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New TWT Amplifiers with Provision for Simulating Special Microwave Signals

ABOUT a year ago these pages described two new traveling-wave tube amplifiers for the 2-4 kilomegacycle range.[1] These amplifiers were distinguished by the fact that they could amplify the entire frequency range between 2 and 4 kmc as a band, and that they offered 30 db of gain for this band. Their power outputs of 10 milliwatts for one amplifier and 1 watt for the other were sufficient to enhance the power output of signal generators, while the r-f gain property made the amplifiers useful for improving the sensitivity of square-law detectors and for amplifying the output of harmonic generators.

Since the introduction of those amplifiers, two new twt amplifiers have been placed in production. These amplifiers operate over the 4-8 and 7-12.4 kmc ranges with gains of 25 db or more and with maximum power outputs greater than 10 and 5 milliwatts, respectively, at 50-ohm input and output levels. A modulating grid enables the amplifiers to be used to pulse- or amplitude-modulate the r-f wave.

As indicated in Fig. 2, the new amplifiers consist of the traveling-wave tube with suitable power supplies and modulation inputs. The mechanism of the traveling-wave tube itself is to produce amplification by transferring energy from a d-c electron beam passing axially through a helical transmission line to the r-f wave traveling down the helix. The r-f wave to be amplified or modulated is coupled into and out of the helix by special broad-band helical couplers which permit realization of the inherent wide-band capa-

[1] P. D. Lacy and D. E. Wheeler, "New Broadband Microwave Power Amplifiers Using Helix-Coupled TWT's," Hewlett-Packard Journal, Vol. 6, No. 3-4, Nov.-Dec., 1954.

Fig. 1. *New -hp- 492A and 494A Traveling-Wave Tube Amplifiers give more than 25 db of gain over 4-8 and 7-12.4 kmc ranges. Special modulation provision enable the amplifiers to be used to simulate doppler effects, to obtain amplitude-modulated signals or to form high-sensitivity linear detectors.*

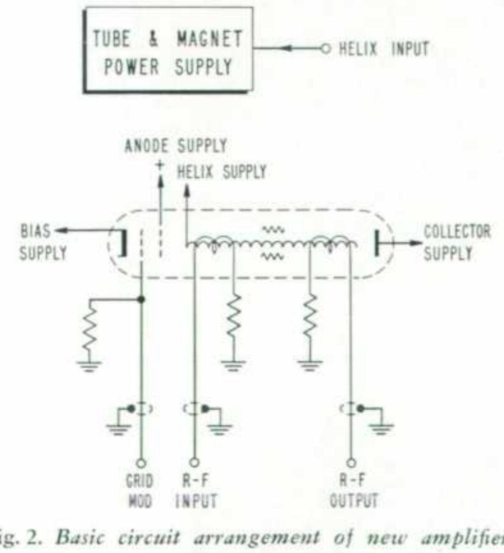

Fig. 2. *Basic circuit arrangement of new amplifiers.*

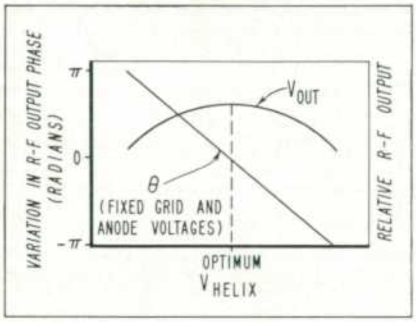

Fig. 3. *Effect of helix voltage on phase shift and output voltage from twt.*

bilities of the basic traveling-wave tube structure. A modulating grid in the electron gun of the tube permits pulse or amplitude modulation of the r-f output wave. An amplifier is provided in the helix power supply to permit modulation of the r-f wave by the helix voltage, a feature which lends considerable flexibility to the amplifiers. This feature will be described later in detail.

The special modulation arrangements provided in these amplifiers permit them to be used for producing a number of special signals at microwave frequencies. Included among these signals are offset carriers, combined sine- and pulse-modulated carriers, and frequency-modulated carriers.

OFFSET CARRIERS

In some microwave applications such as in testing doppler velocity systems, it is necessary to generate a signal which is offset by only a few kilocycles or tens of kilocycles from a known microwave frequency. This has always been a difficult problem. By use of the traveling-wave tube, however, the problem can be solved neatly and in addition a great deal of flexibility can be achieved.

