DOPPLER FREQUENCY SHIFT SIMULATION AT MICROWAVE FREQUENCIES USING TRAVELING WAVE TUBE AMPLIFIERS

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Considerable interest has been exhibited recently in the simulation of doppler frequency shift as a means of checking radar, navigational and other instrumentation systems. This memorandom details the circuit modifications required to adapt the Hewlett-Packard 490A Traveling Wave Tube Amplifier to such an application and presents some qualitative data on the use of traveling wave tube amplifiers in doppler frequency shift simulation.

I. Introduction

In a typical radar system, microwave pulses are transmitted from a source towards a target. A portion of the energy contained in the pulses impinge on the target and returns to the source. The time it takes for the pulses to make the round trip is measured and the distance from the source to the target computed as a function of one-half this time.

If, during the time the pulses are being emitted and returned, the target and the source are approaching or receding from each other, the frequency of the returning pulses will be shifted in direct proportion to the velocities involved. This phenomenum, known as doppler shift after the German mathematician who, in 1842, first observed its effect in relation to sound and light, is widely used in many instrumentation systems to determine velocities. The frequency shift is proportional to twice the relative velocity of the target and/or the source divided by the wavelength of the original transmitted pulse. If the velocity (v) and wavelength (λ) are measured in the same units and the doppler shift (F_d) measured in cps, the relation may be written:

$$F_d = \frac{2\,v}{\lambda} \qquad \text{or} \qquad v = \frac{F_d\,\lambda}{2}$$

The factor 2 is included to account for the rf wave round trip, since signals emitted from the source are reradiated from the target back to the source. Velocity may be determined in feet per second, miles per hour, mach number, or other convenient units. For example,

$$v\ (\text{in MPH}) = \frac{F_d\ (\text{in cps})}{3\ F_t\ (\text{in kmc})}$$

and,

$$v\ (\text{in mach number}) = \frac{F_d\ (\text{in kc})}{2.3\ F_t\ (\text{in kmc})}$$

In the above equations, the transmitted frequency (F_t), has been substituted for the less convenient terms of wavelength and in the last equation, velocity determined in terms of the speed of sound at standard temperature and pressure.

The need for a convenient method of checking measuring systems based on doppler frequency shift principles is obvious. Until recently, however, most frequency shift simulation systems have been based on mechanical principles. At best these systems are cumbersome, expensive and relatively inaccurate. However, since traveling wave tube amplifiers have become commercially available, a simple, accurate, relatively inexpensive electronic method of doppler frequency shift simulation is now possible.

II. Theory of Traveling Wave Tube Doppler Frequency Shift Simulation

Traveling Wave Tubes consist basically of an electron gun which projects a focused electron beam through a helically-wound coil to a collector electrode (see cutaway diagram, Figure 1). Focusing of the beam throughout the helix is preserved by a static magnetic axial field. If a wave is coupled into the gun end of the helix, it will interact with the electron beam in such a way as to provide an amplified wave at the collector end of the helix.

