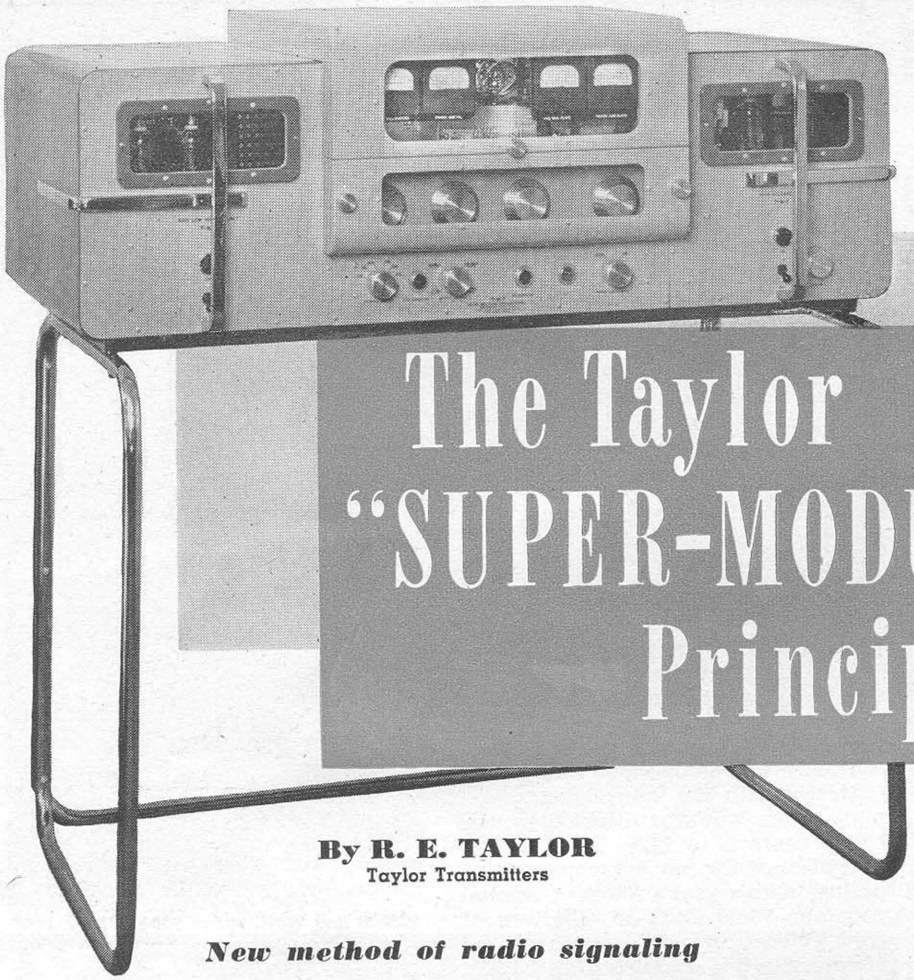


Front view of Taylor Type 900-A transmitter incorporating the new "super-modulation" principle.

The Taylor "SUPER-MODULATION" Principle

By R. E. TAYLOR
Taylor Transmitters

New method of radio signaling allows greater over-all efficiency with compressed carrier and emphasized sideband operation.

SUPER-MODULATION, a new method of radio signaling, was discovered some years past by the author, but its development for general application was delayed by the war. Several hundred broadcast transmitters were built for the Armed Forces using the method.

After several years' delay in presenting this new method to the industry, development has brought the practical application at a time when an improvement is seriously needed in the amateur and other phases of communication service. Many experimental transmitters have since been constructed, using this new system. One of the latest, Type 900-A, a 1 kw. unit, is in service by W6GT, and its operation has been watched by many with considerable interest.

Circumventing previous sideband power restrictions, and applying heretofore unknown principles, the super-modulation use of emphasized sidebands and semi-suppressed carrier transmission provides far greater signaling efficiency than was previously considered feasible.

With more than four times the true sideband power at full modulation, and one-half or less the bandwidth required in conventional practice, transmission efficiency is about equal that claimed by some for single sideband operation, and in some operational respects is superior to single sideband.

Fifteen to twenty times or more peak power output at full modulation with a bandwidth of two or three kc. each side of carrier and no spread or splatter, is possible. Conventional systems are limited to four times or less peak power. Effectively, this is a sideband or modulation power output increase of from 6 db. upward with no increase in power input to the carrier production equipment.

