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DEVELOPMENT OF
C- AND X-BAND
POWER GENERATORS

Report No. 1

Contract DA-36-039-SC90757

First Quarterly Period
1 June 1962 to 31 August 1962

Submitted to

U. S. Army Signal Research
and Development Laboratory
Fort Monmouth, New Jersey

SYLVANIA ELECTRONIC SYSTEMS-CENTRAL
A Division of Sylvania Electric Products, Inc.
175 Great Arrow Avenue
Buffalo 7, New York

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A35-5-5.0-10
5 October 1962

**DEVELOPMENT OF
C-AND X-BAND
POWER GENERATORS**

Report No. 1

Contract DA-36-039-SC90757

Technical Requirement SCL7629A

Dated 7 November 1961

Project 3A99-21-002

First Quarterly Period

1 June 1962 to 31 August 1962

**The objective of this program is to conduct research
work leading to development of C-Band, 10 watt; and
X-Band, 2.5 watt, solid-state power generators.**

Prepared by

J. Kellett

SYLVANIA ELECTRONIC SYSTEMS-CENTRAL

**A Division of Sylvania Electric Products, Inc.
175 Great Arrow Avenue
Buffalo 7, New York**

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1.0 PURPOSE

The purpose of the program under Signal Corps Contract DA-36-039 SC90757 is to conduct research work leading to the development of the following solid-state pulsed-power generators:

- 1). A C-band, 5 gc, 10 watt generator.
- 2). An X-band, 10 gc, 2.5 watt generator.

2.0 ABSTRACT

This report (Report No. 1) covers the first quarterly period (1 June 1962 to 31 August 1962) of Sylvania's program to develop C- and X-band solid-state, pulsed-power generators for the Signal Corps under Contract DA-36-039-SC90757.

The indirect power generation technique employing a transistorized exciter and a cascaded chain of frequency multipliers was selected. The exciter output frequency has been tentatively set at 156.25 mc and the multiplier chain being considered is a cascade chain of six frequency doublers.

The exciter design objectives were established and detailed investigations of oscillator stability under pulsed operation, power amplifier pulsed power gain and pulse generation techniques were initiated.

An analytical treatment of oscillator load impedance variations predicts frequency stability of 1×10^{-6} for the selected configuration. The effect of junction temperature variations upon transistor power gain is treated and an expression for the maximum power output of a transistor is derived.

2.0 An experimental evaluation of the pulse power gain of two transistor
(Cont.) types was conducted and an increased power gain of 25% was observed
for pulsed operation over cw operation.

3.0 CONFERENCES

A project conference was held on 15 August, 1962, at Fort Monmouth, New Jersey. Participants were Messrs. J. Kellett, R. McIntyre, J. Murphy, and G. Voight representing Sylvania and Messrs. V. Boxer, G. Hambleton, and W. Matthei representing USASRDL. At this meeting, the technical requirements of the program and the program status to date were reviewed. In addition, a tentative early November 1962, date was established for a design review.

4.0 FACTUAL DATA

4.1 Introduction

This section contains the results that were obtained during the first quarterly period of Sylvania's C- and X-band pulsed-power generator program conducted under Signal Corps contract DA-36-039-SC90757.

4.2 General Considerations

The design objectives of this program were based upon the state-of-the-art of related programs (for example Signal Corps Contract DA-36-039-SC87330); therefore, these results are compared in table I with the current objectives. The primary differences between the present objectives and previous results are: (1) pulsed, as opposed to CW operation, (2) a ten-fold increase in output power and (3) efficiency increases of 1 percent for C-band and 2 percent for X-band generators.

Table No. I

Comparison of Current Design Objectives
And Previous State-of-the-Art Performance

<u>Characteristic</u>	<u>Unit</u>	<u>Design Objective</u>	<u>Previous Performance</u>
Frequency: C-band	gc	5	4.5
X-band	gc	10	9
Power Output:			
C-band	watts	10 (peak)	1.0 (cw)
X-band	watts	2.5 (peak)	0.3 (cw)
Efficiency (overall):			
C-band	%	5 (peak)	4 (cw)
X-band	%	3 (peak)	1 (cw)
Pulse Repetition Frequency	PPS	100-4000	---
Pulse Width	μ sec	0.5	---
Temperature Coefficient			
C-band	mc/°C	0.00005	0.000001*
Temperature Range	°C	-40 to 60	-20 to 80
Spurious Content	---	30 db below rated output	23 db below rated output

* Oven controlled

4. 2 A program objectives review was conducted early in the period to
(Cont.) define: (1) the method of power generation to be employed, and
(2) critical areas requiring early investigation or extensive development. This resulted in selection of the "indirect" generation technique employing a transistorized exciter and a cascaded chain of six varactor frequency doublers as the method of pulsed-power generation. A preliminary block diagram of the pulsed-power generator is shown in figure 1. The crossover frequency (defined as the transistorized exciter output frequency) for the pulsed-power generators was selected as 156. 25 mc. Since this frequency is also the input frequency to the passive multiplier chain, it represents the highest frequency at which the signal is amplified.

A crossover frequency of 156. 25 mc is considered to be the highest practical frequency for the selected configuration (cascaded chain of frequency doublers having a 10 gc output) using presently available transistors and varactors.

Operation of the exciter at a lower frequency can be accomplished by increasing the number of frequency multipliers in the cascaded chain or increasing the multiplication factor of the first multiplier in the chain. While lowering the exciter frequency results in increased exciter efficiency, it also requires that the exciter output power be increased to compensate for the additional conversion loss of the multiplier chain. While the selection of 156. 25 mc for the exciter frequency appears optimum at this time, it will be reconsidered and may be revised downward as transistor and varactor performance data become available. Power levels indicated in figure 1 assume that doubler conversion efficiencies previously obtained on Sylvania's S- and X-band power generator program can

