SYNTHESIS

of a

TRANSISTOR BLOCKING OSCILLATOR

TIME BASE GENERATOR

by

Harold Griffith Robb

A Thesis Submitted to the Faculty of the DEPARTMENT OF ELECTRICAL ENGINEERING in Partial Fulfillment of the Requirements For the Degree of MASTER OF SCIENCE In the Graduate College of THE UNIVERSITY OF ARIZONA 1961
STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in their judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: [Signature]

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

[Signature]

DR. ROBERT L. WALKER
Professor of Electrical Engineering

4 May 1961
ACKNOWLEDGEMENT

The author wishes to take this opportunity to express his appreciation to Dr. Robert L. Walker under whose guidance this work was accomplished.

Thanks are also due to the staff and members of the Tucson Engineering Laboratory, Hughes Aircraft Company. This work was carried out while the author was a member of the Technical Staff of the Hughes Aircraft Company and a holder of the Hughes Master of Science Fellowship.
ABSTRACT

A vacuum tube blocking oscillator time base generator is analyzed to establish the required functional characteristics of the active device employed, and to develop a model circuit which provides the basis for synthesis of the transistor circuit.

An idealized transistor is presented and a circuit configuration using this transistor model is evolved. The properties of the real transistor are evaluated and an equivalent circuit representation for the transistor is developed.

The transistor circuit configuration is analyzed to determine its performance characteristics. Experimental evaluation of the transistor blocking oscillator time base generator provides verification of the analytic description and establishes the performance characteristics of the circuit.
# TABLE OF CONTENTS

## Chapter 1

1.1 Significance ........................................ 1
1.2 Nature of the Problem ................................. 4
1.3 Objective and Scope .................................. 4
1.4 Method of Treatment ................................ 5

## Chapter 2

2.1 The Blocking Oscillator ............................. 6
2.2 The Time Base Generator ............................. 8
2.3 The Blocking Oscillator Time Base Generator ... 10

## Chapter 3

3.1 Required Transistor Properties ................... 20
3.2 Transistor Circuit Configuration ................... 24

## Chapter 4

4.1 Large Signal Behavior ............................... 31
4.2 Linear Equivalent Circuits ......................... 35

## Chapter 5

5.1 Blocking Oscillator Analysis ....................... 40
5.2 Bootstrap Analysis ................................ 44
5.3 Summary ............................................ 48
Chapter 6

6.1 Practical Considerations .......................... 51
6.2 Experimental Evaluation .......................... 55
6.3 Summary of Results ............................... 62

Chapter 7

7.1 Compliance with Objectives ....................... 64
7.2 Suggestions for Further Study .................... 65

Bibliography ........................................... 68
CHAPTER 1
INTRODUCTION

1.1 Significance

A class of circuits generally referred to as pulse and digital circuits is extensively used in the electronics industry as building blocks for complex systems such as radar, television, digital computers, nuclear instrumentations, and pulse communication networks. A wide variety of wave shaping circuits, used to generate waveforms which include square waves, wide pulses, narrow pulses, and time bases, exists. The blocking oscillator and the time base generator are two of these pulse and digital circuits.

The blocking oscillator, a regenerative circuit used primarily to generate narrow pulses, exists in both astable and monostable forms. Basically, the blocking oscillator consists of an active device which functions as an amplifier, a pulse transformer which provides coupling between the input and output of the active device, and a capacitive charging network. Operation of the free-running blocking oscillator is characterized by a period of short conduction of the active device during which the pulsed output is formed, and a long time
interval during which the active device is maintained in the OFF state by a voltage which is developed across the capacative input network when the active device is conducting. The period of non-conduction terminates when the capacitor timing voltage decays to a value which again permits conduction of the active device. The waveforms associated with the circuit operation are shown in Figure 1.1.

![Waveforms](image)

a) Output

b) Timing Waveform

**Figure 1.1 Blocking Oscillator Waveforms**

The time base generator is a circuit which generates an output waveform that exhibits a linear variation of voltage or current with time. Typical waveforms of the voltage time base generator are given by
The period of linear variation of voltage with time is referred to as the sweep time, and the time required for the circuit to recover before the initiation of a second voltage is called the restoration time or the flyback time. The voltage time base generator has been developed to a high degree of precision. Several forms of the circuit which are in widespread use are the Miller Integrator, the Bootstrap Sweep, and the Thyatron Sweep.
1.2 Nature of the Problem

In some applications it is necessary to provide a time base waveform having a restoration time much shorter than is obtainable with the conventional time base generator. The blocking oscillator has been used in this application by utilizing the timing waveform as the circuit output. There are two objections, however, to the use of the blocking oscillator as a time base generator. First, the timing waveform of the basic blocking oscillator is exponential in form rather than linear. In addition, the blocking oscillator is not a precision device. The characteristics of the circuit output are greatly influenced by the age and condition of the active device, supply voltage variations, and residual magnetism of the transformer.

1.3 Objective and Scope

The objective of this thesis is to develop a transistor blocking oscillator which posses the following properties:

(1) The circuit timing waveform shall exhibit a deviation from linearity of no more than five percent.

(2) The period of the blocking oscillator shall be independent of supply voltage variations of 25 percent.

(3) The circuit outputs (the timing waveform and the pulse output) shall not be affected in form or duration by changes of active device characteristics up to 30 percent.
In short, the objective of this thesis is to make the blocking oscillator a precision device which can be used to provide a time base voltage having a short on-to-off time.

An additional objective is to present analysis and synthesis techniques which will make possible the prediction of circuit output characteristic to within 10 percent accuracy. The analytic techniques will be limited to describing the circuit behavior during its several states of operation. Circuit behavior in the transition between states will not be considered in this thesis.

1.4 Method of Treatment

A vacuum tube blocking oscillator which possesses the properties required has been designed. The vacuum tube blocking oscillator time base generator circuit will be presented and evaluated. An ideal circuit which functionally represents the vacuum tube circuit will then be established. Next, the physical attributes demanded of the transistor will be evaluated in terms of the ideal circuit. A circuit configuration based on the assumed transistor properties will then be developed. Next, an equivalent circuit based on actual transistor properties will be evolved for the purpose of analytic determination of circuit components. Finally, a circuit will be built and tested to provide experimental verification of the design techniques presented and to evaluate circuit performance as a voltage time base generator.
CHAPTER 2

DEVELOPMENT OF THE VACUUM TUBE MODEL CIRCUIT

2.1 The Blocking Oscillator

The blocking oscillator is a regenerative circuit used to generate pulses of large magnitude and short duration. The circuit can be used to produce pulses periodically (in a free running mode of operation) or singly. A typical circuit configuration of the free running blocking oscillator is presented in Figure 2.1.

![Diagram](image)

**Figure 2.1 The Blocking Oscillator**

Operation of this circuit can be described qualitatively by assuming that initially a negative charge exists on $C_g$. 