In semi-suppression or compression of the carrier power under full modulation, when the sideband power is driven upward to high level output, the carrier is reduced at the same time, to allow room for additional sideband power. This also allows the reduction of the heterodyne or interference level at the receiver end. The reduction in the noise level is also allowed at the receiver when receiving a super-modulated signal, due to the compressed carrier and narrow bandwidth. Greater signal voltage out of a standard receiver linear detector results in 6 db. or more gain over a conventional signal, without modifications. The first difference that will be noted is that the signal is so sharp that it is hard for those used to the conventional broad signals to find. However, when tuned, the signal is louder than anything on the band.

At the receiver end, the super-modulated signal sounds unusually loud. In many cases when the b.f.o. is turned on, the carrier heterodyne is barely audible, and in many instances possible interfering heterodynes from other nearby signals are not heard at all.

Far better speech quality is provided than in most conventional amateur transmitters, as the system reproduces the speech in true color without the necessity for limiters or clippers.

Reception of a super-modulated signal from a 900-A transmitter, in many cases, is not bothered by a strong signal 2 or 3 kc. away in the band. Two 1 kw. 900-A super-modulated transmitters were operated under tests about 2½ kc. apart in the band, using full modulation for maximum sideband power production, with the "S" meter on the receiver several miles away "pinned" by both signals. Either transmitter could be tuned in as desired, without interference from the other. Tuning between the two super-modulated signals resulted in the heterodyne being audible but with the sidebands of the two signals beating together producing a typical "monkey chatter" interference. By tuning 1 kc. each side of center between the two signals either could be readily copied with little interference from the other.

This modulation system has the following advantages:

1. Shows considerable reduction in BCI. Many cases of BCI have been cured by use of super-modulation because of the lack of "buck shot" and splatter.

2. Provides more than double the over-all operating efficiency of conventional systems with far less complicated tuning and adjustment.

3. The audio power in the 1 kw. amateur transmitter is only about 8 watts.

4. Provides far greater plate efficiency than conventional practice.

5. The power amplifier and positive modulator tubes, being audio pulsed for operation, allow greater power input and output. This feature is not new to the radar people as plate dissipation over a period of time for power output can be engineered and used to advantage.

6. More db. of talk-power per size and weight as well as more power input than any other conventional system is offered.

7. About the same power distribution capabilities under full\ modulation, with respect to sideband power and carrier, as wide-band FM with 30 kc. total deviation for 15 kc. audio frequency response.

8. Provides a substantial effect in reducing the noise level of a conventional receiver for this type of operation.

Sideband power alone, irrespective of how it is generated, is that part of a transmitted radio telephone carrier wave which conveys the intelligence to the receiver at the distant point in communications or amateur radio. The undesirable carrier is one of the greatest contributors to the noise and interference in most receivers.

Thus, the greater the true sideband power produced by the transmitter, the stronger the received signal with less interference. If the sideband power is a true reproduction of the modulation, the bandwidth required is about one-half that necessary with usual high modulation percentages with their attendant distortion, phase shift, and splatter. Further, if the carrier can be reduced, we find a correspondingly lowered noise and interference level in the receiver. Theory shows that a true 2½ kc. modulation frequency produces sidebands 2½ kc. removed from the carrier. In many transmitters the harmonic and distortion produce sidebands 5 to 10 kc. removed from the carrier.

Therefore, if we utilize only significant and basic sideband components, by means of appropriate high efficiency production or modulation methods, we wind up with quite a reduction in bandwidth or about 2½ kc. each side of carrier frequency, with far greater range of communication because of the increased sideband power, or talk power of the transmitter.

When we examine conventional transmitter and receiver practice, we find that the radio transmitter as normally operated along with the receiver has a very low intelligence transmission efficiency. Hereafter we shall refer to this as ITE. In other words, ITE represents the true sideband or talk power in one sideband produced by the transmitter.