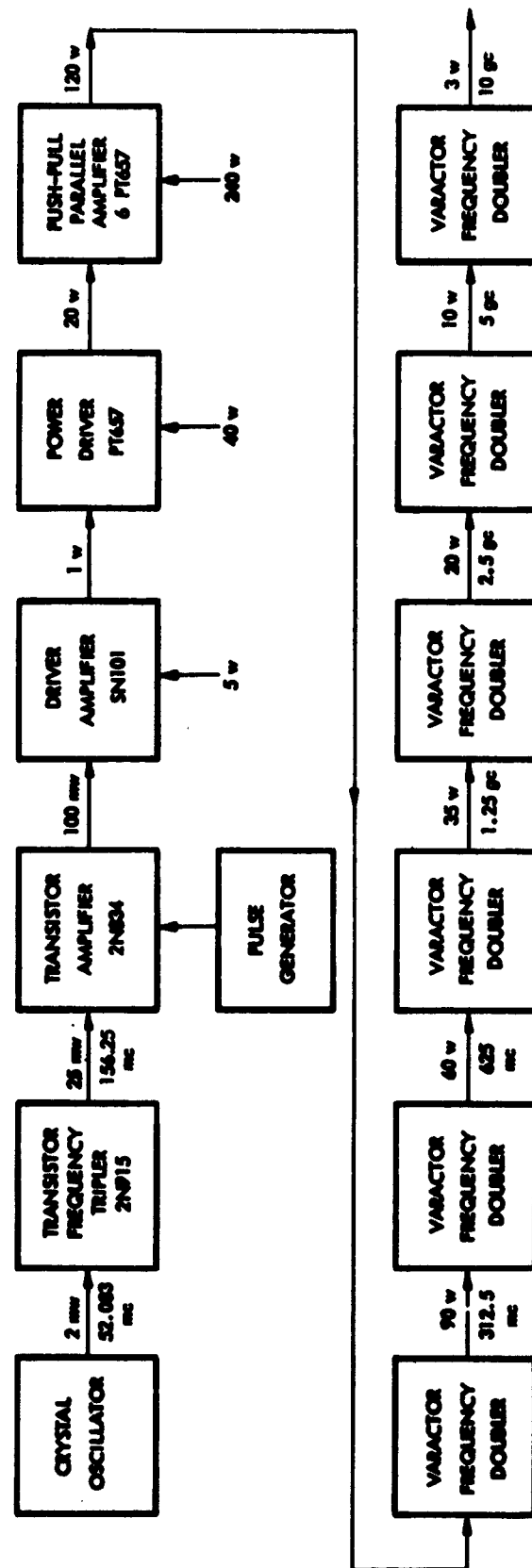


Figure No. 1 Preliminary Block Diagram of Pulsed-Power Generator

4. 2 be maintained at higher power levels and that a 3 db improvement in
(Cont.) transistor power gain can be achieved for pulsed operation as opposed to CW operation.

The transistor pulse power capability and the varactor doubler performance were designated as critical areas requiring prompt attention. Since the power requirement of the varactor doublers is entirely dependent upon the amount of power supplied by the transistorized exciter, the period was directed to investigating the pulsed-power capability of the exciter.

4. 3 Transistorized Exciter

4. 3. 1 Design Objectives

Following are the major design objectives for the transistorized exciter of the pulsed-power generators:

1. Power requirement - 120 watts (maximum)*
2. Pulse width - 0.5 μ sec
3. Repetition frequency - 400 to 1000 pps
4. Frequency - 156.25 mc
5. Oscillator Stability - 0.00005 mc/ $^{\circ}$ C
6. Temperature Range: - 20 to 80 $^{\circ}$ C

(* This value was obtained from extrapolating results obtained on Sylvania's S- and X-Band Program for the Signal Corps under contract DA-36-039-SC87330.)

Figure 2 is a block diagram of the transistorized exciter.

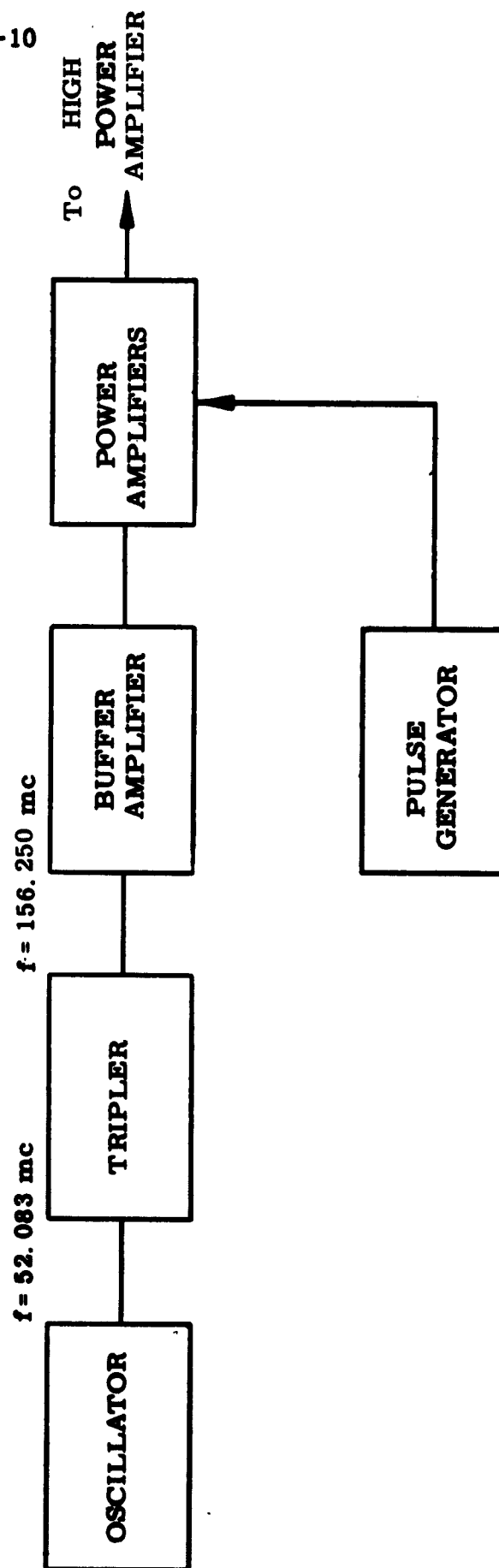


Figure No. 2 Block Diagram, Transistorized Exciter

4. 3. 2 Discussion

4. 3. 2. 1 Power Output

Maximum development effort will be required to attain the required power output specified in the design goals. The desired power of 120 watts at 152 mc is definitely a state-of-the-art objective and the feasibility of achieving this power in a "practical" configuration is dependent to a large degree on the availability of high-frequency, high-power transistors. Current high-frequency, high-power device development programs are being surveyed to determine availability of units for this program.

Present indications are that experimental units having a 25-watt capability at 100 mc may be available early in 1963.

Increased power output in pulsed-mode operation is another major factor to be considered in obtaining the desired power level. A detailed discussion of the effects of pulsing transistors appears in 4. 3. 2. 3.

4. 3. 2. 2 Oscillator Stability

Compliance to the oscillator stability requirement of 0. 00005 mc/°C has previously been demonstrated during Sylvania's S- and X-Band Power Generator program. With minor design changes, for better matching during voltage variations this oscillator will be utilized in the C- and X-Band Pulsed-Power generator. Figure 2 shows the block diagram arrangement of the first three stages of the transistorized exciter.

4. 3. 2. 2 Pulsing of the exciter is to be accomplished in the power amplifier (Cont.) following the buffer stage. To assure that no spurious responses will occur at the output of the varactor multipliers, it is of paramount importance that frequency stability be maintained during application of pulses to the power amplifier. Therefore, it is necessary to insure that load variations at the oscillator are minimum. The oscillator load variation determined in Appendix A to be in the order of 1 percent is not expected to have an adverse effect on frequency stability. Experimental evaluation of the oscillator stability as a function of load variation is presently in process and will be reported on during the next period.

