ENGINEERING REPORT

DESIGN OF A COMPLETELY SOLID STATE 1 KW AM BROADCAST TRANSMITTER

HARRIS
COMMUNICATIONS AND INFORMATION HANDLING

DESIGN OF A COMPLETELY SOLID STATE 1 KW AM BROADCAST TRANSMITTER

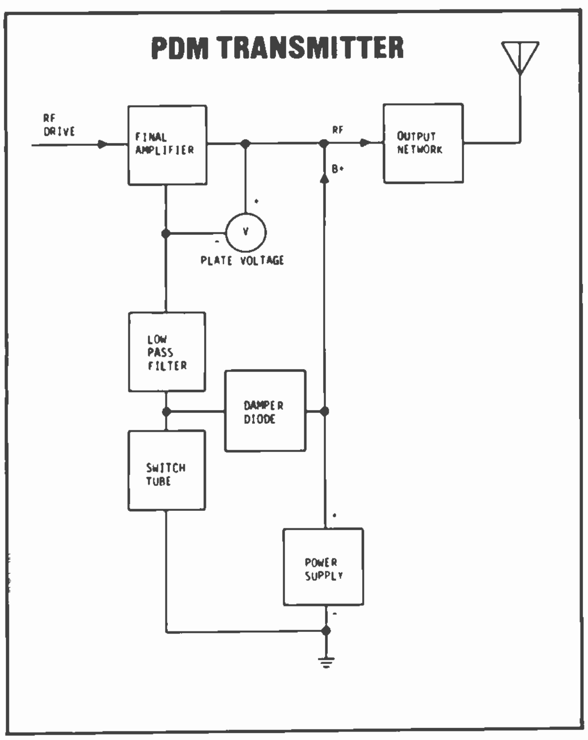
By E. C. Westenhaver

INTRODUCTION

There has recently been a number of important developments in AM transmitter design. The last several years have been a period of rapid changes in the old and mature technology of Amplitude Modulation. Since it is important for broadcast engineers to keep their knowledge current and up to date in this field, this paper will review some of these advancements and show how they were incorporated in an all solid state transmitter. It will then discuss several important design areas of the solid state transmitter. These design areas contain fundamentally sound concepts that will be part of basic transmitter concepts for many years. Series modulation, progressive series modulation (PSM), a solid state final amplifier, combining techniques, and some field performance experience will be covered.

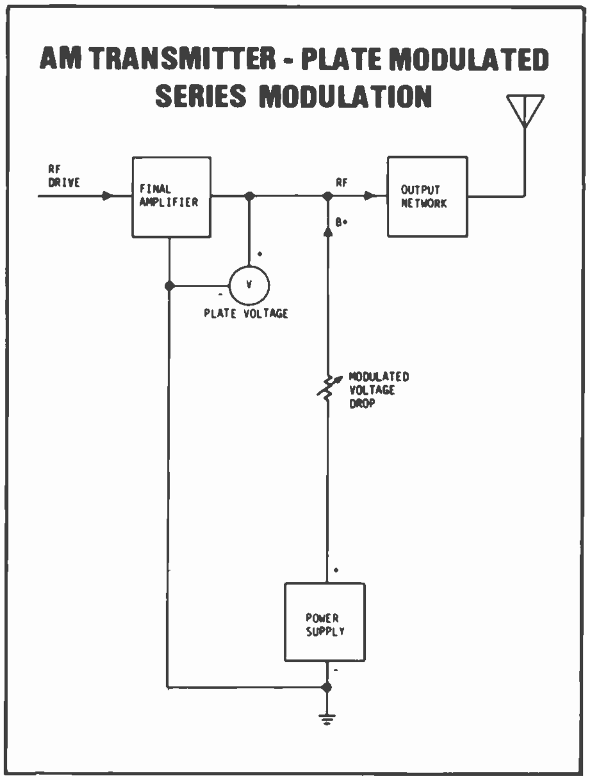
REVIEW OF SERIES MODULATION

For many years AM transmitters could be loosely grouped into two categories -- plate modulated and various transformerless concepts. Most broadcast engineers will agree that the push-pull plate modulated rigs were simple, easy to adjust, reliable, and gave good performance. An illustration of the non-critical nature of high level plate modulation is the fact that most amateur radio AM transmitters were built this way. The transformerless concepts have as a primary goal elimination of the modulation transformer. Good performance was usually realized at the expense of more critical adjustments.



THE PDM CONCEPT

The now familiar PDM technique was developed to utilize the best features from both categories. The non-critical plate modulated final amplifier was retained from one category and the elimination of the modulation transformer was used from the other category. PDM can be thought of as a modulated series regulator connecting the power supply and the final RF amplifier. The resulting benefits exceeded those of either category. The term "Series Plate Modulation" describes PDM. This combina-



tion of high level plate modulation with an efficient, DC coupled, modulated, series voltage drop connecting the power supply and the final amplifier was so outstanding that Hilmer Swanson of Harris Broadcast Products Division developed a system with the same features optimized for use with transistors. This is the progressive series modulator (PSM) that will be covered in detail later.

The benefits of a series, DC coupled, modulated voltage drop should be recognized because these apply to both PDM and PSM.

First, the fundamentally non-critical, efficient, high level modulated final amplifier is used.

Second, the wideband, DC coupled modulator faithfully reproduces the distribution of the input audio peaks. This freedom from overshoot, tilt, bounce, and transient disturbances allows very significant increases in loudness without overmodulation.

