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COINCIDENCE PHASE DETECTOR FOR SPECIAL CONTROL APPLICATIONS

by

Donald M. Waters, Donald P. Harris

and

Moody C. Thompson, Jr.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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PREFACE

This report describes a phase detector circuit capable of providing a large DC output voltage isolated from ground. The Circuit employs a gated beam vacuum tube or similar coincidence device to produce a carrier signal amplitude-modulated as a function of the relative phase shift between two input signals. The resulting carrier may be coupled across any desired DC potential, and then demodulated with a simple AM detector. Output voltages as high as 500 volts have been obtained with the circuit.

INTRODUCTION

In many servo-systems, including automatic frequency control and phase-locked oscillator control systems, the control signal appears as a phase modulated carrier. A phase detector is then used to develop the final control signal. In many applications it is desirable to retain the DC reference output voltage of the phase detector, and to apply it directly to a high impedance, high voltage control element, such as a klystron repeller.

A gated beam tube phase detector [1, 2] would be ideal for such applications except that its normal output voltage is tied directly to its anode and power supply. A DC connection from the tube to the controlled circuit may be unsatisfactory because of problems concerning DC isolation of the tube and its power supplies, and concerning adequate shielding and by-passing of high impedance control circuits. To overcome these problems and still make use of the simplicity and large output of the gated-beam tube, it may be followed by a DC blocking capacitor and an amplitude detector. In order to understand the resulting requirements and characteristics, an analysis of the normal operation of a coincidence phase detector will first be presented.

BACKGROUND

Gated-beam tubes such as the 6BN6 have been developed as phase detectors for use primarily in FM phase discriminators.[3] As phase detectors they offer the advantage of a linear characteristic of average output voltage vs. input phase.

In FM discriminator circuits the 6BN6 makes use of electron coupling inside the tube to excite a resonant circuit that translates frequency deviation into relative phase deviation. In most other phase detector applications the tube may be simply regarded as an A + B switch (see Fig. 1). The control grids are normally biased so that a positive voltage is required on both grids to complete the circuit. The same sort of linear phase detector action may be obtained with any sort of element that can provide an A + B switch control circuit. Conventional relays could be used, or diode switches, as shown in Fig. 2, to build a linear phase detector. The input signals are first heavily clipped, then added; the negative pulse corresponding to "neither A nor B" is then clipped off to give the