6
which is adequate to bias the tube beyond cutoff. The capacitor discharges through the resistor, $R_g$, until the voltage across $C_g$ is more positive than the tube cutoff voltage. At this time the tube starts to conduct. The flow of plate current through the primary winding of the transformer induces a voltage in the secondary winding of a polarity such that the grid is driven in the positive direction. An increase of the grid voltage produces a further increase in plate current which through the coupling of transformer drives the grid more positive. This regenerative action continues until the plate current is limited by the nonlinearity of the tube. When the plate current reaches a maximum value and becomes constant there is no $\frac{di}{dt}$ to maintain a secondary voltage. The regenerative process, therefore, stops.

The plate current continues to flow and remains relatively constant until the grid voltage decays sufficiently to reduce tube conduction. The reduction in plate current induces a voltage in the transformer secondary winding of such a polarity to further reduce the grid voltage. The drop in grid voltage further reduces the plate current. The process is again regenerative and in such a direction that the grid voltage is rapidly driven far below the tube cutoff voltage. The circuit is again in its original state with a negative voltage across the capacitor and the tube
nonconducting at the termination of the regenerative cycle. The tube remains cutoff until the voltage across the capacitor decays to a value more positive than the grid cutoff voltage, when the entire operation is repeated.

The operation of the blocking oscillator can be separated into the following phases:

1. regenerative turn ON state
2. ON state
3. regenerative cut-off state, and
4. timing state (OFF state)

2.2 The Time Base Generator

The time base generator is a circuit which produces an output waveform that exhibits a linear variation of voltage or current with time. The voltage time base generator is the topic of the discussion to follow. In elementary form, the voltage time base generator is an RC integrator. The output waveform is taken across the capacitor. The output of the integrator is given by equation 2.1. \( E_o = E_i \left(1 - e^{-\frac{t}{RC}} \right) = \frac{E_i t}{RC} \left(1 - e^{-\frac{t}{2RC}} \right) \)  

2.1

The inherent disadvantage of the simple RC integrator is that for an output of a given time duration the time constant, RC, must be much longer than the required time interval in order that equation 2.1 may be accurately represented as \( E_o = \frac{E_i t}{RC} \). This requires that the input
voltage to the circuit must be very large to produce a time base voltage of useful amplitude. Various circuits have been designed to overcome this undesirable feature.¹

One such circuit is represented by Figure 2.2. This circuit is referred to as a bootstrap sweep. Operation of the bootstrap sweep is explained by considering that the switch is closed until the initial instant. When the switch is opened, the voltage across the capacitor rises from zero. The increase in the capacitor voltage is felt by the tube grid. Consider that the cathode follower has unity gain. The voltage across $R_k$ increases with the input voltage and thus maintains a constant bias; the tube operates in its

---

linear region. The voltage across the resistor, R, remains essentially constant as $V_C$ and $V_R^k$ are assumed to change equally. Since the voltage across R is essentially constant, the charging current for the capacitor is constant, resulting in a linear voltage slope on the capacitor.

2.3 The Blocking Oscillator Time Base Generator

The blocking oscillator time base generator is a circuit which possesses the properties of both the blocking oscillator and the time base generator. Specifically, the circuit will generate both a linear time base voltage and a pulse of large amplitude and short duration. Two avenues of approach can be considered in establishing the characteristics of the blocking oscillator time base generator. First, the circuit can be thought of as a blocking oscillator having a linear charging circuit, which controls the timing state by charging the grid capacitor at a constant rate. An alternate approach is to treat the circuit as a time base generator which utilizes the blocking oscillator as a low impedance switch to quickly discharge the capacitor. Both methods will be used to analyze the blocking oscillator time base generator as a means to develop a model circuit which functionally represents the actual circuit.

The circuit diagram of the blocking oscillator time base generator is shown in Figure 2.3. Analysis of the
Figure 2.3 The Blocking Oscillator Time Base Generator

circuit as a blocking oscillator will be considered first. The analysis will be confined to an investigation of the blocking oscillator ON time. The turn-on and turn-off states will be assumed to take place instantly and will therefore be neglected. The timing state of the blocking oscillator will be analyzed when the circuit is treated as a time base generator.

An equivalent circuit representation of the blocking oscillator is presented in Figure 2.4. The linear charging circuit is represented as a voltage source and a series resistor. The time duration of the timing state is considered to be short in comparison with the charging circuit time constant such that the capacitor is charged at a linear rate.
The transformer is represented by an ideal transformer and a shunt inductance corresponding to the magnetizing inductance of the actual transformer. The leakage inductance of the real transformer is considered to be negligible, corresponding to the assumption that the turn ON is instantaneous. The grid circuit of the tube is represented as a resistor in series with a diode. The plate circuit consists of a switch (which closes when the grid to cathode voltage reaches $E_{co}$, grid cutoff voltage) a voltage source, and a series resistor.

Consider now that the switch has closed by virtue of a voltage in excess of $E_{co}$ and $C_g$. The plate of the tube is clamped to $E_b$. A current, $i_b$, is flowing in the plate circuit. A current, $i_c$, is flowing in the grid circuit, and
a current, \( i_d \), is flowing through the diode. Current has not yet had time to build up in the magnetizing inductance. A voltage \( E_{bb} - E_b \) appears across the transformer primary winding. The secondary voltage is also \( E_{bb} - E_b \) since the ideal transformer passes d.c. The secondary or grid current is equal to \( \frac{E_{bb} - E_b}{r_g} \) and is also equal to \( i_p \). Initially, the diode current is equal to the difference between the plate current and the primary current since current has not built up in the magnetizing inductance.

\[ i_d = i_b - i_p \tag{2.2} \]

Current builds up in the inductor as required by the equation

\[ E = E_{bb} - E_b = L \frac{di_m}{dt} = L \frac{i_m}{t} \tag{2.3} \]

The assumption that \( i_b \) is constant implies that \( e_{gk} \) is constant. The grid to cathode voltage can remain constant only if \( i_c \) is fixed. It follows therefore that \( i_p \) must remain constant since the ampere turns of both the primary and secondary windings of the ideal transformer must remain constant. As \( i_m \) increases, \( i_d \) must decrease since all other currents at the node \( P \) are fixed. The current, \( i_m \), continues to increase until it is equal to the initial value of \( i_d \). When \( i_m \) is equal to \( i_{do} \) the diode, \( D_1 \), is reversed biased. Any additional increase of \( i_m \) therefore is forced into the primary of the ideal transformer in a direction to oppose \( i_p \). The secondary current, \( i_c \), is in turn decreased resulting in a reduced grid to cathode voltage. The reduction of \( e_{gk} \) causes the plate current to decrease.
A decrease in $i_b$ forces additional magnetizing current through the transformer primary. The effect is cumulative and the tube is very rapidly turned off.

From this discussion, it is seen that the ON time of the blocking oscillator is the time required for the current in the inductor to build up to a value equal to the initial diode current.

\[
i_m = \frac{(E_{bb} - E_b)}{L_m} = i_b - i_p \quad 2.4
\]

\[
i_b = g_m (E_{bb} - E_b) \quad 2.5
\]

\[
i_p = i_c = \frac{E_{bb} - E_b}{r_g} \quad 2.6
\]

\[
T_n = L_m \left( g_m - \frac{1}{r_g} \right) \quad 2.7
\]

Values of $r_g$ and $g_m$ can be determined from the positive grid characteristics of the tube in use by the following procedure:

1. Find the plate current and grid current corresponding to a plate voltage $E_b$ and a grid voltage $E_{bb} - E_b$.

2. Calculate $g_m$ from equation 2.5

3. Calculate $r_g$ from equation 2.6

The voltage to which the capacitor charges during the blocking oscillator ON time can be approximated by the relationship

\[
V_{cn} = \frac{1}{C_g} \int_0^m i_c \, dt \cong \frac{i_c \, T_n}{C_g} . \quad 2.8
\]
The final voltage across the capacitor at the end of the ON time is

\[ E_{co} - \frac{i_c T_n}{C_g} \]  \hspace{1cm} 2.9

The assumption that the transformer does not saturate is implicit in the above analysis.