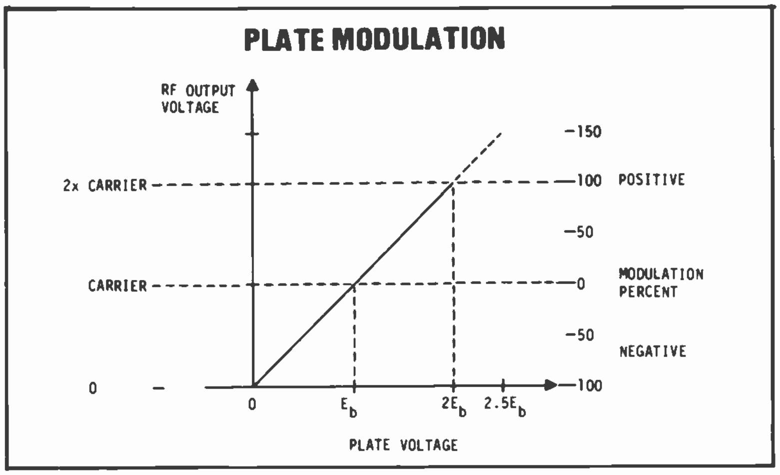
Third, the series connection allows the modulator to function as a voltage regulator, an output power control, and as an easy, quick method to remove B+

voltage in case of any fault.

Fourth, it is possible to build these modulation systems without critical adjustments or components.

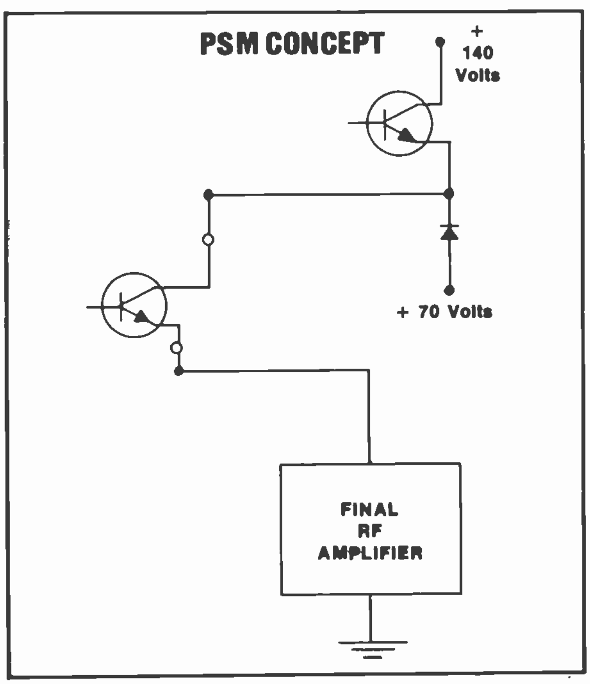
Fifth, these systems can be built with excellent efficiency.

The high value of these benefits has been demonstrated by actual operating experience. These systems will become the "conventional" method in future years.



PROGRESSIVE SERIES MODULATION (PSM)

The fundamental concept of PSM includes a high level modulated final amplifier. As in the conventional plate modulated transmitter, a specific PA voltage produces an unmodulated carrier. The modulator then produces PA voltage changes that are a linear function of the input audio. The instantaneous PA voltage may go to zero on a 100% negative peak, and to 2.25 times carrier conditions for 125% positive peaks. The audio has an average value of zero. Therefore, the average PA voltage is constant at the unmodulated carrier value.

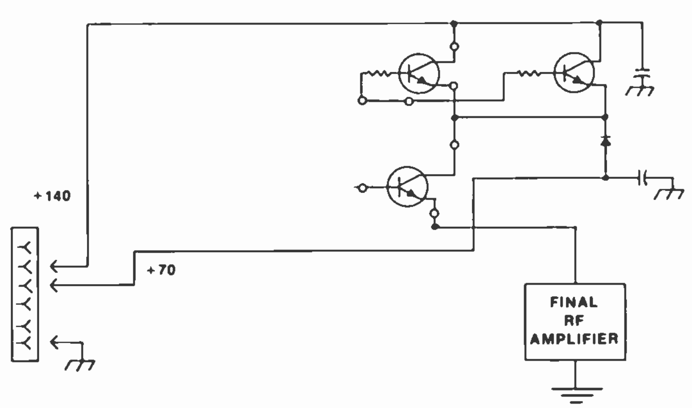


A conceptual view of PSM shows a modulated final amplifier, two series connected transistors, a power supply voltage of 140, and the 1/2 voltage tap of the power supply connected between the transistors with a gating diode. With this simplified picture the operation of the modulator is easy to follow. The unmodulated carrier occurs with a PA voltage slightly less than the 1/2 voltage power supply tap. Under these conditions the lower audio transistor conducts and passes the full PA current from the 1/2 voltage tap through the gating diode. Since the drop across the lower transistor is low, the power dissipated is low. The upper audio transistor is cut off and passes no current.

On a negative modulation audio excursion the drop across the lower audio transistor increases; therefore, the PA voltage decreases. As 100% negative modulation is approached the PA voltage approaches zero. The PA current approaches zero. Therefore, even though the voltage across the transistor is now high, its dissipation approaches zero. Since the lower transistor is connected as an emitter follower, the PA voltage is an exact replica of the base voltage with approximately 1 volt base to emitter offset.

