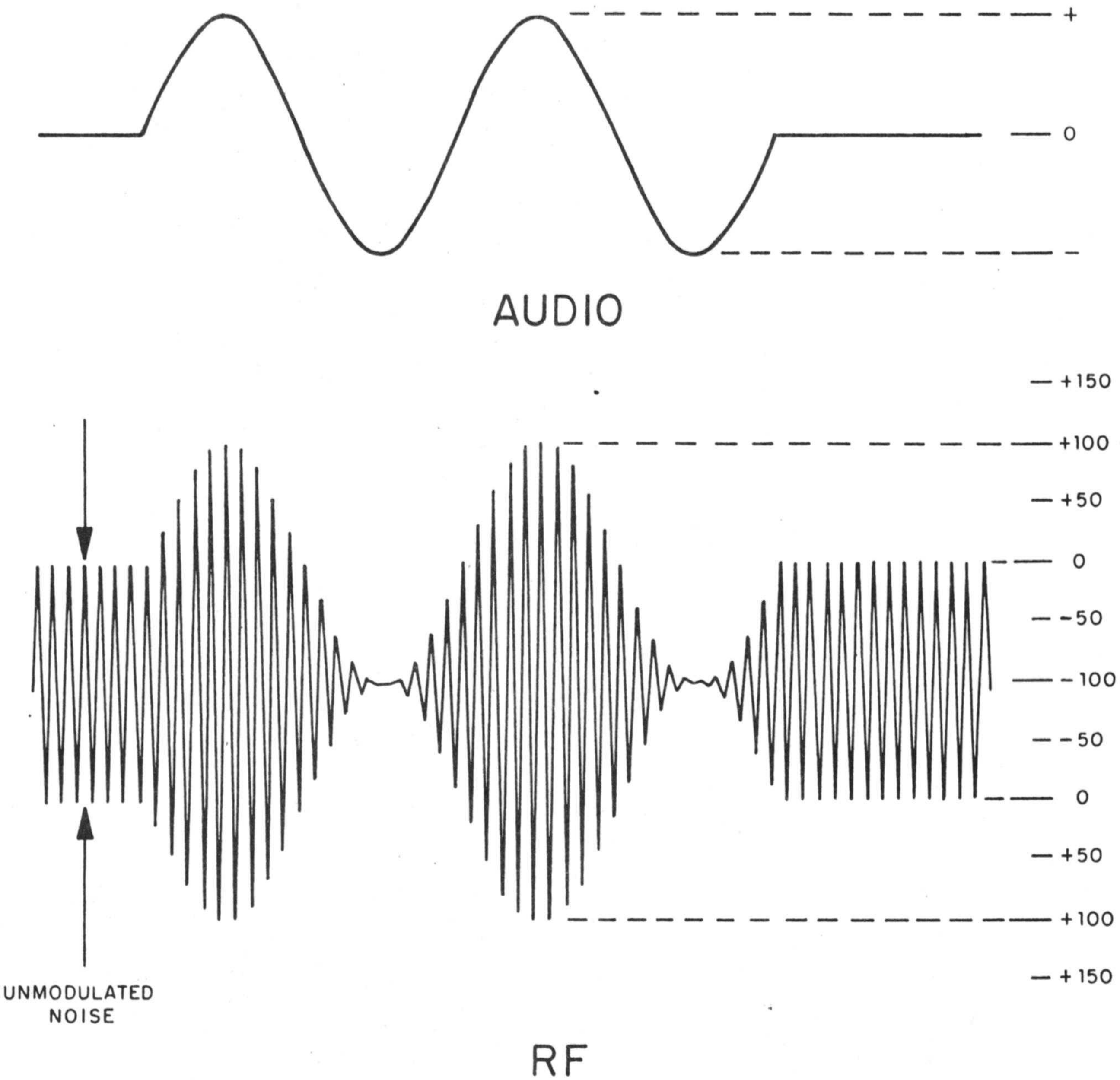
Since its introduction in 1967, Pulse Duration Modulation has proved to be clearly superior to any other method of modulation of high power AM transmitters. The fundamental benefits of PDM in the areas of efficiency, simplicity, reliability, fidelity and transient response have become well accepted. The following review of how PDM works is intended to give a confident understanding of how this modulation process works.

II. AM REVIEW

It is necessary to start with a basic review of Amplitude Modulation (AM) and what the modulation process should accomplish, then a review of the basic plate modulated AM transmitter, the push-pull class B modulated AM transmitter and show how the same process can be accomplished with a series modulator. This leads to the concept of PDM as a series plate modulation process, then step by step, show how the width modulated pulses are developed. Next, we show how modulation is accomplished, and review the wave forms that exist in PDM. (PDM IS SERIES CONNECTED PLATE MODULATION.)

A. Basic AM

The first figure reviews some basics of Amplitude Modu-



BASIC AM

FIGURE 1

lation. At the top are shown two cycles of a sine wave representing the audio information. The audio swings positive and negative about a zero voltage point.

The instantaneous audio information will typically be complex wave forms, but shown here is a sine wave for simplicity. In the bottom half of the picture on the lefthand side is shown the unmodulated RF carrier that exists when there is no audio information.

This unmodulated carrier voltage represents the unmodulated output power of the transmitter. When the audio information goes positive, the RF carrier simply gets increased in magnitude; and when the audio information goes negative, then the RF output voltage gets smaller. This wave form is called the RF envelope and is often displayed on the oscilloscope. In this figure, we are looking at the transmitter output in the time domain.

B. <u>Modulation Percentage</u>

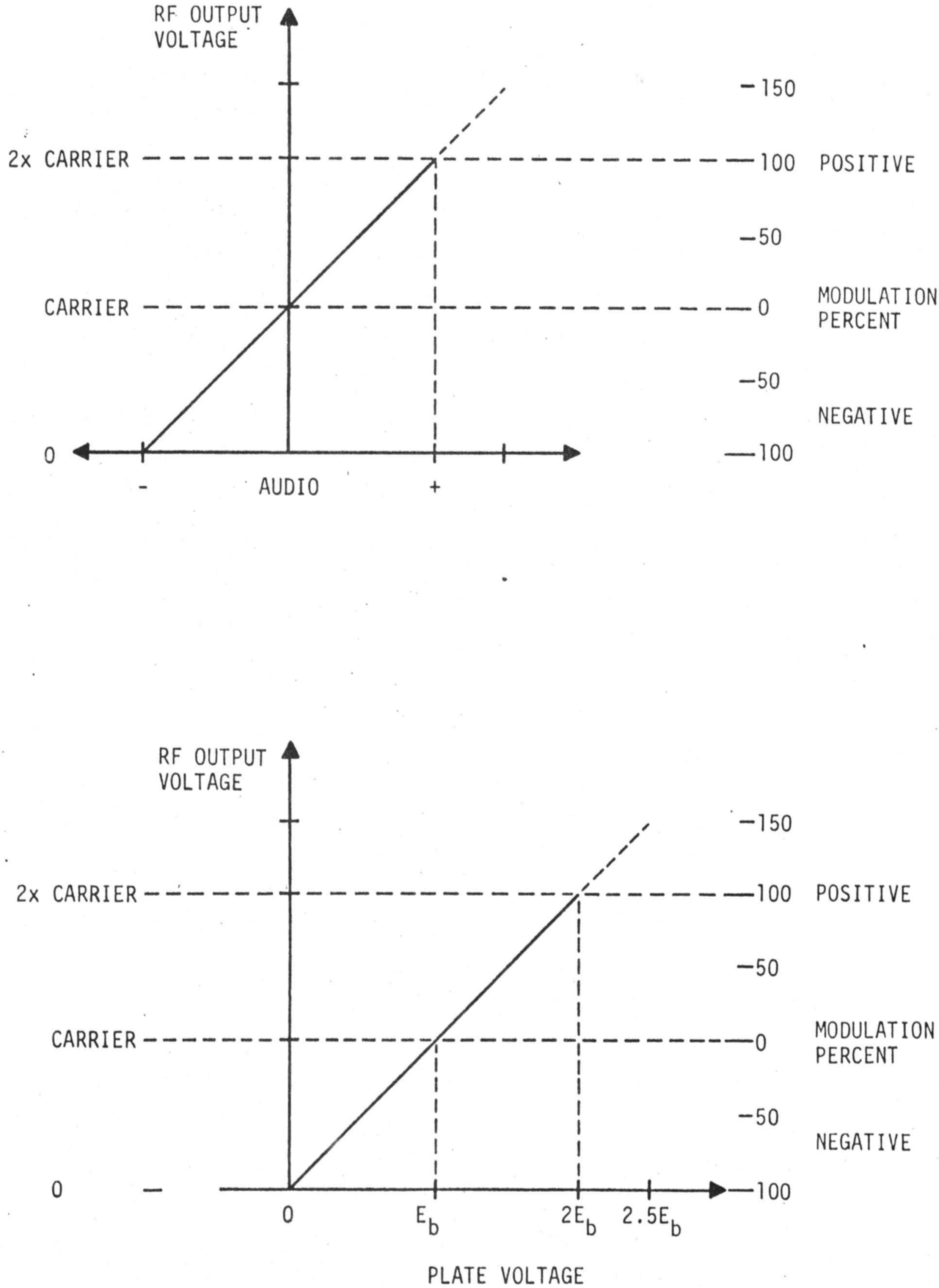
On the right-hand side is a scale which illustrates the modulation percentage. When the carrier has no modulation on it, it has a fixed value which defines the output power of the transmitter. If the instantaneous output voltage is twice the unmodulated carrier voltage, we have 100% peak positive modulation. And when the instantaneous RF voltage swings to zero, we have 100% negative modulation. If the peak positive voltage of the RF carrier is two and one-half times the unmodulated carrier voltage, we have 150% peak positive modulation. From this figure note that it is impossible to exceed 100% negative modulation, due to the fact that you can have no less than zero carrier voltage. But, on the other hand, the peak positive modulation is not fundamentally limited except by the capability of the transmitter. Shown in this first figure is an illustration of the results that the transmitter should obtain.

C. Transmitter Configurations

In Figure Two, we see pictures of the characteristics of the transmitter to achieve the results of the first figure. In the top half of the picture, the vertical scale is labeled RF output voltage. The horizontal scale is labeled audio voltage. The audio scale is labeled audio voltage. The audio voltage can be either plus or minus about a zero point, however, the carrier voltage is always positive. We see that the point where the audio voltage is zero, the RF output voltage is labeled carrier, or zero modulation percentage. This point represents an unmodulated carrier. As the audio voltage swings along the horizontal axis, either plus or minus, the RF output voltage varies, either to a larger value or to a lesser value. If this transfer characteristic or line is perfectly straight, we have no distortion. When the audio voltage swings negative to the point that the RF output voltage is reduced to zero, we have achieved 100% negative modulation. When the audio voltage swings positive to the point that the RF output voltage is twice the carrier voltage, we have a point called 100% positive modulation. We also see that the audio voltage could swing positive so that the carrier voltage exceeds twice the unmodulated carrier voltage to achieve positive modulation greater than 100%. Figure 2 shows that the RF output voltage is a linear function of the instantaneous audio voltage.

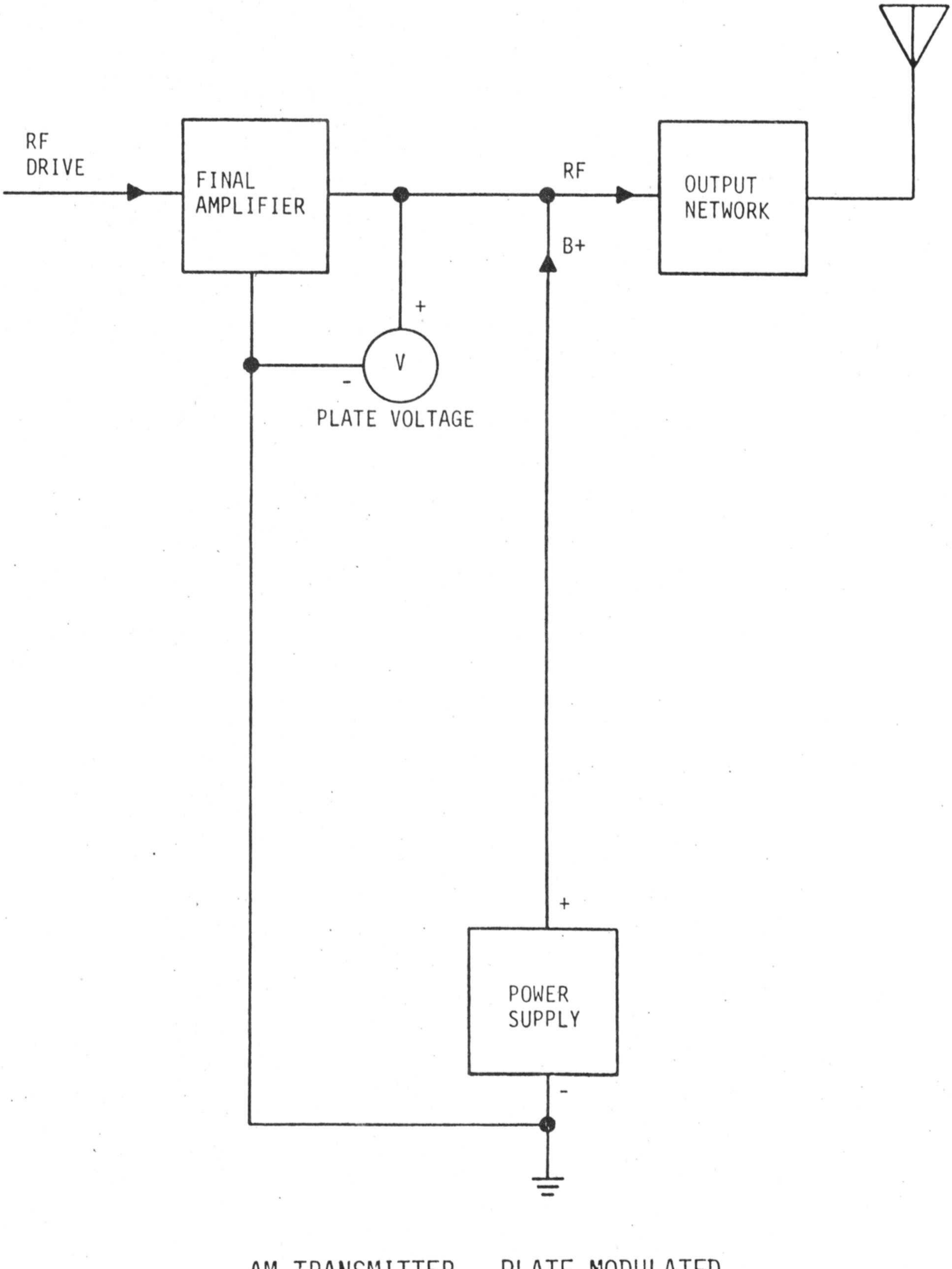
1. Plate Modulation

The lower part of Figure 2 shows how the transfer characteristic is obtained in a plate modulated AM transmitter. Here the vertical axis is exactly the same as above. It is labeled "RF Output Voltage".