The blocking oscillator time base generator will next be treated as a time base generator which uses a blocking oscillator to discharge the capacitor, \( C_g \). The circuit diagram is given in Figure 2.5. The blocking oscillator

![Circuit Diagram](image)

Figure 2.5 Time Base Generator with Blocking Oscillator Switch

is represented as a voltage source of magnitude \( \frac{i_c t}{C_g} \) and a switch which closes for \( T_n \) seconds after the voltage on the capacitor has been charged to \( E_{co} \) by the time base generator.
Before an equivalent circuit for the time base generator can be developed, it is necessary to determine the region of operation of the tube. A brief discussion of the circuit operation will provide the necessary insight.

Assume that initially the tube is conducting and a voltage, $V_k = i_1 R_k$ is developed across the cathode resistor. Each time the switch closes, the capacitor, $C_c$, will be charged through the grid leak resistor. In the limit, the voltage across the capacitor will approach $V_k$ and will remain constant at that value if it is assumed that the time constant $R_g C_c$ is large compared with the period of the blocking oscillator.

The grid to cathode voltage of the tube can be determined from the relationship

$$E = V_k = e_{gk} + i_2 R$$  \hspace{1cm} (2.10)

The magnitude of $E = V_k$ is given by the equation

$$E = \frac{i_b R R_k}{R + R_k}$$  \hspace{1cm} (2.11)

Assume now that $R_k$ is much larger than $R$. Equation 2.11 reduces to $E = i_b R$. An additional consequence of the above assumption is that $i_2 = i_b$. Equation 2.10 can be rewritten as $i_b R = e_{gk} + i_b R$. The grid to cathode voltage therefore is zero. The tube is operating in its active or linear region. The operating point of the tube is essentially constant, resulting in a constant plate current. If it is
assumed that \( i_2 = 0 \), the capacitor is charged at a constant rate, giving a voltage across the capacitor which is a linear function of time.

Development of the equivalent circuit is given in Figure 2.6.

---

Figure 2.6 Equivalent Circuit Development

In Figure 2.6a the tube is represented by its linear equivalent circuit. The capacitor charging network, consisting of \( R_g \) and \( C_c \), is replaced by a constant voltage \( E \) in keeping with the assumption that the voltage across
the capacitor is constant. The resistor \( R_k \) is replaced by an open circuit by virtue of the assumption that it is much larger than \( R \). The voltage source, \(-\mu i_p R\), can be replaced by a resistor, \( \mu R \), since \( i_p \) is flowing through the loop containing the source. Figure 2.6b results. The following equations are derived by evaluating the circuit of Figure 2.6b.

\[
e_c(t) = (E_{bb} + \mu E) - (E_{bb} + \mu E - V_{C0}) e^{-t/(r_p + (\mu+1)R)C_g} \quad 2.12
\]

\[
e_0(t) = i_b R + e_c(t) \quad 2.13
\]

\[
T_p = (r_p + (\mu+1)R) \int \ln \left( \frac{E_{bb} + \mu E - V_{C0}}{E_{bb} + \mu E - E_{co}} \right) \quad 2.14
\]

\[
M = \text{initial slope} = \frac{E_{bb} + \mu E + V_{C0}}{[r_p + (\mu+1)R] C_g} \quad 2.15
\]

\[
M = \frac{\mu E}{[r_p + (\mu+1)R] C_g} = \frac{E}{R C_g} \quad 2.16
\]
Model circuits have been developed for both the time base generator and the blocking oscillator. The composite model circuit is given by Figure 2.7.

![Figure 2.7 Blocking Oscillator Time Base Generator](image-url)
CHAPTER 3

DEVELOPMENT OF THE TRANSISTOR CIRCUIT CONFIGURATION

3.1 Required Transistor Properties

The vacuum triode has three distinct regions of operation. These regions of operation are the cutoff region, the linear region, and the saturation region. The cutoff region is one in which no plate current flows by virtue of a negative grid to cathode voltage. This region of operation is referred to as region I. Region II, the linear region, is one where active coupling exists between the grid and plate circuits, and amplification is possible. In region III, the grid circuit effectively loses control of the plate circuit. The tube functions as a diode in this saturation region. Operation is characterized by high grid and plate current.

A model circuit employing the vacuum triode as the active device was developed for the blocking oscillator time base generator in Chapter 2. An investigation of the function of the vacuum tube in the model circuit will provide the necessary insight to determine the properties the transistor must exhibit in order that it may be used as the active device in the circuit. When the required transistor properties have been established, a circuit configuration
utilizing the transistor can be devised.

It was established in Chapter 2 that the active device in the time base portion of the circuit functions as a voltage amplifier. The grid to cathode voltage is maintained at zero volts, hence the input impedance can be considered infinite, since no grid current flows. The device, therefore, functions as a voltage amplifier having infinite input impedance.

The active device in the blocking oscillator portions of the circuit operates in both regions I and II. The tube is held in region I during the blocking oscillator timing state by a negative voltage on the grid capacitor. When the voltage across the capacitor exceeds the cutoff voltage, plate current starts to flow. The device is now operating in region II and is functioning as an amplifier. Two modes of operation in region II are required. Initially, when plate current first starts to flow, the grid circuit input impedance is infinite. The transformer coupling between the grid and plate circuit, in conjunction with the amplifying property of the device, drives the grid positive as the plate voltage drops. Grid current starts to flow when the grid to cathode voltage exceeds zero volts. The input impedance to the grid circuit has a finite value.

Plate voltage continues to drop until it is caught by the
catching diode. Operation in the linear region has shifted from near cutoff to near saturation. The properties of the active device of the blocking oscillator, thus, are that of a voltage actuated switch which functions as an amplifier when the switch is closed.

The required functions of the active device have now been established. The next step is to investigate the properties of an idealized transistor to see if it can functionally replace the vacuum tube in the model circuit. Figure 3.1 is an idealized representation of an NPN transistor.

![Transistor Circuit Model](image)

Figure 3.1 Transistor Circuit Model
The transistor consists of two diodes back to back and a current generator, $\beta I_b$ which shunts the collector-base diode. The emitter base diode is ideal. The collector-base diode has zero forward resistance and a finite but large reverse resistance $r_c$. The current generator is actuated by a base input current as shown in the Figure. This transistor model has three regions of operation comparable to those of the vacuum tube. Operation in region I requires that the emitter-base diode be reverse biased such that $I_b$ is zero. The current generator therefore has zero magnitude. The collector-base diode is reverse biased such that the collector circuit is essentially open circuited.