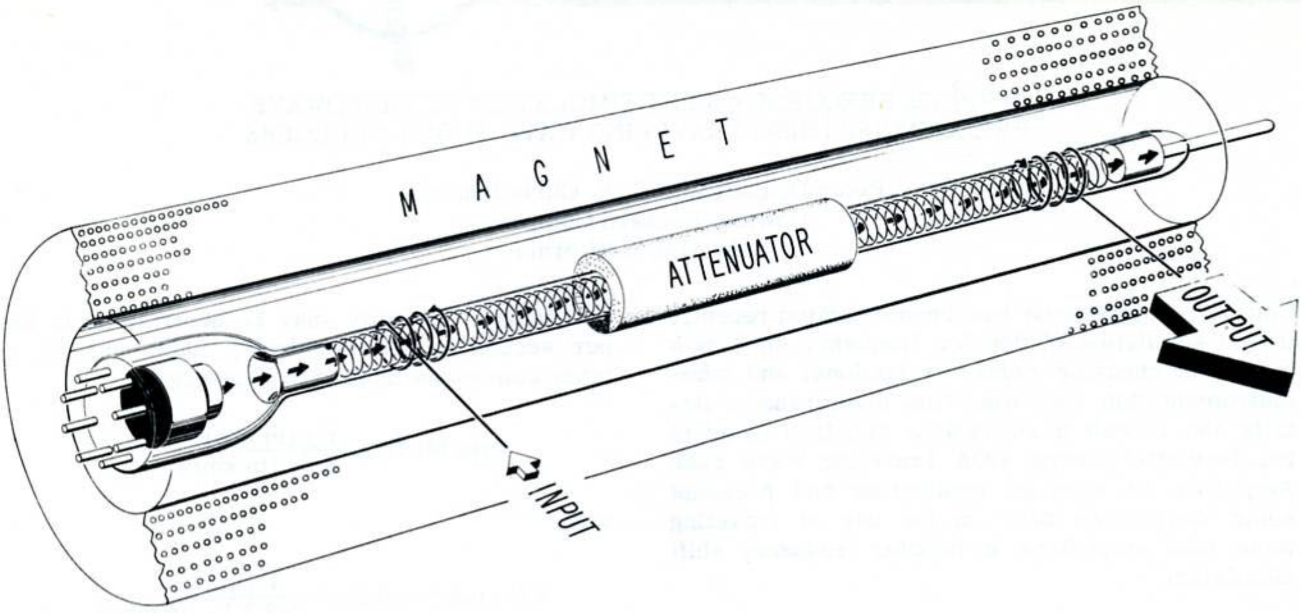


Figure 1. Traveling Wave Tube Amplifier, Assembly and Magnet Cut-Away View

The physical length of the helix is sufficiently large to represent some 50 or 60 wavelengths of the input frequency. Therefore, a relatively small percent change in helix voltage effects beam electron velocity sufficiently to produce a relatively large net output phase shift. Thus, the simple frequency offset involved in doppler frequency shift simulation will be produced if helix voltages are increased or decreased at a constant rate.

Sawtooth helix modulation offers a convenient way of providing this constant rate of change. Under such conditions, (Figure 2), the desired frequency shift f_1 is produced during the sweep. The undesired frequency shift f_2, produced during the flyback time, is of little concern in practical systems, since rapid flyback times produce sufficiently large, oppositely directed, frequency shifts to be rejected by the frequency shift measuring circuits. Moveover, the portion of power expended in flyback action is equal to the ratio of flyback time to the sawtooth period. In typical cases involving, say a 50 kc frequency shift, a one microsecond flyback time would consume 5% of the power; 95% of the power would appear in the desired 50 kc signal.