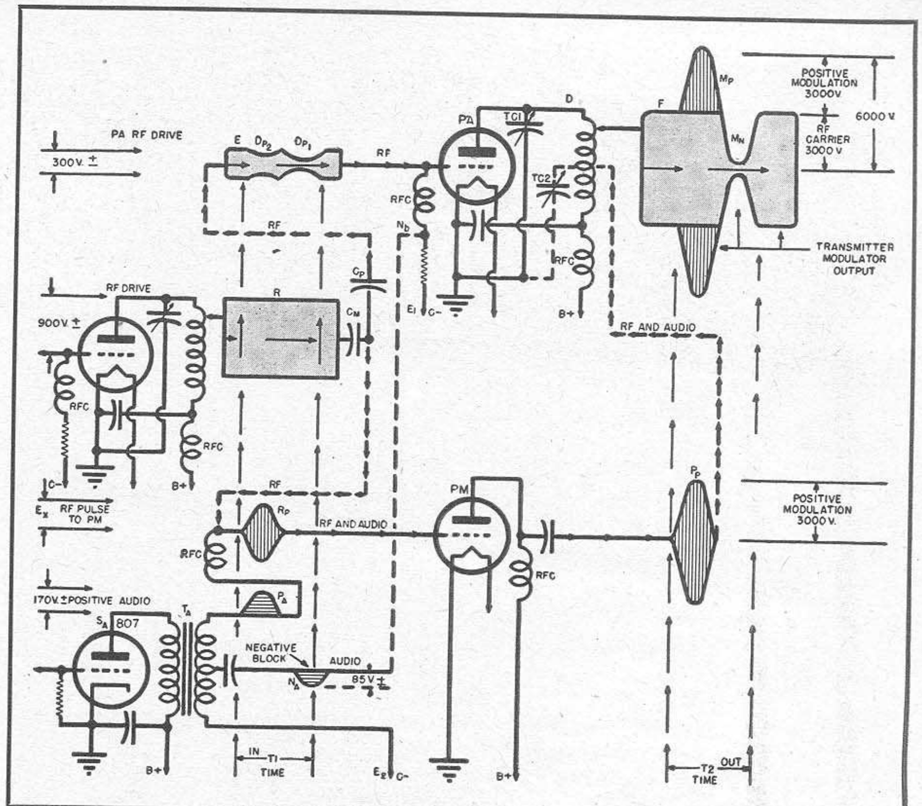


Fig. 1. Operational example of the "super-modulation" system.

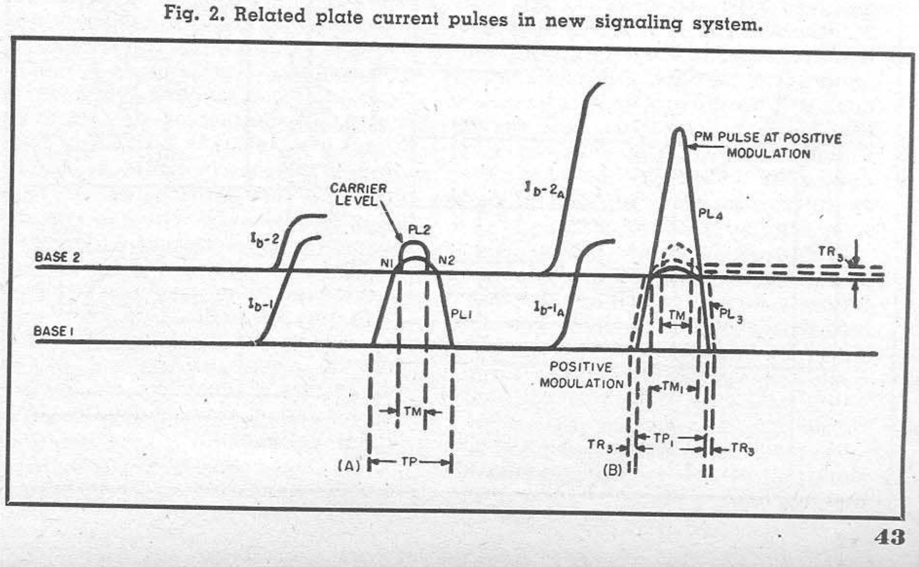
The broad signal, and limited communication range, of many transmitters using conventional modulation, is often caused by sideband power limitations.