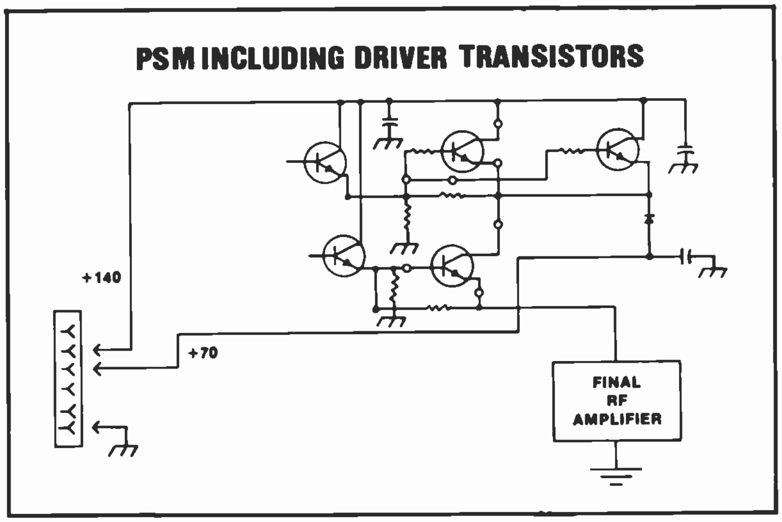
On positive modulation excursions the lower audio transistor is biased on into saturation. The upper transistor begins to conduct, which raises the PA voltage toward the full power supply voltage. Since the emitter voltage rises above the 1/2 voltage tap, the gating diode effectively disconnects the 1/2 voltage tap. The dissipation in the upper transistor rises from zero at carrier conditions to an instantaneous large value at the beginning of the positive excursion, and again becomes small near full positive modulation. This upper transistor also acts as an emitter follower; therefore, the PA voltage is a replica of the base voltage.

PSM OUTPUT TRANSISTORS

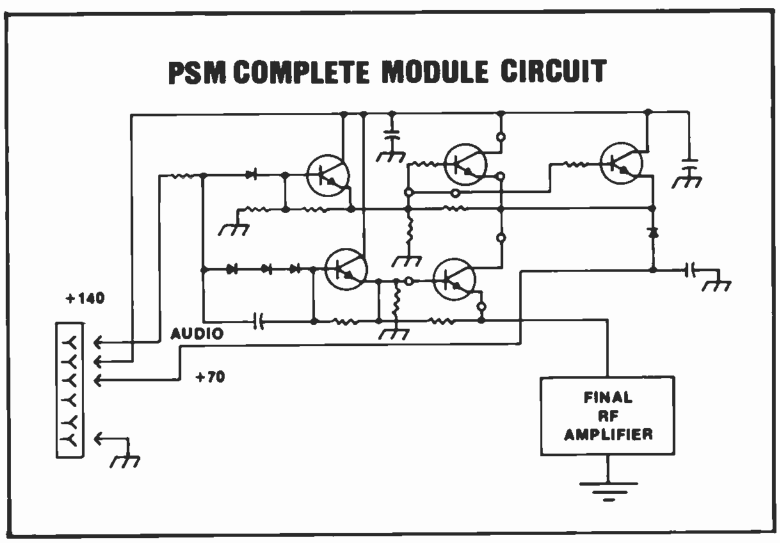


PSM CIRCUIT OPERATION

Since the PA presents a linear resistive load to the modulation, the current is much higher on positive modulation excursions than on negative modulation. At the beginning of a positive excursion the upper transistors have, for an instant, high voltage drop and significant current. This means that the upper transistor works harder than the lower transistor. An efficient selection of transistors results in 2 in parallel for the upper unit, and a 3rd unit of the same type for the lower transistor.



The driver stage must provide gain. The driver transistors are also connected as emitter followers. This provides current gain, with excellent voltage linearity.



Since transistors are somewhat limited in base to emitter reverse breakdown capability, a diode is used to disconnect the bases of the upper transistors when the audio drive voltage is lower than the 1/2 voltage tap. The resistor dividers maintain the base voltage near the emitter voltage on negative modulation excursions.

Diodes are used in the base of the lower transistors to provide a controlled voltage drop to divert appropriate base drive current to the upper transistors on positive modulation, and to provide a smooth cross-over of the 1/2 voltage region.

The PSM modulator at this point requires an audio drive signal of modest current; with the full peak to peak audio swing desired on the final amplifier, and centered at a DC level of the desired PA carrier voltage. Note that this circuit is DC coupled, has no significant frequency components except the transistors, has excellent linearity, and very little phase shift. It is wideband, low distortion, and has excellent transient response. It can be used to adjust output power, perform power reduction, and quickly remove PA voltage, if necessary.

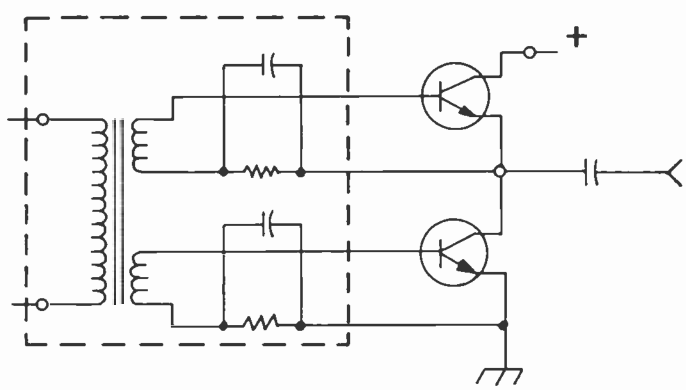
The schematic shows the complete PSM modulator used on each of the 12 100 watt modules used in the MW-1. Under normal carrier conditions each modulator passes approximately 55 volts at 2 amps to its companion RF final amplifier. It has excellent linearity to almost full power supply voltage of 140 volts, or positive modulation capability of well over 125%.