AM TRANSMITTER CHARACTERISTICS

FIGURE 2



AM TRANSMITTER - PLATE MODULATED

FIGURE 3

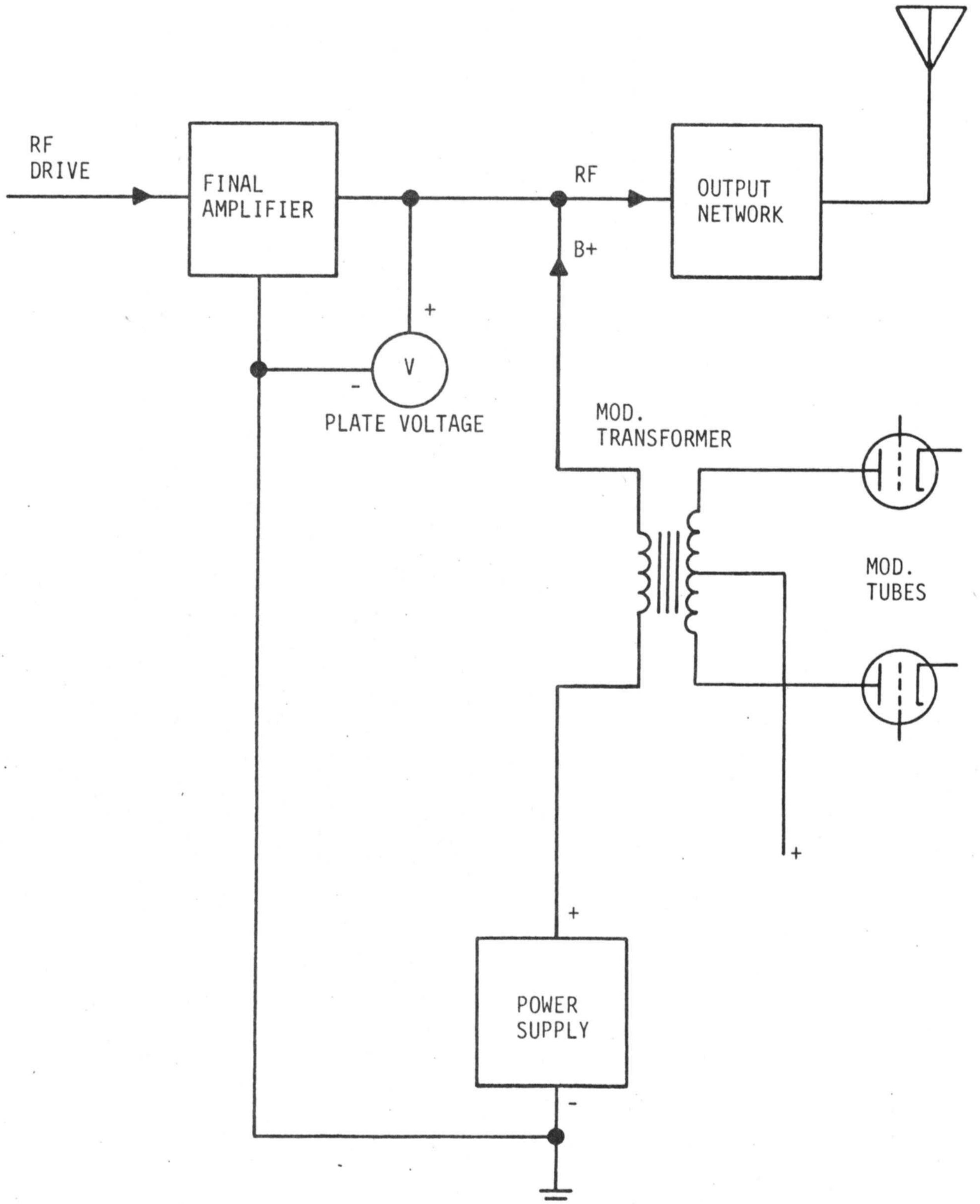
The unmodulated Audio RF voltage, labeled "Carrier" is achieved at a plate voltage labeled "E_b". This is the Final Amplifier plate voltage. This is a value read on a plate voltage meter of the transmitter. Now if we vary the plate voltage along the horizontal axis as a function of the audio, we achieve the results illustrated in the upper half of Figure 2. Therefore, the plate voltage is instantaneously varied exactly in step with the desired audio information. This causes the RF output voltage to vary exactly in accordance with the audio information. The result is Amplitude Modulation, by means of the plate modulation process. Figure 2 shows that the instantaneous plate voltage may swing as low as zero volts or it may swing as high as twice the average plate voltage for 100% modulation. To obtain modulation greater than 100% positive, we simply swing the PA plate voltage higher than twice the average plate voltage. Note, at this point that audio information has no DC value, that is, it is passed through a transformer or capacitor its average value is zero. This means that the area above the zero axis is exactly equal to the area below the zero axis. Its average is zero. Therefore, the average plate voltage is equal to E_b in this condition. Any variation in the average plate voltage E_b results in carrier shift. Even though complex audio information has zero average value, that is, the area above the axis is equal to the area below the axis, it may have peaks which are not symmetrical. That is to say, it may swing positive to a greater peak value than it swings negative. In naturally ocurring audio, the positive and negative peaks are not symmetrical that is, they have different values, but we should remember that their average value is zero. Therefore, the average plate voltage remains at the point labeled "E_b" in Figure 2.

So the lower half of Figure 2 shows what is accomplished in plate modulation.

In Figure 3, three important elements of a plate modulated transmitter are shown. The modulator is not shown. We have a Power Supply whose job is to furnish the DC power to the amplifiers. We have the final amplifier which under proper R.F. excitation converts the DC power to RF energy. We have an output network whose job is to deliver the RF energy to the antenna. The next series of figures will show these fundamental elements of plate modulated transmitters in exactly these same positions, but will connect them together in several different fashions to show the various methods of plate modulation. The voltmeter labeled "Plate Voltage" illustrates the plate voltage shown along the horizontal axis in Figure 2. In the plate modulation transmitter, the task of the modulator will be to vary this instantaneous plate voltage as a linear function of the desired audio information. Again, Figure 3 shows the fundamental elements of a plate modulated transmitter without the modulator.

2. Push-Pull Modulation

Figure 4 shows the exact same elements but with the addition of push-pull class B modulator. Once again, we have the Final Amplifier, the output network and the power supply. But here we've added a modulation transformer and class B push-pull audio amplifiers. The job of this modulator is to add to the power supply voltage an audio voltage which is exactly the audio information to be reproduced. This voltage added in series with the power supply voltage causes the plate voltage of the final amplifier to vary in common use. This is one that is

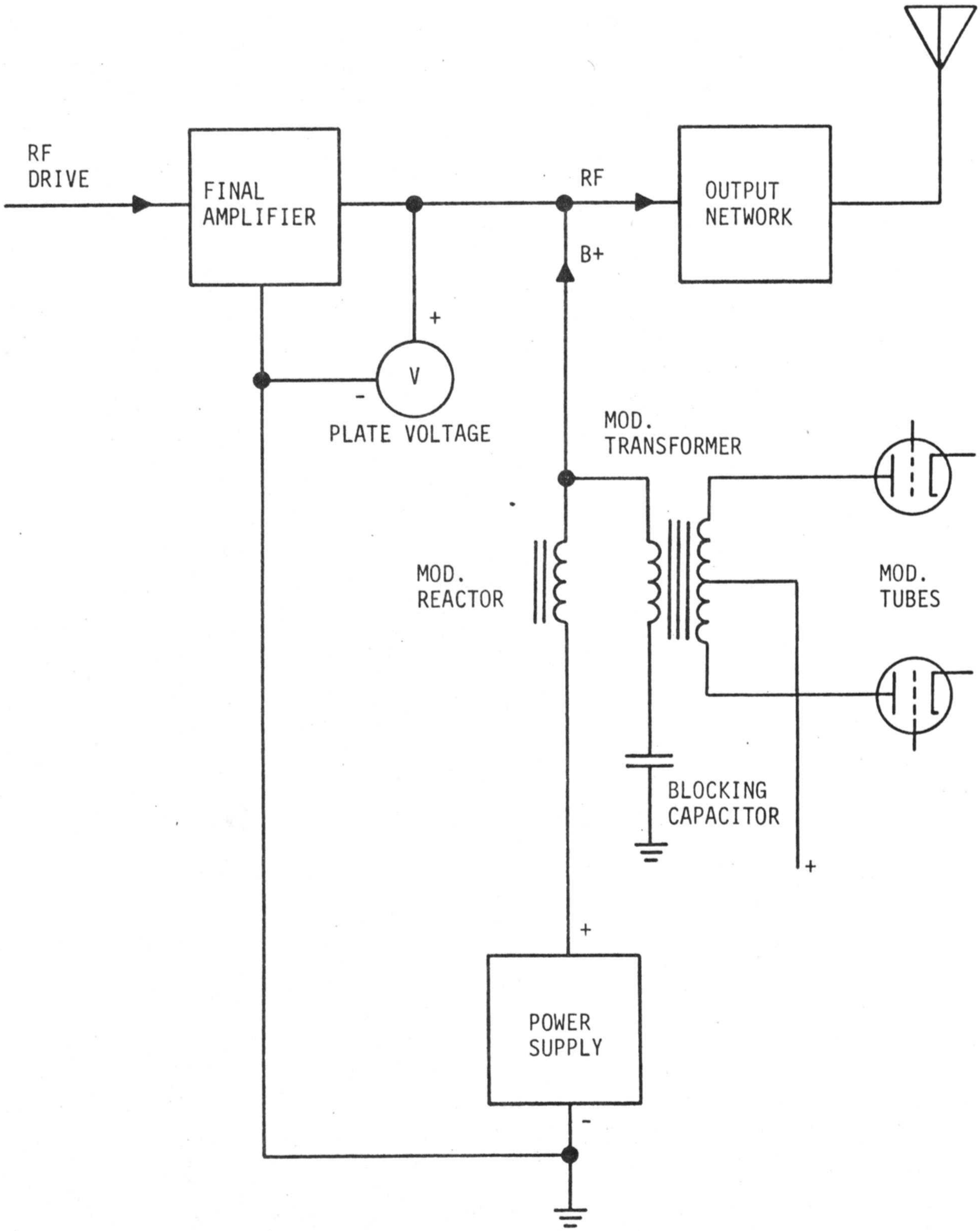


AM TRANSMITTER - PLATE MODULATED
PUSH PULL CLASS B MODULATOR

FIGURE 4

often the first type of modulation studied by someone who is beginning to understand AM transmitters. So here we have the basic elements of a plate modulated AM transmitter and have added to it push-pull class B modulators.

Figure 5 is almost exactly the same as the previous one, where we have a plate modulated AM transmitter with push-pull class B modulators. Figure 5 adds the modulation reactor and blocking capacitor that is found in most transmitters using this type of modulation. The technique shown here is exactly the same as on Figure 4, except that the modulation reactor and blocking capacitor serve to eliminate the average plate current from the secondary of the modulation transformer. This is done to allow the modulation transformer to be a more practical device. Most people are familiar with the fact that a DC current through the transformer winding causes a heavy burden on the iron of the transformer. Constant magnetic bias is placed in the core, therefore, much more iron must be used in order to achieve the dynamic swings with good linearity. The modulation reactor can be viewed as



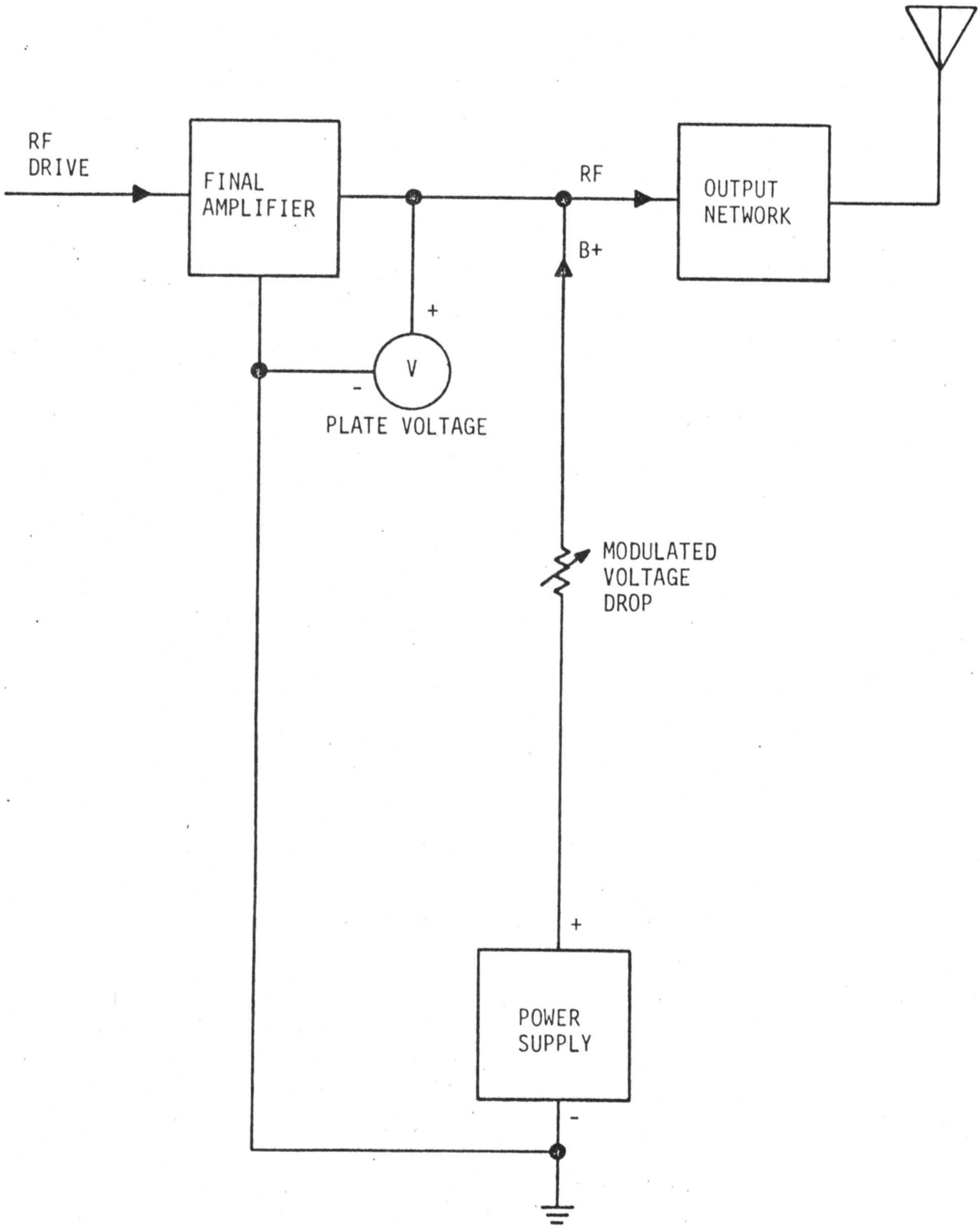
AM TRANSMITTER - PLATE MODULATED
PUSH PULL CLASS B MODULATOR
WITH MODULATION REACTOR AND BLOCKING CAPACITOR

FIGURE 5

a short circuit for the average plate current to the transmitter, but an open circuit for the audio component of modulation. Conversely, the blocking capacitor can be viewed as an open circuit for the DC plate voltage to the final amplifier, but it is a short circuit for the audio components of the modulation. Everyone working with an AM transmitter should be quite familiar with this technique. There have been more transmitters built using these circuits than any other method. Often the positive voltage for the anodes of the modulator tube is connected directly to the power supply so that the power supply serves not only for the average plate voltage but also to supply current to the modulator anodes. Figure 5 shows the practical plate modulated AM transmitter with push-pull class B modulators.