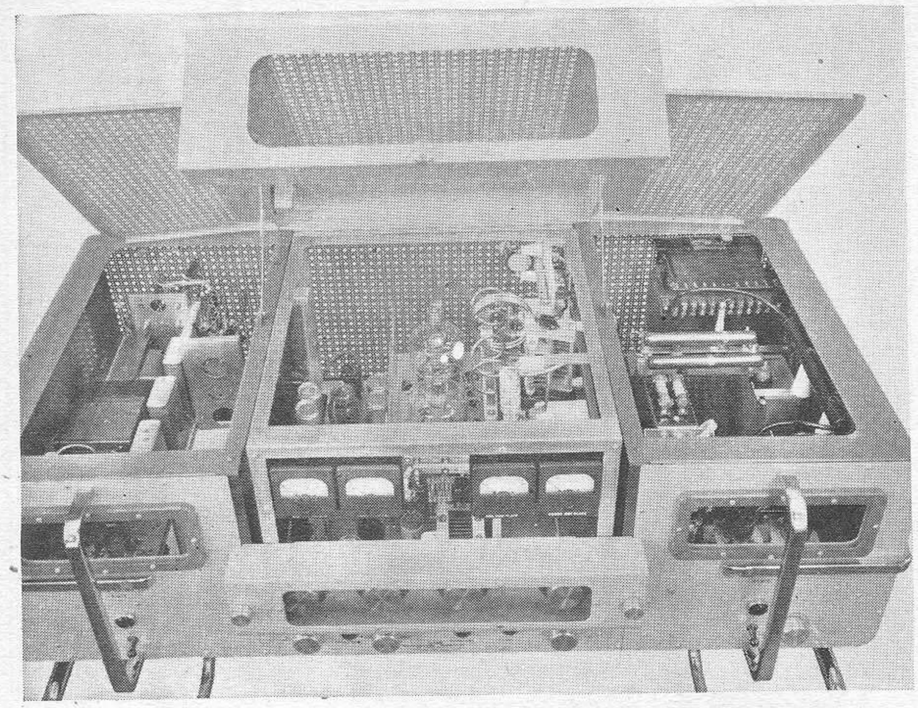
The basic functioning of this new system is shown in Figs. 1 and 2 with the simplified schematic diagram at Fig. 3. Fig. 1 at *D* represents a conventional power amplifier capable of about 900 watts input, adjusted for maximum carrier power output of about 700 watts. Proper tuning, matching, and loading is assumed and correct values of bias, screen, and d.c. plate voltage for the maximum efficiency is provided. This output tube is indicated in Figs. 1 and 3 as *PA*. In Fig. 1, the r.f. drive power at *E* of about 300 volts is supplied to the grid of this tube from the buffer stage through capacity C_p. The output r.f. voltage shown at *F* is about 3000 volts or the maximum that may be developed by tube *PA* within the limits of its input capability and efficiency.

The plate current pulse of this tube is shown by PL_1 in Fig. 2A operating from base line 1 during the time *TP*.

Referring again to Fig. 1, when modulation or intelligence is applied to this r.f. carrier output at *F* for the sideband power production, the 3000 volts of carrier is increased to 6000 volts or more for the positive or upward modulation. This same r.f. car-

Fig. 2. Related plate current pulses in new signaling system.





Top view of the Type 900-A transmitter which incorporates "super-modulation" system.

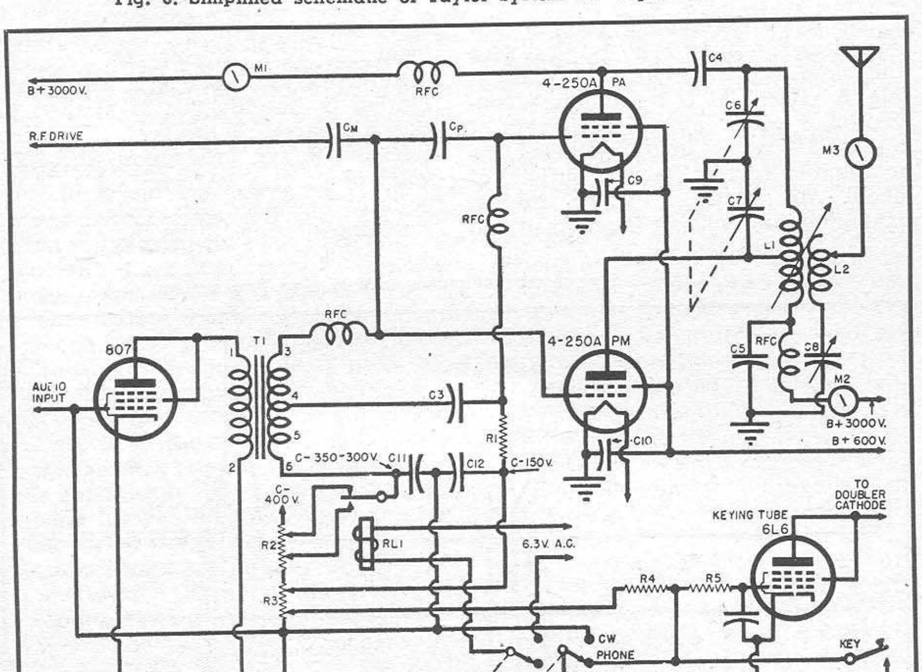
rier of 3000 volts is reduced to almost zero for the negative one-half modulation cycle. These two points are shown as M_p and M_n respectively.