4. 3. 2. 3 Pulsed-Power Gain

An analytical solution of the variation of small signal gain as a function of temperature was conducted to determine the transistor power gain variations with temperature. A power gain variation of 3.4 db was found to exist for a junction temperature variation of 125°C as shown in Appendix B. This gain variation is based on the temperature dependence of transistor parameters and does not necessarily apply to power amplifying devices where maximum collector current and voltage are utilized. Appendix C shows that the maximum power output independent of high frequency effects, is defined by:

$$P_{\max} = \frac{V_{cbo} I_{c \max}}{8}$$

This indicates that in a specified device, no increase in power will be achieved by pulsing or operating at reduced temperatures unless $I_{\max}$ or V_{cbo} are increased. Considerable difficulty is encountered

4.3.2.3 in determining the $I_{c \max}$ value for a specified transistor. This is
(Cont.) an area in which additional investigation will be considered since it
would yield a parameter defining maximum power attainable from
a specified unit.

The following approach was employed to determine the pulsed-power gain available from transistors, particularly the PDT670. The cw amplification capability of the PDT670 was investigated and h_{fe} , as a function of I_c (figure 3), was determined. Curves of power output vs, efficiency, and collector current of a typical unit were plotted and are shown in figure 4.

The maximum cw output from the PDT670 is shown in Table II

To determine the pulsed-power gain from these units, a three-stage amplifier was designed and fabricated to effect pulsing at a low-level stage. Low-level pulsing of r-f power is employed to minimize the effect of input-to-output coupling encountered at higher power levels. A schematic of the three stages is shown in figure 5.

The switching circuit (comprised of Q1 and Q2) is designed so that, in the absence of a pulse, Q1 is biased "off" and Q2 is biased "on". The emitter of Q1 provides the PDT670 base current only during the presence of a pulse thus preventing heating of the transistor when no r-f signal is present. Q2 places the high end of L1 and C1 at ac ground potential except during application of a pulse from the pulse generator.

Typical pulsed-power gains from this amplifier are shown in Table III.