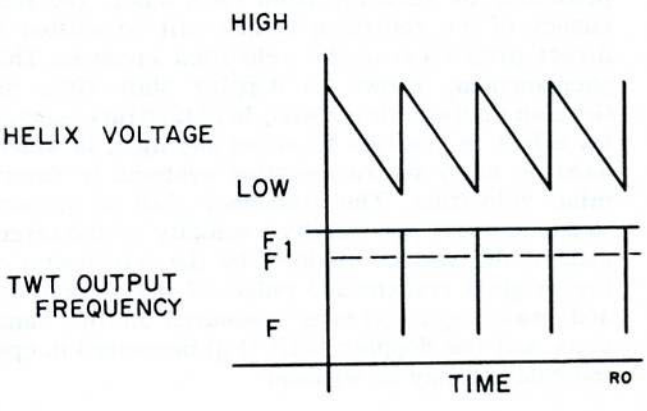


Figure 2. Traveling Wave Tube Frequency Shift Due to Sawtooth Helix Modulation

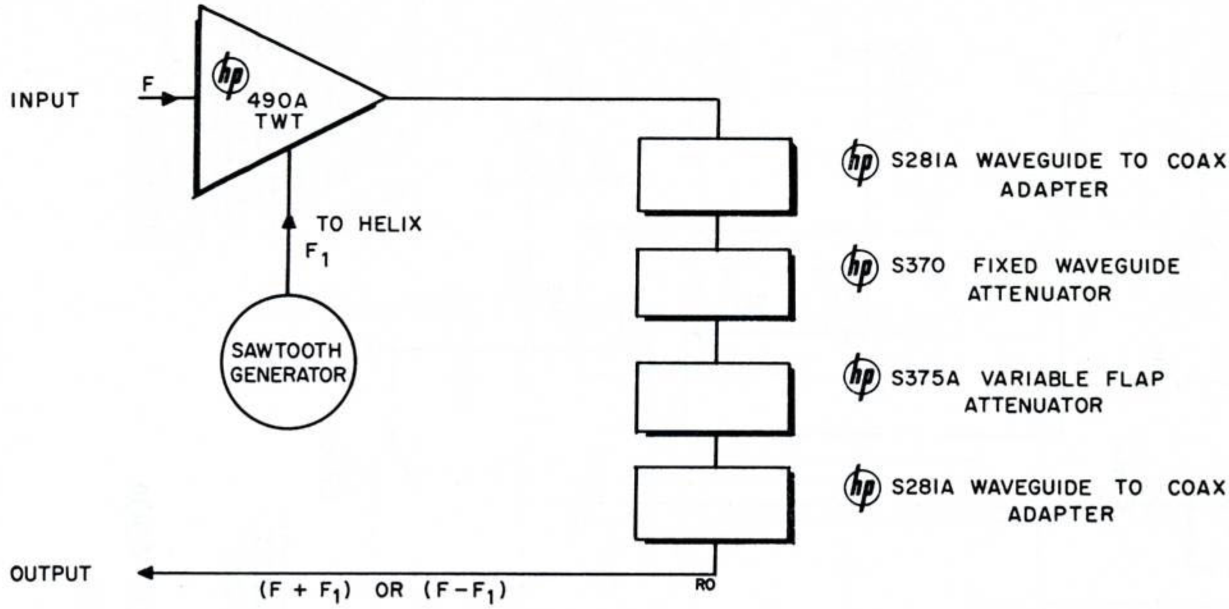