Common past practice has been to have the increase and decrease of the carrier controlled and timed so that it follows the waveform of the speech or intelligence applied, with the upward increase at M_p of equal amplitude and duration to that of the negative modulation M_n.

In Fig. 1, arrangement is made for a second tube of about the same power input capacity as the power amplifier tube *PA*. This is shown as *PM*, or the positive modulator. A second output tank condenser TC_2 is added for separate flywheel action of the second tube *PM*. The output of *PM* is connected about half way up the output tank inductor, at that point where the second tank condenser TC_2 is connected.

The tank inductance is now slightly reduced to compensate for the added capacity of TC_2, with both condensers TC_1 and TC_2 ganged to one control. These condensers are of approximately equal capacity.

Fig. 3. Simplified schematic of Taylor system of "super-modulation."



Tuning is the same as before with the dual tank condenser adjusted for minimum dip of the power amplifier tube *PA* plate current. Tube *PM* although attached to the output tank circuit, contributes almost no carrier under no-modulation conditions. This is shown at PL_2 in Fig. 2A above base line 2 during time *TM*. This low output is due to the high bias at E_2 in Fig. 1, and the low r.f. drive from the buffer reservoir, through the coupling capacity C_m.

With the positive one-half cycle of modulation, tube *PM* conducts. Operation is at a high degree of efficiency and with a very small angle of plate current flow, as shown by the plate current pulse PL_4 in Fig. 2B. In Fig. 1 is shown, over period of time T_2, the additional r.f. power of about 3000 volts at P_p supplied from tube *PM*. This is applied to the output tank circuit, and added to the carrier power present from tube *PA*, permitting the positive modulation shown at M_p, above the unmodulated carrier level *F*.

M_p is then a reproduction in waveform of the r.f. drive pulse R_p from the r.f. reservoir *R*, driving tube *PM* up the desired power output during the required time.

Triggering control and amplitude of the r.f. drive pulse R_p, as well as the waveform of the pulse, is effected by the positive one-half cycle of audio shown at P_a, generated by the audio stage at S_a, and separated from the negative one-half cycle of audio at the secondary of transformer T_a. This positive one-half cycle of audio at P_a opens the bias gate from the r.f. reservoir *R* during the required time shown at "T_1 *IN*" and corresponds to "T_2 *OUT*." During this period positive modulation of the carrier at M_p is developed by power from tube *PM*.

This is applied directly to and is additive with the carrier power already present in the output tank circuit. There is no increased plate input to tube *PA* during this interval. By allowing operation of the tube *PM* only during the positive modulation one-half cycle, a considerable saving in over-all input is permitted. In plate modulation this same high power modulation energy is used to develop the negative modulation of the carrier at a considerable waste of power.

During the function of positive modulation, the average power amplifier efficiency with respect to carrier, is caused to increase a small degree over that of carrier level. Power input during this period, to the power amplifier tube *PA*, is reduced slightly as shown by TR_3 of Fig. 2. The normal carrier power level is maintained.

As the plate current pulse of tube *PM* is arranged to effectively extend the plate current pulse of the tube *PA* for positive modulation, we have an over-all pulse of two times or more the amplitude of that of *PA* at carrier level. This is shown in Fig. 2A.

During this period part of the car-

(*Continued on page* 96)

"Super-Modulation"
(Continued from page 44)

rier power can be supplied by the tube *PM* as well as the power for positive modulation. This allows a small reduction in the plate input and output of the power amplifier tube *PA*.

The reduction of plate power input and output of the tube *PA* is effected by a small reduction in r.f. drive during positive modulation as shown at DP_2 of Fig. 1. This is the result of a predetermined impedance ratio between voltage divider condensers C_m and C_p.

With the higher efficiency and narrow angle of flow of the plate current pulse at PL_2 of tube *PM* operating from base 2, the over-all pulse of the two tubes shows a small nick at N_1 and N_2 of Fig. 2 at carrier level. This is not important, as the flywheel effect of the output tank serves to correct this.