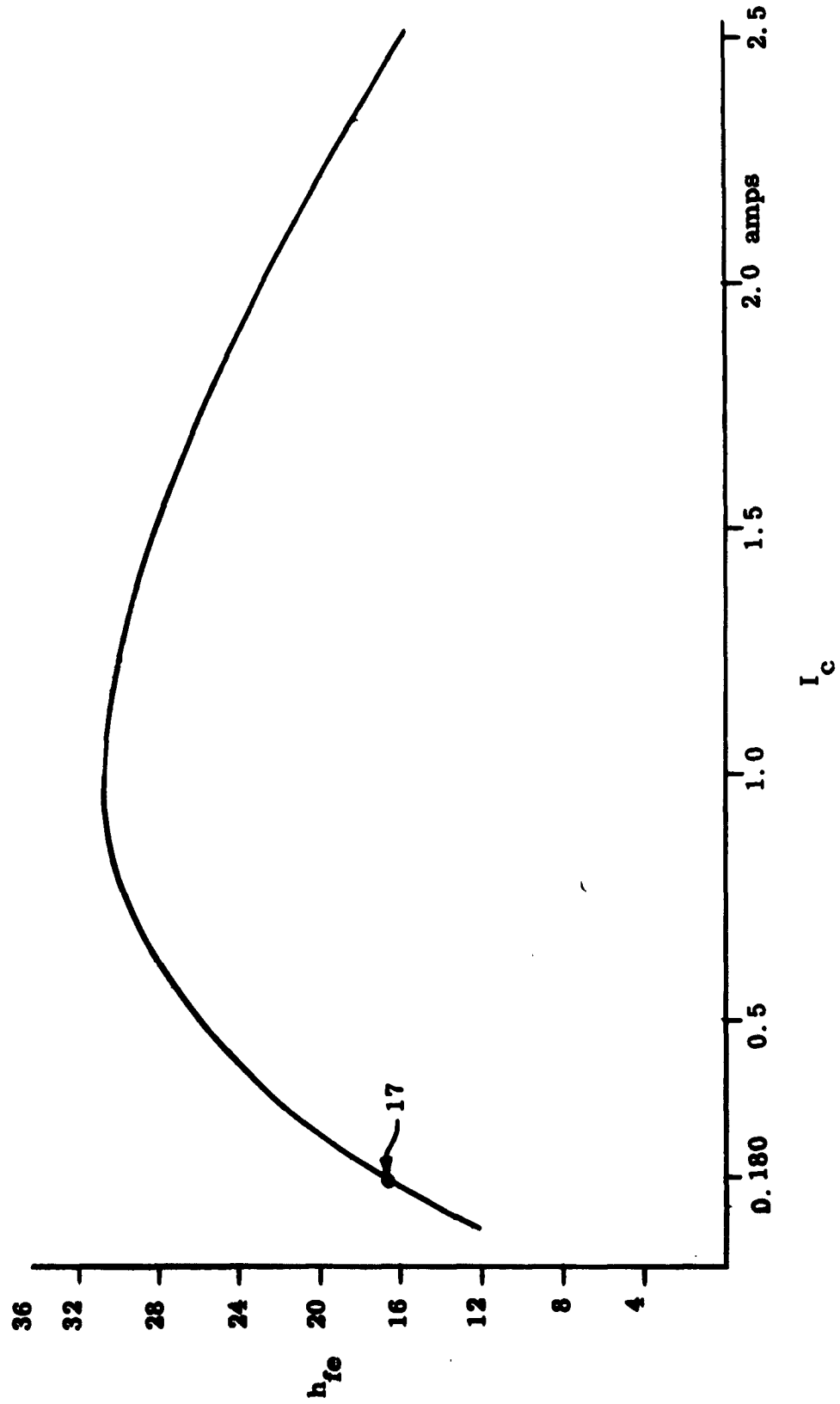


Figure No. 3, h_{fe} vs I_c of a PDT670

I_c = Collector current
 P_o = Output power
 Eff. = Efficiency
 P_{in} = 2 w

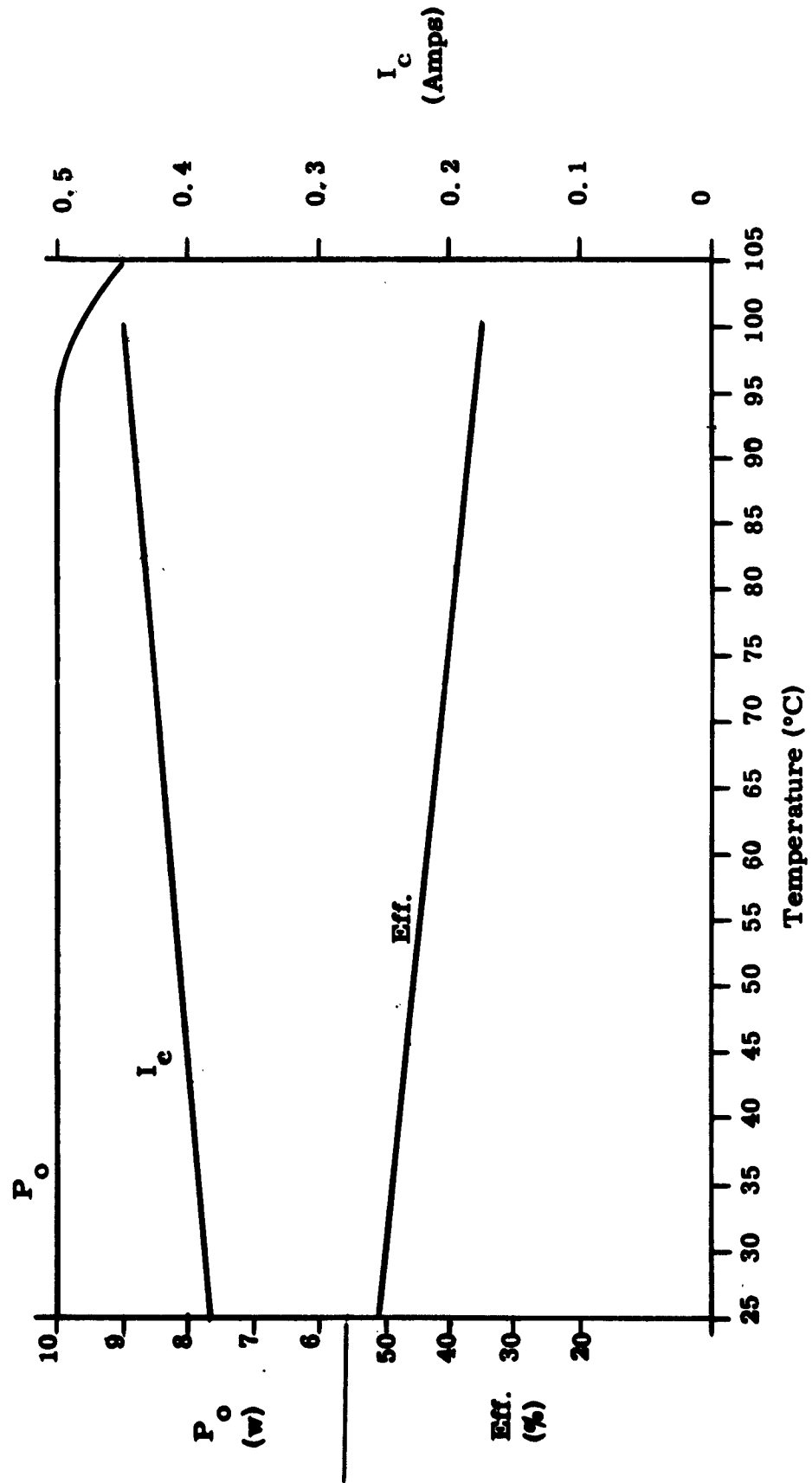


Table II
Performance-PDT 670

Power Out	Power In	V_{cc}	I_c	Eff
11.5 w	4.0 w	50 V	600 ma	38%

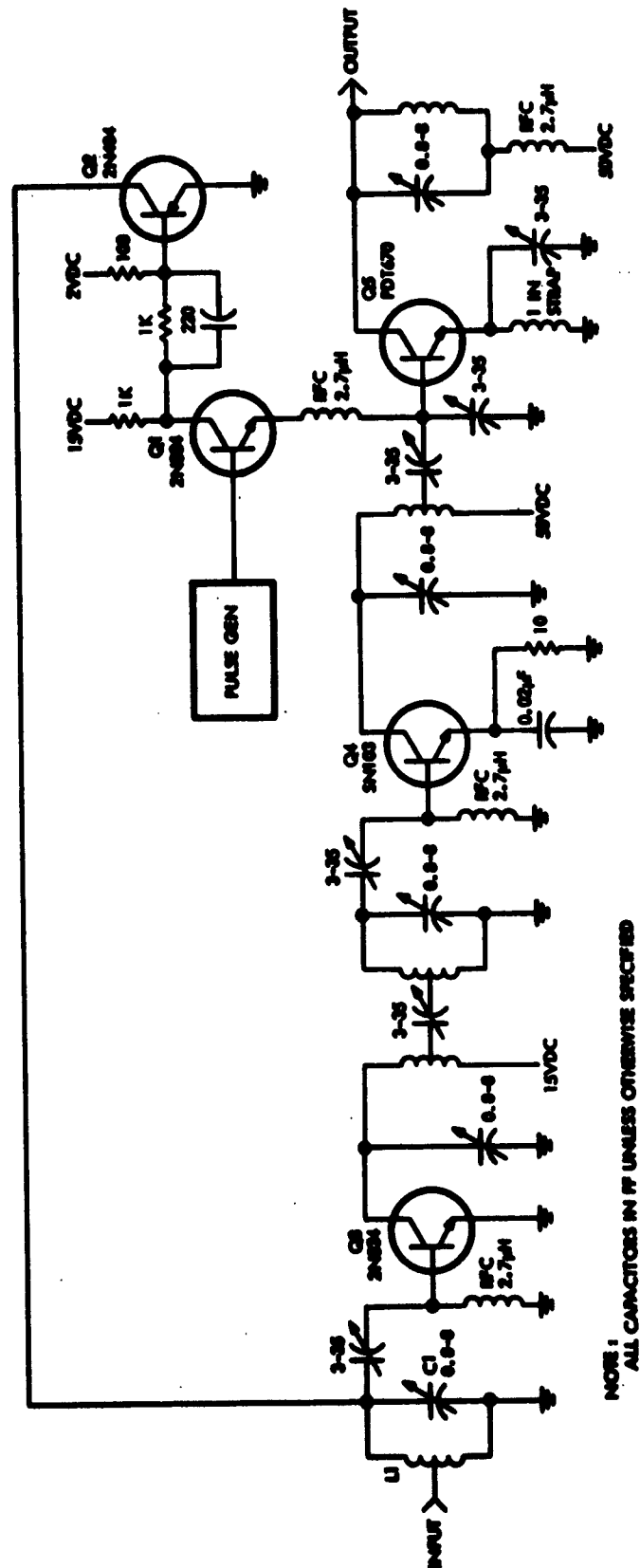


Figure No. 5 Schematic, Three-Stage Pulsed Amplifier

Table III
Three-Stage Amplifier Pulsed-Power Gain

Pulse Width	Peak Power (Exp)	Peak [*] Power (theor)	CW Power (Exp)
1 μ sec	5.0 watts	5.8 watts	5.8 watts
10 μ sec	5.0 watts	5.8 watts	5.8 watts

* Assuming No Increase In Power Gain

4.3.2.3 No discrepancy in the theoretical and experimental results would
(Cont.) be observed if problems such as matching, coupling bias variation,
and interpretation of results could be adequately controlled and
predicted.

To minimize these problems an evaluation of the PDT670 and SN103 was conducted in a single amplifying stage. The SN103 is the electrical equivalent of the TA2084 with which Sylvania's initial pulse investigations were conducted. It was anticipated that the problem of r-f power leakage (resulting from the use of a single amplifying stage) would be less than the additional problems encountered in three amplifiers and test results would be more informative.

Figure 6 shows the block diagram of the test setup utilized in testing the amplifier using the PDT670.

Data obtained at a power input of 0.5 watts is shown in Table IV.

The power output remained unaffected for pulse widths ranging up to 10 μ sec. Maintaining V_{cc} and I_c values the same for both pulsed and cw operation a 0.97 db increase in output power was observed for pulse operation as compared to cw operation.