If a voltage is applied across the emitter-base terminals to forward bias the emitter-base diode, an input current, $I_b$, flows and the current generator has a magnitude $\beta I_b$. This mode of operation corresponds to operation of the vacuum tube in region II. Two significant differences exist however. The first of these differences is seen in method of controlling the output current. The output current of a vacuum tube is controlled by an input voltage while with the transistor an input current exercises control over the output current. The second difference, a consequence of the first, is found in the input impedance level. The input impedance of the ideal transistor is zero while the input impedance to the vacuum tube is infinite.
Operation in region III is initiated by forward biasing both the collector-base diode and the emitter-base diode. In this mode of operation, the ideal transistor can be represented as three terminals shorted to a common node.

3.2 Transistor Circuit Configuration

The model circuit for the blocking oscillator time base generator is repeated in Figure 3.2

![Diagram of blocking oscillator time base generator](attachment:image.png)

**Figure 3.2** Blocking Oscillator Time Base Generator

A transistor circuit configuration for the blocking oscillator time base generator can be developed by replacing the active
device in Figure 3.2 with the transistor model of Figure 3.1. Consider first the time base portion of the circuit. Figure 3.3a shows the time base circuit with the tube replaced by the linear voltage equivalent of the transistor model.

![Device Diagram](image)

*Figure 3.3 Transistor Time Base Equivalent Circuit*
Figure 3.3b is developed by first writing the loop equation for Figure 3.3a and solving for \(i_b\),

\[ i_b = \frac{E - i_c R_e}{R_e} \]  \hspace{1cm} (3.1)

The voltage sources is \( B_i p = \frac{B E r_c}{R_e} - i_c r_c \beta \).

Since \( i_c \) is flowing through the loop containing the voltage source, \(-i_c r_c \beta\) can be replaced by a resistor having a magnitude \(B r_c\). Next the circuit to the right of the terminals \(x-x'\) is replaced by its Thevinin equivalent, giving a voltage \(E\). Figure 3.3b results. This circuit can be simplified by making the assumption that \(B \frac{E r_c}{R_e}\) is greater than \(E_{cc} - E + V_{co}\). The simplified circuit is presented in Figure 3.3c. The output across the capacitor is given by the equation

\[ e_c(t) = \frac{B E r_c}{R_e} \left(1 - e^{-\frac{t}{(B+1)R_e c}}\right) \]  \hspace{1cm} (3.2)

If the assumption is made that \((B + 1) r_c C\) is much greater than \(T_p\), Equation 3.2 reduces to

\[ e_c(t) = \frac{B E r_c t}{R_e (B+1) R_e C} = \frac{E t}{R e C} \]  \hspace{1cm} (3.3)

The circuit operates as a linear charging circuit to the extent that the above assumptions are valid.

The vacuum tube time base circuit makes use of a grid leak resistor-coupling capacitor network to maintain a constant input voltage (see Figure 2.5). This technique
Figure 3.3b is developed by first writing the loop equation for Figure 3.3a and solving for $i_b$,

$$i_b = \frac{E - i_c R_e}{R_e} \quad 3.1$$

The voltage sources is $V_i = \frac{B E_r}{R_e}$.

Since $i_c$ is flowing through the loop containing the voltage source, $-i_c R_c \beta$ can be replaced by a resistor having a magnitude $B R_c$. Next the circuit to the right of the terminals $x-x'$ is replaced by its Thevinin equivalent, giving a voltage $E$. Figure 3.3b results. This circuit can be simplified by making the assumption that $B \frac{E_r}{R_e}$ is greater than $E_{cc}-E-V_{co}$. The simplified circuit is presented in Figure 3.3c. The output across the capacitor is given by the equation

$$e_c(t) = B \frac{E_r}{R_e} \left( 1 - e^{-\frac{t}{(B+1)R_c}} \right) \quad 3.2$$

If the assumption is made that $(B + 1) R_c C$ is much greater than $T_p$, Equation 3.2 reduces to

$$e_c(t) = B \frac{E_r t}{R_e(B+1)R_c} \approx \frac{E t}{R_e C} \quad 3.3$$

The circuit operates as a linear charging circuit to the extent that the above assumptions are valid.

The vacuum tube time base circuit makes use of a grid leak resistor-coupling capacitor network to maintain a constant input voltage (see Figure 2.5). This technique
cannot be used with the transistor. The transistor is maintained in its linear region of operation by a bias voltage which forward biases the emitter-base diode and causes current to flow into the base of the transistor. If a resistor were shunted across the emitter base diode to provide a current path through which a capacitor in the base circuit could be charged, a voltage would be developed across the resistor of such a polarity as to reverse bias the emitter base diode. Operation would therefore be confined to region I. Figure 3.4 shows the transistor time base generator circuit complete with a biasing circuit arrangement which confines the transistor to operation in region II.

![Diagram of Transistor Time Base Generator](image)
Substitution of the model transistor for the active device in the blocking oscillator portion of Figure 3.2 results in Figure 3.5.

![Diagram of Transistor Blocking Oscillator Model](image)

**Figure 3.5 Transistor Blocking Oscillator Model**

The circuit is turned on when the capacitor voltage charges to a value greater than zero at which time the emitter-base junction is forward biased and base current starts to flow. The subsequent flow of collector current causes the collector voltage to drop and induces a voltage in the transformer secondary winding which maintains a positive potential across the emitter-base junction. The collector is clamped to $E_c$ by the catching diode, $D_c$. $I_b$ is constant during the ON
time so long as the emitter-base junction is forward biased. Turn OFF is initiated when the magnetizing current equals the initial diode current.

Another possibility exists, however. Turn OFF could be initiated if the voltage charge across the capacitor becomes equal to the induced secondary voltage before the magnetizing current builds up to

\[ V_c = \frac{1}{c} \int_0^{T_n} i_b \, dt = \frac{i_b T_n}{c} = \frac{E_{cc} - E_c}{b} \]

Under these conditions, the ON time is

\[ T_n = C \frac{(E_{cc} - E_c)}{i_b b} \]

The ON time is dependent upon the size of \( C \) and the magnitudes of the supply voltages.

This undesirable dependance can be eliminated by the addition of an emitter resistor, \( R_e \). The voltage change across \( C \) can be made small by requiring that \( R_i C \) is large compared with \( T_n \).

\[ R_i = \text{base input resistance} = (B+1)R_e \]

The base current is very nearly constant, hence the ON time is the time required for the magnetizing current to change from 0 to ido.
With the addition of the emitter resistor, the transistor blocking oscillator model circuit is functionally equivalent to the vacuum tube circuit. The composite transistor blocking oscillator time base generator is presented in Figure 2.6.
CHAPTER 4

LARGE SIGNAL TRANSISTOR PROPERTIES

4.1 Large Signal Behavior

A transistor circuit configuration for the blocking oscillator time base generator was developed in Chapter 3. An idealized transistor circuit model was the basis of the development. The topic of this chapter is the evaluation of the properties of the real transistor. The behavior of the transistor will be described in terms of its static properties.