With completion of the positive modulation one-half cycle and carrier level restored, the negative one-half cycle modulation from carrier level to almost zero and back is the next function. This is effected by reduction of the 3000 volts of normal carrier to zero and back, as shown at M_n in Fig. 1.

The negative modulation is a duplicate in waveform of the positive modulation. This negative modulation duplicates in waveform the negative one-half cycle of about 85 volts shown at N_a in Fig. 1. The blocking effect of the negative audio is applied at N_b, and provides the reduced input drive power to the power amplifier as shown at DP_1.

This results in a great reduction of the carrier during the negative modulation peak at M_n. During this period, tube *PM* is completely inactive. The negative carrier modulation function is accomplished with only 85 volts of negative audio as compared to about 3000 volts required in plate modulation.

Further inspection of the schematic diagram at Fig. 3 shows the basic circuit to be unusually simple and composed of fewer parts and adjustments than other systems. Of special interest are the fixed capacitance values at the input of both the power amplifier and positive modulator, with only conventional tuning and loading of the output. The r.f. is fed to the power amplifier tube *PA* through the two fixed condensers C_m and C_p, with r.f. injection power for the grid of the positive modulator tube *PM* supplied from the junction between the two condensers. These condensers act as an r.f. voltage divider.

Bias for tube *PA* is taken from the voltage divider R_3 and fed through resistor R_1 through the r.f. choke to the grid of the tube. Bias for tube *PM* is taken from the top voltage divider resistor R_2 with the high tap for phone and the low tap for c.w., switched by relay RL_1 as desired. This is fed to tap 5 on the secondary of the modulation transformer.

C_{11} and C_{12} are 2μfd. filter condensers across the high and low voltage bias leads to the tubes *PA* and *PM*.

The secondary of the modulation transformer is tapped and delivers 80 to 90 volts of negative audio through the 2 μfd. coupling condenser C_3. This is the blocking voltage used in negative modulation.

Tap 3 on the modulation transformer delivers 160 to 180 volts of positive audio through the r.f. choke for the triggering action of tube *PM* during positive modulation. The 807, last stage speech tube, is triode connected and fed to the primary of the transformer.

110 to 120 volts of audio is developed across the primary for full modulation. C_9 and C_{10} are screen bypass condensers for the two tubes *PA* and *PM* with the 600 volts for the screens supplied from a fixed and regulated source.

Although both tubes are fed from the common d.c. plate supply of about 3000 volts, the power amplifier tube *PA* is shunt fed through meter M_1 and the r.f. choke to the plate. Condenser C_4 is used as a blocking condenser to isolate the d.c. between the two tubes and at the same time transfer power generated by *PA* to the output tank circuit consisting of L_1, C_6, and C_7.

C_5 is the r.f. bypass for the cold end of the tank coil. Plate voltage for tube *PM* is fed through meter M_2 and the r.f. choke through the tank inductor to the plate of *PM*. The plate of *PM* is tapped about mid-point on the tank coil so that tank condenser C_7 may be charged separately as required.

The voltage developed by this condenser will discharge at this point of the coil, and will be stepped up by the autotransformer action of the complete coil. Operation of tube *PM* and its associated components provides at least double the current and voltage of carrier level, as required for positive modulation.

The inductor L_2 is coupled to the tank inductor L_1 for the power transfer to the load or antenna as desired, with condenser C_8 for matching of the load, and meter M_3 measuring the antenna current.

Also shown is the 6L6 electronic keying tube and associated components, with switch S_1 as the phone-c.w. changeover switch. Bias blocking voltage for the keying tube is fed from the voltage divider R_3. Change of the phone-c.w. switch to the c.w. position allows several functions at the same time.

The keying circuit to the doubler cathode is opened, the grid of the 807 audio tube is grounded, and the bias of the positive modulator tube is reduced so that it may act as a booster for the power amplifier tube *PA* for increased output in telegraph service. When a conventional telephone transmitter is used for c.w. the modulator tubes are of no use.

Adjustment procedure is somewhat different than with other systems inasmuch as it is simpler. The power amplifier tube has screen voltage of a fixed value, limiting the dissipation, either in or out of adjustment. The r.f. drive is in the neighborhood of that required for telegraph service, at a lower value than that required for plate modulation.

The power amplifier tube actually has its plate input lowered during the positive modulation, permitting far less r.f. drive power with greater stability and less strain on the tubes during all functions.