3. Series Modulation

Figure 6 shows the familiar elements of an AM plate modulated transmitter, but with a different modulator technique. This technique is called series modulation and we have represented it here with a variable resistor. We have called the variable resistor a modulated voltage drop. The resistance of the resistor or the voltage drop across this element varies as the linear function of the desired audio information. This causes the plate voltage to vary as a linear function of the audio information. This produces plate modulated AM. Now of course when there is no audio information the modulated voltage drop must assume some fixed value and the power supply must deliver a voltage equal to that fixed value plus the required plate voltage. Thus, we have increased the voltage to the power supply. Remember that with no modulation, there is some drop across the variable resistor. As the audio information varies, the voltage drop across the resistor varies, and we have then accomplished the variation of the plate voltage of the final amplifier to achieve plate modulation. The basic elements of the plate modulated AM transmitter are exactly the same as in the previous figures. The only minor exception is in this case; the power supply voltage is higher than in the previous figures. No transmitters are built as shown in Figure 6, but here we want to illustrate the technique or philosophy behind series plate modulation.



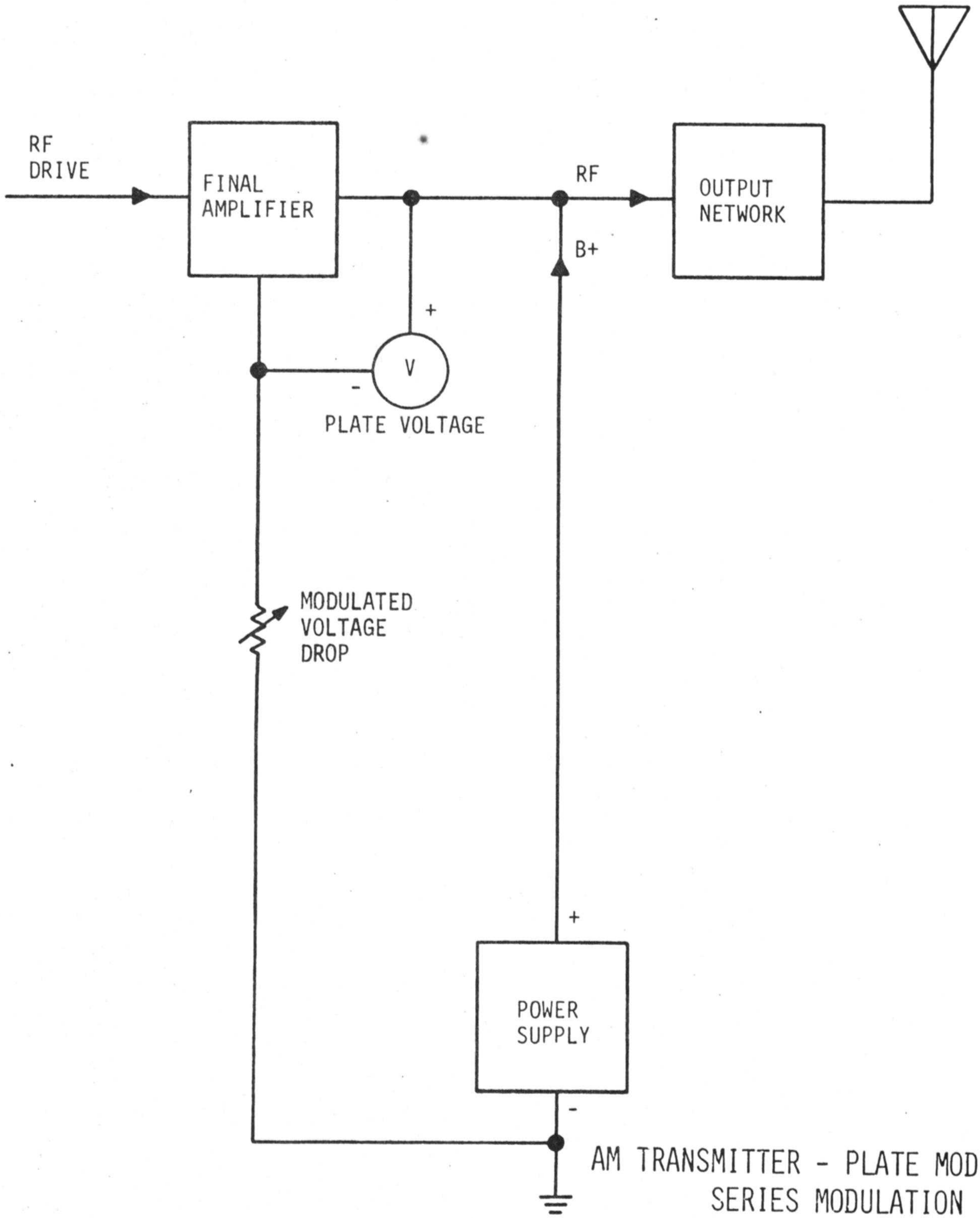
AM TRANSMITTER - PLATE MODULATED
SERIES MODULATION

FIGURE 6

4. Power Supply Configuration

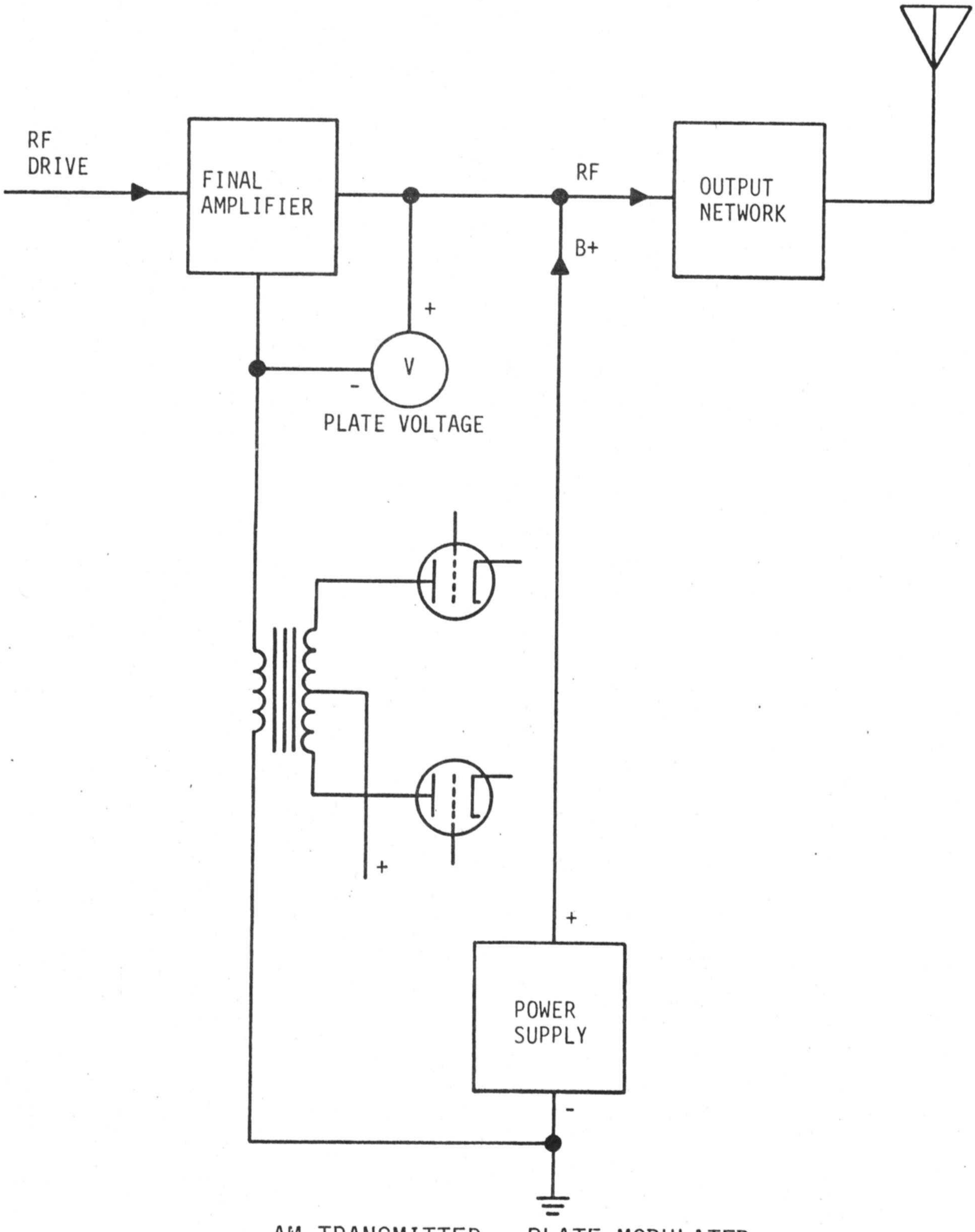
a. Figure 7 is exactly the same as the previous one except that we have moved the modulated voltage drop into the negative lead of the power supply rather than the positive lead of the power supply. Now this technique will achieve exactly the same form of plate modulation. It will achieve exactly the same swings of the plate voltage as in the previous techniques. The only difference here is the negative or cathode side of the final amplifier is above ground potential. However, the plate voltage across the final amplifier can be made to vary in exactly the same manner as shown in the previous figure (6).

b. In fact in Figure 8, we see a push-pull class B modulator shown in a negative side of the power supply. This technique would work very similar to the class B modulator shown previously. The audio voltage variations are simply added in a negative lead rather than in a positive lead. The plate voltage across the final amplifier varies exactly as shown before. Of course, there are no transmitters built with this particular schematic but it is shown simply to illustrate



AM TRANSMITTER - PLATE MODULATED
SERIES MODULATION
NEGATIVE SIDE OF POWER SUPPLY

FIGURE 7



AM TRANSMITTER - PLATE MODULATED
PUSH PULL CLASS B MODULATOR
NEGATIVE SIDE OF POWER SUPPLY

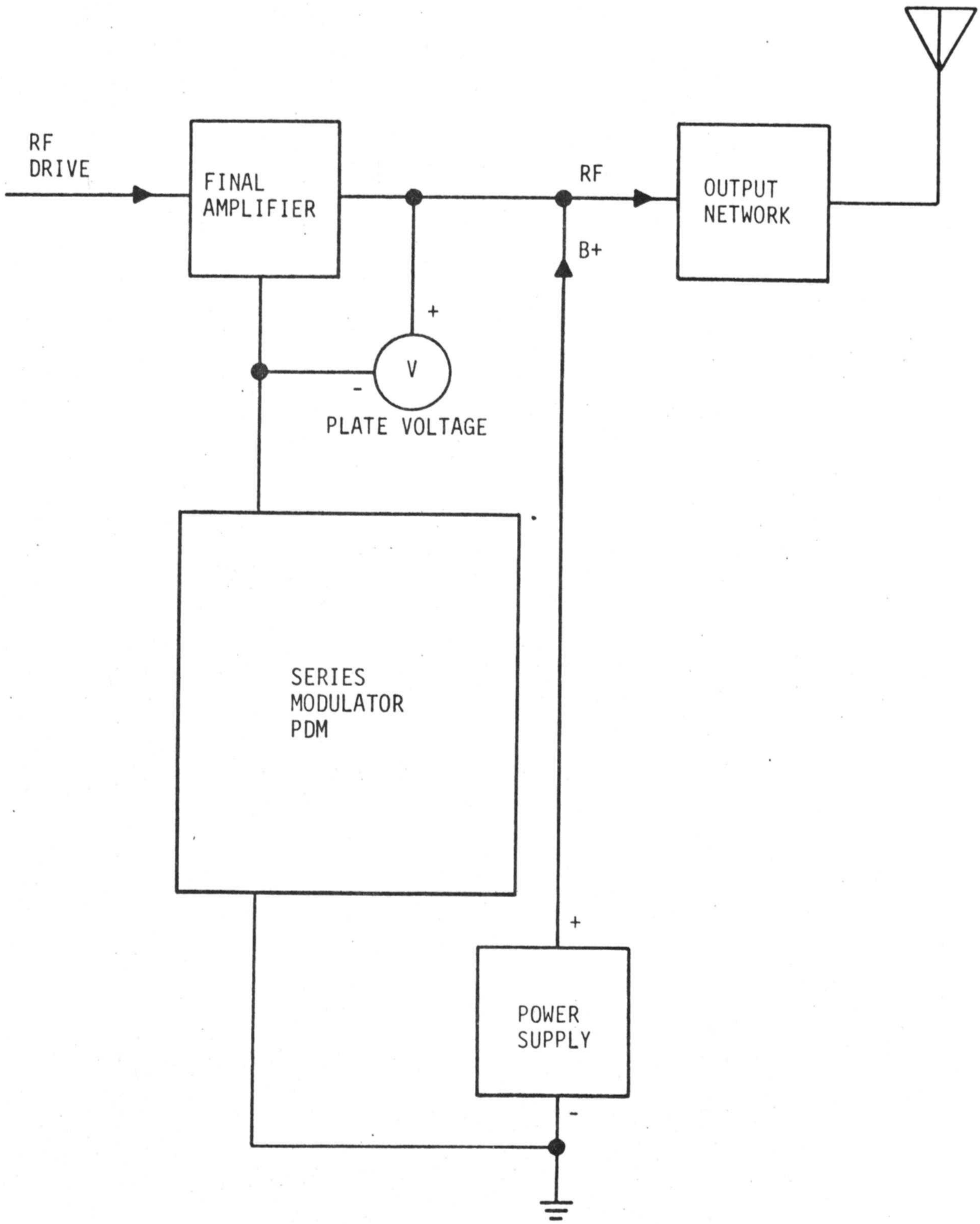
FIGURE 8

the fact that the modulated audio voltage could be introduced into either the negative or positive lead of the final amplifier.

III. PDM

A. PDM Configuration

Figure 9 shows where the PDM modulator is connected. The PDM modulator achieves plate modulation of the final amplifier. It achieves this by virtue of being a series voltage drop in a negative lead of the power supply. The series PDM modulator could have been placed in the positive lead of the final amplifier but greater performance and less complexity is achieved in practical transmitters in the negative lead. With no modulation, a specific value of PA plate voltage is acquired to deliver the output power of the transmitters. With no audio modulation, the series PDM modulator produces a voltage drop approximately equal to this value of plate voltage. The power supply then has a voltage equal to the sum of these two values. On a positive modulation excursion, the series drop across the PDM modulator becomes smaller and smaller.



AM TRANSMITTER - PLATE MODULATED
SERIES MODULATION
PDM

FIGURE 9

This means that the full power supply voltage begins to be impressed on the final amplifier. Conversely, as a negative modulation peak is approached, the voltage drop across the series PDM modulator becomes greater and greater. Thus, the plate voltage of the final amplifier becomes smaller and smaller.

B. Basic PDM Analogy

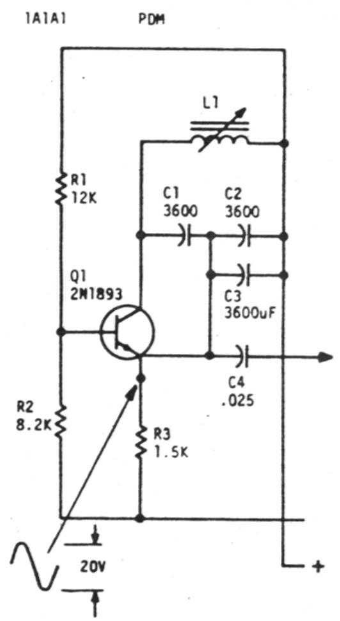
It is very convenient to think of the series PDM modulator in terms of a voltage regulator attached to the power supply. The regulation is varied, in a linear fashion as a result of the audio information. Therefore, the plate voltage of the final amplifier varies. The drop through the series modulator can be changed to achieve the desired changes in plate voltage of the Final Amplifier. These changes in the plate voltage of the Final Amplifier result in plate modulation. This picture sums up the first important point of understanding PDM. A PDM Series Modulator creates plate modulation in the Final Amplifier in exactly the same fashion as a classical plate modulated transmitter. The PDM Modulator is in the negative lead of the Final Amplifier and the power supply voltage is approximately twice the value required for carrier conditions of the final amplifier.