OPERATION OF GATED BEAM TUBE

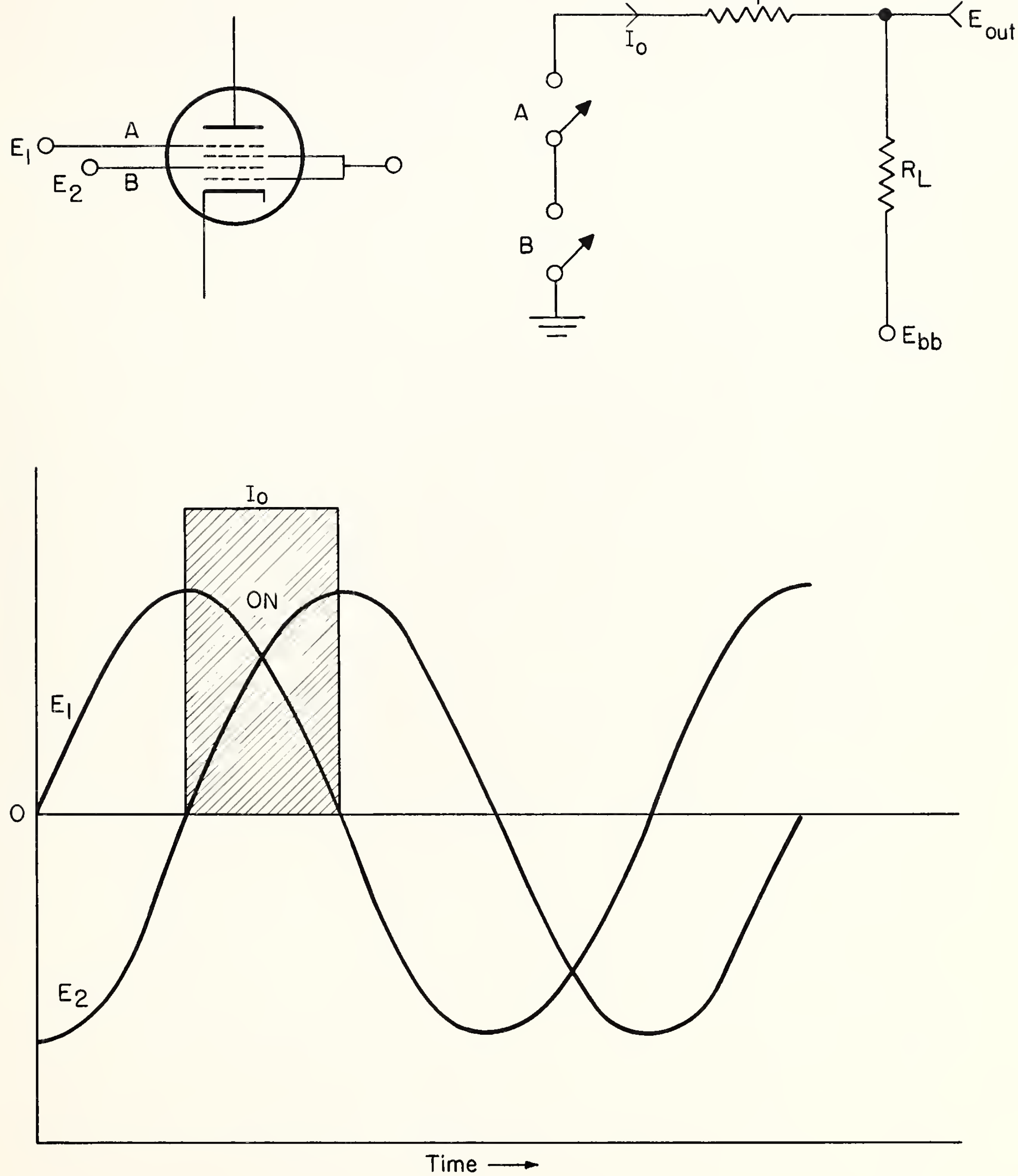


Figure I

LINEAR PHASE DETECTOR USING DIODE SWITCHES