A plate modulated tube takes an increased input during positive modulation, whereas the power amplifier tube in the *Taylor* system is allowed a pulsed cooling period under positive modulation. As the tube is operated at telegraph ratings, it has a cooling period similar to that of the key up conditions in telegraph service.

The positive modulator tube is not subjected to continuous use as it operates only on pulses. Its power is delivered directly to and on the carrier without the troublesome impedance matching modulation transformer.

The r.f. drive and last stage speech tube requirements are conventional. However, reserve power delivery capacity should be provided as the modulated output of the system requires full positive peaks of voltage from both the r.f. drive source and the audio output tube.

Complete and ready for operation, including all power supplies, speech and modulation equipment, the 900-A unit is easily portable.

The 1 kw. transmitter section of the console, complete on a single main frame sub-assembly chassis, contains the complete r.f. chain consisting of a 6V6 oscillator, 6V6 doubler, TB-35 buffer-amplifier and the 4-250A power amplifier.

All controls of these stages are front panel operated. A 6L6 keying tube is mounted under the chassis and is front panel controlled for phone-c.w. operation.

The second 4-250A, as positive modulator and c.w. booster, is located on the power amplifier tube deck in the center of the chassis. The 807 last speech tube, modulation transformer, and 6SJ7 speech amplifier tube are located at the left rear of chassis.

Four sub-panel mounted meters are provided, with two of 0-500 ma. range, for reading the plate current of the power amplifier and positive modulator. The third meter of 0-10 volts range, meters the filament of the power amplifier, and the fourth meter, a 0-100 ma. type, is front panel switched for measurement of the plate current of all other r.f. stages and the 807 audio stage.

Unusual ease and simplicity of tuning is allowed, as the four front panel controls tune only the plate circuits of the r.f. stages. This eliminates any adjustment or tuning of the grid circuits. The only variable coupling circuit in the unit is that of the output link for the transmission line or antenna.

All r.f. stages are highly biased so that in tuning an out-of-resonance condition of any of the r.f. exciter stages causes no damage to any of the tubes in the following stages. The positive modulator is not affected by tuning, as it draws very little plate current with no modulation.

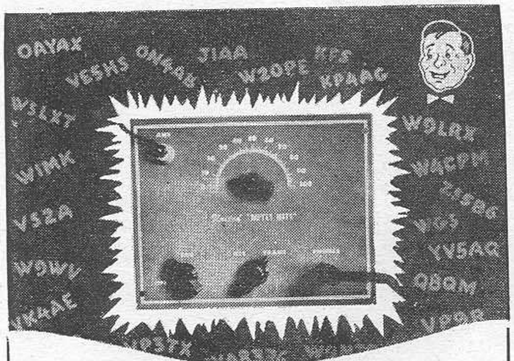
Plate current off resonance is not excessive as the high bias and the fixed screen voltage on this tube allows only a slight increase in plate current in the out of resonance condition.

By providing high fixed bias on all stages, and limiting screen and plate voltages, we have a pretty safe transmitter, that under a momentarily detuned condition, operates without damage to tubes or equipment.

The plate tank coils of all the r.f. stages are of the plug-in type, with band change requiring about 30 seconds. This type of band change was selected after deciding that maximum efficiency and stability at the high frequencies was more important than the convenience of bandswitching.

No neutralization is required, and no suppressors are required in either grid or plate leads in any of the tubes.

The power supplies are of conventional design. A 5Z3 tube is used as a



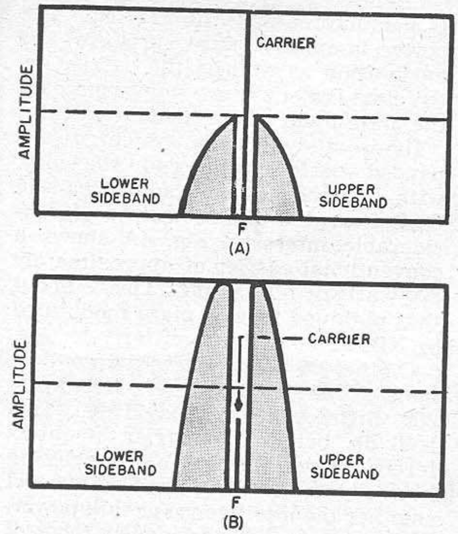


Fig. 4. Expanded super-modulation possibilities with greatly increased talk power and reduced interference.

bias rectifier, a pair of 866A's as rectifiers for the low voltage supply, and a second pair of 866A tubes are used as high voltage rectifiers.