The d.c. properties of the transistor can be represented by the symmetrical current-form equations.\(^2\)

\[
I_e = I_{e0}(e^{qV_{eb}/kT} - 1) - \alpha_1 I_c \quad 4.1
\]

\[
I_c = I_{co}(e^{qV_{eb}/kT} - 1) - \alpha_n I_e \quad 4.2
\]

The emitter current, defined by Equation 4.1, consists of a diode current, \(I_{e0}(e^{qV_{eb}/kT} - 1)\), which results from an applied voltage across the emitter-base diode, and a transistor current, \(\alpha_1 I_c\). \(\alpha_1 I_c\) is the fraction of the diode current from the collector-base diode which is collected by the emitter junction. Equation 4.2

represents the collector current. $I_{co}(e^{qV_{eb}/kt} - 1)$ is the collector-base diode current, and $\alpha_n I_e$ is the fractional emitter-base diode current collected by the collector junction.

Equation 4.3 describes the current-voltage relationship of the p-n junction diode.

$$I_D = I_s(e^{qV_d/kt} - 1) \quad 4.3$$

$I_s$ is the diode reverse saturation current, $V_d$ is the voltage across the junction, $q$ is the electron charge, $k$ is Boltzmann's constant, and $T$ is the junction temperature in degrees Kelvin. The similarity of the diode equation to the diode current component of Equations 4.1 and 4.2 suggests that a circuit approximation of the junction diode will be useful in establishing a circuit representation for the transistor. A plot of the diode equation is given by the volt-ampere characteristic of Figure 4.1.

![Figure 4.1 Junction Diode Volt-Ampere Characteristics](image-url)
When the applied junction voltage is a few volts positive, Equation 4.3 reduces to

\[ I_D = I_e \frac{qV_o}{kt} \quad 4.4 \]

since the exponential term dominates. This characteristic is shown in the positive IV plane of Figure 4.2. Under positive bias conditions the diode behaves like a resistance in series with a voltage source. The size of this resistance is equal to the reciprocal slope of the VI characteristics, and the voltage sources equals the slope intercept. A negative voltage across the junction results in a negative exponential argument which rapidly approaches zero as a function of the applied voltage.

\[ I_D = -I_s \quad 4.5 \]

The diode can be represented as a large (near infinite) resistance in this mode of operation. The magnitude of the resistance in equal to the reciprocal of the slope of the VI characteristics in the negative plane.

A circuit approximation to the diode is shown in Figure 4.2.\(^3\)

The circuit consists of an ideal diode in series with a resistor, $r_f$, and a resistor $r\_p$, which shunts the ideal diode and the series resistor. The resistor $r\_f$ corresponds to the forward resistance of the real diode. The reverse resistance of the real diode is represented by $r\_p$.

Refer again to the symmetrical current-form Equations 4.1 and 4.2. The diode current component of each equation can be approximated by Figure 4.2. The transistor current component can be represented by a current generator. Figure 4.3 results. A resistor $r\_b\_1$, is added in the base lead to account for the finite resistance of the base region. The circuit of Figure 4.3 constitutes a large signal equivalent circuit which represents the d.c.
Figure 4.3 Large Signal Equivalent Circuit

behavior of the transistor. The circuit accounts for the effects of saturation current and reverse current transfer in the transistor. The circuit cannot be used for determining the transient response of the transistor. Evaluation of the transient behavior of the transistor is beyond the scope of this work.¹

4.2 Linear Equivalent Circuits

The large signal equivalent circuit is somewhat unwieldy for circuit analysis. In addition, the circuit components are nonlinear and depend upon transistor operating points. It is convenient, therefore, to develop several linear circuits which approximate the transistor behavior.

over limited regions of operation. Considerable utility can also be gained by presenting graphical techniques for evaluating the circuit parameters in the several regions of operation. Parameter evaluation will be made only for the common-emitter connection since this configuration is used in both portions of the blocking oscillator time base generator.

Three regions of operation were defined in Chapter 3. The regions were defined according to the transistor bias condition. Region I is characterized by reverse bias of both the emitter-base and collector-base junctions. Operation in region II requires forward bias of the emitter-base junction and reverse bias of the collector-base junction. Both junctions are forward biased in region III. These regions of operation are indicated on the common-emitter output characteristics as shown in Figure 4.4.

![Figure 4.4 Regions of Operation](image-url)
The boundary of region I and region II is the line corresponding to $I_b = 0$. The circuit of Figure 4.3 can be simplified in region I. Both junctions are reverse biased; therefore the diodes can be represented by open circuits. Under reverse bias conditions, reverse current transfer within the transistor is negligibly small. $\alpha_i I_c$ and $\alpha_n I_e$ can be omitted. The equivalent circuit for the transistor in region I is presented in Figure 4.5. Two representations are shown.

![Figure 4.5 Transistor Equivalent Circuit Region I](image)

The choice of the two circuits depends upon the external circuit. The reverse diode resistances were included in
Figure 4.3 to account for the reverse saturation current. If the external circuit contains large resistances, the reverse saturation current must be accounted for.

The boundary between region II and III is the line where the curves of constant $I_b$ merge. Region II extends from the $I_b = 0$ line to the boundary of region III. The emitter-base junction is forward biased while the collector-base junction is reverse biased. The emitter diode can be replaced by a short circuit. $\alpha_1 I_C$ is small compared with the forward diode current and can be neglected. The collector diode can be represented as an open circuit. The linear equivalent circuit is given by Figure 4.6. The circuit is shown in the common-emitter form.

![Figure 4.6 Region II Equivalent Circuit](image)
Evaluation of the circuit parameters of Figure 4.6 is accomplished through use of the common-emitter input and output static characteristics. These characteristics appear in Figure 4.7.5

\[ R_L = R_b + \beta + 1 \cdot R_c \]

\[ \text{Slope} = \frac{1}{R_L} \]

\[ \beta = \frac{\Delta I_c}{\Delta I_b} \]

\[ I_b = b \]

\[ I_b = a \]

Figure 4.7 Region II Parameter Evaluation

---

CHAPTER 5
CIRCUIT ANALYSIS

5.1 Blocking Oscillator Analysis

A transistor version of the blocking oscillator time base generator was developed in Chapter 3. A preliminary analysis was undertaken to establish functional equivalence between the vacuum tube circuit and the transistor circuit. The transistor was represented by an idealized circuit model. A detailed analysis of the blocking oscillator time base generator will be performed in this chapter. The transistor equivalent circuits developed in Chapter 4 will be used.

The blocking oscillator time base generator is represented by Figure 5.1.

Figure 5.1 Blocking Oscillator Time Base Generator
Analysis of the blocking oscillator portion of the circuit will be considered first. For the purpose of this analysis, the turn on of both the transformer and the transistor are assumed to take place instantly. In addition, the collector is clamped at some voltage more positive than the emitter to base voltage when the transistor is on. This assumption confines the transistor to operation in the linear region; saturation of the transistor is avoided. The transistor is therefore represented by its region II equivalent circuit.

The transformer can be replaced by an ideal transformer plus a shunt inductance, \( L_m \), accounting for the transformer magnetizing inductance. The resulting equivalent circuit is shown in Figure 5.2. The diode, \( D_3 \), is reverse biased.

![Figure 5.2 Blocking Oscillator ON Circuit](image-url)
during the ON time and is therefore neglected.