Figure 3. Two Port Doppler Frequency Shift Simulator

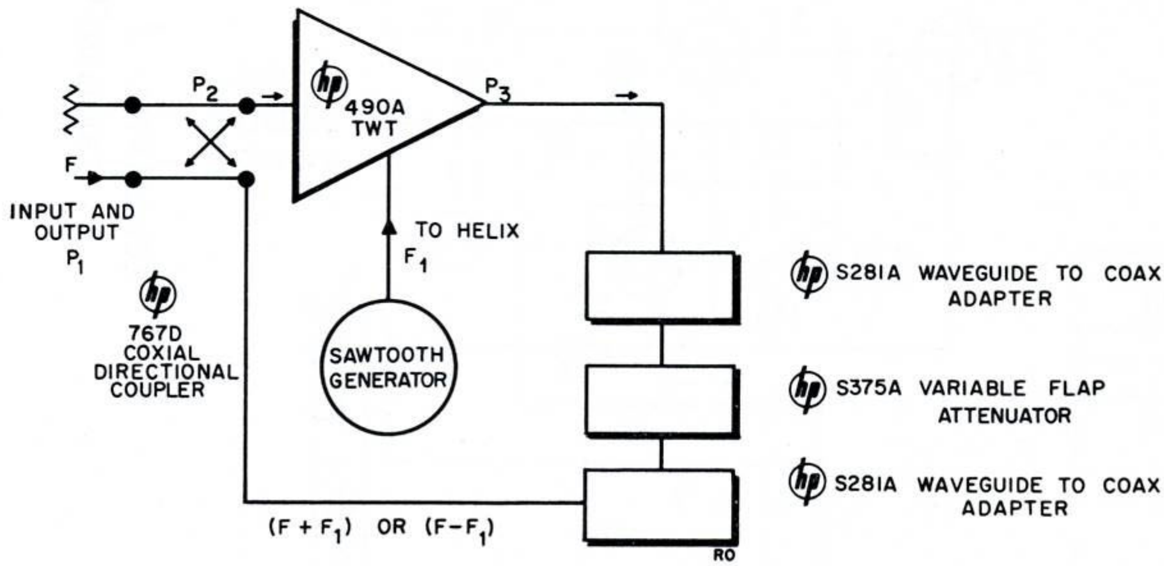
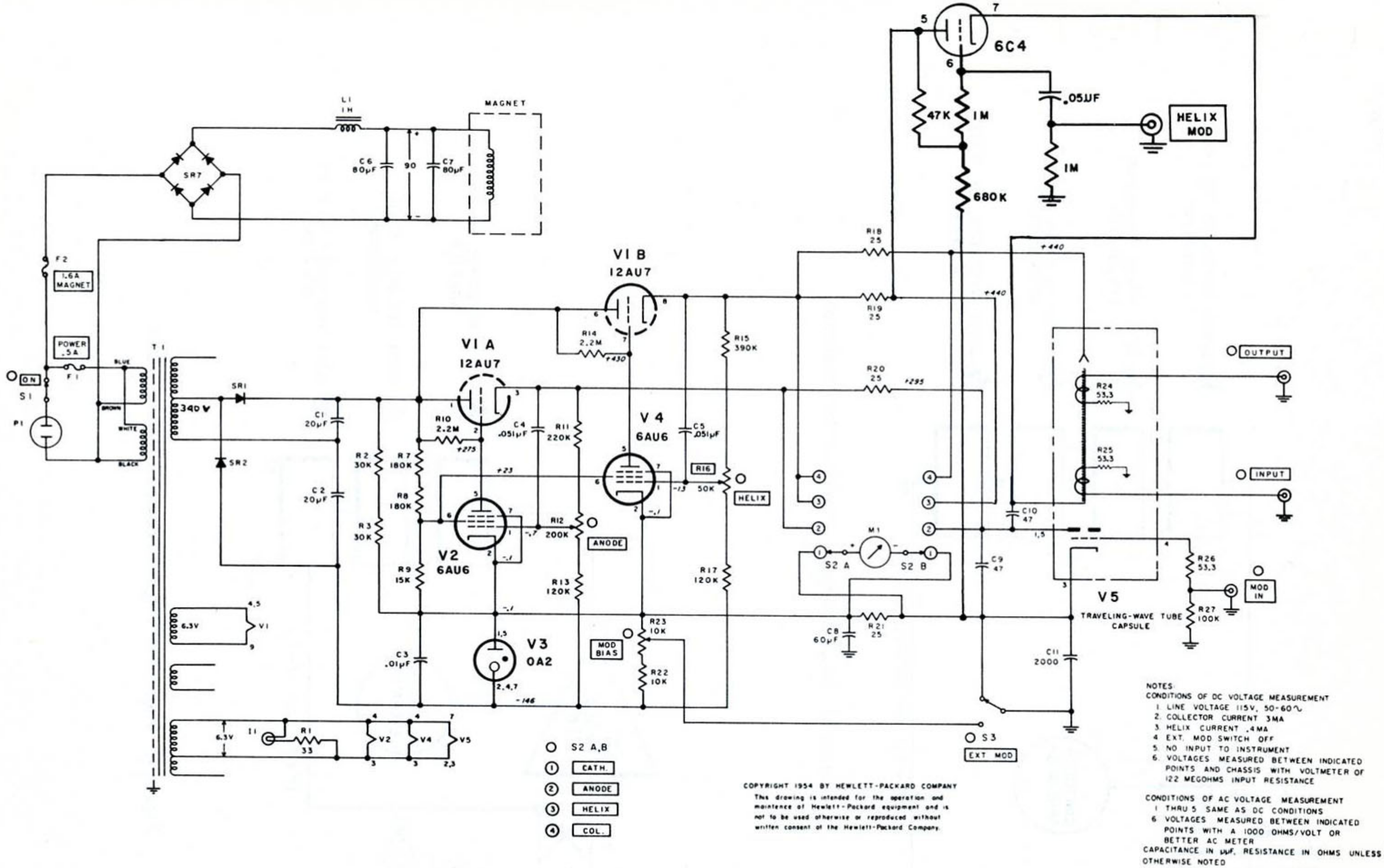