SOLID STATE FINAL RF AMPLIFIERS

The solid state final RF amplifier has the same job as in any transmitter. It must convert DC power to RF power with the best possible efficiency and modulation linearity. It is useful to consider this process as a switching process. Although Class D tube type amplifiers are sometimes called switching mode amplifiers, the term does not have wide usage. An analysis of the process of converting DC to RF will show that an ideal switch operating at the carrier frequency is the most efficient method possible. Since transistors can operate as efficient switches, the design and explanation follow this concept.

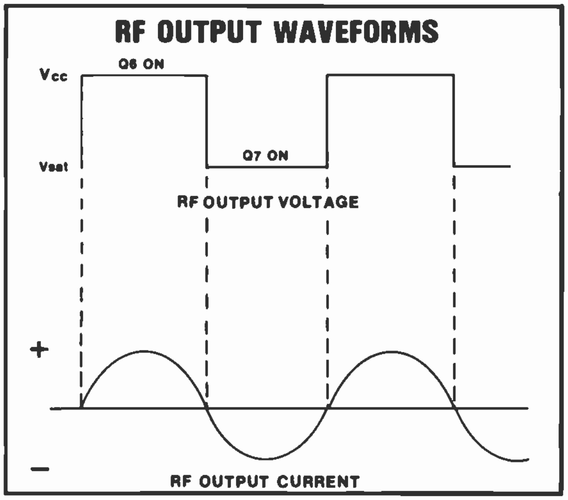
Push-pull amplifiers have the same advantages for transistors as for vacuum devices. The output power from two devices is achieved in an amplifier with a circuit complexity no greater than a single-ended amplifier. Proprietory engineering studies at Harris Broadcast Products Division have shown that the series connected, push-pull, voltage switching amplifier configuration is best suited for transmitter

PUSH PULL TRANSISTOR FINAL AMPLIFIER



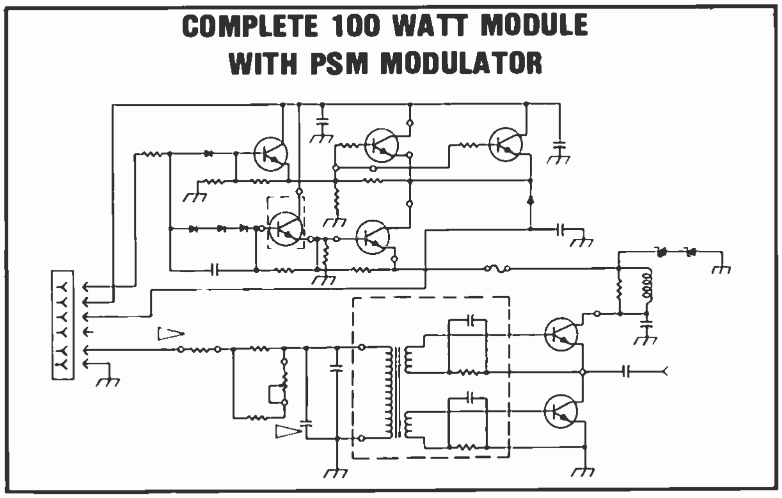
applications. From the schematic several principles are obvious. The two transistors are in series between the DC supply voltage and ground. The inputs to the bases are 180^0 out of phase or push-pull connected. The RF output is taken from the center connection between the two transistors.

The operation of the amplifier should be visualized as follows: The transistors operate as push-pull or alternate switches. The output voltage at the center connection between the transistors is a square wave switched between the supply voltage and the saturation voltage. Since the output network is series resonant, only fundamental current will flow, and this current is in phase with the voltage waveform. Because the switching occurs rapidly, because the saturation voltage is low, and because the switching occurs during a time when the current is low, then the efficiency is very high.

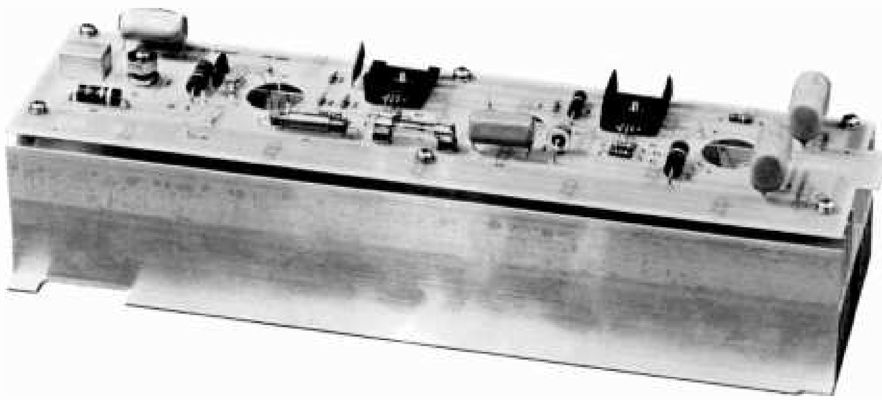


To understand some of the design principles remember that the RF output voltage taken from between the transistors is a square wave and that the output current is approximately sinusoidal and in phase with the voltage. The transition occurs at a time of very low collector current. Due to the nature of transistors, this mode of operation is most efficient because the effects of collector storage time are minimized. Consideration of the fact that transistors are fundamentally a device with current gain will show that this mode has simpler base drive requirements. The base current driving waveform can be nearly sinusoidal.