We haven't yet said what's in this box labeled "Series Modulated PDM". We should thoroughly understand that the drop across this box varies indirectly as the audio information varies. When there is no audio information, it has a fixed drop. Audio varies the voltage drop across the PDM modulator which causes the plate voltage to the Final Amplifier to vary. Now to develop the ideas of what's in this PDM Modulator block we will start off with the generation of the low level PDM signal.

C. PDM Circuit

1. 75 kHz Oscillator

In the next series of figures, we are going to start at another end of the transmitter. Here we see the 75 kHz oscillator in the PDM chassis. We are going to look at each function within the PDM exciter chassis and understand the functions before we return to the modulation of the transmitter. The 75 kHz oscillator is the first stage of the PDM exciter. As shown in Figure 10, it's a simple Colpitts LC oscillator which delivers from its cathode approximately 30 volts peak-to-peak



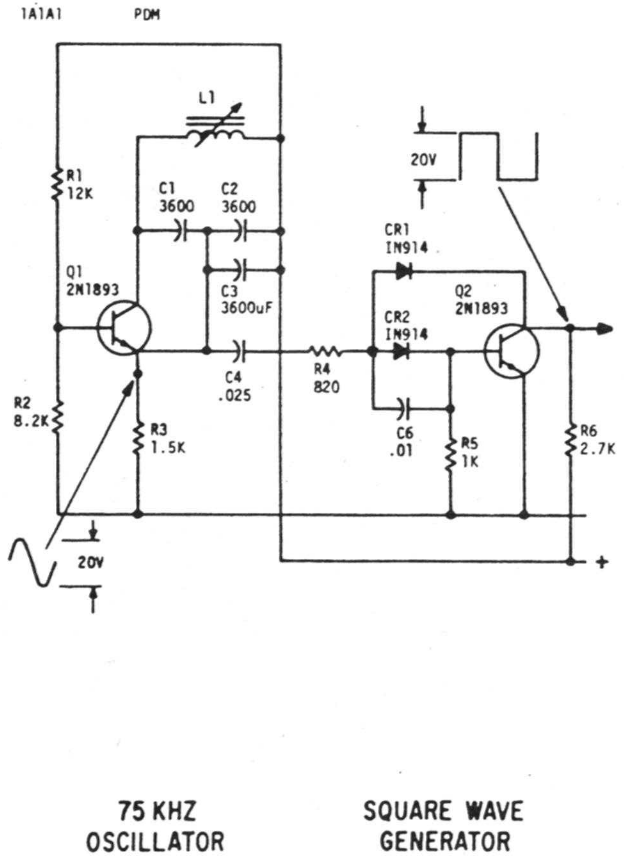
75 KHZ
OSCILLATOR

NOTE:

UNLESS OTHERWISE SPECIFIED;

RESISTOR VALUES ARE IN OHMS
CAPACITOR VALUES ARE IN PICOFARADS

FIGURE 10



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RESISTOR VALUES ARE IN OHMS
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FIGURE 11

sine wave at 75 kHz. This is a straight-forward, very simple oscillator. The actual frequency of this oscillator is non-critical; therefore, crystal control is not required. The output of this oscillator is shown by an arrow leading from the emitter of the oscillator stage.

2. Square Wave Generator

Figure 11 shows the oscillator plus the next stage of the PDM exciter. This next stage is called a square wave generator. This next stage simply takes the sine wave out for the oscillator and generates a square wave from it. Q-2 operates as a largely overdriven amplifier. Therefore, the sine wave is stretched and then clipped. The result at the collector of Q-2 is a 20 volt peak-to-peak square wave at the frequency of the oscillator. This circuit is very simple and straight-forward. The only thing that might require explanation is diode CRL and CR2. These diodes simply function to keep the base of the transistor from being driven into total saturation. By staying out of saturation the recovery time of the transistor is much faster. This allows a more rapid rise time to the square wave. The output of the square wave generator is shown by the arrow from the collector of Q-2.

3. Integrator

Figure 12 shows that the output of the square wave generator is delivered to an integrator. The integrator takes the square wave and makes a triangle wave form from it. Capacitor C-7 is simply a blocking capacitor. Resistor R-7 and Capacitor C-8 accomplish the integration that results in the triangle wave form from a square wave. Thus, the voltage at C-8 is a constantly re-occurring triangle wave form at a repetition rate determined by the oscillator stage. Again the circuits are very simple, straight-forward and stable.

4. Adder

Figure 13 shows that the output of the integrator goes to an adder circuit. At the junction of the resistors R-9, R-10 and R-11, we have summed together the triangle wave form, the audio information and a DC control voltage. This is simply

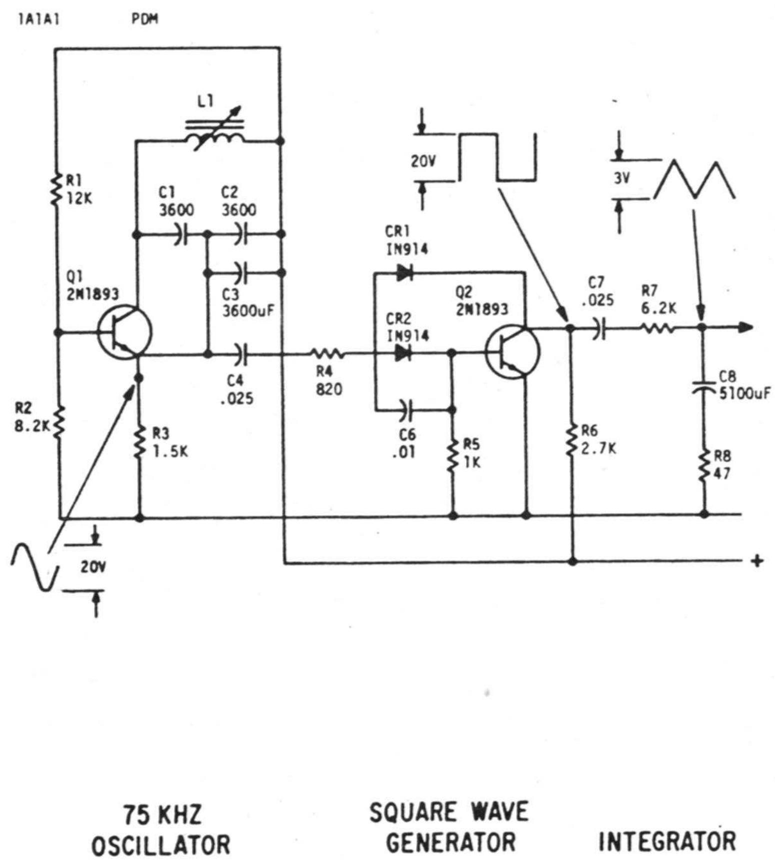

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FIGURE 12

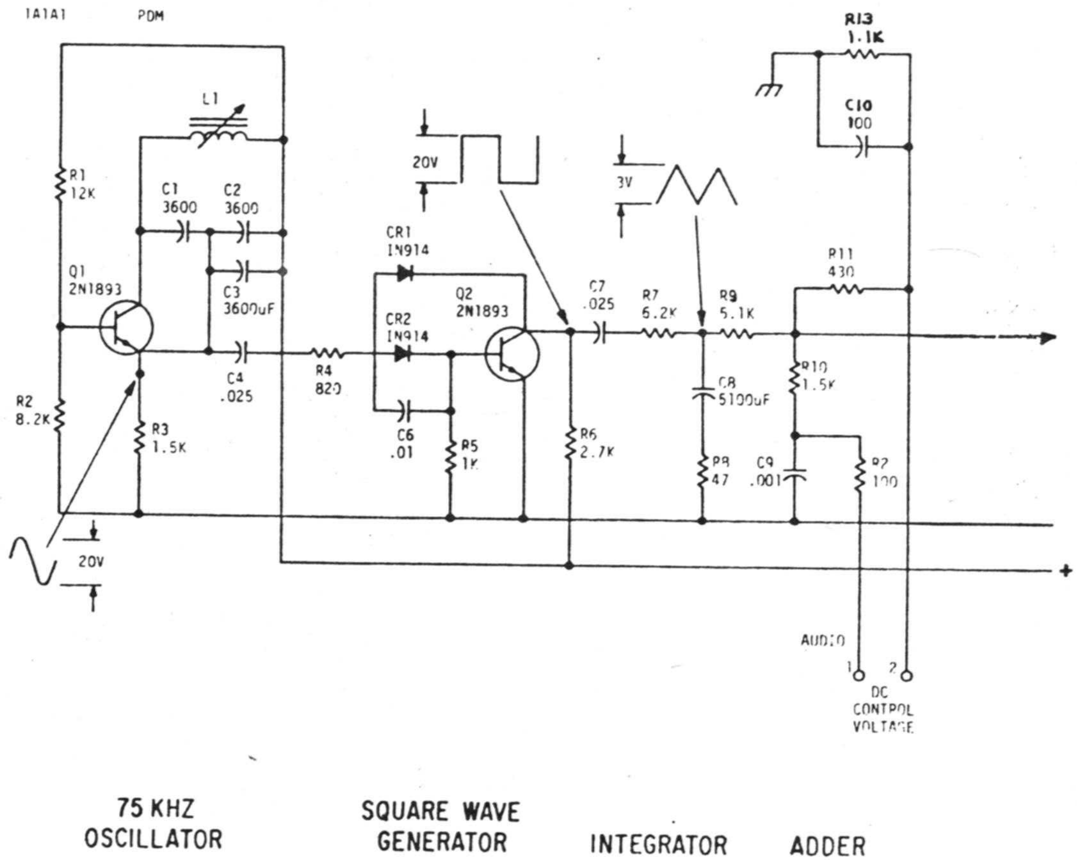

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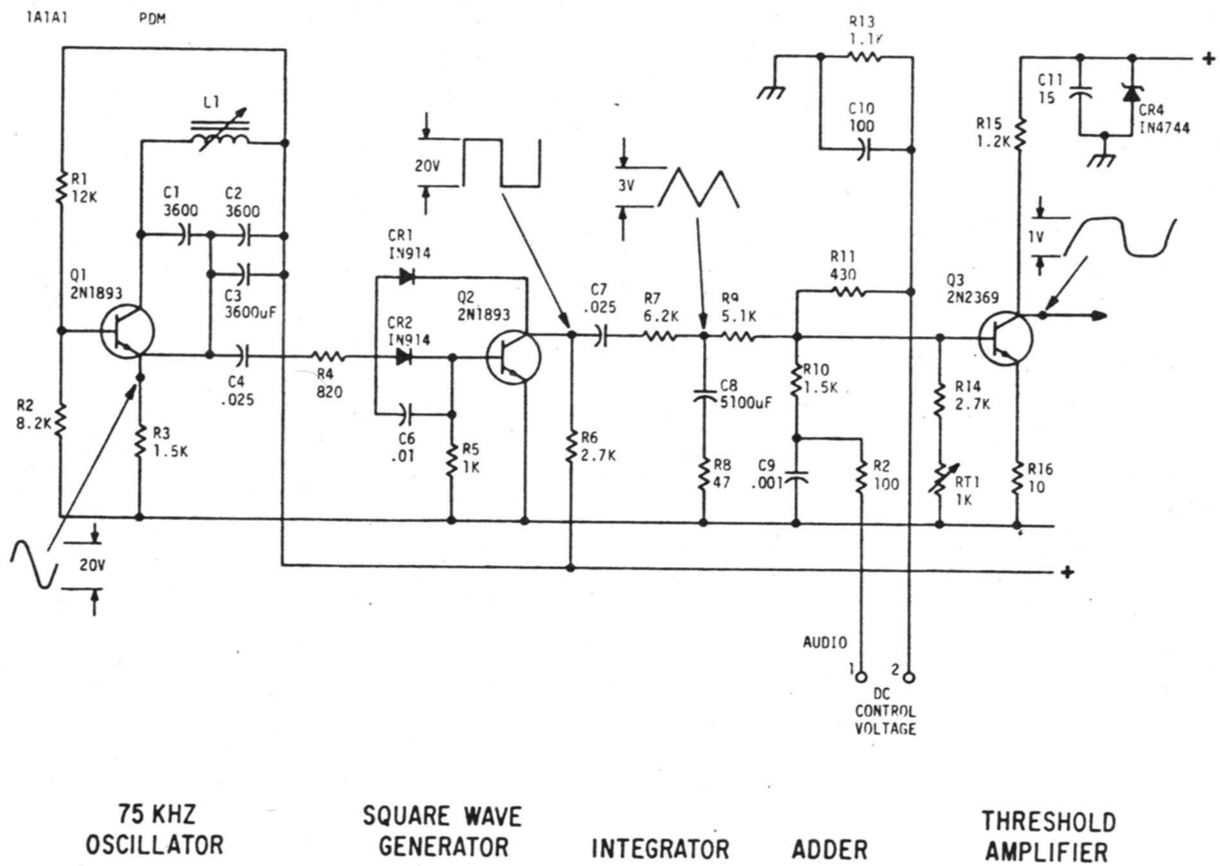
FIGURE 13

a resistor adder network. The triangle wave form repeats itself in a very constant manner at all times. The audio voltage is simply the audio that is fed to the transmitter. The DC control voltage is a small voltage which simply tells this PDM chassis what the desired carrier output power is. So at this point, we have added together the triangle wave form, the audio voltage and the control voltage. The DC control voltage determines the threshold point of the transistor.

5. Threshold Amplifier

Figure 14 shows that these summed together signals are fed to a threshold amplifier. The job of the threshold amplifier is to turn on at any time these summed signals are above its threshold value and to turn off at any time these signals are below its threshold level. The threshold amplifier is either turned on or off. Its output is a 1 volt peak-to-peak signal whose turn on and turn off duration are determined by the points at which the summed signal is above or below its threshold. Thus, out of this threshold amplifier we have a clipping



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RESISTOR VALUES ARE IN OHMS
CAPACITOR VALUES ARE IN PICOFARADS

FIGURE 14

action to produce a square wave whose turn on and turn off duration is determined by the summed signals. If the threshold happens to be half-way up the triangle wave form, then the output of the threshold amplifier will be a 50% square wave. If the summed signal is always below the threshold, there will be no output from the threshold amplifier. And if the summed signal is always above the threshold, it will be "ON" all the time. However, normal operation is between these two extremes. The triangle added with the audio is varying in amplitude. Therefore, the triangle crosses the threshold at various times. This results in the output of the threshold amplifier varying in duration. We will see this more clearly when we look at the wave forms in more detail.

6. Pulse Amplifier - 1

Figure 15 shows that the output of the threshold amplifier is fed to a pulse amplifier. The pulse amplifier does two things: it increases the magnitude of the "On-Off" output signal of the threshold amplifier and it also functions to increase the rise time somewhat as shown in the wave form.