The Clark SN103 was also tested to determine power output variations in a pulsed mode of operation compared to operation in the continuous mode. A power increase of 0.46 db was achieved for pulsed operation with V_{cc} and I_c held constant in both the cw and pulsed mode of operation. A total increase of 2.5 db was obtained upon increasing the collector voltage to 70 volts. These results are shown in Table V.

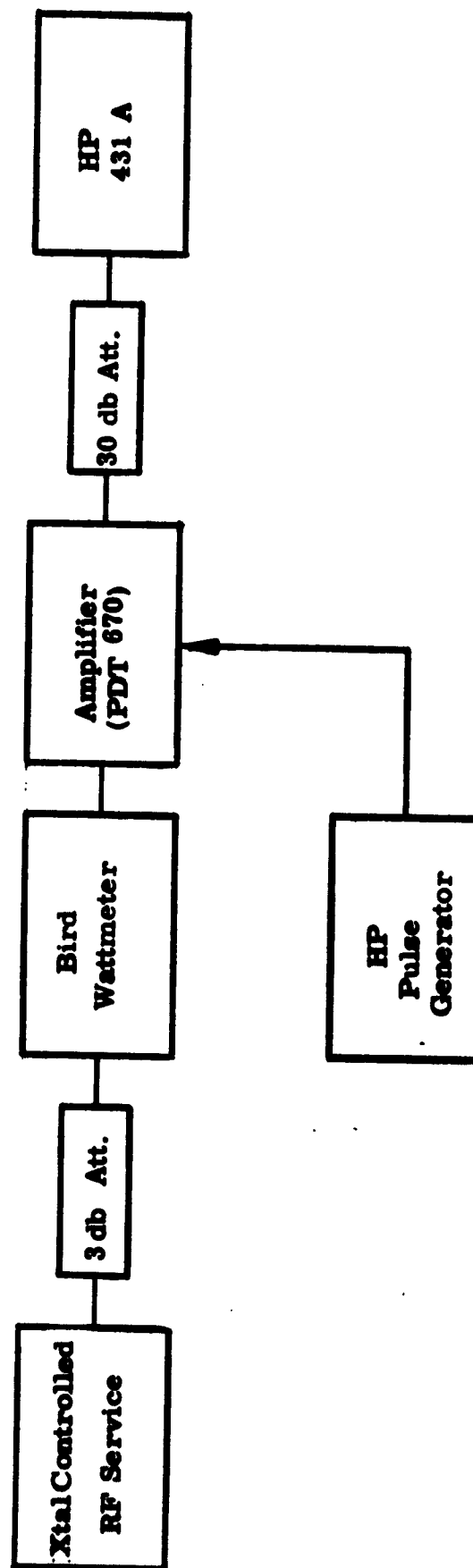


Figure No. 6 (Page 1 of 2) Block Diagram, Test Equipment Configuration

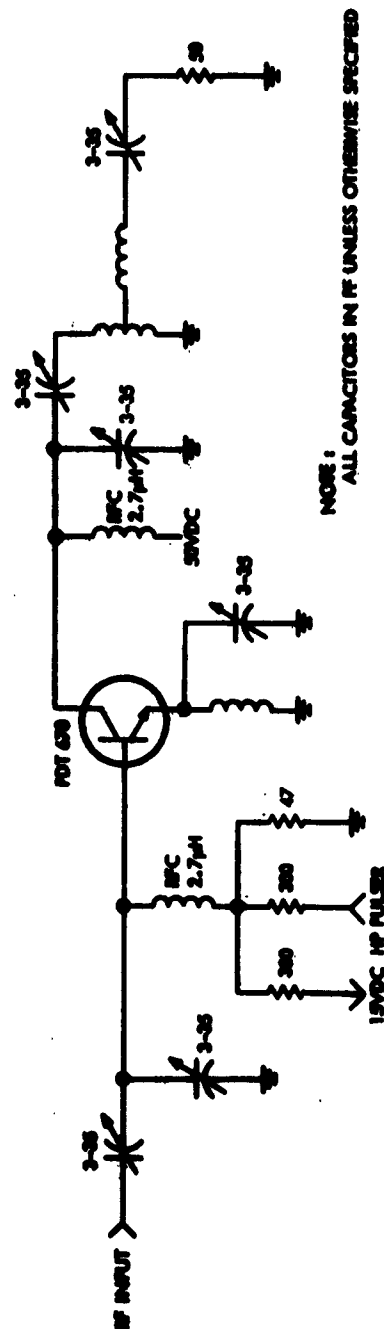


Figure No. 6 (Page 2 of 2) Schematic, PDT670 Power Amplifier

Table IV
PDT670 Power Amplifier Output

Pulse Width	Peak Power Experimental	Peak Power Theoretical	cw Power
4×10^{-6}	5 watts	4 watts	4.0 watts

Table V
SN103 Power Output

Pulse Width	Peak Power Experimental	Peak Power Theoretical	cw Power	V _{cc}
4×10^{-6}	2.5 w	2.2w	2.2w	50 V
4×10^{-6}	4 w	—	—	70 V

4.3.2.3 The SN103 is rated at $V_{cbo} = 140V$ and can be safely operated at
(Cont.) 70V in a pulsed mode. However, for cw operation 70V is not practical due to the high number of catastrophic failures which result. Sylvania has established (through documented experience) that a collector voltage of 50V is realistic for continuous operation of this state-of-the-art device. The major portion of increased power output was obtained when the collector voltage was increased to 70V.

Additional testing is planned to verify results obtained to date; however, it appears that 0.9 db increase in power output is a realistic estimate of the increase in power gain to be anticipated in pulsed operation as opposed to cw operation.

4.3.2.4 Pulse Generator

The pulse generator to be utilized, shown in figure 7, was designed and tested.

The pulse rate is obtained from a MIL-approved uni-junction transistor oscillator. The pulse repetition frequency is continuously variable from 80 to 8335 pps. Q2 and Q3 serve as squaring amplifiers decreasing the rise time of the leading edge of the pulse before differentiation. The differentiated wave is applied to the input of the monostable multivibrator, whose output is a $0.5 \mu\text{sec}$ pulse with rise and fall times of $0.07 \mu\text{sec}$. It is anticipated that after amplification by the switching amplifiers, the rise time will be decreased to $0.03 \mu\text{sec}$.