The basic method[2] of producing an offset carrier with a twt is essentially a phase modulation method. The process arises from the fact that it is possible to alter the transit time of the r-f wave on the helix a significant amount by changing the velocity of the electron beam by a small percentage. Changing the beam velocity is accomplished by changing the voltage on the helix. The effect of the helix voltage on the relative phase of the twt output is shown in Fig. 3 together with attendant amplitude characteristics.

If the helix voltage is altered by superimposing a sawtooth voltage on the d-c helix voltage, the relative phase of the output will be continuously changed during the rise of the sawtooth (Fig. 4). If the amplitude of the sawtooth is adjusted to produce exactly 2π radians of phase shift in the output r-f wave, the phase of the wave will have been changed by one r-f cycle during the rise of the sawtooth, after which the phase will quickly jump back to its starting point during the flyback. This process is thus a phase modulation method in which one r-f cycle is added or subtracted (depending on whether the sawtooth is positive or negative) for each cycle of the sawtooth. A rapid phase recovery then occurs during the flyback.

The waveform of the difference frequency produced by mixing the input and output frequencies is illustrated in a typical case by Fig. 4(c). It will be seen that the waveform is a sine wave which has the frequency of the modulating sawtooth. The sine wave is smooth except for the small discontinuity which corresponds to the flyback of the sawtooth. The discontinuity in Fig. 4(c) is somewhat larger than the typical case for a sawtooth of 50 kc. Other investigators[3] have reported successful modulation using sawtooth frequencies of 30 megacycles with a flyback time of 10%.

[2]Raymond C. Cummings, "The Serrodyne — A Single-Sideband Synchrodyne," 1955 WESCON, San Francisco, California.

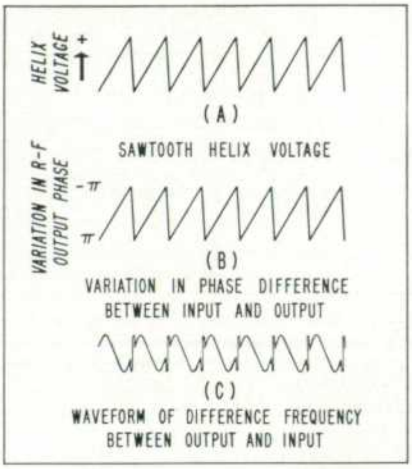

Fig. 4. *Sketch of sawtooth modulating voltage applied to helix and its effect on output of twt. Discontinuity in (c) caused by sawtooth flyback has been exaggerated for illustrative purposes.*

FREQUENCY MODULATION

The foregoing has described how a twt can be modulated to simulate an offset carrier for testing doppler radar velocity systems. For testing c-w radar ranging systems, however, it is necessary to have as a test signal an offset carrier which contains the

[3]loc. cit.

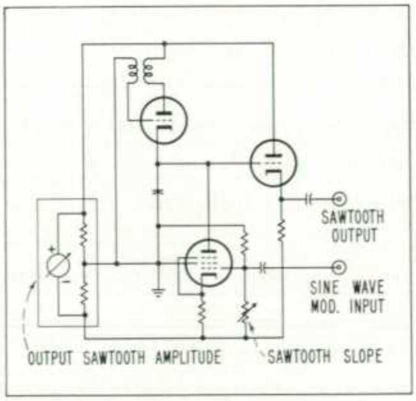

Fig. 5. *Circuit for generating proper modulating waveform to obtain frequency-modulated offset carrier from twt.*

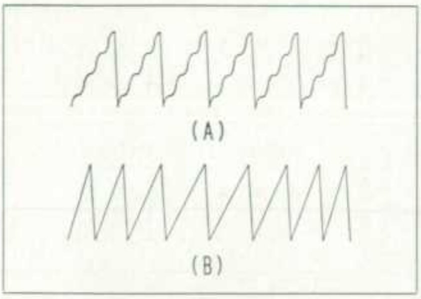

Fig. 6. *Modulating waveforms for obtaining frequency-modulated offset carrier. (a) shows case where f-m deviation rate is greater than carrier offset, (b) where deviation rate is less than carrier offset.*

same type of frequency modulation that the radar carrier contains. This type of signal can also be simulated through suitable twt modulation.

A frequency-modulated offset carrier can be obtained by helix-modulating the twt with the arrangement indicated in Fig. 5. Here the blocking oscillator rapidly charges a capacitor which is then linearly discharged by the pentode, thus producing a sawtooth voltage. The rate of discharge and thus the repetition frequency of the sawtooth is controlled by the pentode bias.

If the pentode grid is now excited with a sine wave of a frequency higher than the sawtooth frequency, the slope of the sawtooth will be modulated at the sine wave frequency. In a typical case the sawtooth will then appear as in Fig. 6(a).