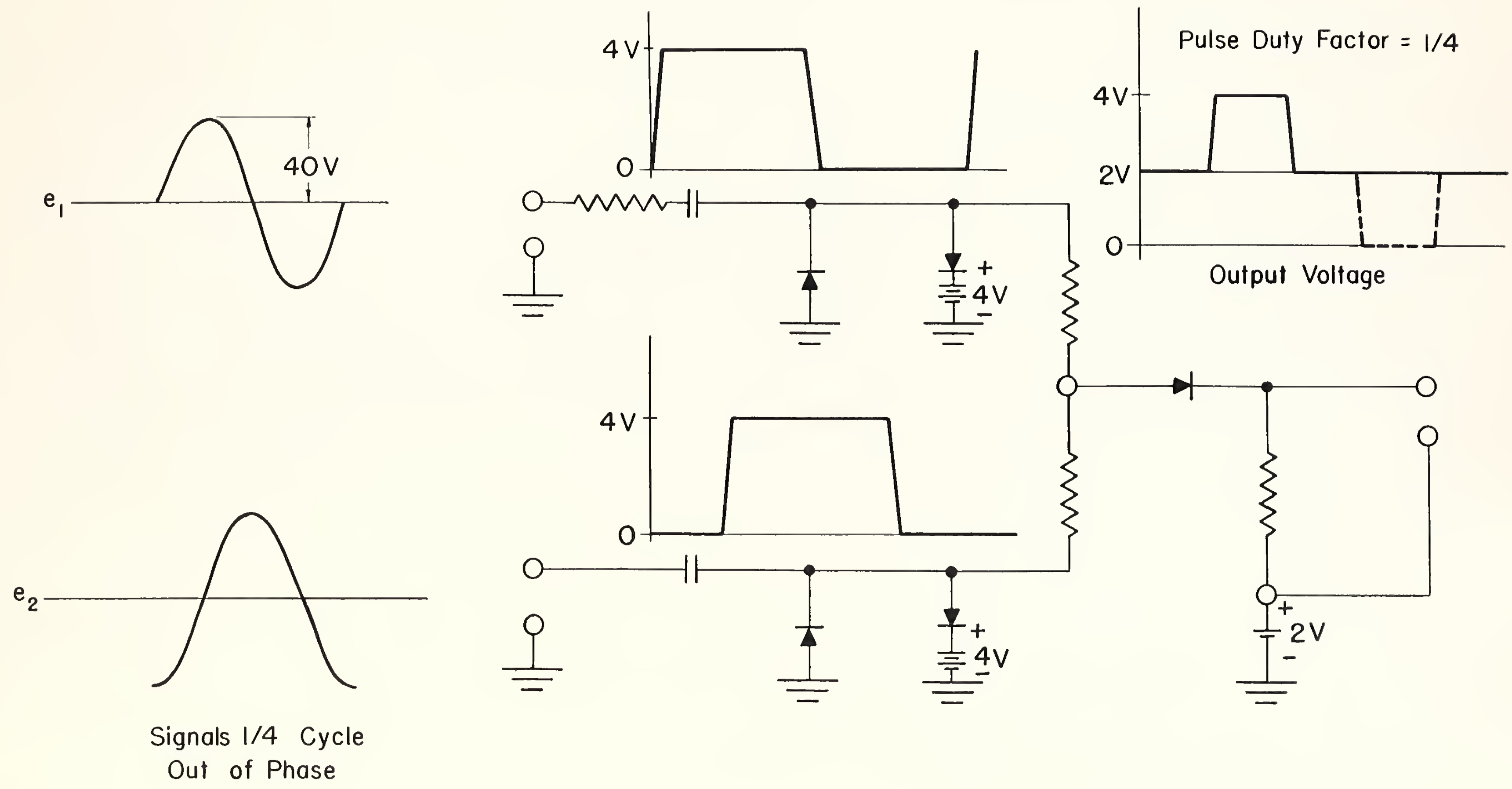
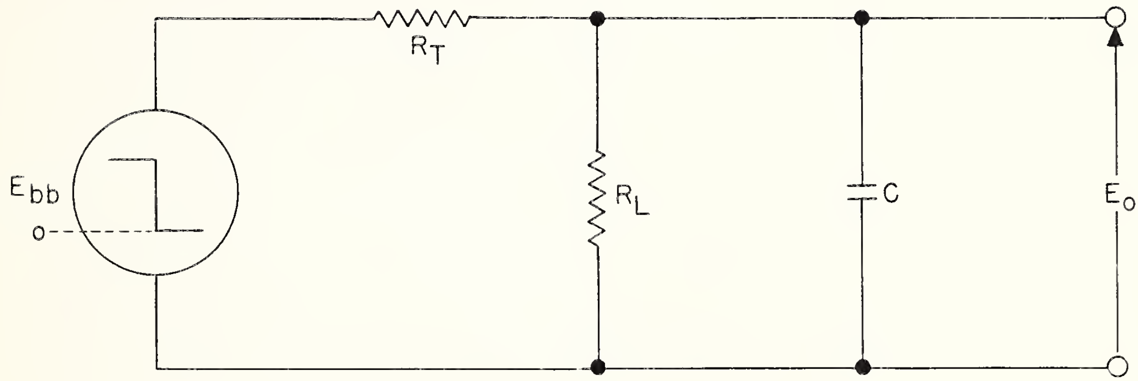
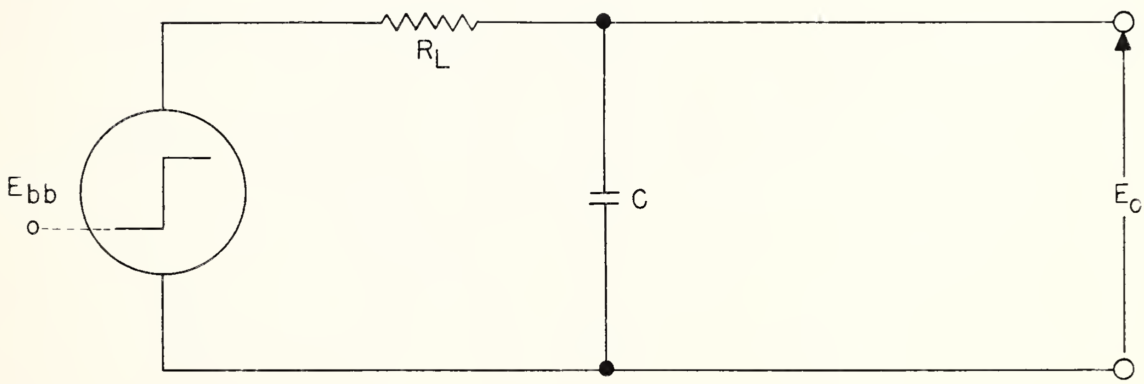