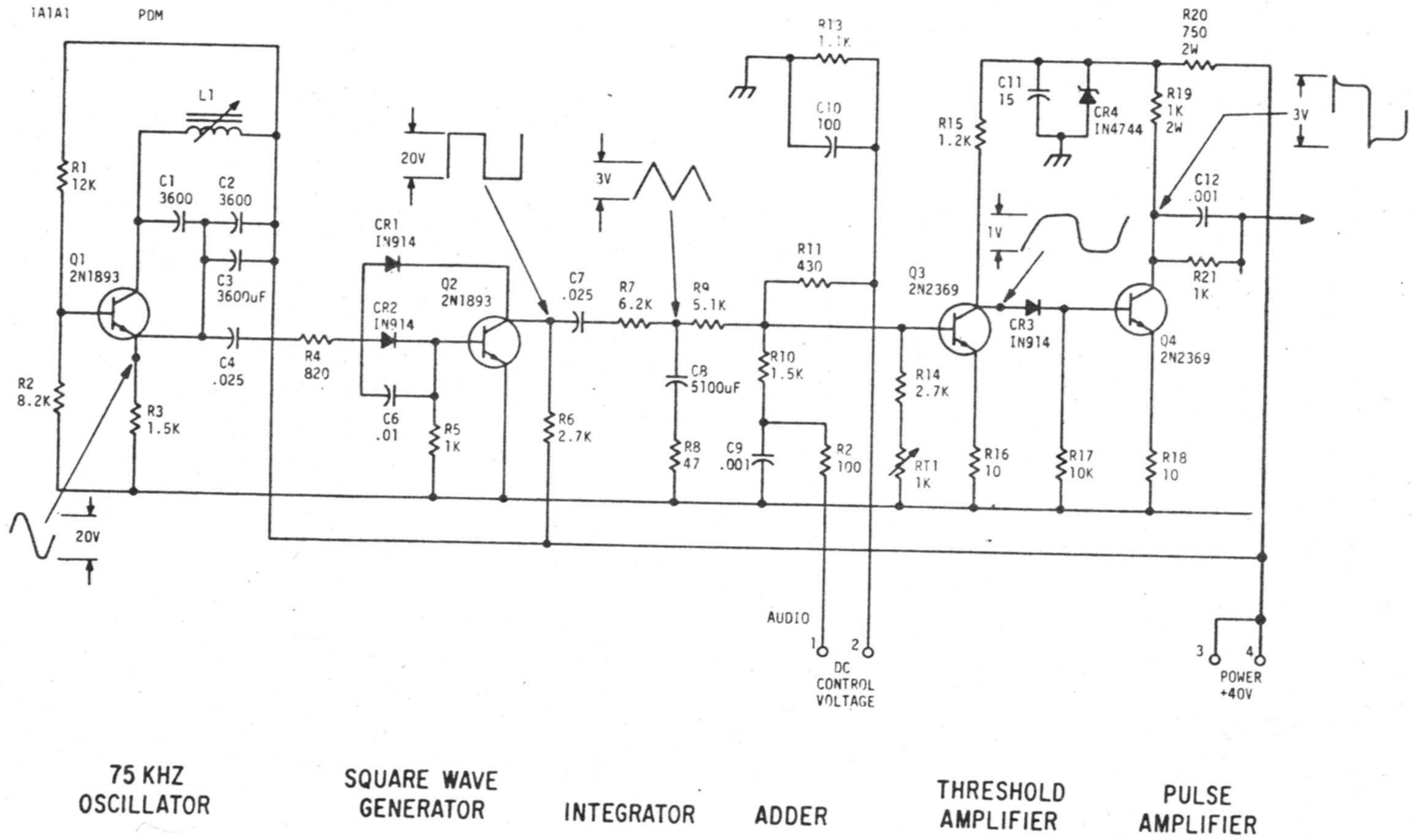

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FIGURE 15

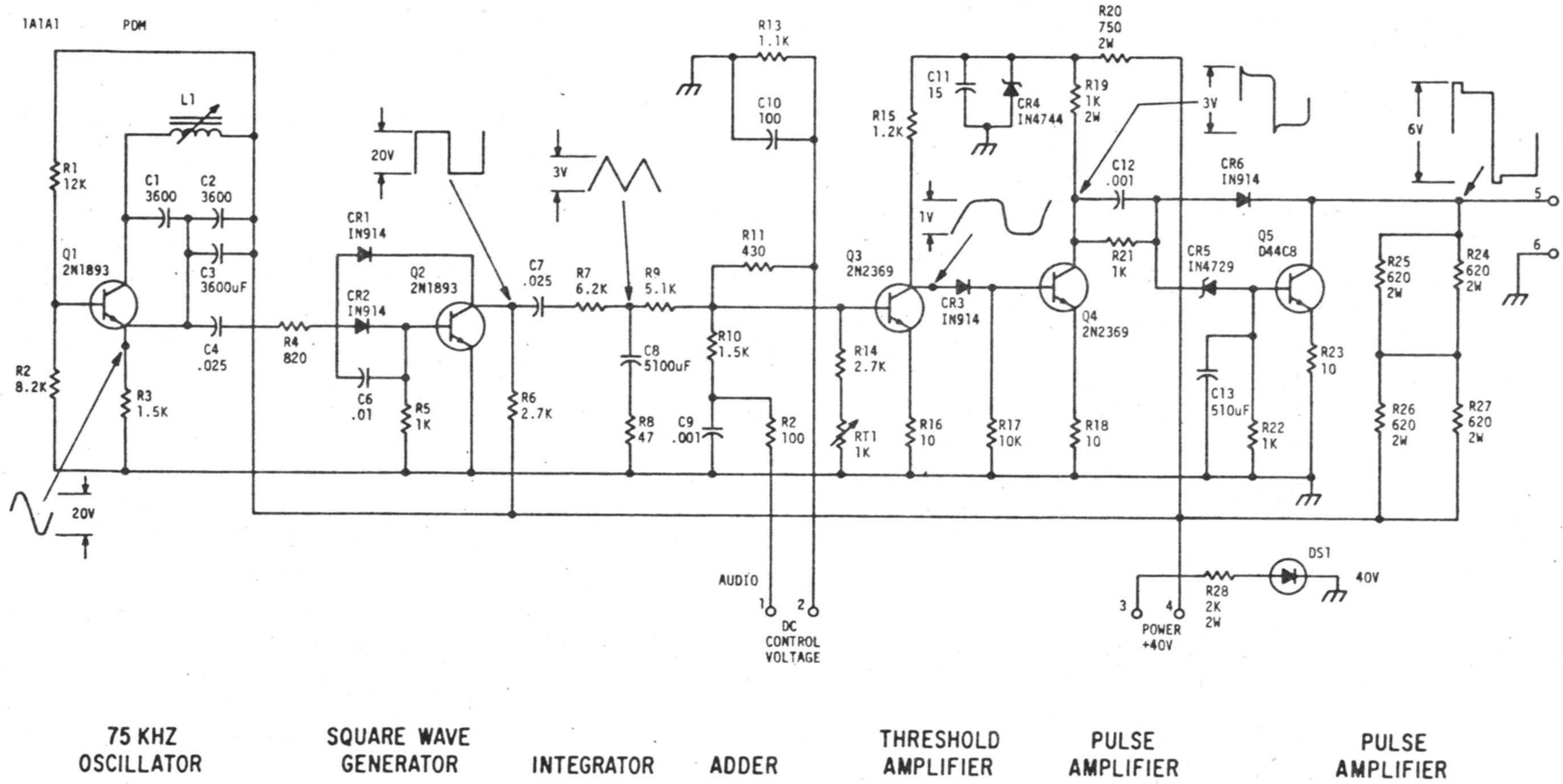

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FIGURE 16

7. Pulse Amplifier - 2

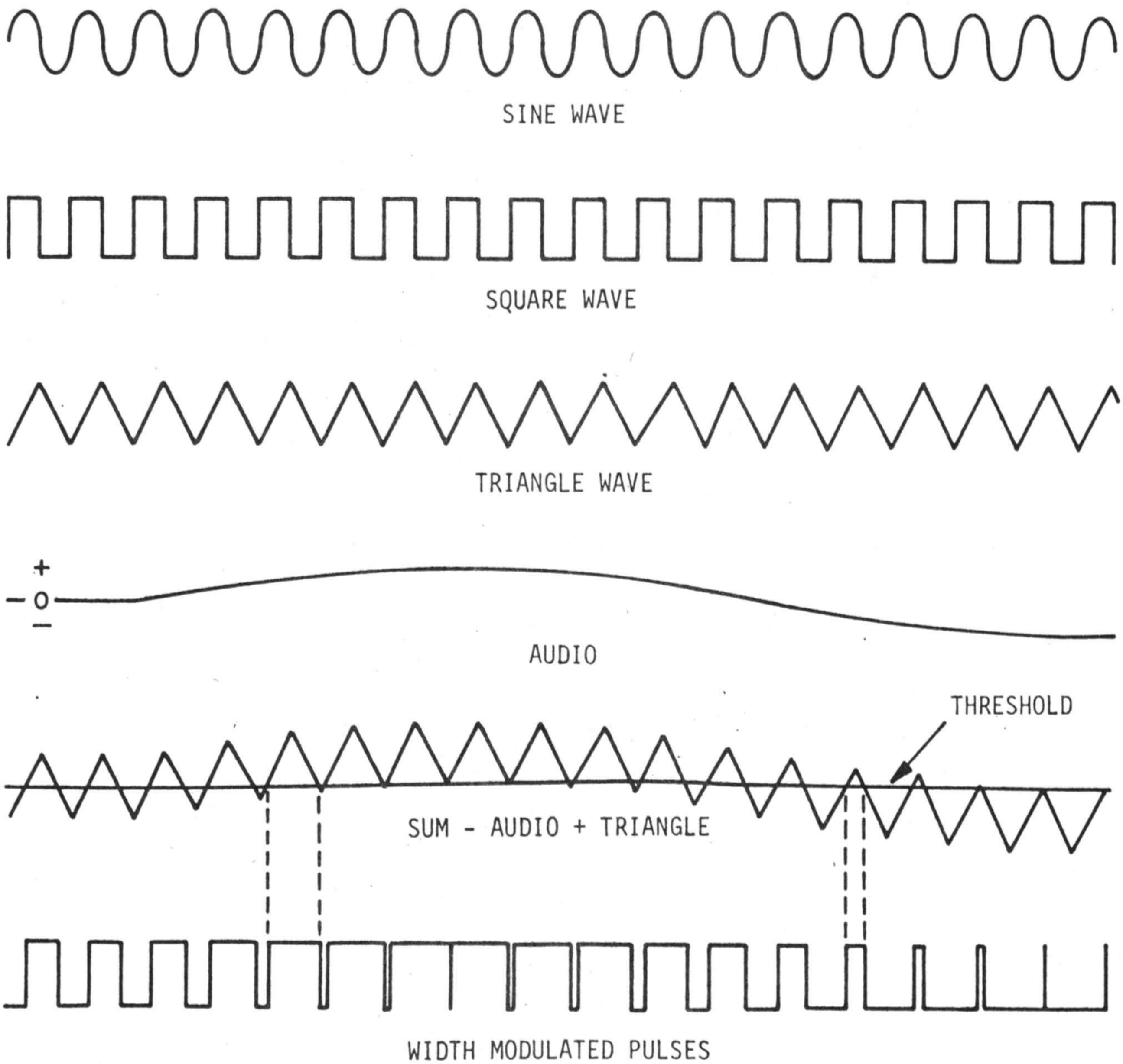
Figure 16 shows the final stage of the PDM exciter board. This final stage is a pulse amplifier which further increases the magnitude of the "On-Off" signal.

8. Summary

Here we have the complete and total PDM exciter chassis. It consists of seven functions: 75 kHz oscillator, square wave generator, an integrator, adding circuits, a threshold amplifier and two pulse amplifiers. These circuits are not critical and they are very simple and reliable. At the output of this board, we have pulses that reoccur at a 75 Khz rate whose width is determined by the audio information and the DC voltage.

D. <u>PDM Wave Forms and Stage Relation</u>

Figure 17 shows the wave forms in more detail. At the top of the picture, we have a representation of the 75 kHz sine wave. Below it, we have the square wave that is generated from this sine wave and below that we have the triangle wave form this is the integration of the square wave. This triangle wave form is continuous



CONSOLIDATED WAVE FORMS

FIGURE 17

and doesn't change as the transmitter is modulated. Next is the representation of the audio. At the far left is a period of no audio input information and then the audio information is shown rising to a positive value and crossing back through zero and decreasing to a negative value. Now look closely at the fifth line. This is the sum of the audio plus the triangle. We have simply added together the lines 3 and 4. What we see is the triangle moving up and down in exact accordance with the audio. We have also shown here the threshold level so we see the triangle moving up in relation to the threshold level and we see it moving down in relation to the threshold level. Remember, the threshold amplifier turns "On" whenever this threshold level is above its threshold and it turns "Off" whenever the signal is below the threshold. Thus, we see the dotted lines transferred down to the last wave form to show the width modulated pulses. Here the pulses vary in with according to when the triangle wave form crosses the threshold. If the triangle wave form is moved up due to the audio, the pulses stay on for a longer time. If the triangle wave form is moved down due to the audio or control voltages, the pulses stay on for a shorter time. So at the far left, we see that at no modulation the pulses are "On" for approximately the same time that they are "Off". But, as we move to the center of the picture, we see that the pulses stay "On" for a longer period of time and on the right-hand side we see that the pulses stay "Off" for the longer period of time. Thus, we have generated width modulated pulses. The width is proportional to the instantaneous audio voltage.

Now a very key point is that these width modulated pulses contain the information. If these width modulated pulses are passed through a low pass filter, we will recover exactly the audio input information. Another way of saying this is that the average of the width modulated pulses is exactly the audio information. Or, if we were to plot the area underneath the "On" pulses, we would be plotting exactly the audio information. In the width modulated pulses, we have the audio in a digital form. The pulses are either "On" or "Off". However, the duration of their "On" time contains the audio information. If the pulses are filtered with a low-pass filter, the average energy that results is exactly the audio information.

Another way of looking at the width modulated pulses is that we have sampled the audio information at a 75 kHz rate. This sample information is contained in the width of the pulses. If we filtered the pulses, we have recovered the audio. Although it is not an exact equivalent situation, an analogy to stereo broadcasting may be helpful to some people. In stereo, the left channel is sampled at a 38 kHz rate and the right channel is sampled at a 38 kHz rate. In the receiver decoder, these samples have a 38 kHz sample rate removed by low-pass filtering and we recover the desired audio information.

Keep in mind the audio information is contained in the "On" time of the pulses. If the "On" time is long, this represents a positive going audio signal. If the "On" time is very short, this represents a negative going audio signal. The "On" time or "Duty Cycle" varies as a linear function of the audio information. Now that we have discussed the generation of the width modulated pulses and some characteristics of these pulses, we are ready to return to the modulation of the transmitter.