The transition or commutation from one transistor to another must be sequenced so that only one transistor is conducting at any instant. Overlap of the conduction angle, such as occurs in push-pull audio amplifiers, must be avoided. This is accomplished with some small bias similar to grid leak bias.



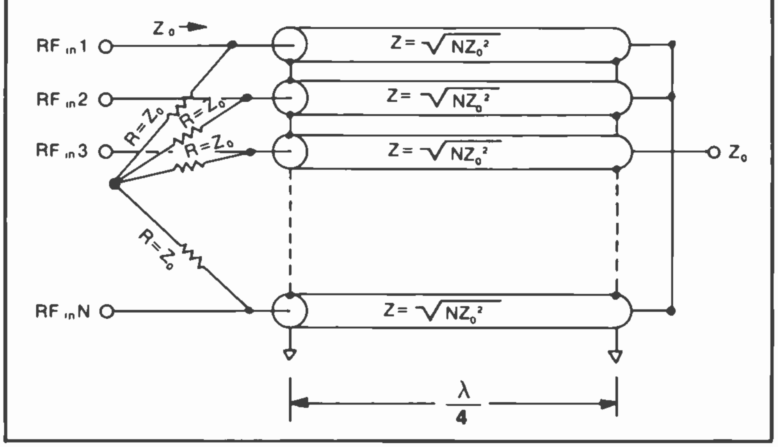
The schematic shows the complete 100 watt module. There is one RF output connection, a 140 volt input, a 70 volt input, an audio input, an RF input, a ground terminal, and a spare. It comfortably produces 100 watts carrier, and 500 watts peak with approximately 13 dB RF gain. The complete module is approximately 1 foot long, and has large area cooling fins to eliminate thermal cycle fatigue failures.



MW-1 POWER AMPLIFIER / MODULATOR MODULE

COMBINING

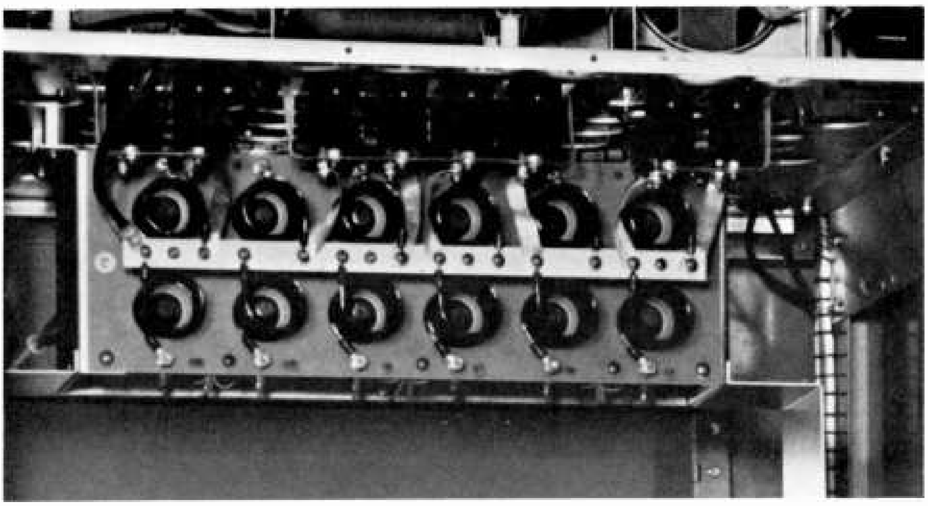
Due to fundamental limitations of the output power available from each transistor, many devices must be used for high power solid state transmitters. Therefore, the method of combining the output of amplifiers becomes very important. To simply connect the devices in parallel or in series brings about lack of isolation, unequal load sharing, and awkward impedance matching. The load and performance of many devices can be affected by one improperly performing device.



CABLE COMBINER

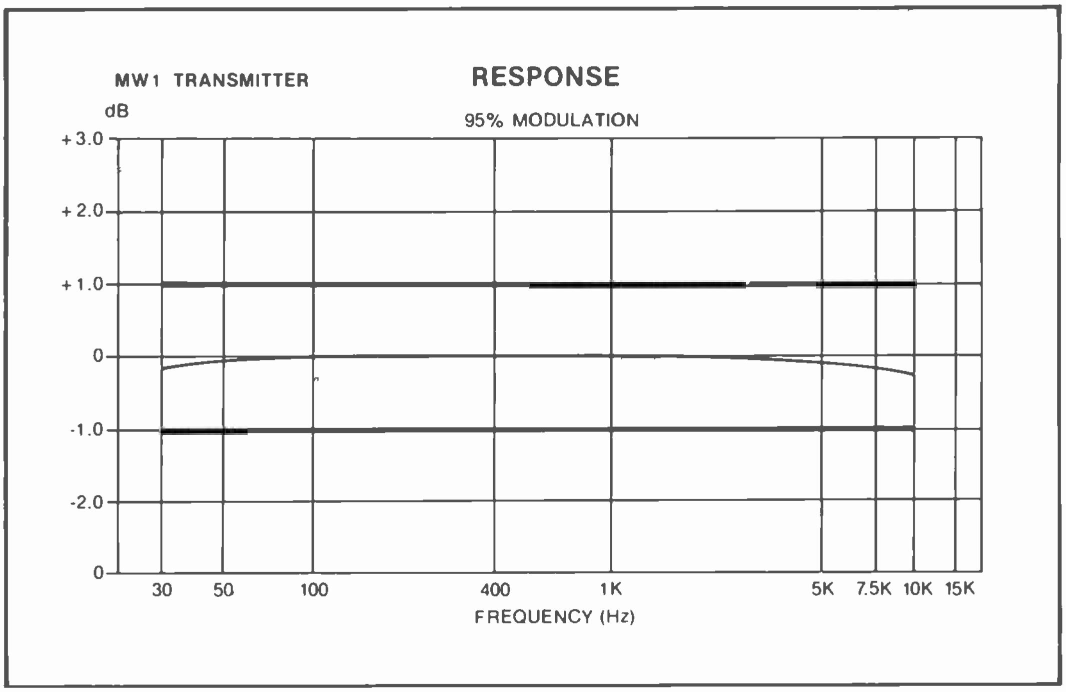
There are many types of combiners, with the required parameters of isolation and low loss, that have been routinely used at VHF through microwave frequencies for many years. Various hybrid junctions, couplers, and transformers and their matching, isolation, and reciprocal properties are discussed in detail in the microwave literature. One technique best suited for many inputs and small bandwidths is the cable combiner. It consists of 1/4 wavelength transmission lines from each source to a common summing point. There is also a resistor from each source to a common reject or waster load. Each 1/4 wave transmission line functions as an impedance transformer which allows the summing point impedance to be a desirable value.