Figure 2

EQUIVALENT OUTPUT CIRCUITS OF 6BN6 PHASE DETECTOR



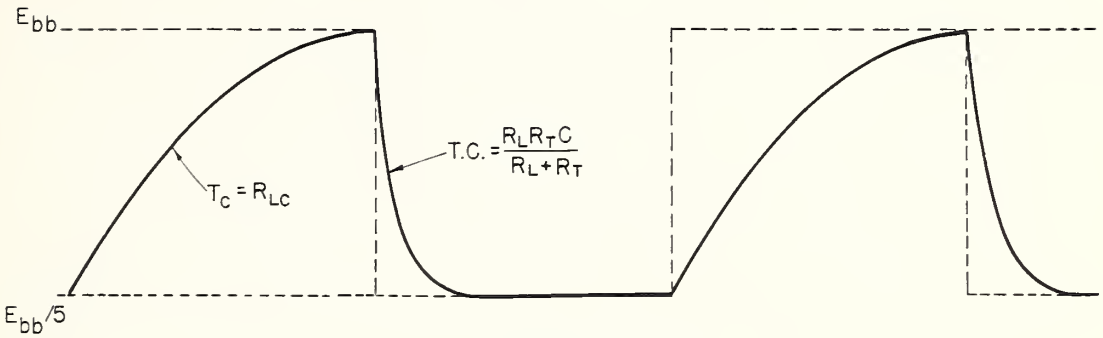
Negative Going Pulse



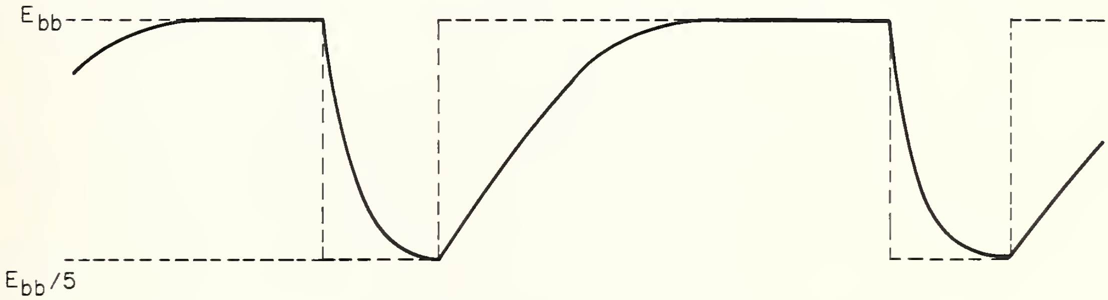
Positive Going Pulse

Figure 3

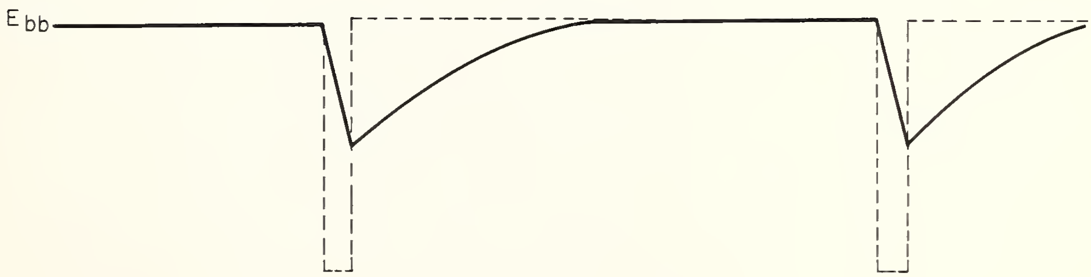
OUTPUT VOLTAGE WAVEFORMS OF 6BN6 PHASE DETETECTOR



E_1 and E_2 in Phase



E_1 and E_2 90° out of Phase



E and E 160° out of Phase

Figure 4

GATED BEAM PHASE DETECTOR WITH ISOLATED OUTPUT PEAK DETECTOR

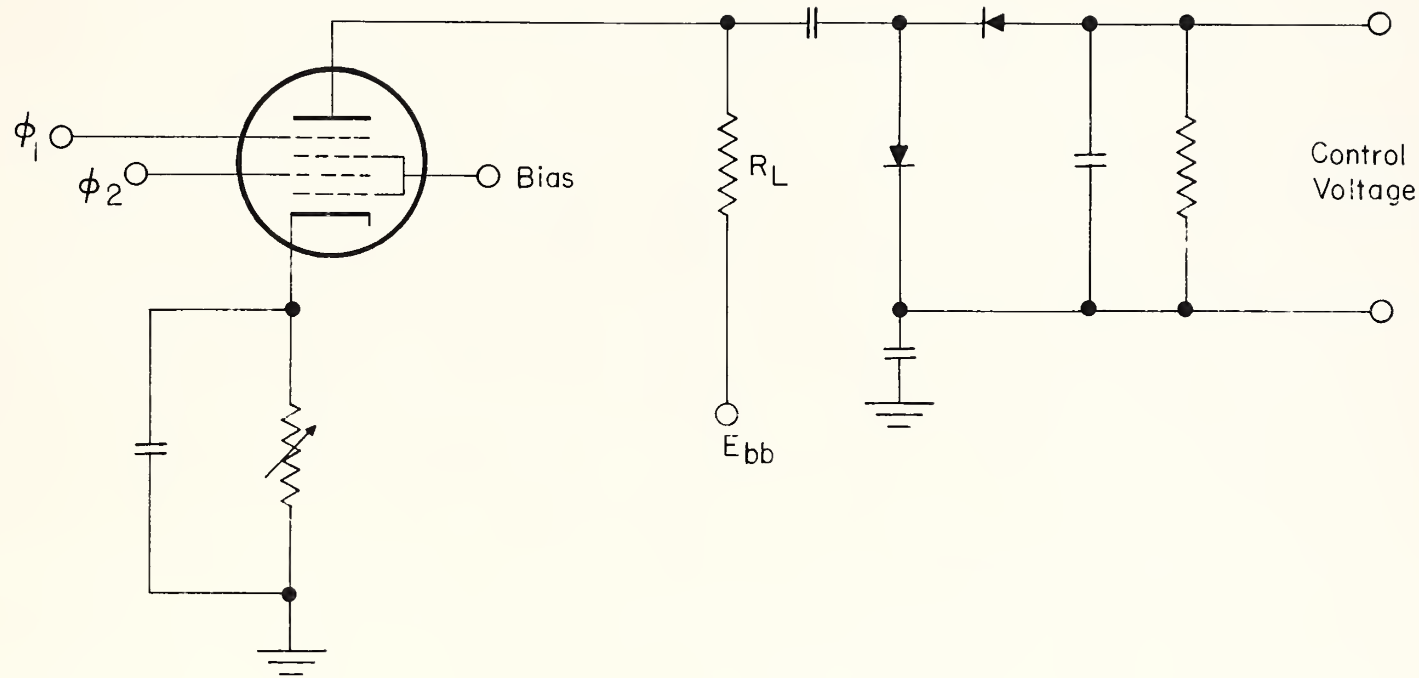


Figure 5

desired A + B indication. The average, or smoothed output signal is then a linear function of relative phase between input signals.

The gated-beam phase detector circuit usually employs a plate load resistor about four times as large as the static plate resistance of the tube during conduction.

The time constant of the negative-going output pulse edge is equal to the total shunt capacity C, times the parallel combination of R_L and R_T as shown in the equivalent circuit of Fig. 3. The time constant of the positive going pulse, when the tube cuts off, is $R_L C$.

If we pick R_L equal to $4R_T$, and an input signal period of ten times the downward pulse edge time constant, or $(10)\left(\frac{R_L R_T}{R_L + R_T}\right)(C)$, the resulting output voltage waveform will be as shown in Fig. 4. The average value can be seen to vary from about $\frac{Ebb}{2}$ to Ebb as ϕ changes from zero to 180°.

AMPLITUDE OF OUTPUT SIGNAL

It can be seen from Fig. 4 that the average amplitude of the output signal will vary with phase, but in a non-symmetrical, non-linear manner. The peak-to-peak amplitude can been seen to vary exponentially with phase angle; changing most rapidly near 180° phase shift, and being almost constant near zero degrees. If good linearity were not required, this signal could be capacitively coupled into a simple amplitude detector operating at any desired DC potential.

If the input signal period is long compared to output circuit time constants, an average detector will yield an output that is a linear function of phase over a wide range. The phase deviation sensitivity will be very nearly the same as at the plate itself.

A peak-to-peak detector, as shown in Fig. 5, could be used to get a highly sensitive phase indication near 180 degrees. Its response to phase changes would be zero for angles near zero, however.

As the signal frequencies are increased above a few hundred kilocycles, the useful AC voltage component approaches zero, because of capacitive loading from the tube and wiring capacities, and amplitude detectors are rendered useless.