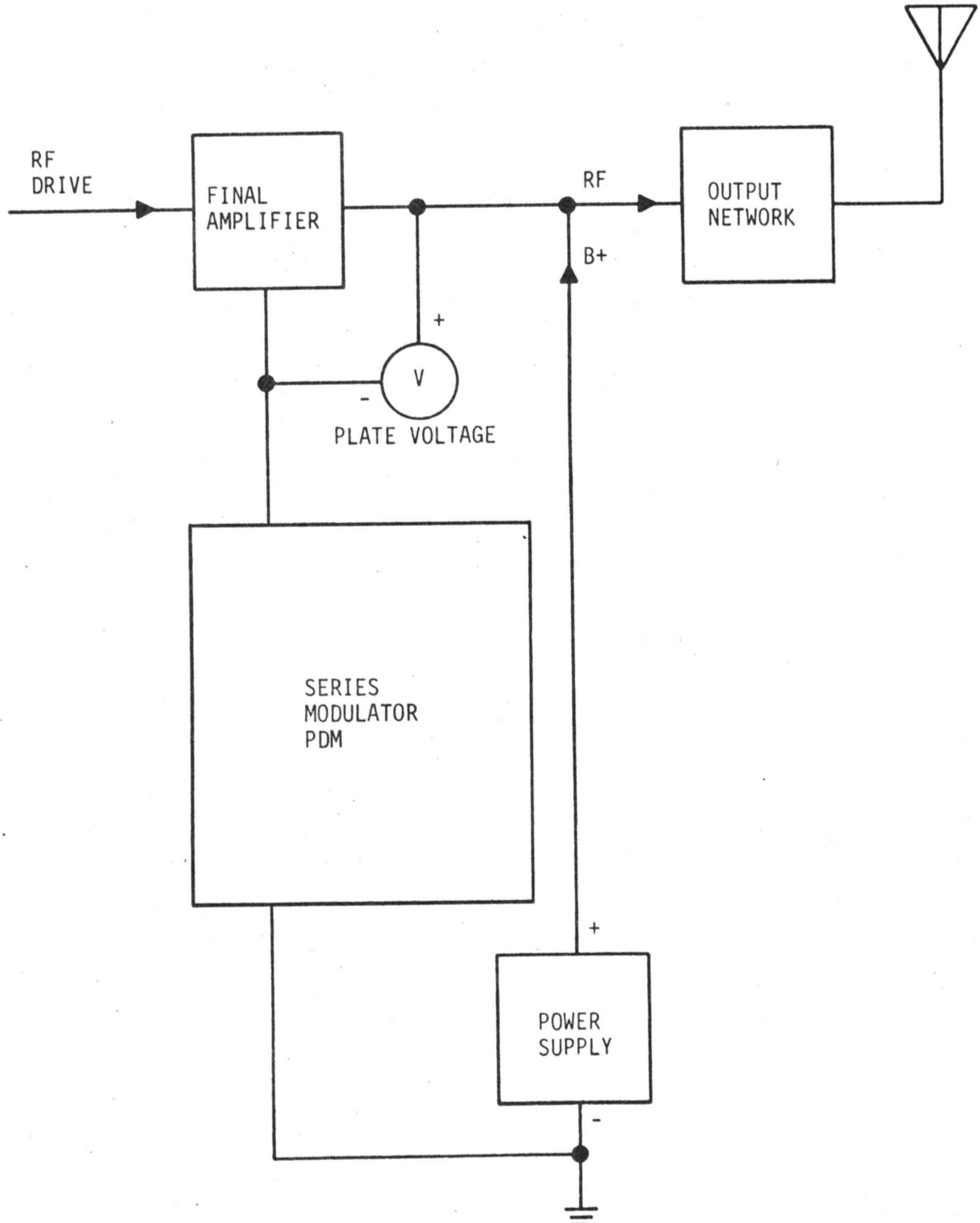
E. PDM Modulator

Figure 18 is a repeat of one we have seen earlier. We are now ready to discuss what is inside the series PDM modulator block. Remember earlier we said that this block represents a voltage drop that varies exactly in accordance with the audio input information.

1. Modulator Components

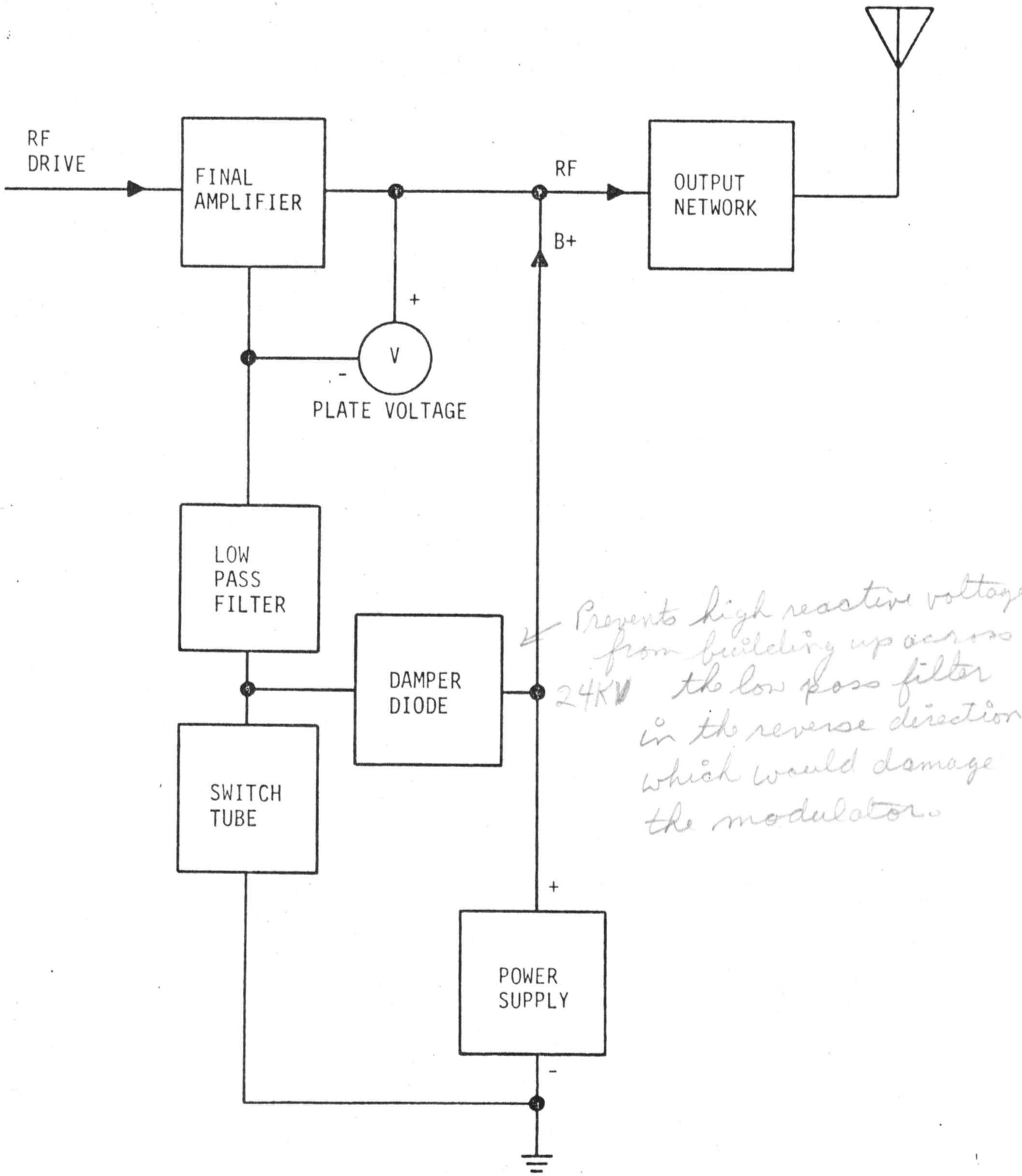
Figure 19 shows the three basic components of PDM Series Modulator. We have a low pass filter, a switch tube and a damper diode. We should first understand the function of the switch tube and then see how the low pass filter functions and finally, what the damper diode does. Remember, that the function of these items is to create a varying voltage drop that is a linear representation of the audio.

Figure 20 shows that the switch tube can be represented by a simple single-pole-single-throw switch. This switch is turned "On" when the width modulated pulses are "Off". This switch can be "On" or "Off". It opens and closes at a 75 kHz rate.



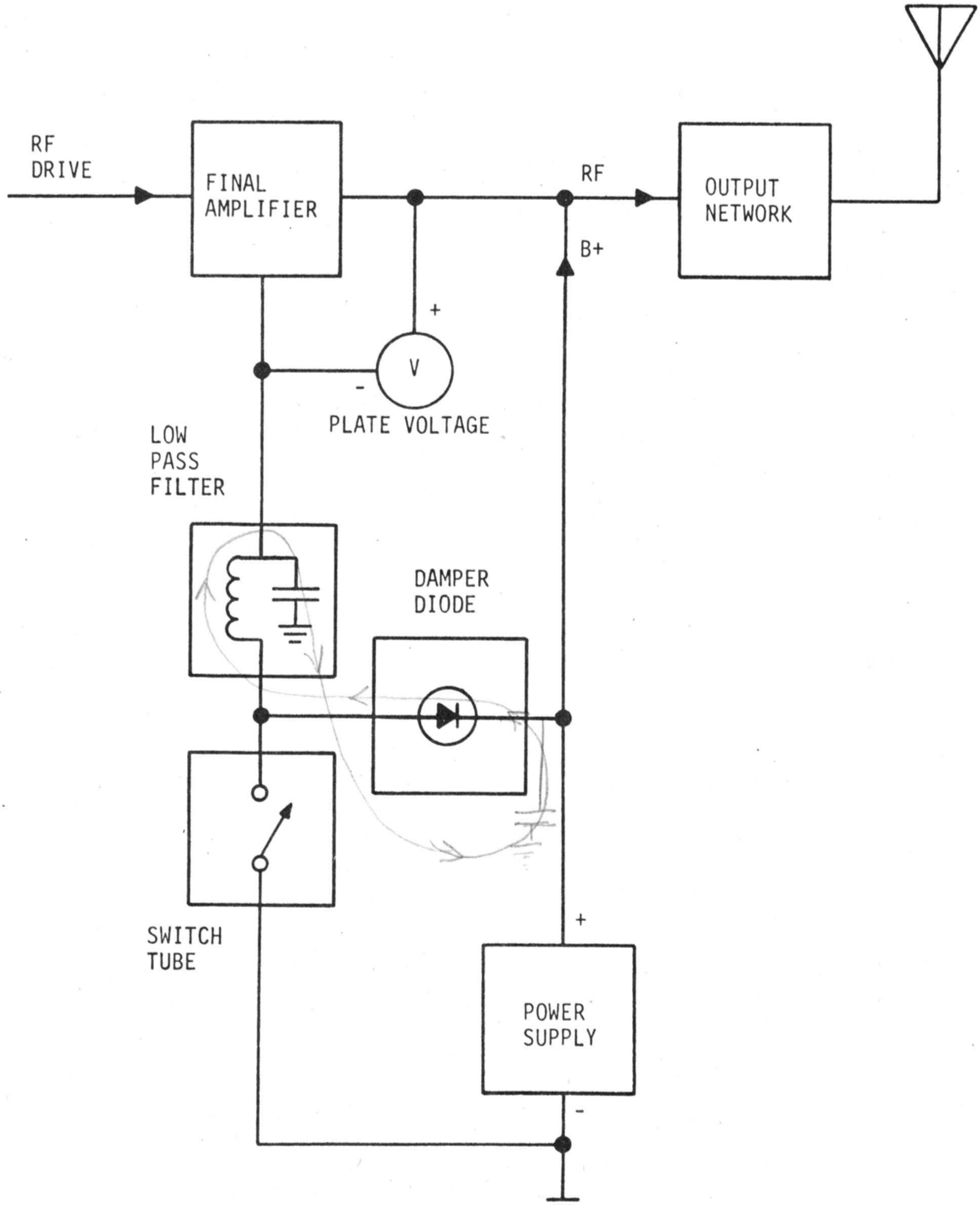
AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM

FIGURE 18



AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM

FIGURE 19



AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM

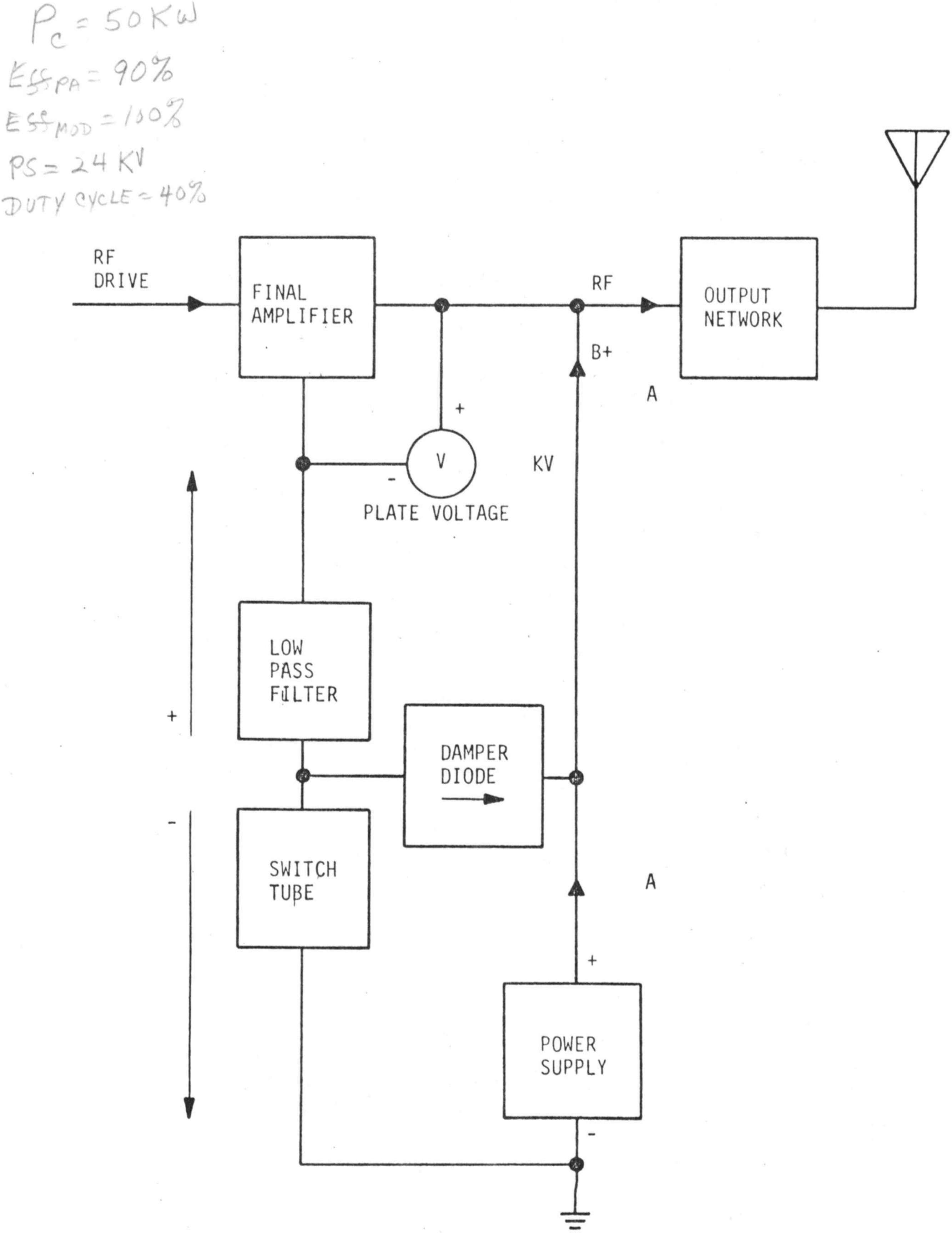
FIGURE 20

The amount of time that it is on is determined by the width modulated pulses. If the audio information is going positive, the switch stays "On" for a longer period of time. But, it does turn on and off at a 75 kHz rate. The amount of time it is "On" and the amount of time it is "Off" does vary.