Figure 4. Single Port Doppler Frequency Shift Simulator



SCHEMATIC DIAGRAM OF MODEL 490A

TRAVELING-WAVE TUBE AMPLIFIER

Figure 5. Modified for use in Doppler Frequency Shift Simulation

III. Doppler Frequency Shift Simulation Using ⓗⓟ490A TWT Amplifiers

For two port doppler shift simulation, the ⓗⓟ490A and sawtooth generator are arranged as shown in Figure 3. For single port doppler shift simulation, a more common situation, the equipment is arranged as shown in Figure 4. In this case, the coupler loss and attenuator setting are arranged so that the power level P_4 is less than the input power level P_1. Under these conditions, the system is quite stable and will remain so unless P_4 becomes greater than P_1. If this situation occurs, regeneration or oscillation may result. In either single or two port simulation, radar system sensitivity can be tested, since return power can be attenuated to correspond to weak target reflections.

Several relatively minor modifications are required to adapt the Hewlett-Packard 490A to this purpose. These modifications are shown in Figure 5 and consist of:

1) Adding an additional tube to the helix voltage supply circuit.

2) Adding a front panel helix input jack.

3) Placing the helix voltage potentiometer on the front panel.

The additional tube operates as a cathode follower and offers a high input impedance to the modulating voltage and a low output impedance to the helix itself. Greater convenience is provided by the installation of the front panel jack and the relocation of the helix potentiometer.

After the modifications have been completed, a sawtooth sweep voltage is applied to the helix modulation input jack. This voltage may be obtained from the sweep output of an oscilloscope or from a special sawtooth sweep generator. If sawtooth voltages similar to those shown in Figure 6 (a) are applied output frequency will be increased. In a like manner, sawtooth voltages similar to those shown in Figure 6 (b) will cause a decrease in output frequency. In most practical applications, the direction of shift is not important and therefore either type sawtooth can be used. However, in applications where direction is important, a single tube phase inverter may be necessary to provide the desired sawtooth waveform polarity.

If the sawtooth voltage amplitude is adjusted to effect a 360° phase shift, one cycle of rf will be added or subtracted during each sawtooth, and the frequency shift in cps produced in the traveling wave tube output will be equal to the sawtooth repetition rate in cps. Sawtooth amplitude can be adjusted to effect this 360° phase shift by observing on an oscilloscope the beat frequency produced by the incoming and outgoing traveling wave tube signals when combined in a suitable mixer. Figure 7 (a) shows the scope indications when a 360° phase shift is obtained; Figure 7 (b) and Figure 7 (c) respectively show too much and too little sawtooth voltage amplitude.