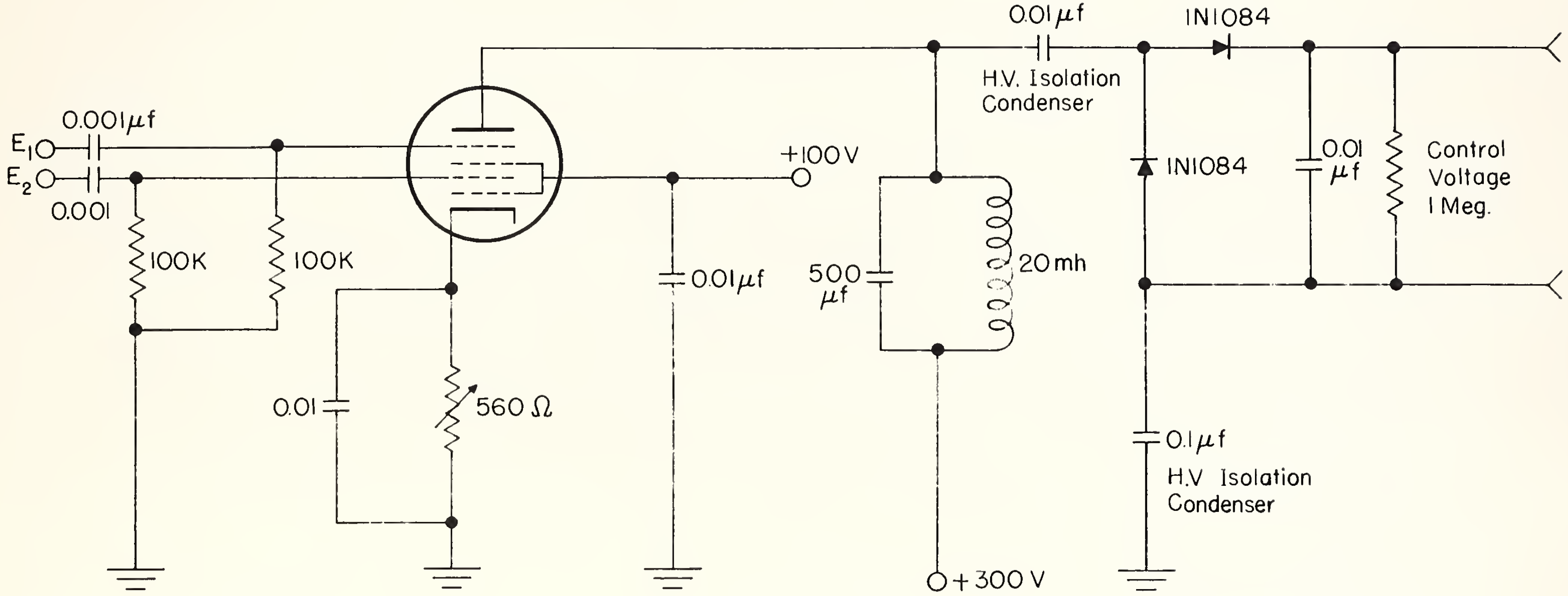
PRINCIPLE OF OPERATION

To overcome the frequency limitation of circuits such as Fig. 5, it is necessary to tune the output circuit. The output signal thus approximates a sine wave. If the output circuit "Q" is made large, an output voltage of 500 volts or more may readily be obtained. Fig. 6 shows a complete phase detector circuit which resulted in a range of output voltage of from zero to 300 volts when ten volt RMS signals were applied to the input terminals.

The circuit of Fig. 6 develops a signal across its tank circuit analogous to a class "C" amplifier with a variable angle of conduction. Since the dynamic plate resistance is quite high, the tube acts like a constant-current source with pulse-width modulation, as shown in Fig. 7.

If the fundamental component of the output current is determined as a function of the angle of conduction, and multiplied by the load impedance, the tank circuit voltage may be determined. If the amplitude detector is made linear, the resulting voltage vs. phase characteristic fully describes the operation of such a phase detector.