To understand this operation, let us first consider two extreme situations: If the switch were "On" for all the time, then the power supply voltage would be applied to the Final Amplifier. This would represent a positive peak of modulation. On the other hand, if the switch were "Off" all the time, there would be no Final Amplifier plate voltage, and thus, no RF envelope voltage. This represents a negative peak of modulation. Now let us consider a third condition: If the switch is "On" for half the time and "Off" for half the time, then the average voltage drop across the switch is half-way between the two extremes just discussed. That is half the voltage drop will be across the switch. This is approximately the condition that exists with no modulation. The switch is "On" half of the time and "Off" half the time. Half the power supply voltage is dropped across the series modulator switch tube and half the voltage appears across the Final Amplifier plate. This yields the unmodulated carrier conditions. Then to modulate the Final Amplifier, we simply vary the percentage of time the switch is on in exact accordance with the instantaneous input audio voltage. Remember, the switch tube is switching "On" and "Off" at a 75 kHz rate and its Duty Cycle, or "On" time varies in accordance with the audio.

The purpose of the low pass filter is to remove the switching transients which leaves only the average of the width modulated pulses. Thus across the low pass filter and switch tube, we have a voltage drop that is an exact replica of the desired audio information.

Now the function of the damperdiode is similar to the damper diode in a television set. When

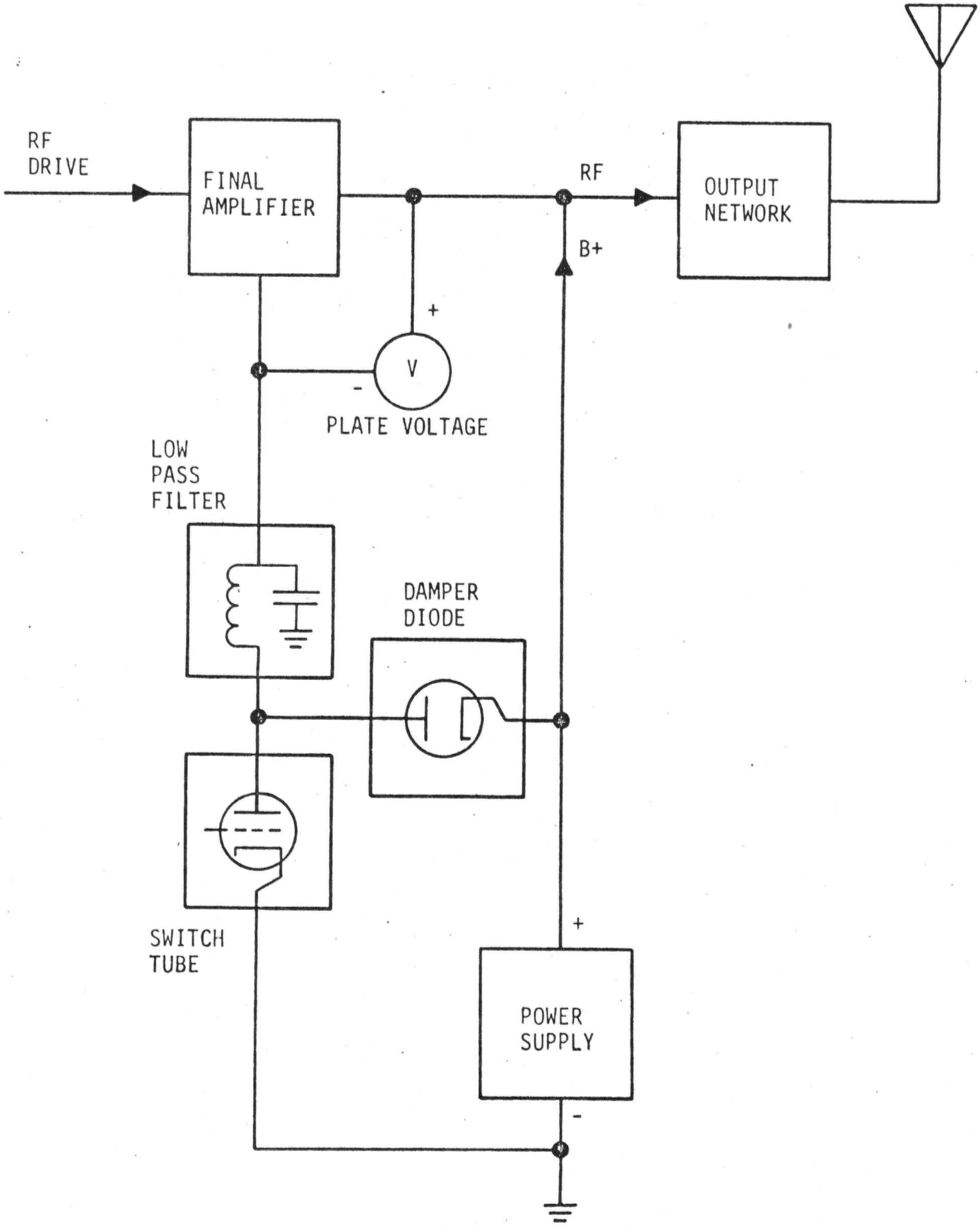


AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM PULSE WIDTH=40%

FIGURE 22

the switch tube is on, there is current that flows through the low pass filter into the switch tube. However, when the switch tube opens, this current can no longer flow through the switch tube. As we all know, when you try to break the current flowing through an inductor the voltage goes very high. This is the principal of the ignition coil in an automobile. Therefore, when the switch tube opens, the current flows through the inductor then passes through the damper diode and back to the power supply. When the switch tube opens the voltage at the anode of the switch tube rises until it is equal to the power supply voltage. Then the damper diode conducts and current flows to the positive side of the power supply. When the switch recloses the voltage at the anode of the switch tube falls to essentially ground potential and current then starts increasing through the switch tube again. Thus, as a natural consequence of the connection of the low pass filter to the switch tube, we must provide a damper diode to shunt the inductor current back to the power supply as the switch tube is opened.

Figure 21 is very similar to the previous one. It shows the more conventional schematic of the switch tube low pass filter and damper diode. The "On-Off" switching shown in the previous pictures accomplished by a large vacuum tube. Its cathode is connected through the negative of the power supply and its anode is connected to the low pass filter. Its grid is driven by the width modulated pulses generated in the PDM exciter chassis. The low pass filter is shown here only as a single LC section, but the actual transmitter consists of several such sections to achieve at least 80 to 100 dB attenuation of the 75 kHz switching transients. The inductors are simple air wound coils and the capacitors are high frequency oil capacitor units. The damper diode may be either a high vacuum diode as shown in Figure 21; or in lower power transmitters, it may be a high speed silicon diode assembly.

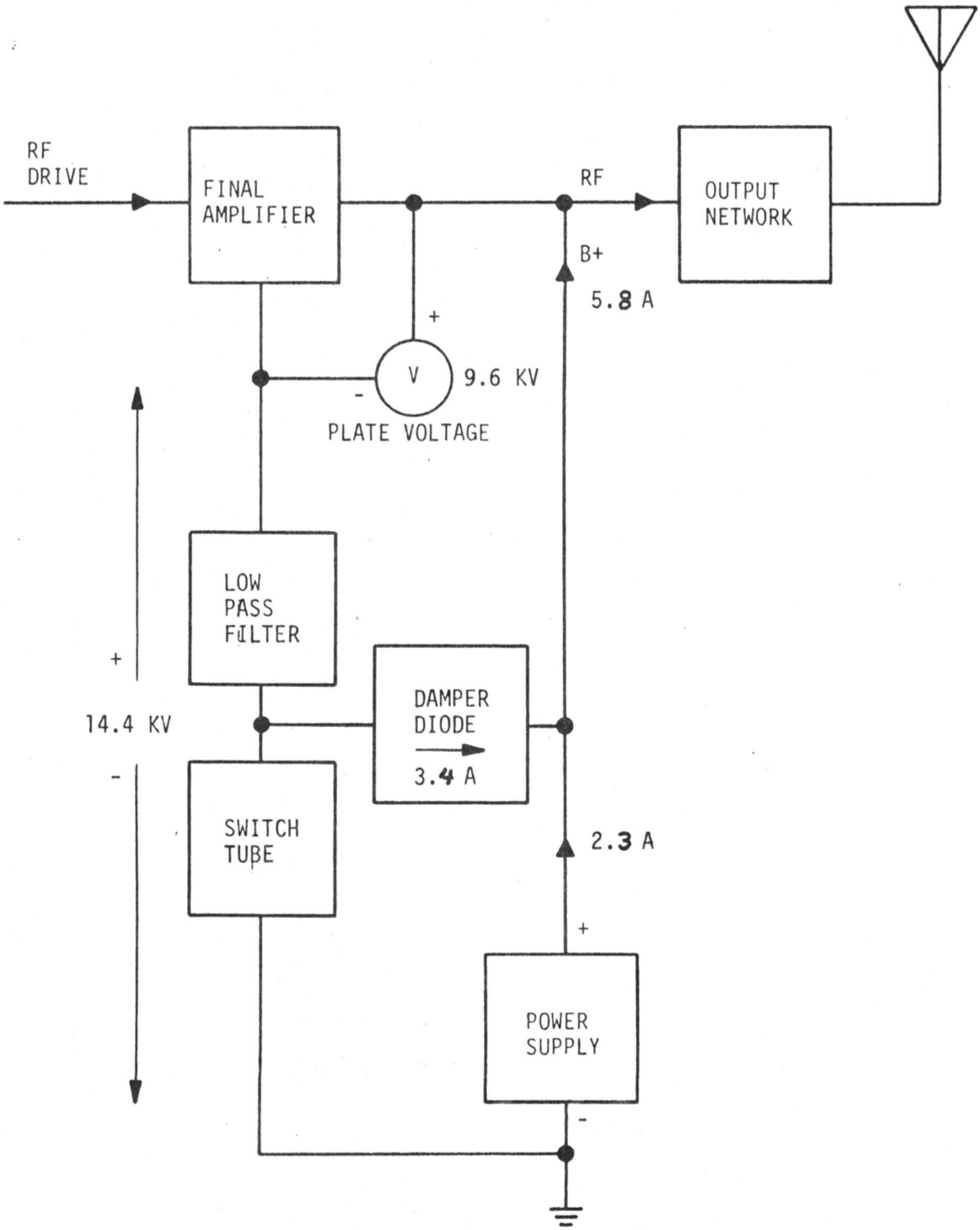


AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM

FIGURE 21

F. PDM Transmitter

Figure 22 shows some typical voltages and currents for a 50 kW transmitter. These were selected under carrier conditions with a pulse width of 40%. That is, the pulses are on 40% of the time and off 60% of the time. The Final Amplifier requires 9.6 kilovolts plate voltage and 5.8 amps plate current for an input power of 55 kW. The amplifier has about 90% conversion efficiency and, therefore, from this 55 kW input power it delivers 50 kW of output power. The power supply delivers approximately 24 kV. Since there are very low losses in the modulator circuits, the power supply, in this case, will be assumed to be delivering 55 kW of energy. This means it is delivering 2.3 amps at 24 kV. With a pulse width of 40%, we have 60% of the power supply voltage dropped across the modulator circuits. This is 14.4 kV. Forty percent of power supply voltage (9.6 kV) is across the Final Amplifier. The PA plate voltage, 9.6 kV, plus the modulator drop, 14.4 kV, equals the 24 kV power supply voltage. Note that a damper diode current of 3.4 amps adds to the power supply current of 2.3 amps to equal the final amplifier plate current of 5.8 amps. Note the high positive peak capability



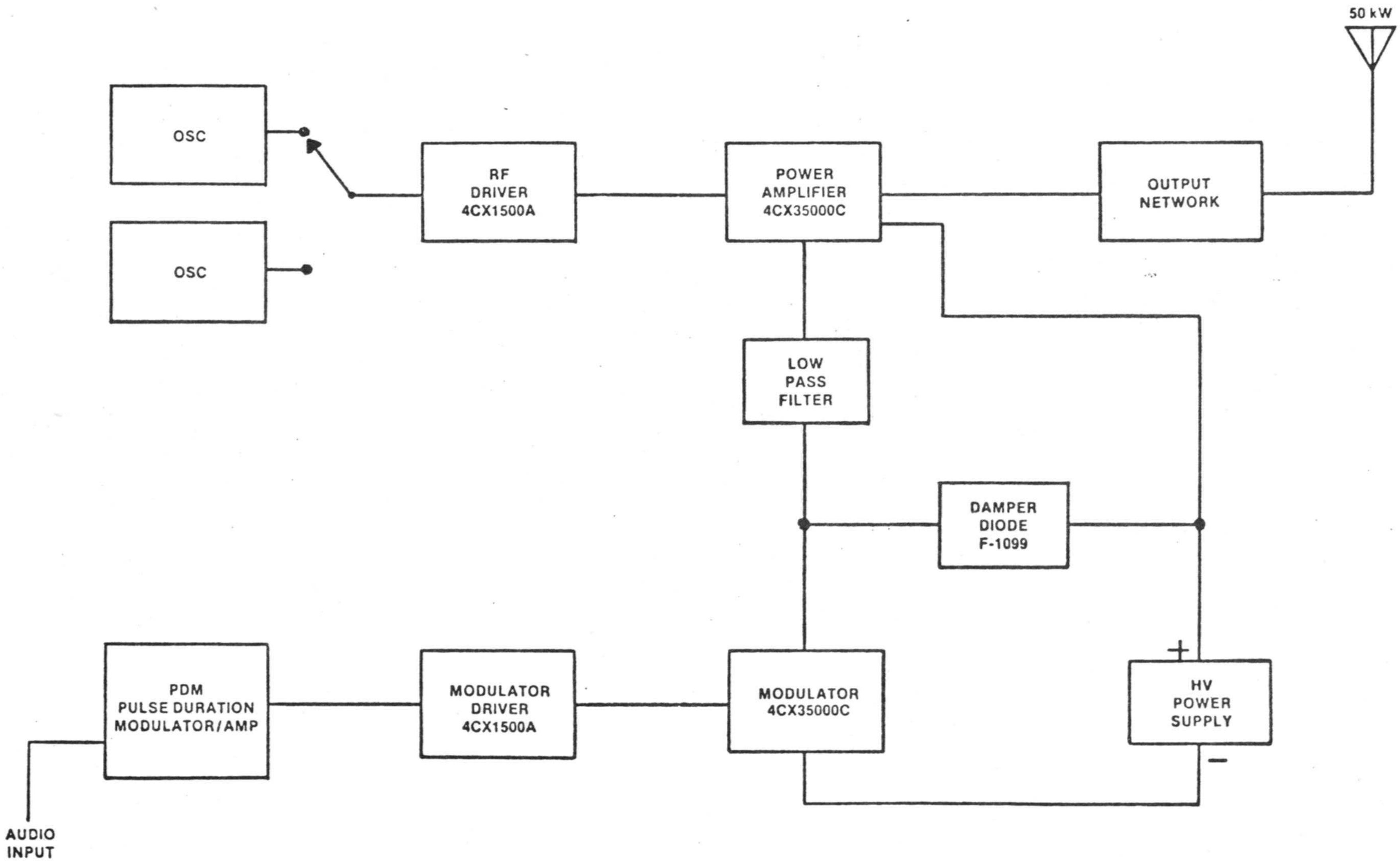
AM TRANSMITTER-PLATE MODULATED SERIES MODULATION PDM PULSE WIDTH=40%

FIGURE 22

with such an arrangement. For 100% peak-positive peak capability with such an arrangement. For 100% peak-positive modulation, the PA plate voltage should double. This would result from a pulse width of 80% and would yield an instantaneous 19.2 kV plate voltage, but we still have 20% pulse width to go before the modulator is fully "On" and about 4 kV more power supply voltage available. This arrangement would yield 140 to 150% peak-positive modulation at 100% pulse width. Of course, if the pulse width goes to 0%, all of the power supply voltage drop is across the modulator. The instantaneous plate voltage to final amplifier goes to 0 and we have 100% negative modulation peak.