The ON cycle is initiated when the voltage across the capacitor becomes sufficiently positive to forward bias the emitter-base junction and cause base current to flow. As base current commences to flow, the collector voltage drops to $E_c$ where it is clamped by the diode. A voltage, $E_{cc} - E_c$, appears across the primary winding of the transformer. A voltage of magnitude $\frac{E_{cc} - E_c}{b}$ is induced in the transformer secondary winding. (The ideal transformer passes d.c.)

At the initial instant of turn ON, current does not flow in the magnetizing inductance. The currents at the collector are related by Equation 5.1.

$$i_d(0) = \beta i_b - i_c = i_b(\beta - \frac{1}{b})$$  \hspace{1cm} 5.1

The base current is given by the equation

$$i_b = \frac{(E_{cc} - E_c)}{bR} e^{-t/RC}$$  \hspace{1cm} 5.2

where $R = r_b + (r_e + R_e)(\beta + 1)$. If $RC$ is large compared with the ON time, Equation 5.2 can be approximated by

$$i_b = \frac{E_{cc} - E_c}{bR}$$  \hspace{1cm} 5.3

$i_b$ can be considered constant during the ON time, when the conditions for the approximation are met. $I_c$ is equal to $\frac{i_b}{b}$ and is therefore constant for the duration of the ON cycle.
After the initial instant, current starts to build up in the transformer magnetizing inductance. Current build up is defined by the Equation

\[ E_{cc} - E_c = \frac{L_m i_m}{dt} = \frac{L_m i_m}{t} \]  

As \( i_m \) increases, \( i_d \) must decrease as all other currents at the collector node are constant. The magnetizing current rises linearly as a function of time until the diode current is reduced to zero. At this time, \( D_1 \) is reverse biased. Any additional increases in \( i_m \) are forced into the primary winding in a direction to oppose \( i_p \). This results in a reduction of \( i_b \) and a subsequent decrease of the collector current, \( \beta i_b \). The process is regenerative, and the transistor is quickly turned off. The ON time, therefore, is the time required for the magnetizing current to change to a value equal to the initial diode current.6

\[ i_m = \left( \frac{E_{cc} - E_c}{L_m} \right) t = i_d (0) \]  

\[ i_d (0) = \frac{E_{cc} - E_c}{bR} (\beta - \frac{1}{b}) \]  

\[ T_n = \frac{L_m}{bR} \left( \beta - \frac{1}{b} \right) \]  

---

The capacitor is charged in a negative direction with respect to the base lead during the ON phase of operation. The voltage change across the capacitor is given by the equation:

\[ V_C = \frac{E_{cc} - E_c}{b} (1 - e^{-T/RC}) \]

This equation reduces to

\[ V_C = \frac{E_{cc} - E_c}{bRC} \]

if \( T \) is much less than \( RC \).

5.2 Bootstrap Analysis

Analysis of the time base portion of the circuit requires a knowledge of the region in which the transistor, \( T_1 \), operates. The region of operation can be determined by evaluating the transistor biasing network. The biasing circuit, which consists of a diode, \( D_1 \); a capacitor, \( C_1 \); and a voltage source, \( E_b \), is shown in Figure 5.1. The capacitor is charged through the diode and the input circuit of the blocking oscillator when the blocking oscillator is conducting. The capacitor charges toward a voltage \( V_C = E_b + \frac{iD}{b} \frac{Rn}{c} \). The polarity of the voltage across the capacitor is such that the emitter-base junction of the time base transistor, \( T_1 \), is forward biased to establish operation in region II. Thus, the input circuit of the time base generator provides a discharge path for the
capacitor during the blocking oscillator OFF time. The diode prevents the capacitor from discharging through the bias voltage source resistance. If the discharging circuit time constant is much greater than the charging circuit time constant \( R_1 C > R_2 C \) and larger than the blocking oscillator timing period, the voltage across the capacitor can be considered constant. The time base generator input current is therefore held at a constant value.

\[
I_{b1} = \frac{E_b + \frac{I_{b2} T_n}{c}}{re + (\beta + 1)(re + R_e)}
\]

Operation of the transistor, \( T_1 \), is maintained in region II.

It was established in section 5.1 that the blocking oscillator ON state is initiated when the voltage across the capacitor, \( C \), rises to a value, \( V_{CT} \), at which the emitter-base junction of \( T_2 \) is forward biased. The blocking oscillator conducts for \( T_n \) seconds, and the voltage change across the capacitor at the termination of the ON state is \( V_{cn} = \frac{I_{b2} T_n}{c} \). The blocking oscillator portion of the circuit given by Figure 5.1 can therefore be replaced by a switch in series with a voltage source, \( \frac{I_{b2} T_n}{c} \). The switch closes for \( T_n \) seconds each time the voltage across the capacitor equal \( V_{CT} \). The time base transistor is represented by a region II voltage equivalent circuit, and the biasing
circuit is replaced by a voltage source.

\[ F = E_b + \frac{i_b 2T_n}{C} - V_d \quad 5.11 \]

\( V_d \) is the forward voltage drop across the charging circuit diode. The equivalent circuit for the time base generator is presented in Figure 5.3.

![Time Base Generator Equivalent Circuit](image)

**Figure 5.3 Time Base Generator Equivalent Circuit**

It is convenient to describe the transistor voltage, \( \beta_i b_1 r_c \), in terms of the input voltage. This is accomplished by solving the loop equation indicated in Figure 5.3.
\[ i_{bl} = \frac{E - i_{cl}(re + Re)}{rb + re + Re} \quad 5.12 \]

\[ \beta_{iblrc} = \beta_{rc} \frac{F}{rb + re + Re} - \frac{i_{cl}(re + Re)}{rb + re + Re} \quad 5.13 \]

The second term of Equation 5.13 is replaced by a resistance of magnitude \( \beta \cdot r_c \) \( \frac{re + Fe}{rb + re + Re} \). This substitution follows since \( i_c \) is flowing in the loop containing the source.

The circuit of Figure 5.3 does not readily lend itself to analysis. The circuit is therefore simplified by replacing the circuit between the terminals, \( X-X' \) by its Thevenin equivalent. The simplified circuit appears as Figure 5.4.

![Figure 5.4 Simplified Equivalent Circuit](image)
Analysis of Figure 5.4 is considered at the instant the switch opens. The voltage across the capacitor is

\[ V_{co} = V_{ct} - V_{nt} \quad 5.14 \]

The capacitor voltage as a function of time is given by the Equation

\[ E_c(t) = \frac{E_{cc} + \beta E_{rc}}{R_b + r_e + R_e} - E_T - \left[ \frac{E_{cc} + \beta E_{rc}}{R_b + r_e + R_e} - E_T - V_{ct} + V_{nt} \right] e^{-\frac{t}{\tau}} \quad 5.15 \]

where \( \tau = \left[ \frac{r_b + \beta (\frac{r_e + R_e}{R_e + r_b + R_e} + 1)r_c}{C_e} \right] \).