When this slope-modulated sawtooth is applied to the helix of the twt, it will result in an offset carrier which differs from the helix r-f input by the repetition frequency of the sawtooth and which contains frequency excursions at the sine-wave frequency. The magnitude of the excursions is a function of the amplitude of the sine wave. Excursions of the order of several hundred kilocycles from the offset carrier frequency have been obtained.

It is not necessary that the sine-wave frequency be higher than the sawtooth frequency. The lower frequency limit is determined only by the time constants of the helix modulating amplifier. The time constants provided allow frequencies as low as 20 cps to be used. Fig. 6(b) shows how the modulating waveform appears on an oscilloscope when the sine-wave frequency is lower than the sawtooth frequency.

The waveform which can be used to slope-modulate the sawtooth is not limited to sine waves. Any arbitrary wave such as speech or combinations of pulses can be used.[4]

AMPLITUDE MODULATION

The modulating grid in the electron gun of the twt permits amplitude modulation of the r-f wave by common waveforms such as pulses, sine waves and square waves. The grid has a wide-band modulating characteristic, being essentially flat from d-c to about 100 megacycles and has response up to about 1,000 megacycles.

[4]Helix-modulation circuitry has also been incorporated in the -hp- 490A 2-4 kmc 10 mw twt amplifier described in previous article (footnote 1). Model number of this instrument is now 490B.

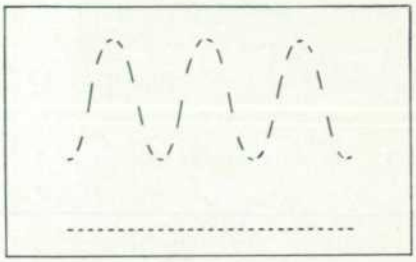

Fig. 7. *Twt modulating grid can be used to obtain combined pulse and sine-wave modulation as indicated by detected waveform shown above.*

Using the modulating grid, sine-wave modulation is possible, while pulse modulation can be obtained at on-off ratios of up to 40 db with a 50-volt modulating pulse. When the tube is pulse-modulated, the rise time of the r-f wave lies in the range from 5 to 20 millimicroseconds, depending on the on-off ratio used. Higher on-off ratios generally give longer rise times, although if sufficient r-f drive is used to saturate the amplifier, the rise time can still be kept in the order of 5 millimicroseconds.

The delay introduced in the r-f path by the twt is approximately 20 to 50 millimicroseconds. This includes transit time delay in the helix and 5-10 millimicroseconds transmission time for the input and output cables.

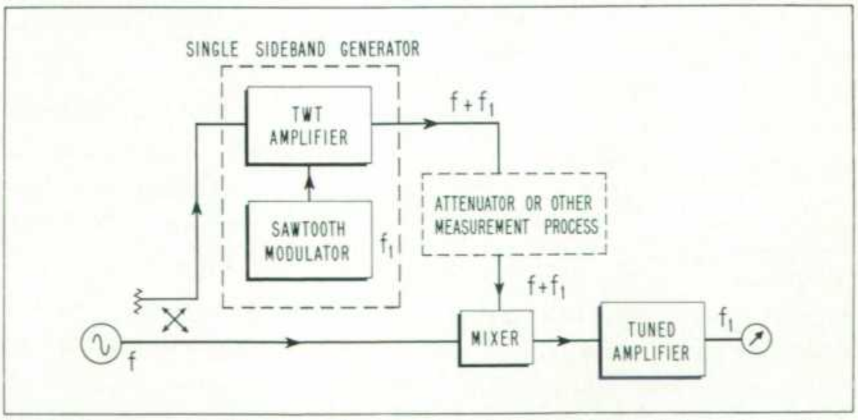

Fig. 8. *Arrangement using twt and sawtooth modulator to form high-sensitivity linear homodyne detector for microwave signals.*

SINE AND PULSE MODULATION

Another useful signal which can be generated with the twt is a combined sine and pulse-modulated r-f wave. Such a wave is useful in tests where antenna lobing and similar effects are to be simulated.

To generate this waveform, the pulse and sine wave can be simultaneously applied to the modulating grid while an r-f wave of the desired frequency is applied to the helix. This arrangement will result in an r-f wave such as that indicated by the detected waveform in Fig. 7.