At this point, we can remember that the modulator serves as a regulator of the series power supply. Therefore, if it is desired to change the output power of the transmitter, a simple change in the pulse width, by changing the DC control voltage, can change the final amplifier plate voltage to any value desired. This is used in the practical PDM transmitters to automatically regulate the output power of the carrier in case of faults. Also note that the PDM System has low frequency and high frequency response. The series modulation has response all the way to DC and the high frequency response is limited only by the low pass filter. This yields excellent transient response and fidelity in the modulation process.

Figure 23 shows how the elements that we have been discussing are combined in a practical transmitter. Here we see a block diagram of the MW-50. We can recognize immediately the several elements we have been talking about. We see the output network, the Power Amplifier, the high voltage power supply, the low pass filter, the damper diode and the modulator switch tube. The block in the lower left is the PDM exciter chassis we have been discussing. Note the PDM configuration is simple and straight-forward. Since the pulses in the modulator are either "On" or "Off", they are amplified very easily, thus the audio chain contains only two tubes. Likewise, the RF chain only contains two tubes. The damper diode is

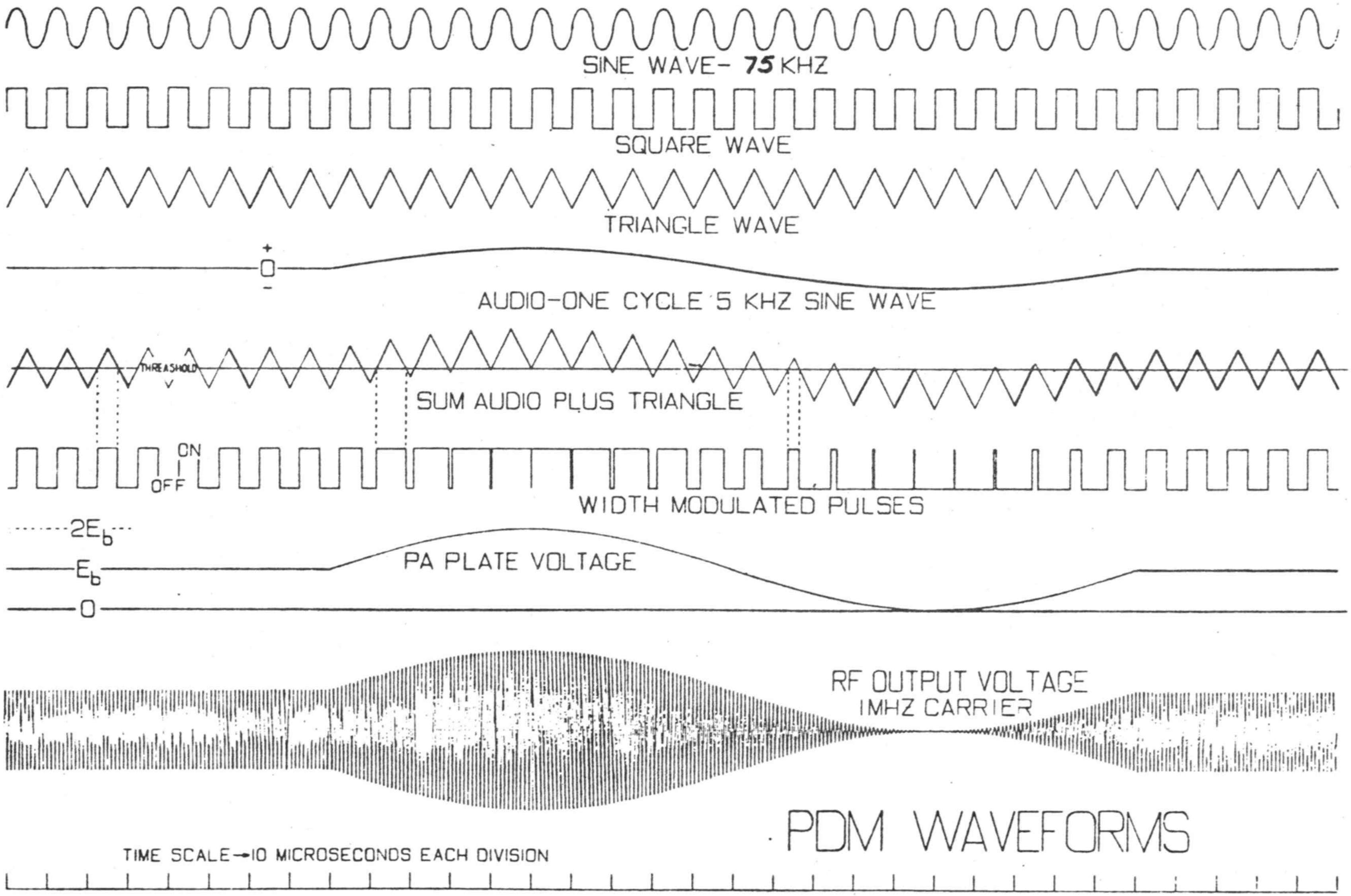


MW-50 BLOCK DIAGRAM

FIGURE 23

one additional tube. Therefore, we have a total of only five tubes in these 50 kW transmitters and only three tube types. Thus, the concepts we have been discussing yield a very high performance and a simple reliable transmitter.

In summary, let's look again at all the wave forms in the transmitter in Figure 24. At the top, we see the sine wave that results in a square wave which generates a triangle wave form. The fourth line shows audio represented by one cycle of a 5 kHz wave. Note that the time scale across the bottom is ten microseconds each division. The audio wave form is zero at the beginning and then completes one cycle of a positive and negative excursion and returns to zero at the right-hand side. The sum of the audio plus triangle varies above and below the threshold as discussed earlier. Therefore, we have width modulated pulses that are either "On" or "Off" and whose width is a function of the instantaneous audio information. Whenever the triangle is above the threshold, the pulse is "On" and when it's below the threshold, the pulse is ""Off". The next line shows PA plate voltage.



CONSOLIDATED WAVEFORMS

FIGURE 24

This is after the switch tube has turned On and Off in accordance with modulated pulses and after the switching frequency has been removed by the low pass filter. Therefore, when there is no modulation at the left-hand side of the picture, we see that the PA voltage is a value called E_b. As the audio rises, we see that the PA plate voltage rises to twice E_b at 100% modulation and then it reduces to zero at 100% negative modulation. Then again when there is no audio, it returns to its average value of E_b. Below that we see the RF output envelope under these conditions. With no modulation at the left-hand side of the picture, we see the RF carrier voltage. As the PA plate voltage swings higher and higher, the RF output voltage swings higher and higher. And, when the PA plate voltage reduces to zero, the RF envelope reduces to zero, and again, when there is no modulation, the RF output returns to carrier condition.

IV. SUMMARY

A. PDM is Plate Modulation. The voltage excursions in the modulation process of the final amplifier are exactly the same in Class B push-pull modulated transmitters.

B. PDM is a Series Method of applying the audio to the final amplifier tube.

C. The PDM signal is generated by various simple circuits that result in width modulated pulses. These pulses are either On or Off and their width is exactly in accordance with the audio input information. With no audio input, they are On approximately half the time. With high positive audio input information, they are On almost all of the time and with high negative audio input information, they are Off almost all of the time.

D. The switch tube in series with the power supply and the PA switches On and Off as determined by the width modulated pulses. The average voltage drop adross the switch tube and the low pass filter is equal to the average of the width modulated pulses, which is exactly equal to desired audio information, thus the PA plate voltage varies exactly as in any plate modulated transmitter.

E. The benefits of this modulation technique are:

1. EFFICIENCY

2. SIMPLICITY

3. RELIABILITY

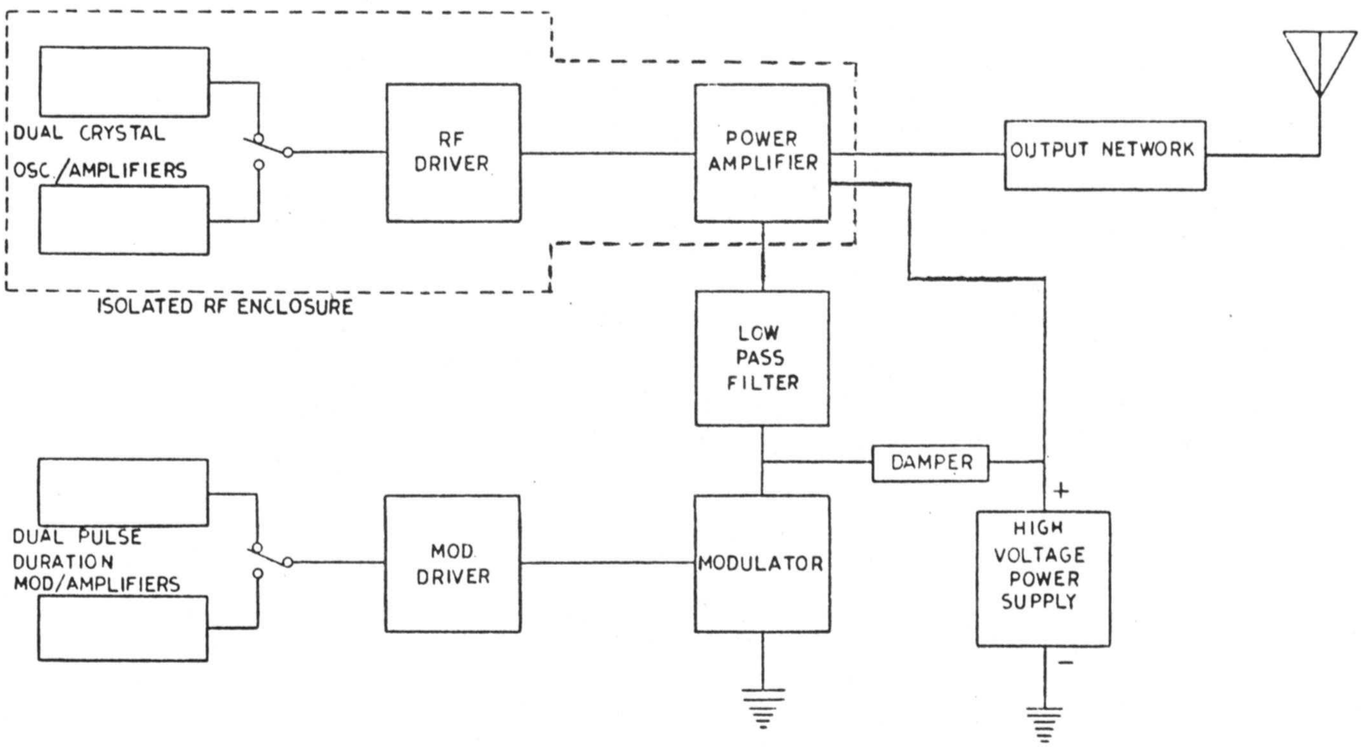
4. FIDELITY

5. EXCELLENT TRANSIENT AUDIO RESPONSE

V. PDM 100 kW TRANSMITTER

A. General

To accomplish 100% percent modulation of the final amplifier of a 100 kW medium-wave transmitter, such as the Harris' model VP-100A, average power in the neighborhood of 50 kW is needed. In the VP-100A, the power gain necessary to raise the level of a +10 dBm audio input signal to the level required to modulate the power amplifier is accomplished in four stages; two transistor amplifiers, Q4 and Q5, and two tubes, V1 and V2.
The block diagram below indicates the relationship of these and other stages.



Block Diagram of VP-100A Transmitter

The modulator V2 is connected through a low-pass filter to the cathode of the power amplifier. The low-pass filter provides the necessary function of removing the 75 kHz frequency component and the harmonics thereof and of recovering the audio as a modulating signal for the power amplifier. Note that the modulator is in series with the power amplifier.

The damper diode V3 is connected between the modulator plate and 29 kV+ and conducts alternately with the modulator, that is at a 75 kHz rate. V3 conducts when the modulator does not, providing a discharge path for the energy stored in the inductors in the low pass filter. This function is necessary in the interest of efficiency and low distortion in the system.

B. Review of PDM Generation

How is PDM generated? A PDM pulse train has a constant repetition rate or frequency. It is a pulse train of variable width pulses, the width of the pulses being a function of the audio amplitude. In Harris' PDM transmitters it is generated by combining a 75 kHz triangular wave with the audio signal at the input of a high gain amplifier.

The output of a 75 kHz oscillator is clipped to form a square wave and integrated to form a ramp or sawtooth voltage. This voltage is summed with the audio signal at the input of a Schmitt trigger threshold amplifier. The output of this amplifier is a modulated rectangular pulse train with a 75 kHz repetition rate pulse-width-modulated in accordance with the input signal. Or, amplitude changes in the audio input signal appear as the duty-cycle change of constant amplitude rectangular wave

The resulting rectangular pulses are amplified by the driver and modulator stages and applied to the power amplifier cathode through a low-pass filter that removes the 75 kHz signal and its sidebands, thereby recovering the audio information. The modulator tube acts like a variable resistor whose resistance varies with the amplitude and frequency of the audio signal. It is connected in series with the cathode of the power amplifier tube to obtain normal amplitude modulation.

As the reader will note, succeeding stages in the modulator chain are simple switches, capable of turning on and off at a 75 kHz repetition rate with not more than 1 - or 2 microseconds rise and fall time.

C. The Audio Signal

How is the audio recovered so that it can be used to modulate the PA tube? The output of the modulator is a train of variable with rectangular pulses of 75 kHz duration. Before this signal can be applied to the PA tube, it must be converted to audio. This is accomplished by means of a low-pass filter. The filter eliminates all of the 75 kHz switching frequency and leaves the desired audio component.

D. Peak Voltages

The peak voltages appearing at the final amplifier stage are of the same magnitude that exists with any plate-modulated class C amplifier. The series-type PDM modulator differs only in the location of the common ground point. With no modulation, the dc plate to cathode is one-half of the HV power supply voltage.

The absence of a modulation reactor greatly reduces the magnitude of the transient peak voltage that can occur in conventional transmitters under certain fault conditions. In a transmitter of conventional design, sudden loss of RF drive to the final amplifier will cause the voltage of the amplifier plate to rise until something flashes over. In the Gates' PDM transmitter, the maximum voltage that can appear across the tube is equivalent to only slightly more than during normal modulation.

The PDM transmitters have been designed with a number of simple, reliable fault protection circuits. They operate full time to take care of equipment induced faults, as well as faults caused by operator error. Any fault occurring in the high-voltage power supply or the voltage applied to the final amplifier tube can exist for only about 10 ms before either the ac input overload or the dc overload circuits turn the transmitter off. All components operate within their design ratings during this period.

E. Summary

1. Under normal operating conditions, the peak voltages are the same as for any conventional plate-modulated amplifier.
2. Transient voltage peaks are less of a problem in the Gates' PDM design because there is no modulation reactor.
3. Maximum plate voltage is limited to a 10 ms time duration by overload circuits.

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HARRIS CORPORATION Broadcast Products Division

P.O. Box 4290 Quincy, Illinois 62301