APPLICATION NOTE

APPLICATION NOTE 10

MICROWAVE SPECTRUM SYNTHESIS WITH THE TRAVELING-WAVE TUBE

Peter D. Lacy
Hewlett-Packard Company
Palo Alto, California

Summary

Of the many ways of providing the microwave modulations necessary for spectrum synthesis, none of the other devices offer in just a few units the ability of the traveling-wave tube to provide almost unlimited modulation capabilities throughout the most-used portion of the microwave spectrum. The versatility provided by broad bandwidth and the flexibility of modulation give the traveling-wave tube great potential.

Introduction

More and more use is continually being made of the microwave spectrum. Radar, for example, has been expanded from military use to use in commercial aeronautical and maritime navigation. Microwaves are also being used in long-distance relay chains as well as being studied for non-radiative uses in microwave spectroscopy and the transformation of video techniques and functions to the microwave domain. Transforming video techniques to the microwave domain is especially attractive since it would increase bandwidths from the tens or hundreds of megacycles now possible to thousands of megacycles. This practice would increase by one to two orders of magnitude the resolution and speed of basic physical measurements, electronic measurements, communications, and computation.

Many of the new uses for microwave require generating signals for test purposes. It is the purpose of this paper to show how many of these special signals can be synthesized using the traveling-wave tube. Traveling-wave tubes are now becoming available that make it possible to employ the more sophisticated approach of a master oscillator-power amplifier system for synthesizing microwave signals. Use of the MOPA system makes it possible to obtain the inherent advantages of frequency stability and phase coherence in the signal produced.

Modulation Characteristics of the Traveling-Wave Tube

Fig. 1 represents schematically the electrodes of the traveling-wave tube. Typical potentials are shown for a 10-milliwatt S-band tube when the cathode is grounded. The grid and anode electrodes determine the current emerging from the electron gun of the tube. The electron velocity under the helix determines the operation as an amplifier and is controlled by the cathode-to-helix potential. At the far end of the helix the collector serves to collect the electron stream and is the least sensitive of all the electrodes in the operation of the tube.

Fig. 2 plots the RF Output signal amplitude and phase as a function of grid potential. In the tube illustrated here the grid is merely the beam-forming electrode adjacent to the cathode in a Pierce electron gun. The grid electrode control is thus far from optimum, but it does give certain useful modulation characteristics. The solid curve indicates the variation in RF Output amplitude with grid-cathode potential. For retarding potentials higher than those shown, the characteristic is exponential. Near zero bias there is a region of linear output vs. grid potential. The dashed curve indicates the change of RF Output phase with grid potential. Approximately a 10 db output amplitude variation results in approximately a quarter of a cycle of RF phase shift. Both the RF amplitude and phase are thus steep functions of the grid-to-cathode potentials.

Fig. 3 shows the effect of cathode-to-helix potential on the RF Output amplitude and phase. In the region of optimum helix voltage there is only a second order variation of the output amplitude with helix voltage. RF phase output, however, varies linearly with helix-to-cathode potential. This phase characteristic is more favorable for phase modulation than is the grid characteristic for pure amplitude modulation.

The traveling-wave tube referred to has an RF amplification band extending from 2000 to 4000 megacycles which is typical of traveling-wave tube performance for low level tubes using the helix circuit. This large RF bandwidth means that the amplitude modulation bandwidth will be limited primarily by the effort expended in constructing the input circuit of the driver. Grid modulation bandwidths of one or two hundred megacycles can easily be obtained. For phase modulation the dispersive transmission line characteristic of the helix limits the modulation bandwidth to a smaller value than for grid modulation. As an alternative, the entire electron gun may be modulated relative to the helix.