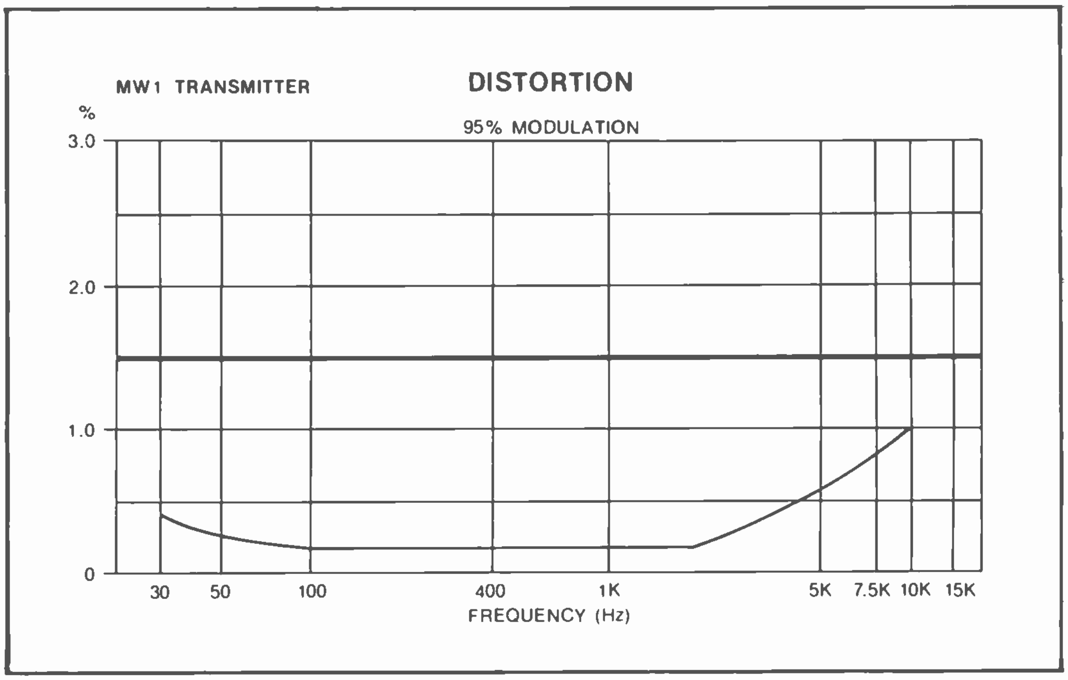
If each source is delivering the same voltage in the same phase, then there is no power flowing to the resistors. All the power is summed at the output. If any source does not deliver its correct voltage or phase, then a fraction of the total power is dissipated in the resistor associated with the improper source. This property allows a simple RF sensor to indicate any incorrect source. The isolation property of the combiner insures that the load impedance on each source remains constant even if any other source is open or short circuited. The power dissipated in each resistor does not exceed the output of a single source; therefore, convenient components can be used. This type of combiner can be expanded to accommodate any number of sources or inputs.



MW-1 COMBINER

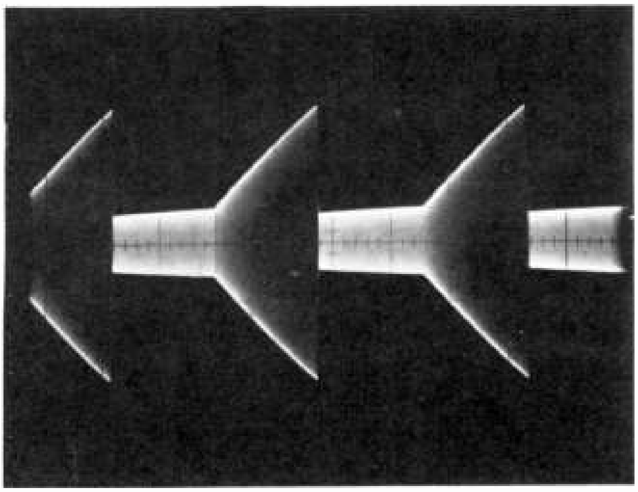
Of course, at the standard AM broadcast band 1/4 wavelengths of transmission are much too bulky to be practical. Therefore, a lumped equivalent circuit is used in the practical transmitter. These 90 degree networks constructed of a coil and capacitors have the essential electrical properties of a 1/4 wave transmission line for use in a combiner. The coils are slug tuned in unison by the plate tuning control. As in tube transmitters, the plate tuning allows the load impedance to the amplifier to be adjusted to resonant or unity power factor. There is a pilot lamp connected to each reject load to allow a very easy determination of which, if any, module is not performing satisfactorily. The initial factory alignment of the combiner is easy. The slugs in each coil are adjusted so that the associated lamp does not glow. In practice, the combiner has a very satisfactory isolation. This allows each module to contribute full performance even if there is a failure of other modules.