Operational tests of 900-A transmitters using elementary super-modulation as described so far were as follows: In one case, power input to the power amplifier tube was 3000 volts at 305 ma., or 915 watts, while the power input to the positive modulator tube was 3000 volts at 25 ma., or 75 watts. This was a total power input of 990 watts at no-modulation carrier level.

Output was 3.3 amps. into a 72 ohm load, representing 800 watts of carrier output or a plate efficiency of 80 per-cent. With modulation, the measured current through the load was 4.1 amps. or 1210 watts.

The r.m.s. power output increase over carrier level was 410 watts or about the customary 50 per-cent increase by modulation. The .8 amp. increase represented the usual 22½ per-cent increase over the unmodulated carrier level.

At this modulation level, with narrow bandwidth and other advanced principles to be described in detail later, input to the power amplifier tube was reduced to 600 watts, represented by a plate voltage of 3000 volts at 200 ma. At a plate efficiency of 75 per-cent this allowed a semi-suppressed carrier output of 450 watts. Input of the positive modulator tube was 960 watts on peaks, which allowed, at a plate efficiency of 85 per-cent, sideband power production of 800 watts, over and above the 450 watts of semi-suppressed carrier power output of the power amplifier.

Therefore, with the plate power input of 1560 watts for carrier and modulation, we have in the output during positive modulation, about 450 watts of semi-suppressed carrier power and 800 watts of sideband power. This is 400 watts in each sideband. This represents about twice the normal side-band or talk power.

Examination of past practice in this system shows why there is such a great difference in talk power efficiency. Limited carrier and sideband output due to required reserve tube capacity for upward modulation, is not needed in this system. The direct application of the positive modulation energy, for the production of sideband power, is in the form of additional audio triggered r.f. voltage added to the output power. This eliminates three or more functions necessary in conventional practice, where first the high power modulating audio must be generated, and then matched and transferred to the plate of the modulated tube.

Then the modulated tube transfers this energy to the power amplifier plate tank circuit, which in turn adds the limited sideband power to the carrier power output.

Dispensing with these troublesome connecting links between the modulation energy and the carrier itself, allows direct carrier super-imposition by the modulation energy for sideband power production.

Further study shows considerable input power wasted in the production of modulation energy for sideband power in conventional practice. Carrier level plate power input in case of the low-level system represents wasted power under no-modulation conditions; about equal to the wasted power input necessary to generate the negative modulation, in the plate modulated system.

In the new system this power input waste is eliminated as the modulator tube consumes power only when needed for positive modulation, with high power amplifier plate efficiency, and little power consumed for negative modulation.

Where the same tube is effectively used to produce both carrier and modulation in plate modulation, there is no direct onnection between the class B modulators and the carrier. The power amplifier must produce the modulation as well as the carrier, as the class B modulators simply increase the plate input of the modulated tube.

Later study of this system in expanded performance and efficiency, with methods of procedure beyond that presented so far, will be of considerable interest. Fig. 4A shows a conventional carrier of approximately 800 watts or plus 51 db. This is about that obtained from a plate modulated or NBFM 1 kw. transmitter.

Of the 400 watts of maximum sideband power, that in one sideband is 200 watts or about plus 45 db. This is 6 db. below the carrier or interference level. Noise or interfering heterodynes at the plus 51 db. level smother the intelligence or talk power.

However, in the expanded form of super-modulation, as covered in the following article, transmission and reception conditions are reversed with the sideband power level far above the carrier or interference level.

This is accomplished by further increased sideband power and a high degree of semi-suppression or compression of the carrier, with results somewhat as shown in Fig. 4b. Non-modulated carrier power of about 800 watts or plus 51 db. is, with full modulation, reduced to about plus 42 db. as at 4B, or 8 to 10 db. below that of the plate modulated carrier or interference level.

Total sideband power of about 1600 watts then allows about 800 watts at plus 51 db. in each sideband or 6 db. more than in Fig. 4A.

By increasing the sideband or talk power level by 6 db. or more in one direction, and the simultaneous reduction of the carrier interference level by 6 db. or more in the other direction, we have a total difference of 12 db. or more in intelligence transmission efficiency.

(To be continued)

This new 300-foot aluminum-sheathed tower which will enable scientists to make extensive microwave experiments, was opened recently by Federal Telecommunication Laboratories, Inc., at Nutley, New Jersey. The laboratories which are housed in this modern building are research headquarters for International Telephone & Telegraph.