The time required for the capacitor voltage to rise to \( V_{ct} \) is given by Equation 5.17

\[ T_p = \tau \ln \left[ 1 + \frac{i_{b2} T_n}{E_{cc} + \beta E_{rc} - V_{ct}} \right] \quad 5.17 \]

The initial voltage slope is

\[ M = \frac{E_{cc} + \beta E_{rc}}{R_b + r_e + R_e} - E_T - V_{co} \left( \frac{r_b + r_e + r_c (\beta r_e + R_e) + t)}{R_b + r_e + R_e} \right) C_e \quad 5.18 \]

5.3 Summary

The total behavior of the blocking oscillator has now been described. Considerable insight into circuit performance can be gained by making some simplifying approximations. An approximation to the blocking oscillator ON time can be made by assuming that \( r_b + (\beta + 1)(r_e + R_e) \) is very nearly equal to \( \beta R_e \). This assumption is valid if \( \beta \) is large and
Re is large compared with \( r_e \).

\[
T_n = \frac{L_m (\beta^{-1/b})}{b \beta Re} \approx \frac{L_m}{b \beta Re} \tag{5.19}
\]

The significance of Equation 5.19 is that \( T_n \) can be made largely independent of the transistor by a proper selection of \( Re \) and the transistor. The voltage change across the capacitor is highly dependent upon the transistor as is illustrated by Equation 5.20.

\[
V_{cn} = \frac{ib^2 T_n}{C_2} = \frac{(Ec_c - Ec)T_n}{b \beta Re_2 C_2} \tag{5.20}
\]

The equations for the time base generator can be simplified by assuming that \( r_e < r_b < Re_1 \). This is a very good approximation since \( Re_1 \) is in general several thousand ohms. A further assumption is that the transistor source, \( \frac{\beta E r_c}{r_e + r_b + Re_1} \) is much larger than \( E_{cc} - E_t - V_{co} \).

\[
E_c(t) = \frac{\beta E r_c}{Re_1 C_2} \left( 1 - e^{-\frac{R_0}{Re_1 RC_2}} \right) \approx \frac{E_t}{Re_1 C_2} \tag{5.21}
\]

The initial slope on the capacitor is

\[
M = \frac{E}{r_e C_2} \tag{5.22}
\]

The slope of the time base voltage is independent of both the supply voltage and the transistor, \( T_1 \), if \( \beta \) is large.
The blocking oscillator period, \( T_p \), is approximated by Equation 5.23.

\[
T_p = \left( \frac{V_{c+} - V_{c0}}{E} \right) \frac{Re_1 C_2}{C} = \frac{ib_2 T_n}{E} \frac{Re_1 C_2}{E_b + ib_2 T_n C} - V_d
\]  

5.23

Assume now that \( \frac{ib_2 T_n}{C} \) is much greater than \( E - V_d \) or that \( E = V_d \). Equation 5.22 reduces to

\[
T_p = Re_1 C_2
\]  

5.24

Equation 5.24 predicts that the blocking oscillator period is controlled only by fixed components, a very desirable feature. An additional interpretation of Equation 5.24 is that if the voltage across the capacitor, \( C \), changes due to a shift in \( \beta_2 \), the slope of the time base voltage will be changed to compensate exactly for the deviation of \( V_{cn} \), so \( T_p \) does not change.

The extent to which the above assumptions are valid will be evaluated in the following chapter.
CHAPTER 6

EXPERIMENTAL EVALUATION

6.1 Practical Considerations

The output waveforms of the blocking oscillator time base generator are described by the following equations, which were developed in Chapter 5:

\[ |e_p| = E_{cc} - E_c \]  \hspace{1cm} 6.1

\[ T_n = \frac{L_m (\beta - \frac{1}{b})}{b (R_{12} + \beta R_{1e2})} \cdot \frac{L_m}{b R_{1e2}} \] \hspace{1cm} 6.2

\[ |e_s| = E_s = \frac{1b2}{C2} \cdot \frac{T_n}{C2} \] \hspace{1cm} 6.3

\[ T_p = \frac{E_s}{E_s + E_b - V_d} \cdot R_{e1} \cdot C_2 \] \hspace{1cm} 6.4

Equations 6.1 and 6.2 describe the magnitude and duration of the pulse output; and Equations 6.3 and 6.4 predict the amplitude and period of the time base voltage. The purpose of the present chapter is to establish experimentally the performance characteristics of the circuit, and to evaluate the validity and accuracy of the analytic circuit description.
The diagram of the experimental circuit is shown in Figure 6.1.

![Experimental Circuit Diagram]

Figure 6.1 Experimental Circuit

The selection of the indicated magnitudes of circuit components is based on an investigation of Equations 6.1 through 6.4. Consider that a sweep period of 500 microseconds is desired. By Equation 6.4 the period is equal to $R_{e1}C_2$ if the bias voltage $E_b$ is adjusted to equal $V_d$. For $C_2$ equal to .01 micro-farads, $R_{e1}$ must equal 50 k ohms. The magnitude of $C_2$ affects the amplitude of the sweep voltage as shown by Equation 6.3. In addition, Equation 6.2 is based on the assumption that the product
$C_2 (R_{12} + B_{Re})$ is much greater than the pulse duration. A further relationship requires that $T_p \gg B_{1e} C_1 > (R_{12} + B_{2e})C_2$

This is necessary to insure that the bias voltage for the time base portion of the circuit remains almost constant for the duration of the sweep period. It is essential, therefore, that the transistor parameters be obtained to select properly the remaining circuit components.

Evaluation of the transistor parameters ($\beta, R_i$) is accomplished through use of the transistor static characteristics, as described in Chapter 4. Since these parameters are a function of the transistor operating conditions, the operating point of each transistor must be determined.

During the blocking oscillator ON time the collector ($T_2$) is clamped to $E_C$; in effect $E_C$ is the circuit supply voltage. A voltage, $E_{cc} - E_b$, is applied to the circuit input through the transformer coupling. The voltage drop across the emitter resistor, $R_{e2}$, is very nearly equal to $E_{cc} - E_b$, since the voltage across the emitter-base junction is typically several tenths of a volt. The emitter resistor serves as the circuit load, and the blocking oscillator functions as an emitter follower during the conduction period. A graphical construction to determine the circuit operating point is made on the collector output characteristics of the 2N335, as shown in Figure 6.2. The transistor
(T₁) in the time base portion of the circuit also operates as an emitter follower; hence its operating point is located by similar construction. The nominal values of Re₁ and Re₂ are 50k ohms and 120 ohms respectively.

![Common Emitter Output Characteristics](image)

Figure 6.2 Blocking Oscillator Operating Point

The transistor (T₁) operating point must be confined to region II during the blocking oscillator conduction period. This is insured by requiring that \( \frac{E_{cc} - E_c}{b} < E_c \). The transformer turns ratio, b, in the experimental circuit is 2; therefore, for \( E_{cc} = 28 \) volts, \( E_c \) must be greater than 9.3 volts. \( E_c \) is therefore chosen to be 10 volts.
6.2 Experimental Evaluation

The output waveforms for the experimental circuit are pictured in Figure 6.3.

![Sweep Output](image)

**a) Sweep Output**

![Pulse Output](image)

**b) Pulse Output**

**Figure 6.3 Output Waveforms**

$E_b$ is adjusted to equal $V_d$; therefore the predicted period is 500 microseconds. The period of the sweep output is 500 microseconds as shown by Figure 6.3a. To provide further verification of Equation 6.3, the resistor $R_{eq}$ was varied from 10 to 90kΩohms. The results of this evaluation are
shown in Figure 6.4.