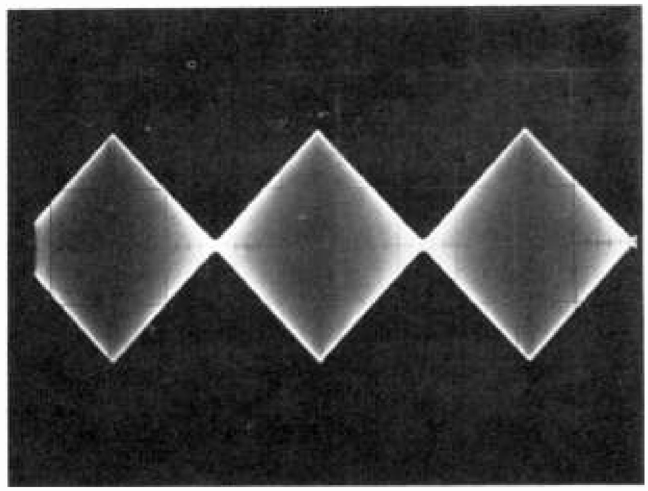


FIELD PERFORMANCE EXPERIENCE

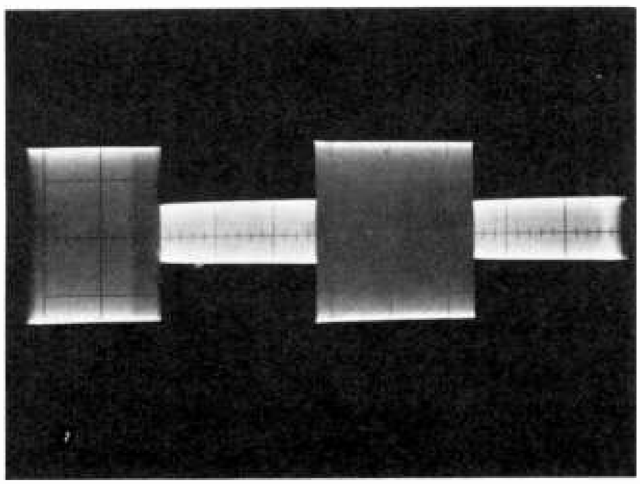
Since an all solid state AM broadcast transmitter is new, performance and actual operating experience are an important indication of the practicability of the concept. The audio performance exceeds that of any other transmitter on the market. The frequency response is specified as less than ±1 dB from 20 Hz to 10 kHz. Typically it is very flat and smooth, with 0.3 to 0.4 dB drop at the extreme limits. The total harmonic distortion is specified at 1.5% or less, 20 Hz to 10 kHz, 1KW output and 95% modulation. Typical measurements show less than 1/2% in the mid-audio frequencies, rising slowly to about 1% at 10 kHz.