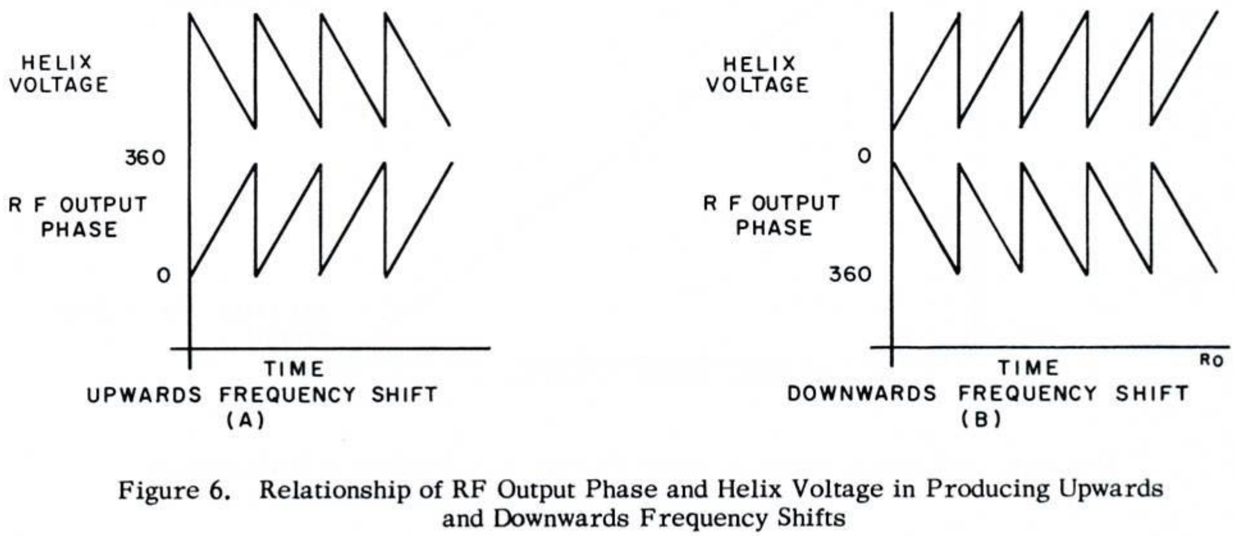


Figure 6. Relationship of RF Output Phase and Helix Voltage in Producing Upwards and Downwards Frequency Shifts

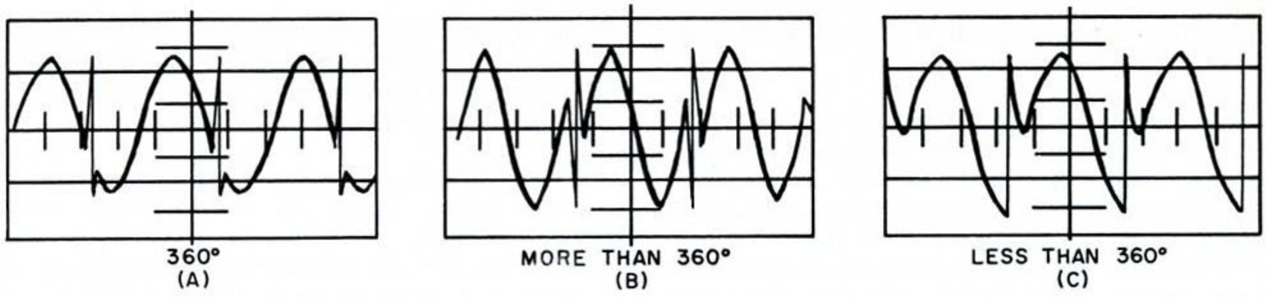


Figure 7. Sawtooth Phase Shift

IV. Miscellaneous Considerations.

a. Delay Time

The nominal delay time of the ⓗⓟ490A is about 20 millimicroseconds for the tube and 5 to 10 millimicroseconds for the associated cabling. In many applications, this delay will be of no consequence. However, in some applications, traveling wave tube delay times may have to be supplemented by the use of suitable delay lines.

b. Traveling Wave Tube Gain Stabilization

Although rf phase change is nearly a linear function of the helix voltage, traveling wave tube rf output levels tend to vary, being maximum at optimum helix voltage and diminishing on either side. This situation is shown graphically in Figure 8. In some measuring systems, rf level variations may be undesirable. In such cases, a simple feedback system may be used to stabilize rf output. This arrangement is shown in block form on Figure 9 (a); various voltage and phase relationships resulting from its use are indicated graphically on Figure 9 (b). It will be noted that this system is not wholly linear with respect to rf output phase. However, for many applications, the elimination of rf amplitude variation may outweigh the effect of phase characteristic distortion.