Pulse modulation

Fig. 4 shows pulse oscillograms obtained by modulating the cathode-to-grid potential. Oscillogram B shows some deterioration of pulse

COMPLETE COVERAGE IN
ELECTRONIC MEASURING EQUIPMENT

HEWLETT-PACKARD COMPANY
1501 PAGE MILL ROAD
PALO ALTO, CALIFORNIA, U.S.A.
CABLE: "HEWPACK" DAVENPORT 6-7000

RUE DU VIEUX BILLARD NO. 1
GENEVA, SWITZERLAND
CABLE: "HEWPACKSA" TEL. NO. (022) 26.43.36

PRINTED IN U.S.A.

rise time caused by electron beam-helix interaction in the video frequency domain. Oscillograms A and C do show, however, that rise times of a few millimicroseconds have been obtained under restricted conditions. A recent paper by Beck[1] describes another method of producing millimicrosecond duration pulses by sweeping the helix voltage through a region of amplification by a steep wave front and then using the grid to blank the tube during the return wave.

Phase modulation

Phase modulation of the traveling-wave tube is accomplished by varying the electron velocity through the helix. Phase modulation ranges are limited to about 1 r-f cycle. A basic new method, termed the serrodyne, which is applicable to the traveling-wave tube has been introduced for obtaining frequency offsets through the use of piece-wise continuous phase shift with phase jumps in the opposite direction of an integral number of cycles of the carrier signal.

Fig. 5 illustrates the serrodyne phase modulation. The sawtooth waveform displaces the output signal of the traveling-wave tube to a frequency higher than the incoming c-w signal. This procedure can be generalized to provide frequency or phase modulation with unlimited phase deviation corresponding to arbitrary input signals.

Fig. 6 shows some slope-modulated sawtooth waveforms. In both cases the sawtooth slope is negative with an average rate of 250 kilocycles. The upper oscillogram shows the effect of slope modulation at a rate higher than the average sawtooth rate. The lower shows the effect of slope modulation at a rate lower than the sawtooth.

The fly-back time in the sawtooth illustrated is approximately one-tenth of a microsecond. This can be used as a criterion of the modulation bandwidth available with such a sawtooth generator. A 3-db point would be reached when half of the time of the sawtooth waveform is occupied in fly-back. This would give a bandwidth of 10 megacycles. With further effort on circuit development it could be expected to reduce fly-back time and also to provide sawtooth waveforms with both positive and negative slopes. This would allow frequency deviations in both directions from the original carrier.

Fig. 7 illustrates a modulation function which combines both amplitude and phase modulation. This is a method of producing suppressed carrier modulation. A modulating sine-wave is first full-wave rectified and then applied to the grid of the traveling-wave tube to produce amplitude modulation. The original sine wave is also formed into a square wave which is applied as phase modulation on the helix. The peak-to-peak phase shift is one-half cycle -- giving the necessary phase inversion characteristic of suppressed carrier modulation between half cycles of the modulating wave. There will be attendant phase modulation when the grid is modulated, but first order correction can be made by applying a certain portion of amplitude modulation signal to the helix to give phase correction.

Any type of spectrum can be obtained by appropriately combining amplitude and phase modulation -- subject to the bandwidth limitations of the amplifier and its modulation elements. The traveling-wave tube with its amplitude and phase modulation capabilities is thus a powerful tool for the synthesis of any type of microwave spectral distribution. The modulation capabilities of the traveling-wave tube can be applied directly to microwave systems. We shall confine our attention here, however, to the use of the traveling-wave tube in the generation of signals and small spectral displacements that are useful in the testing of radar and navigational systems.[2]

Spectra for Radar Testing

The use of the traveling-wave tube for two types of microwave spectrum synthesis will be considered. Fig. 8 shows a traveling-wave tube as a modulated amplifier in a MOPA microwave signal generator. The traveling-wave tube is shown with three general types of modulation: pulse, amplitude and phase or frequency modulation. These modulation types can be applied singly or in any combination.

Another basic function of the traveling-wave tube is the generation of slight phase or frequency displacements. Some examples of the use of this function in radar testing will be discussed later. Fig. 9 shows a block diagram of the traveling-wave tube arranged to produce such spectral displacements.

We will now discuss the use of these

[1] "Waveguide Investigations with Millimicrosecond Pulses" by A.C. Beck, B.S.T.J. Vol. 35 No. 1 January 1956.