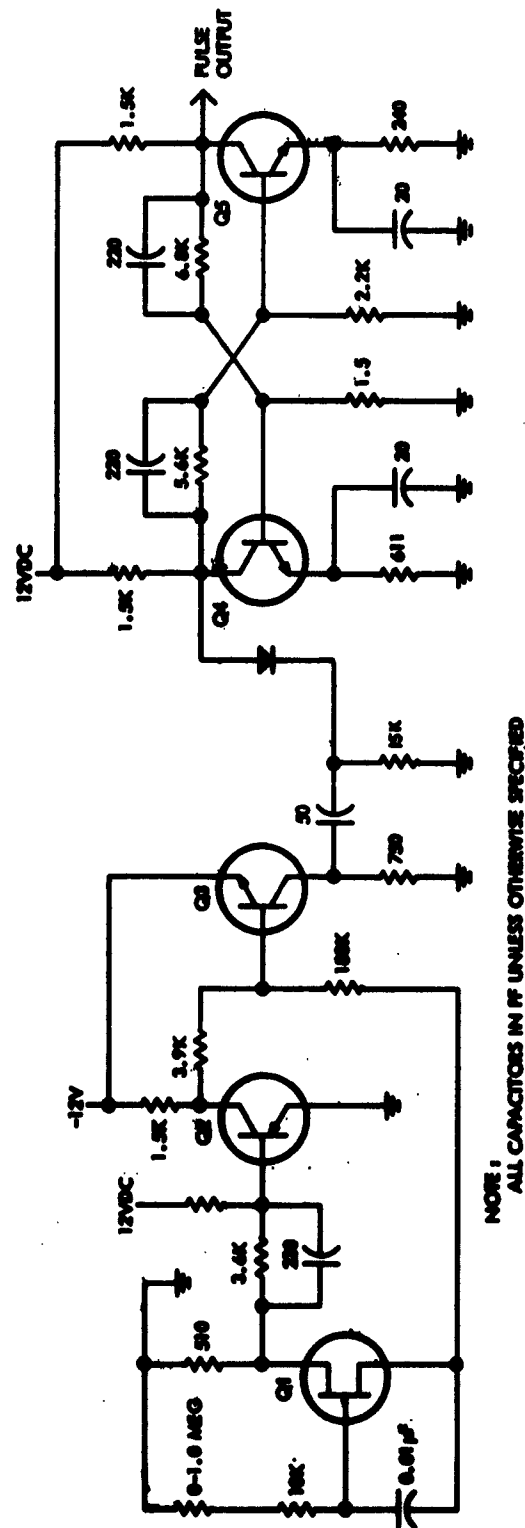


Figure No. 7 Schematic, Pulse Generator

4. 3. 2. 5 Power Amplifier Configuration

Since obtaining the required output power level in a practical configuration is a major design objective of this program, alternate methods of obtaining this power level are being considered. In view of recent developments of high-power varactors (particularly the CK303) various configurations are being considered for a possible revision of the exciter output frequency. Three configurations are compared in Table VI based upon manufacturers specified performance. An evaluation of these devices to verify manufacturers specifications has been initiated and is currently in progress. While configuration "A" appears optimum, based upon circuit complexity, output power capability, and cost, the pulse width requirement of 0.5 μ sec precludes the use of this configuration. It is anticipated that further testing in the pulsed mode of operation will confirm that the specified pulse width of 0.5 μ sec will prohibit the use of high-power transistor or varactor circuits below 50 mc. This is based on the following equation for rise time (t_r) of a single pole resonator to an instantaneously applied r-f signal:

$$t_r = \frac{1}{\Delta f \pi} \quad \text{where: } \Delta f = \text{bandwidth between 3 db points.}$$

To utilize configuration "A" it is anticipated that a pulse width of 1.6 μ sec would be required permitting a rise time equal to one tenth of the pulse width at an r-f frequency of 10 mc. Configuration "A" is limited to 10 mc operation if the power output capability of the PT900 is to be retained.

Table VI
Configuration Comparisons

Configuration	Stage	Power In	Power Out	#Transistor	#Var.	X	Eff.	Freq. Out
A	1	3	30	1**	0	1	60%	9.765 mc
	2	30	250	4**	0	1	60%	9.765 mc
	3	250	200	0	2	4	80%	39.0625 mc
	4	200	120	0	2	4	60%	156.25 mc
Totals		120		5*	4			
B	1	3	12	1*	0	1	60%	78.125 mc
	2	12	42.5	4*	0	1	60%	78.125 mc
	3	42.5	170	12*	0	1	60%	78.125 mc
	4	170	120	0	2	2	70%	156.25 mc
Totals		120		17*	2			
C	1	3	14	2*	0	1	60%	156.25 mc
	2	14	42	4*	0	1	60%	156.25 mc
	3	42	120	12*	0	1	60%	156.25 mc
Totals				18	0			

** PT900

* PDT657/670

4.3.2.5 Since it is anticipated that configuration "A" will not be used
(Cont.) (based on bandwidth consideration) future effort will be directed
to comparing configurations "B" and "C" for use as the final
exciter design.

4.3.2.6 Frequency Multiplier

A search for high-power varactors was initiated and two CK303
varactors (having typical characteristics of $C_{\min} = 7 \text{ pf}$,
 $f_{\text{cvb}} = 6 \text{ gc}$, $V_b = 800\text{V}$) were obtained and investigated in a
150 to 300 mc multiplier circuit. While this effort was initiated
during the period, only preliminary results have been obtained.
The best conversion efficiency obtained for two CK303 varactors
in a push-push doubler configuration was 25 percent over an input
power range of 8 to 20 watts. Since the anticipated conversion
efficiency of 75 percent (based on varactor characteristics) was
not achieved, the investigation will be continued into the second
quarterly period.

A preliminary investigation of the frequency multiplier chain was
conducted to determine the areas where improvements would be
most advantageous. Figure 8 is a functional description of a
typical frequency multiplier.

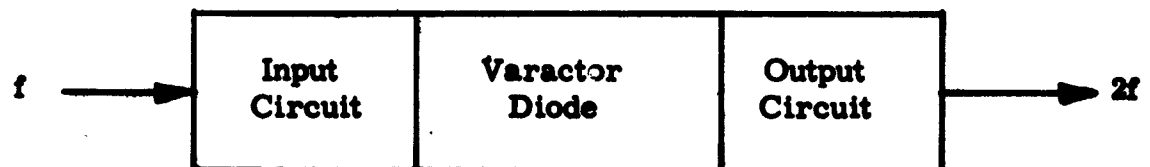


Figure No. 8 Functional Diagram, Typical Frequency
Multiplier

4. 3. 2. 6 The overall efficiency of the multipliers would be the product of the
(Cont.) efficiencies in the input, diode and output circuits:

$$P_o = P_{in} N_i N_d N_o$$

Using this functional diagram as representative of a single doubler, the complete multiplier chain may be represented as in Figure 9. Based on tentative varactor selections the theoretical efficiencies of the diode operating as a doubler was obtained for each stage. The efficiencies of the input and output circuits were determined by dividing the overall efficiencies obtained from similar doublers by the theoretical efficiencies of the diode and dividing the losses equally between the input and output coupling circuits. This can be expressed as:

$$N_{in} = N_{on} = \sqrt{\frac{N_{mn}}{N_{dn}}}$$

where: N_{in} = efficiency of Nth input coupling circuits
 N_{on} = efficiency of Nth output coupling circuits
 N_{mn} = overall efficiency of the Nth doubler obtained by comparison with efficiencies measured on similar doublers
 N_{dn} = calculated theoretical efficiency of diode operating as a doubler.

Efficiencies obtained from these calculations are given in the top row within the respective multipliers on figure 9. The power levels required throughout the six doublers are illustrated by the solid steps. These power levels were calculated for an X-band output power level of 3 watts.