SPECIAL GATED BEAM PHASE-DETECTOR CIRCUIT



Values for 50 kc Input Signals

Figure 6

OUTPUT CURRENTS OF GATED BEAM TUBE

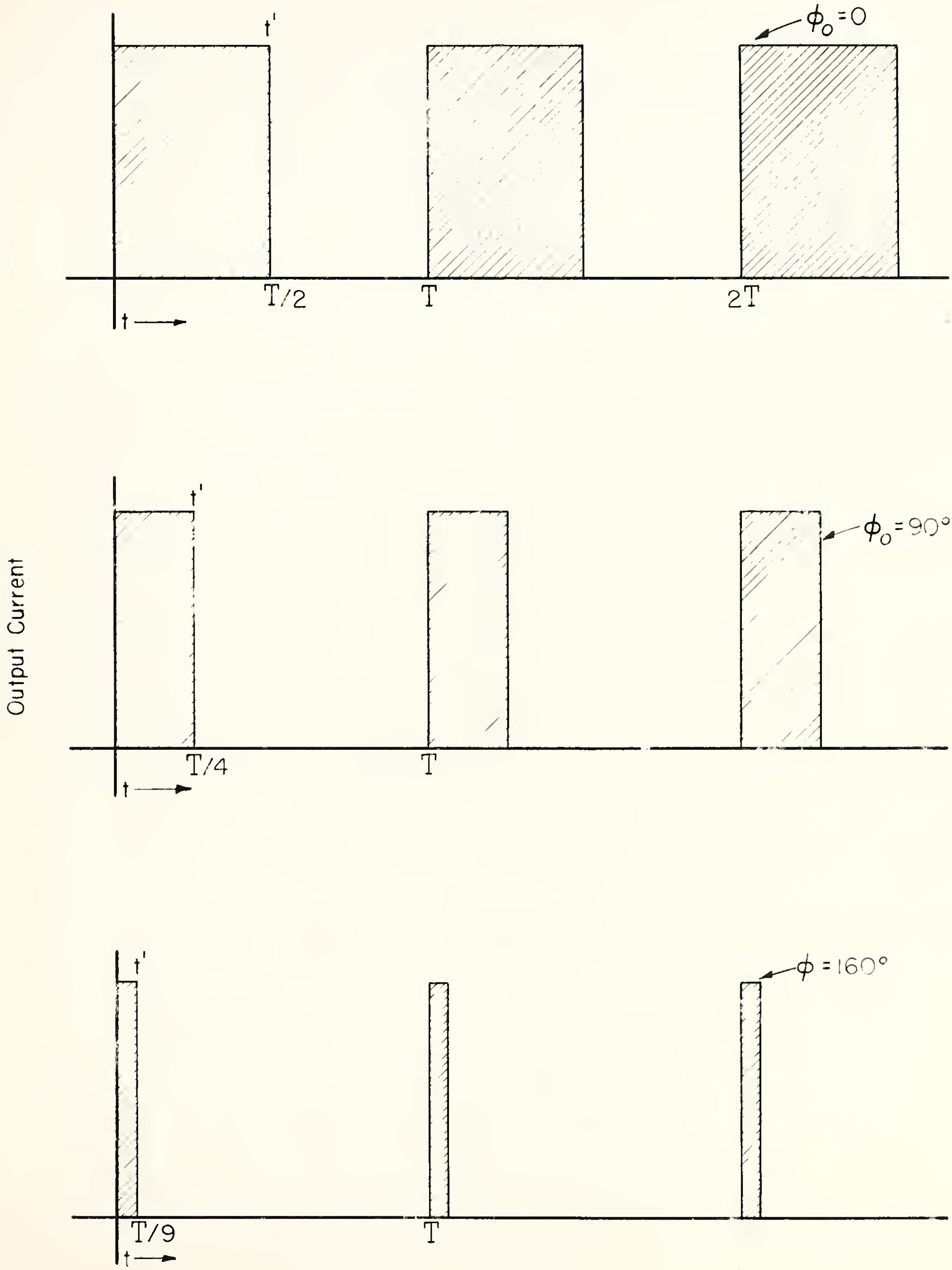


Figure 7

RMS OUTPUT VOLTAGE OF SPECIAL PHASE DETECTOR
VS.
PHASE DIFFERENCE OF INPUT SIGNALS

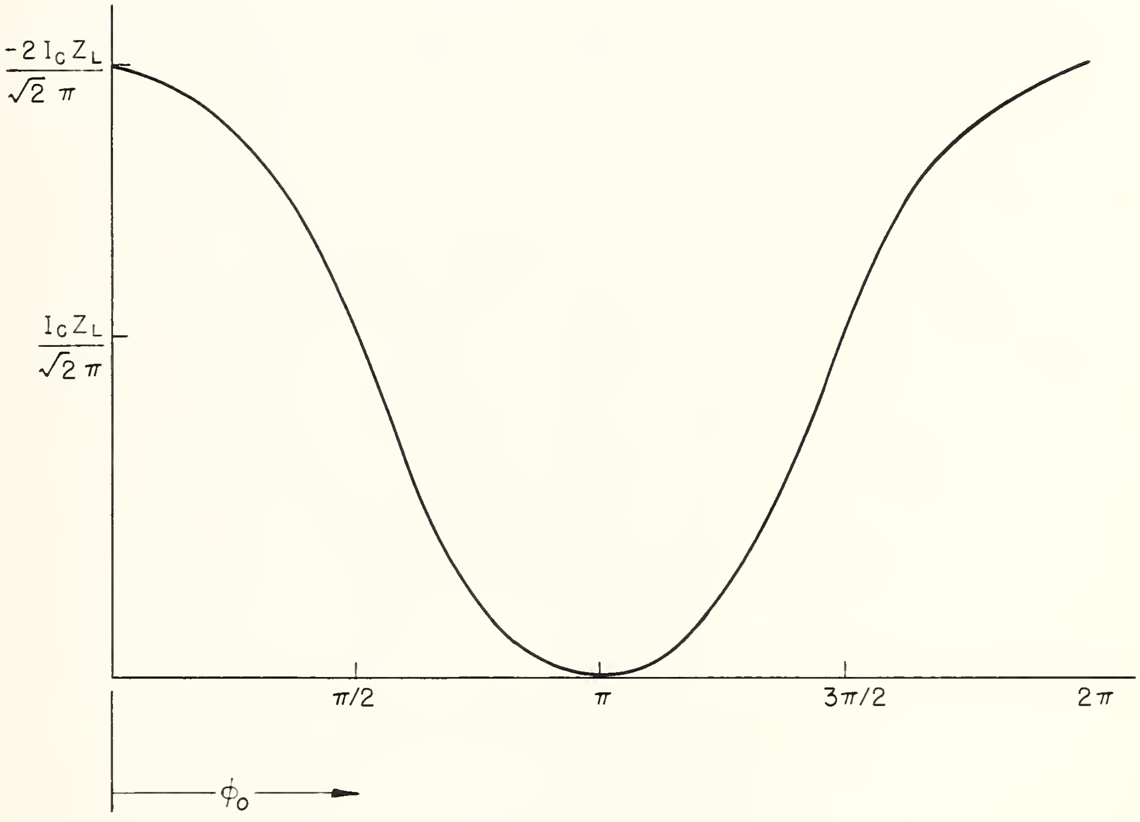


Figure 8

If we let f (t) be the current out of the gated beam tube, as shown in Fig. 7, ϕ_d equal the phase difference of the input signals, t' be the conduction time of the current pulse, and I_c be the tube "on" current, we may determine the peak fundamental output current as follows.

Let $f(t) = \frac{a_o}{2} + a_1 \cos \frac{2\pi t}{T} + \cdots + b_1 \sin \frac{2\pi t}{T} + \cdots$

$$\int_o^T f(t) \sin \frac{2\pi t}{T} \, dt = 0 + 0 + \cdots \int_o^T b_1 \sin^2 \left(\frac{2\pi t}{T} \right) dt + 0 + \cdots$$

$$= \frac{T}{2\pi} \left(\frac{b_1}{2} \right) \left[\frac{2\pi t}{T} - \sin \frac{2\pi t}{T} \cos \frac{2\pi t}{T} \right] \Bigg|_o^T$$

$$= \frac{b_1 T}{2}$$

$$b_1 = \frac{2}{T} \int_o^T f(t) \sin \frac{2\pi t}{T} \, dt$$

$$= \frac{2I_c}{T} \int_o^{t'} \sin \frac{2\pi t}{T} \, dt$$

$$= \frac{2I_c}{T} \left[\frac{- \cos \frac{2\pi t}{T}}{\frac{2\pi t}{T}} \right] \Bigg|_o^{t'}$$

$$= \frac{I_c}{\pi} \left[1 - \cos \frac{2\pi t}{T} \right]$$

$$= \frac{I_c}{\pi} \left[1 - \cos \left(\pi - \phi_d \right) \right]$$

$$b_1 = \frac{I_c}{\pi} \left[1 + \cos \phi_d \right]$$

Values of output voltage from the above equation are shown in Fig. 8. It can be seen that such a phase detector now gives cosine output response rather than the linear response obtained from a coincidence detector used in the conventional manner.

CONCLUSIONS

The phase detector shown in Fig. 6 should be found useful in applications requiring a large output voltage isolated from ground. It will not provide the linear phase characteristic of the gated beam circuit with output directly from the anode, but the cosine characteristic should be found satisfactory for many servo applications.

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