[2] Radar System Engineering, edited by L.N. Ridenour, McGraw-Hill 1947.

methods in testing various information-gathering functions of radar systems. Fig. 10 shows various radar range methods and the characteristic of traveling-wave tube test-signal generation. The first method is that of pulse radar. For this type of system the traveling-wave tube offers fast, jitter-free rise time of the generated test pulse.

The next method is the frequency-modulation radar technique and in this case the traveling-wave tube can be used to produce small spectral displacements. Arbitrary frequency displacements of the c-w transmitter signal can be generated to accurately simulate the return echo signals. By generating the proper sawtooth type phase modulation, known frequency displacement of the transmitter signal can be performed to realistically produce signals corresponding to distant echoes.

Another method of obtaining radar range information is the use of multiple single-frequency c-w sources. To test this type of system each single frequency must be handled separately by a separate traveling-wave tube modulation channel. The necessary frequency displacement can be performed from the individual channels to provide both the range and the radial velocity signals that are present in the target echo signal.

Consider next the radar angle determination function. Usually, the approximate direction of the illuminated target is determined by the main lobe of the radar antenna. More accurate angular determination requires resolution within the main lobe. In Fig. 11, the basic method of improving angle resolution is that of antenna lobing. This produces amplitude modulation of any outgoing signal. This lobing modulation can be accomplished simultaneously with either the pulse or frequency modulation displacements that are necessary for a range test. Another method of angle determination is the comparison of the incoming phase at two separated antennas. This method was described in the paper [3] by Dr. Page on the Mono-Pulse Radar System presented at the IRE convention last year. Usually, comparing the incoming phase only requires power splitting and producing a relative phase shift of known amount to supply pairs of test signals to the antenna inputs. This can be accomplished with passive devices except for systems subject to fast bearing changes. In that case, the traveling-wave tube can be used to accomplish such fast changes.

Another function of some radar systems is the determination of radial velocity or the discrimination against non-moving targets. Fig. 12 lists two methods of accomplishing this function. The method of video subtraction on pulse radar systems requires only a varying position of successive pulses. This is usually accomplished by a time-varying delay for the pulse generator. As a further refinement the target echo can be amplitude-modulated to simulate target echo fluctuation simultaneously with the changing pulse position. The other method is that of the frequency displacement of moving targets. The doppler frequency shift can be generated by the serrodyne phase modulation method simultaneously with any other modulation required to test the radar system.

Other radar systems incorporate various further types of modulation for communication or identification purposes. With the availability of pulse-amplitude, phase or frequency modulation characteristics in the traveling-wave tube, however, any such additional modulations can easily be included. Another function that can also be performed by the traveling-wave tube signal generator is that of phase or amplitude fluctuations to realistically test these effects on the performance of the radar system.

Comparison of the traveling-wave tube with other microwave modulators

There are many alternative ways of providing the microwave modulations necessary for spectrum synthesis. Space-charge-control vacuum tubes can be used in the frequency ranges in which they are available as amplitude modulators and in frequency-modulation systems of the Armstrong type. The associated r-f circuits are tuned, however, and thus restrict bandwidth. In addition, each of the modulation functions requires a special circuit configuration.

Other velocity modulation vacuum tube amplifiers include the klystron, the backward-wave amplifier, and the resistance-wall amplifier. All of these tubes can be both amplitude and phase-modulated. The klystron's useful frequency-range is restricted by the narrow-band tuned circuits associated with it. The backward wave amplifier is voltage-tunable but can operate only as a narrow-band amplifier although over a wide frequency band. The resistance wall amplifier is

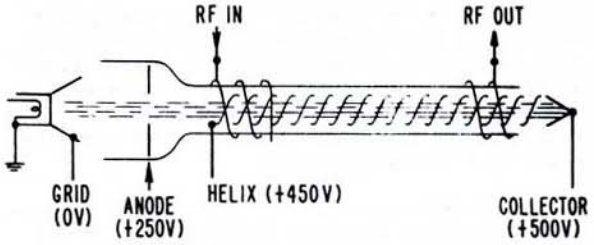
[3] "Monopulse Radar" by R. M. Page, IRE Conv. Record. Part 8, 1955.

broadband and its phase modulation characteristic is even better than the traveling-wave tube. Its gain and efficiency are lower than the traveling-wave tube, however. In any case, its principal determent as a signal modulator is a lack of commercially-available tubes.