The experimental results compare exactly with the predicted results of Equation 6.4. It is noted, however, that the accuracy of measurement for sweep periods up to 500 microseconds was within plus or minus 5 microseconds, while for sweep periods greater than 500 microseconds the accuracy of measurement was plus or minus 10 microseconds. The maximum error is plus or minus two percent.

Further verification of Equation 6.4 was accomplished by keeping $R_{el}$ constant at 50 kilohms and changing the bias voltage, $E_b$, from 0 to 5 volts. The results of this test
appear in Figure 6.5.

The maximum percent error between experimental and analytic curves is 2.5%. The linearity of sweep voltage was evaluated through use of the oscillogram shown in Figure 6.6.
Deviation of linearity is defined by Equation 6.5.7

\[ E_s = \frac{\text{difference in slope at beginning and end of sweep}}{\text{initial value of slope}} \]

By this definition the deviation from linearity of the waveform shown in Figure 6.6. is two percent.

Equation 6.2 predicts the duration of the pulse output. Its validity was tested by measuring the pulse duration for several values of \( R_e \). The experimental results are shown in Figure 6.7.

---

Figure 6.7 Pulse Duration

The pulse duration is calculated from both forms of Equation 6.2, and plotted in the figure. The maximum

---

error obtained with the approximate form of the equation is 9.9%. It is noted that the error decreases as Re₂ increases. The approximate form of the equation is based on the assumption that β Re₂ is approximately equal to r_b + (r_e + Re₂)β. This approximation is in error for the values of Re₂ and β₂ used here. However, as Re₂ is increased the approximation becomes better. The effect of changing the supply voltage for the time base transistor is shown in Figure 6.8.

![Figure 6.8 Supply Voltage Variation](image)

From this figure is seen that no change in sweep duration occurs for supply voltage changes from 3 to 25 volts. As the supply voltage becomes higher its effect is no longer negligible in the charging circuit.
The effect of transistor $\beta$ change is shown in Figure 6.9. For $\beta$ changes from 31.5 to 77 the maximum change in sweep period is 3%.

![Figure 6.9 Transistor Parameters Vs Sweep Period](image)

The effect of supply voltage variation in the blocking oscillator portion of the circuit is given by Figure 6.10.

![Figure 6.10 Supply Voltage Variation](image)
From this figure it is seen that at lower supply voltages considerable change in timing period is obtained. The input voltage to the blocking oscillator during the ON time is $\frac{E_{cc}}{b} - E_a$. At lower values of $E_{cc}$, the input voltage becomes very small. When the magnitude of this voltage is sufficiently reduced, the charging current for $C_l$ (in the time base bias network) is decreased to a point that the diode, $D_l$, is just conducting in the forward direction. Under these conditions the diode voltage, $V_d$, is smaller than normal and is no longer equal to $E_b$. The sweep period is therefore reduced. For fifty percent change in supply voltage (about the nominal value of 28 volts) a maximum change in blocking oscillator period of 8% is obtained. The duration of the pulse output is not affected over the entire range of supply voltage variation.

The effect of transistor parameter variations on the circuit output waveform is shown by means of Figure 6.11.

![Figure 6.11 Transistor Parameter Variations](image-url)
62

\[ \beta \] is changed from 38 to 83. The maximum percent change in a blocking oscillator period is 2%, and the maximum change in pulse duration is 2.02%.

6.3 Summary of Results

The blocking oscillator time base generator has been tested experimentally. The performance characteristics of the circuit are shown in Figures 6.4, 6.5, 6.6, and 6.7. The blocking oscillator sweep period is linearly related to the circuit time constant \( R_c L \). The repetition frequency of the blocking oscillator is linearly related to the bias voltage. The sweep period can be made independent of the supply voltage by adjusting the bias voltage to be equal to the voltage drop across the bias network diode. The effect of supply voltage variation on the sweep duration is ordinarily negligible. As the supply voltage is increased to high values, its effect influences the slope of the sweep voltage and hence the period. Characteristics of the time base output are predicted analytically within 2%. Changes in \( \beta \) of the time base transistor of one hundred percent result in a 2% change in sweep duration.

The pulse output of the blocking oscillator is defined accurately by Equation 6.2. The duration of the pulse output was predicted analytically to within 2.5% of experimentally obtained values. An approximate form of
this equation provides prediction of the pulse output duration to within 10%, even though it completely neglects the parameters of the transistor. The duration of the pulse output has been shown experimentally to be independent of the supply voltage. The blocking oscillator period, however, shows an 8% change at a low supply voltage level. This effect is caused by reduced input drive to the circuit. Changes in the transistor β of 90% result in a 2% change in period and a 2.5% change in pulse duration. It is concluded that the blocking oscillator time base generator is a precision device.
CHAPTER 7
CONCLUSIONS

7.1 Compliance with Objectives

The blocking oscillator time base generator is a circuit which possesses the properties of both the blocking oscillator and the time base generator; the circuit will generate a linear sweep voltage and a pulse of large amplitude and short duration. The output waveforms of the circuit are presented in Figure 7.1. The timing

![Waveforms](image)

a) Sweep Voltage  
b) Pulse

Figure 7.1 Output Waveforms

waveform shown in Figure 7.1a is a linear ramp having a maximum deviation from linearity of two percent. The pulse output is shown in Figure 7.1b.

Analytic techniques which make possible the prediction of these circuit output characteristics
(sweep and pulse duration) to within two and one-half percent have been developed and experimentally verified. The circuit behavior is largely independent of variations in active device characteristics and supply voltage. Equations which neglect the transistor parameters have been developed and evaluated. The circuit outputs can be predetermined with these equations to an accuracy of ten percent. The blocking oscillator time base generator is a precision circuit which can be used to provide a time base voltage having a very short off-to-on time.

7.2 Suggestions for Further Study

The blocking oscillator time base generator has four distinct phases of operation. The ON time and the OFF time were analytically and experimentally evaluated. For the purpose of this thesis, the transition ON and transition OFF were assumed to take place instantly. That this is not true may be verified by an investigation of Figure 7.1b. The short but finite time intervals required to turn the blocking oscillator ON and OFF are shown by the rise time and fall time of the pulse output. An analysis of the circuit behavior in these transition states to determine the turn ON time and the turn OFF time would be useful.
In some applications, it is necessary to provide a current time base rather than a voltage ramp. A specific application is the magnetic deflection of the beam of a cathode ray tube. It has been shown that to produce a linear current sweep in a deflection coil these components of current are necessary: an impulse, a step, and a linear rise. The current requirements for a periodic current sweep are shown diagramatically in Figure 7.2.

Figure 7.2 Required Current Components

---

A close investigation of Figure 7.1a shows that the linear rise and a step component of voltage are present in the sweep voltage output. This suggests that the sweep voltage output can be used to provide a current time base, since the series combination of a resistor and a voltage generator is equivalent to a current generator and a shunt resistor. A means to introduce an approximation of the required impulse component in the sweep voltage output would provide a topic for further study.
BIBLIOGRAPHY