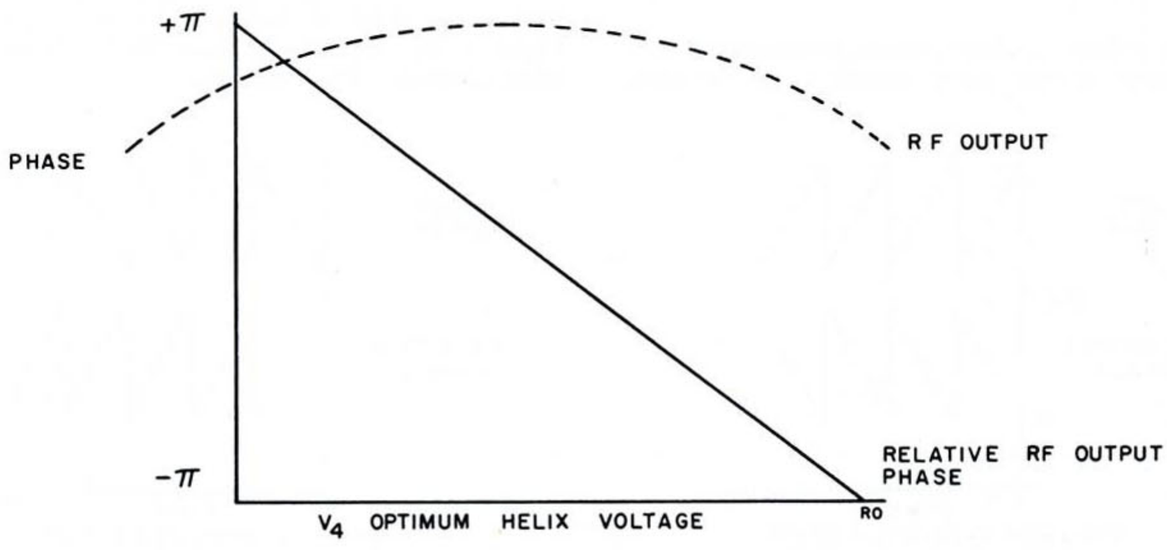


Figure 8. RF Output Phase and Level Changes as a Function of Helix Voltage Under Constant Beam Current Conditions