Gas discharge tubes can be used as amplitude or phase modulators, but the modulation bandwidth of these tubes is severely restricted by the de-ionization time limitations of the gas discharge.

Silicon or germanium crystal diodes can be used to provide amplitude or frequency modulation when used in appropriate microwave circuits, but presently available crystals suffer from excess reactance which often results in extremely frequency-sensitive configurations. Crystals do have the advantage of providing inexpensive modulators throughout the microwave spectrum.

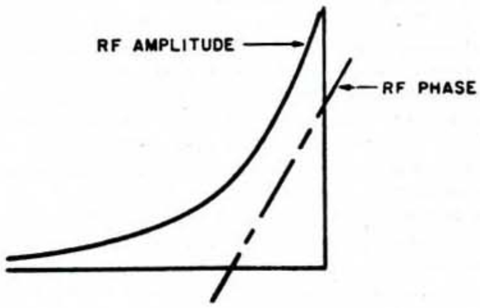
Ferrites can provide amplitude or frequency modulation, but the various functions require different physical arrangements and broadband operation presents design problems. Ferrites' main limitation, however, is the power required to obtain high modulation rates.



(TYPICAL POTENTIALS FOR A 10MW "S" BAND TUBE)

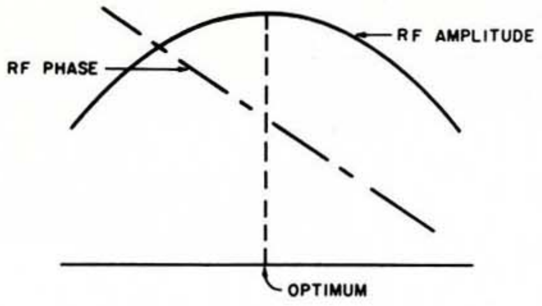
TRAVELING-WAVE TUBE ELECTRODES

Figure 1.



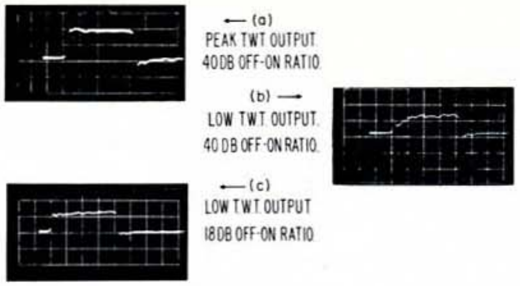
RF OUTPUT VS. GRID VOLTAGE

Figure 2.



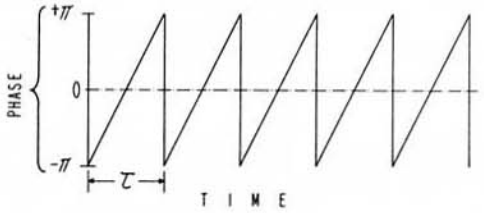
RF OUTPUT VS. HELIX VOLTAGE

Figure 3.



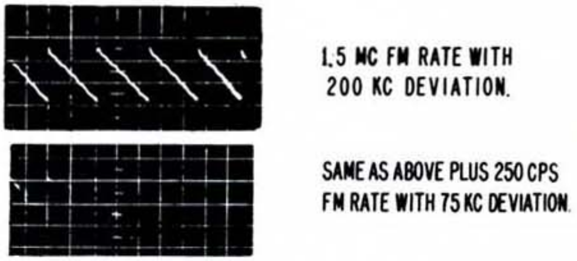
10 MW, 2-4 KMC T.W.T. DETECTED PULSE OSCILLOGRAMS
(SWEEP 20 MμSEC DIV.)