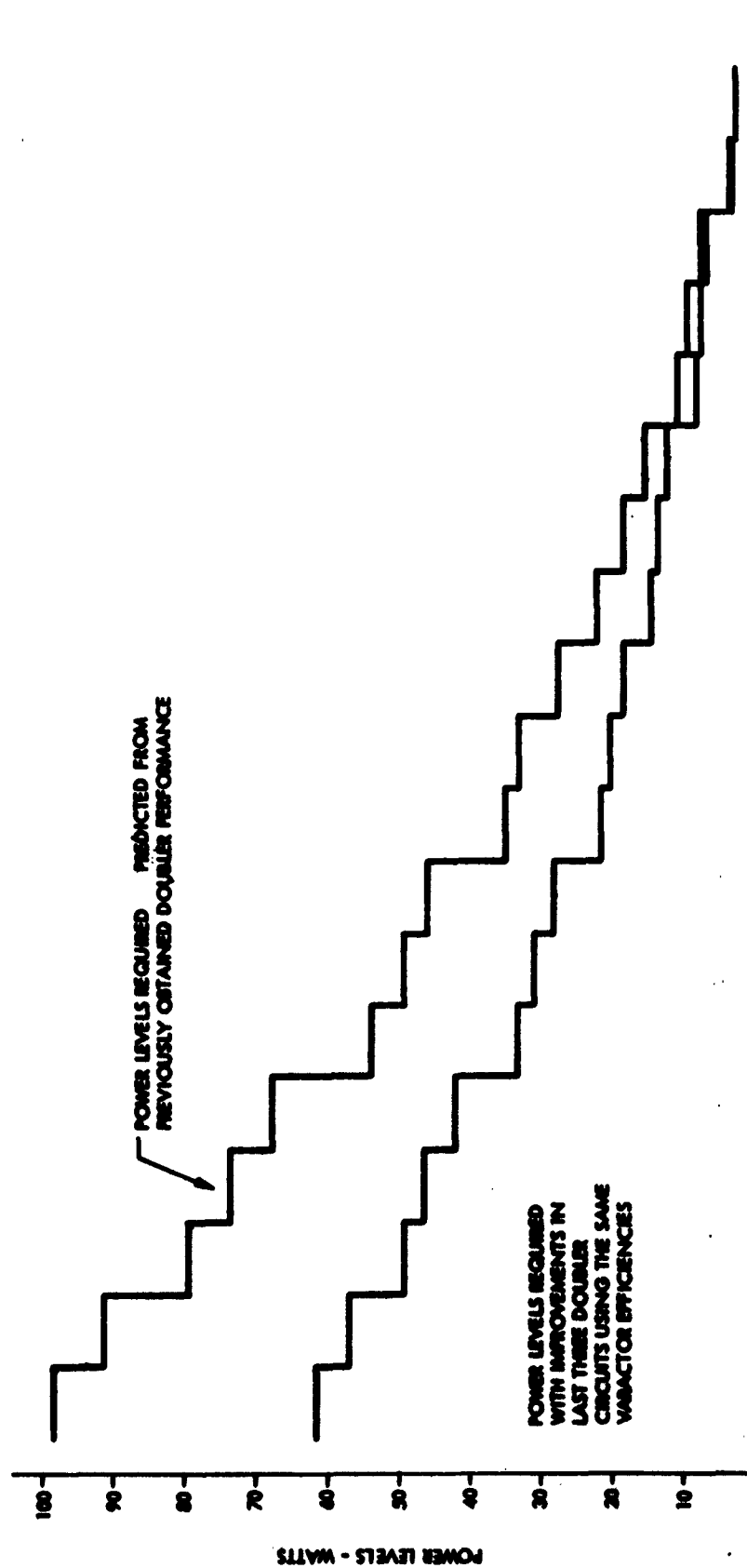
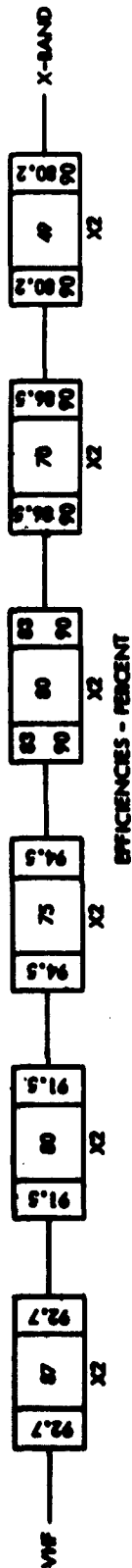


Figure No. 9 Frequency Multiplier Chain Performance Chart

4.3.2.6 To illustrate the magnitude of the improvements which may be
(Cont.) obtained by improved coupling circuits, the power levels for
an assumed coupling efficiency of 90 percent for the last three
doubblers using the same varactor diode efficiency are also plotted.
It should be noted that coupling efficiencies greater than 90 percent
have been obtained in the first three doublers.

It is also important to note that any improvement in the last few
stages allows a large reduction in the total amount of power re-
quired from the preceeding stages.

This reduction in power handling requirements can be capitalized
upon by either reducing the number of diodes per stage or increasing
the operating efficiency of the diode by using varactors having higher
cutoff frequencies with the inherent lower power handling capability.

5.0 SUMMARY AND CONCLUSIONS

The "indirect" method of power generation was selected and the
crossover frequency was tentatively established at 156.25 mc. The
frequency multiplier chain will be comprised of six frequency doublers.
The transistor power amplifier initially was expected to require six
PDT 670/PT 657 transistors in parallel to obtain the required power
output, based on the anticipated 3 db improvement over the cw
capability for pulsed operation.

Testing to date has yielded an improvement of only 0.97 db and is
considered to be an accurate estimate of the output power increase
achievable in a pulsed-mode of operation. The absence of the
anticipated 3 db improvement in pulsed-power gain mandates in-
creasing the number of transistors in the last power amplifier
stage to 12 units to obtain the required power output. The significant

5.0 increase in transistors required prompted an investigation to deter-
(Cont.) mine alternate methods of achieving the output power. Configuration
"A" of Table VI employing five transistors and four varactors is
considered optimum based on circuit complexity and output power
capability. However, utilization of this configuration requires
lowering the crossover frequency to 9.76 mc which prohibits use
of a pulse width of less than 1.6 μ sec duration due to bandwidth
limitations imposed by circuit requirements.

The realization of an exciter configuration employing 12 parallel
transistors in the final stage appears to be beyond the scope of the
program at this time. An exciter configuration employing six
parallel transistors in the final stage and producing 60 watts of
pulsed output power at 156.25 is being considered.

The input power to the multiplier chain is significantly dependent
upon the conversion efficiencies of the last three multipliers. If
input and output coupling efficiencies of 90 percent can be obtained,
for each of the last three multipliers, the input power requirement
to the multiplier chain will be reduced from 100 watts to 60 watts.
Since this value is compatible with the predicted output power from
a practical exciter configuration future effort will be directed to
achieving high input and output coupling efficiencies for the multiplier
circuits.