LINEAR DETECTION

By using the arrangement described previously for obtaining an offset carrier, it is possible to use the twt to form a linear homodyne detector arrangement which will extend the dynamic range of detectors in decibels by a factor of 2:1. Instead of the 40 db range obtainable with a conventional square law detector, therefore, ranges in the order of 80 db are obtainable with the linear arrangement. Such a linear detector is of considerable value in such applications as calibrating attenuators, increasing the range of slotted line detectors, etc.

Fig. 8 indicates how the twt can be arranged to form such a linear detector. A c-w signal is applied to the twt input for amplification. At the same time the twt is helix-modulated to produce an offset carrier as discussed previously.

The twt output is then applied to the device or system under investigation that produces the low-level output. This output is combined in a crystal mixer with a strong sample of the original c-w signal. The strong signal causes linear operation of the crystal so that a difference frequency output is provided in proportion to the level of the weak signal. This difference frequency will be equal to the sawtooth modulating frequency and can be applied to a high-gain amplifier such as a vswr amplifier to operate an indicator. When the vswr amplifier is calibrated to be used with square-law detectors, as most such amplifiers are, the db readings on the vswr indicator must be doubled in this usage.

—Peter D. Lacy and Geo. W. C. Mathers

CORRECTION

In the first column of the back page of the December, 1955 issue (Vol. 7, No. 4), the phrase "11% or 1 db" in the third line of the next to last paragraph should read "11% or ½ db."

Last sentence of paragraph should begin "One-half db should be added. . . ."

SPECIFICATIONS
-hp-
TRAVELING-WAVE TUBE AMPLIFIERS

	MODEL 492A	MODEL 494A
FREQUENCY RANGE:	4 kmc to 8 kmc.	7 kmc to 12.4 kmc.
GAIN:	30 db minimum.	25 db minimum.
OUTPUT POWER:	10 milliwatts minimum into 50-ohm load.	5 milliwatts minimum into 50-ohm load.
NOISE FIGURE:	Less than 25 db.	Less than 25 db.
PULSE RISE & DECAY TIME:	Approx. 15 millimicroseconds.	Approx. 15 millimicroseconds.
MODULATED PULSE DELAY:	Approx. 20 millimicroseconds.	Approx. 15 millimicroseconds.
GRID MODULATING VOLTAGE:	Approx. 50 volt peak positive pulse will produce a 40 db change in r-f power level. Sensitivity, approx. 1 db/volt.	Approx. 50 volt peak positive pulse will produce a 40 db change in r-f power level. Sensitivity, approx. 1 db/ volt.
HELIX MODULATING VOLTAGE:	Approx. 30 volts peak to peak provides 360° phase shift. Input impedance 100 K ohms.	Approx. 30 volts peak to peak provides 360° phase shift. Input impedance 100 K ohms.
HUM & SPURIOUS MODULATION:	At least 30 db below signal level.	At least 30 db below signal level.
ADJUSTMENTS PROVIDED:	Grid Bias. Helix Voltage.	Grid Bias. Helix Voltage.
METER MONITORS:	Cathode Current. Anode Current. Helix Current. Collector Current.	Cathode Current. Anode Current. Helix Current. Collector Current.
INPUT IMPEDANCE:	50-ohms, SWR less than 2.	50-ohms, SWR less than 2.
OUTPUT INTERNAL IMPEDANCE:	50-ohms, SWR less than 3.	50-ohms, SWR less than 3.
CONNECTORS, RF INPUT & OUTPUT: *MODULATION INPUT:*	Type N. BNC.	Type N. BNC.
SIZE:	7" wide, 10¾" high, 18" deep.	7" wide, 10¾" high, 18" deep.
WEIGHT, APPROXIMATELY:	55 lbs. net, 95 lbs. packed.	55 lbs. net, 95 lbs. packed.
POWER SUPPLY:	115 volts ±10%, 50-60 cps, approx. 175 watts.	115 volts ±10%, 50-60 cps, approx. 175 watts.
TRAVELING-WAVE TUBE:	Huggins Laboratories HA-3B.	Huggins Laboratories HA-4.
ACCESSORIES FURNISHED:	*-hp-* Power Cord (812-68).	*-hp-* Power Cord (812-68).
REPLACEMENT TUBE PRICE, INCLUDING CAPSULATION:	$750.00, less $125.00 credit for return of defective tube and capsule. Specify *-hp-* 492A-73A.	$750.00, less $125.00 credit for return of defective tube and capsule. Specify *-hp-* 494A-73A.
PRICE, TRAVELING-WAVE TUBE AMPLIFIER, COMPLETE, INCLUDING CAPSULATED TUBE:	$1,500.00.	$1,500.00.

All prices f.o.b. Palo Alto, California
Data subject to change without notice