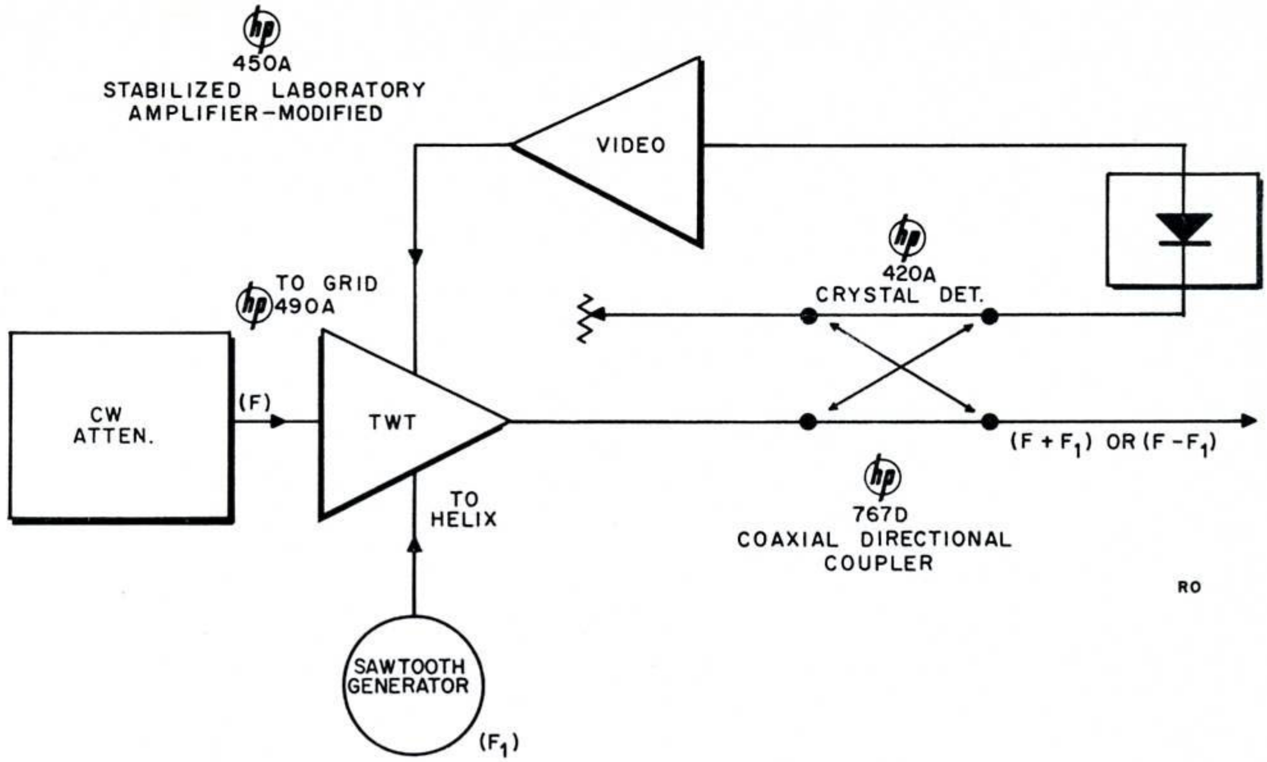


Figure 9(A). Block Diagram of TWT Gain Stabilization System

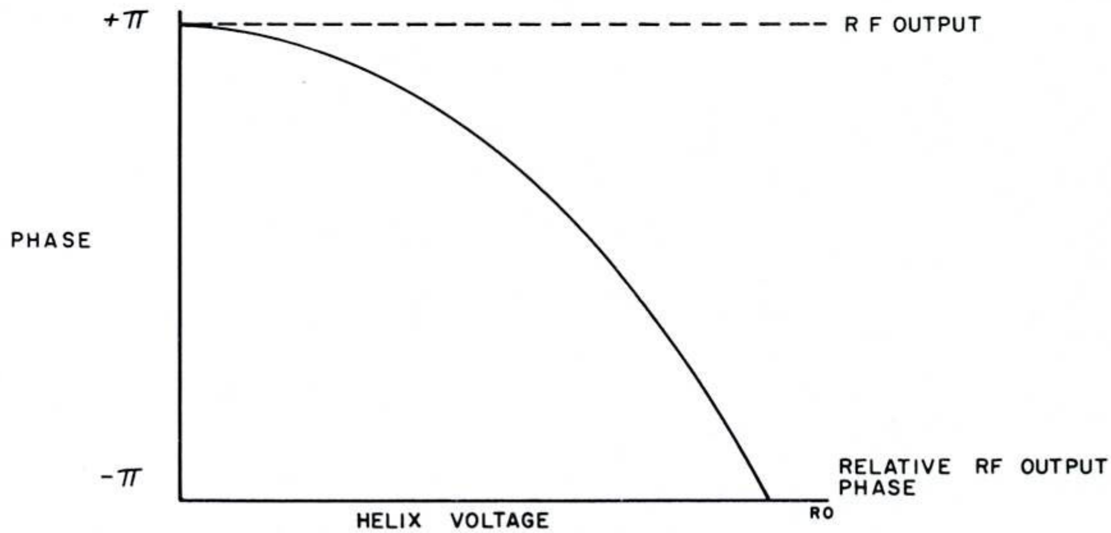


Figure 9(B). RF Output Phase Changes as a Function of Helix Voltage in a TWT Gain Stabilized System in Which Beam Current is Varied to Provide Constant RF Output.