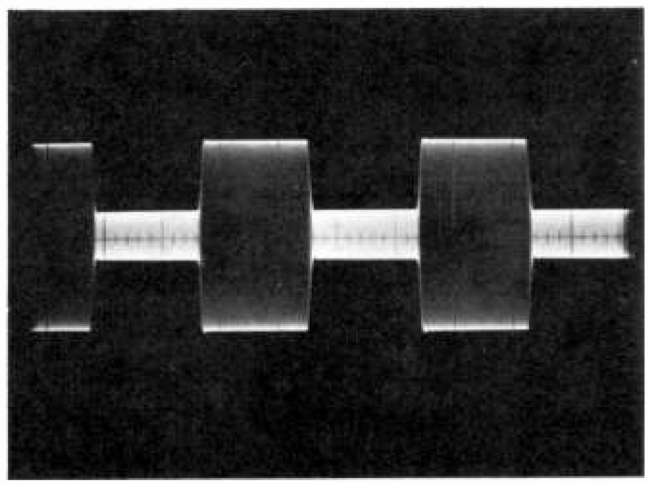
RAMP TO 125%



TRIANGULAR WAVE

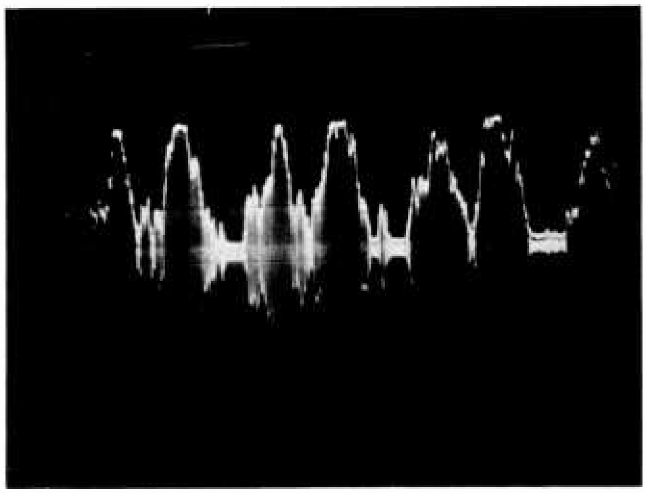


30 Hz SQUARE WAVE



1000 Hz SQUARE WAVE

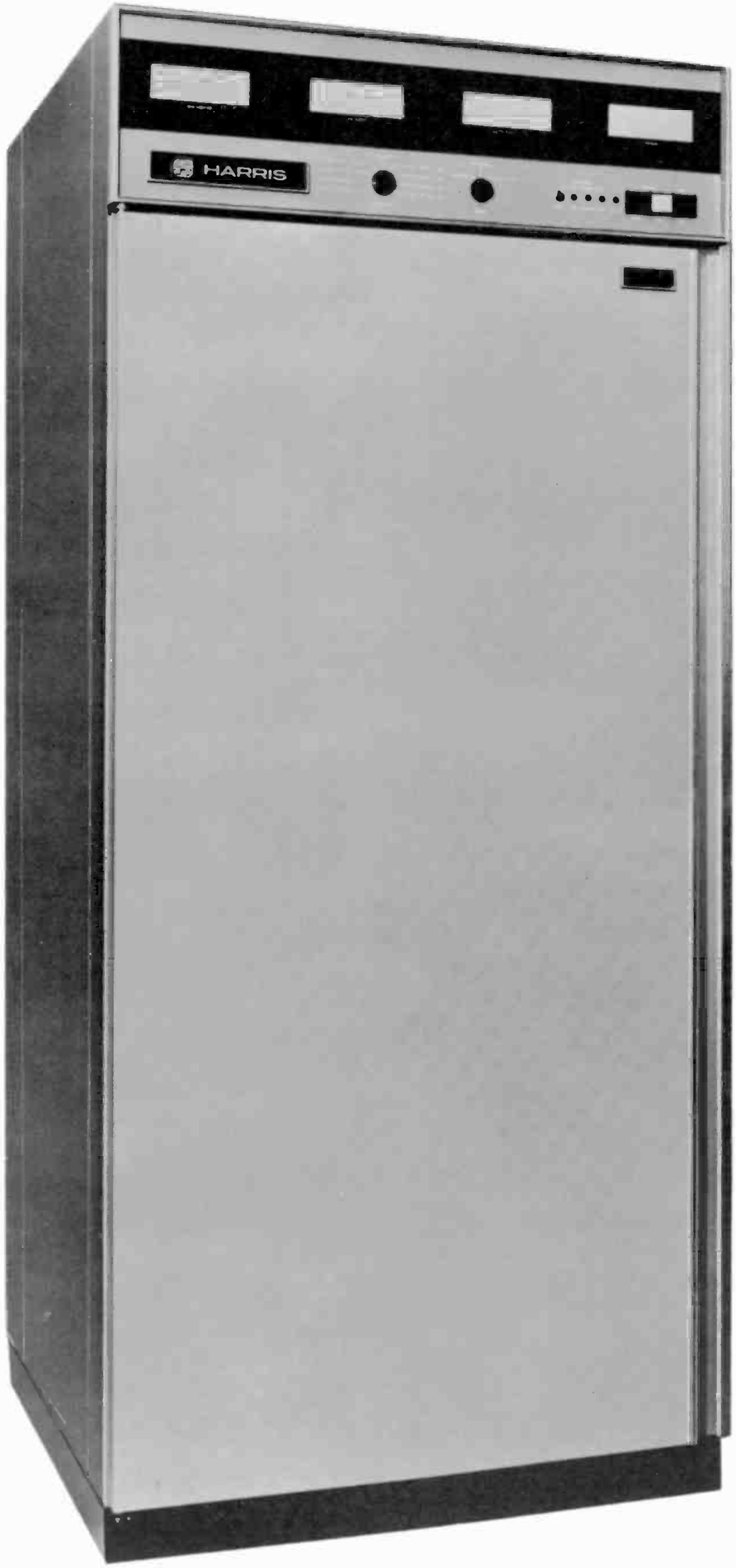
Demonstration of the transient response and positive peak linearity is best done with a function generator and oscilloscope. Use of an asymmetrical ramp shows that the linearity is nearly perfect to over 125% peak positive modulation. Lack of low frequency tilt, good rise time, and freedom from overshoot is also demonstrated. A symmetrical triangle shows excellent linearity from 100% positive to 100% negative modulation. This illustrates why the intermodulation distortion is less than 2%. A 30 Hz square wave shows the excellent low frequency response resulting from a DC coupled modulator. A 1000 Hz square wave shows excellent reproduction. These tests, plus tone bursts, show freedom from phase shift, gain, linearity, tilt, or overshoot problems. A dual trace oscilloscope with highly processed audio on one input and the transmitter RF output on the other input shows that the output envelope follows the input faithfully.



HIGHLY PROCESSED AUDIO

The operating experience began with very rugged overstress testing in the factory during the Fall of 1974. The first all solid state MW-1 began full time broadcast service in December 1974 at KXEO, Mexico, Missouri. By early Fall, 1975, Harris has shipped approximately 20 transmitters, and has orders for many more. There have been enough of these transmitters operating through lightning storms without failure to allow the conclusion that the MW-1 is as safe from lightning as tube type transmitters. The protection techniques, the laboratory testing and the careful analytical work have been confirmed through actual operation experience.

The field problems that have occurred in actual operation have been less than usually experienced with a new production item. They have been confined to simple component, workmanship, or interface problems. The users of these new transmitters are finding that the basic benefits of performance and reliability promised by solid state are actually realized by the MW-1.



HARRIS ONE-KILOWATT MW-1 — THE WORLD'S FIRST
FCC TYPE ACCEPTED 100% SOLID STATE
AM BROADCAST TRANSMITTER

NOTES

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