Figure 4.



SAW TOOTH PHASE MODULATION

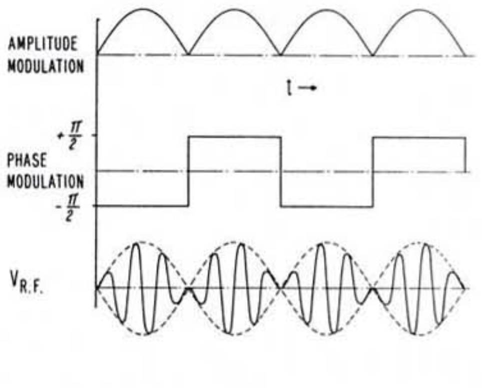
Figure 5.



(TIME SCALE = 20 μ SEC TOTAL SWEEP)

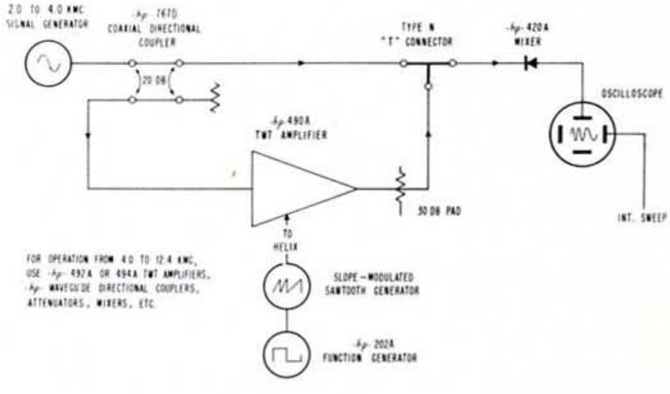
SLOPE-MODULATED SAWTOOTH WAVE

Figure 6.



SUPPRESSED CARRIER MODULATION

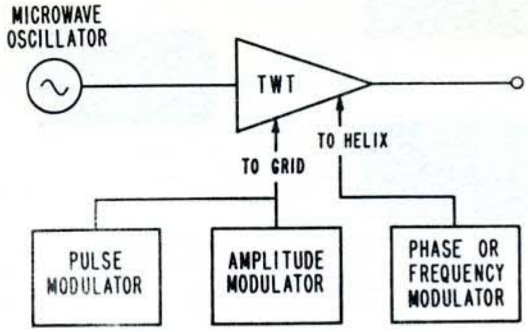
Figure 7.



FOR OPERATION FROM 4.0 TO 12.4 KMC, USE -hp- 492A OR 494A TWT AMPLIFIERS, -hp- WAVEGUIDE DIRECTIONAL COUPLERS, ATTENUATORS, MIXERS, ETC.

M.O.P.A. MICROWAVE FREQUENCY MODULATION SYSTEM

Figure 8.



MOPA MODULATED MICROWAVE GENERATOR

Figure 9.

RADAR METHOD	CHARACTERISTICS OF TWT TEST SIGNAL GENERATION
Pulse	Fast, jitter-free rise time.
FM	Arbitary frequency displacements of CW transmitter can be generated to accurately simulate field tests.
Multiple CW Sources	Range and radial velocity signals can be generated by individual signal modulations.

RADAR RANGE TEST SIGNALS

Figure 10.

METHOD	CHARACTERISTICS OF TWT SIGNAL GENERATION
Lobing	Lobing modulation can be accomplished simultaneously with pulse or frequency displacement modulation.
[illegible] Comparison (As in Monopulse)	Not required except for fast bearing change or phase angle measurement.

RADAR ANGLE TEST SIGNALS

Figure 11.

METHOD	CHARACTERISTICS OF TWT SIGNAL GENERATION
Video Subtraction (Pulse Radar)	Target echo amplitude flucuation can be generated simultaneously with changing positive pulse.
Doppler Frequency	Doppler frequency shift can be generated by serrodyne method simultaneously with any other modulations.

RADAR RADIAL VELOCITY TEST SIGNAL

Figure 12.