6.0 PROGRAM FOR NEXT QUARTER

During the next quarterly period, effort will be directed to investi-
gation and development of the individual multipliers in the frequency
multiplier chain. In particular, techniques for achieving multiple
varactor doubler circuits with minimum input and output coupling losses
will be developed.

6.0 The optimum output frequency for the transistorized exciter will
(Cont.) be determined and the pulse performance of the exciter breadboard
will be evaluated.

Effort to closely monitor developments in, and availability of, high power-high frequency transistors and varactors will continue.

7.0 IDENTIFICATION OF PERSONNEL

Key personnel contributing to this project are listed below, along with the approximate number of manhours of effort expended by each during the period covered by this report.

- | | | | |
|----|-------------|-----------------------------|-----------|
| 1. | W. Maciag | - Department Manager | 12 hours |
| 2. | J. Kellett | - Advance Research Engineer | 100 hours |
| 3. | R. McIntyre | - Senior Engineer | 390 hours |
| 4. | K. Baker | - Engineer | 66 hours |

**Walter J. Maciag - Department Manager, Microwave Equipment
and Techniques Department**

Mr. Maciag received his A. S. degree from Erie County Technical Institute in 1951 and his B. S. E. E. degree from the Massachusetts Institute of Technology in 1955. He has since completed his academic requirements for the M. S. degree at the University of Buffalo and is pursuing further graduate studies.

Since joining Sylvania in 1955, Mr. Maciag has engaged in research, design, and development of microwave components and systems. He has served as a project engineer on a number of solid-state, microwave transmitter programs for the Air Force.

7.0 **Mr. Maciag is a member of Tau Sigma, the American Rocket**
(Cont.) **Society, the IRE and the Professional Groups on Microwave Theory**
 and Techniques, Military Electronics, Space Electronics and
 Telemetry, and Communication Systems.

James D. Kellett - Advanced Research Engineer
 Microwave Equipment and Techniques Department
 Microwave Communication Laboratory

Mr. Kellett received his B. S. E. E. degree from Rensselaer
Polytechnic Institute in 1957 and has taken graduate work at North-
eastern University.

After joining Sylvania in 1957, Mr. Kellett was engaged in research
and development on microwave components for countermeasures
systems. In addition to switching techniques he has been engaged
in investigating high frequency power generation utilizing tunnel
diodes and varactor multipliers.

Mr. Kellett is a member of the IRE and the Professional Group on
Microwave Theory and Techniques, and is an associate member of
Sigma Xi.

Robert C. McIntyre - Senior Engineer
 Microwave Equipment and Techniques
 Department
 Microwave Communication Laboratory

Mr. McIntyre received his B. S. E. E. and M. S. E. E. from the
Missouri School of Mines and Metallurgy in 1959 and 1960, respec-
tively.

7.0 Upon joining Sylvania in 1960, Mr. McIntyre was engaged primarily
(Cont.) in Analog Transistor Circuit Design and Development. He has
 actively participated in system analysis and evaluation, self verifica-
 tion studies, and is currently investigating transistor pulse effects.

Mr. McIntyre is a member of the IRE and Eta Kappa Nu.

Kenneth E. Baker - Engineer, Microwave Equipment and Techniques
 Department
 Microwave Communication Laboratory

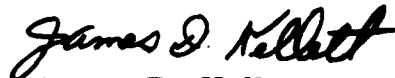
Mr. Baker received his B. S. E. E. from Syracuse University in 1960.
He is currently studying for his M. S. E. E. at the University of Buffalo.

Since he joined Sylvania in June 1960 Mr. Baker has carried out a
study to determine a practical method of predicting the VSWR of a
system of microwave components. He has participated in the develop-
ment of an X-band parametric amplifier and investigated coherent
power summing techniques at S-band frequencies.

His most recent efforts have been the theoretical investigation and
experimental verification of microwave techniques for summing r-f
powers under conditions of failure.

He is a member of the IRE and belongs to the professional groups on
Microwave Theory and Techniques and Antennas and Propagation.
He is also a member of Eta Kappa Nu.

Respectfully submitted



James D. Kellett
Project Engineer
Sylvania Electronic Systems-Central

APPENDIX A

INFLUENCE OF OSCILLATOR LOAD VARIATIONS UPON STABILITY

To determine the impedance variation at the output of the oscillator, the reflected impedance of the buffer and the tripler must be calculated. Based on figure 2, a load impedance variation of zero to infinity at the buffer output was assumed. The reflected impedance through the tripler to the output of the oscillator was determined.

The small signal parameters of the 2N916 utilized in the buffer and tripler are:

$$Y_{11} = (12 + j12)10^{-3}$$

$$Y_{12} = -(0.5 + j2.5)10^{-3}$$

$$Y_{21} = (10 - j45)10^{-3}$$

$$Y_{22} = (1 + j5)10^{-3}$$

The buffer amplifier input impedance is defined as:

$$Z_{in} = \frac{1 + Y_{22} Z_1}{Y_{11} + \Delta Y Z_1}$$

where:

$$\Delta Y = Y_{11} Y_{22} - Y_{21} Y_{12}$$

$$Z_{in} \Big|_{Z_L = \infty} = \frac{1}{Y_{11} - \frac{Y_{21} Y_{12}}{Y_{22}}}$$

$$Z_{in} \Big|_{Z_L = 0} = \frac{1}{Y_{11}}$$

$$Z_{in} \Big|_{Z_L = \infty} = 43.3 + j25$$

$$Z_{in} \Big|_{Z_L = 0} = 41.6 - j41.6$$

With a typical coupling network the tripler tuned load incurs an increase in Q of 20 percent and a resonant frequency change of 7 percent for the above variation in buffer input impedance. Since the tripler load is tuned to three times the input frequency, it reflects an inductive reactance approximately equal to $1/10$ of the load impedance at the input. Thus, the following inequalities exist in the tripler:

$$1 > Y_{22} Z_L \quad \text{where: } |Z_L| = \left(\frac{R_o \text{ (at the third harmonic)}}{10} \right)$$

$$Y_{11} > \Delta Y Z_L$$

This results in a tripler input impedance variation on the order of 1 percent. Oscillator stabilities of 2×10^{-6} for a 2:1 load variation are realizable with transistor oscillators; therefore, the anticipated 1 percent variation is expected to have negligible effect on the oscillator frequency.

APPENDIX B

POWER GAIN VARIATION AS A FUNCTION OF TEMPERATURE

To determine gain variations as a function of temperature, parameter values as a function of temperature were obtained from a study made by W. W. Gartner.¹ Gain was determined for a temperature variation of 125°C. While the device considered in this analysis does not possess the same parameters as transistors currently utilized in experiments the results are indicative of silicon transistors in general. The parameters of the transistor are:

$$\begin{aligned} h_{11} &= m_{11} + jn_{11} = 172 + j135 & h_{12} &= m_{12} + jn_{12} = (0.8 + j5)10^{-3} \\ h_{21} &= m_{21} + jn_{21} = -0.35 + j0.58 & h_{22} &= m_{22} + jn_{22} = (4 + j20)10^{-6} \end{aligned}$$

The expression for maximum available gain is:

$$G_{\max} = \frac{|h_{21}|^2}{m_{11} m_{22} [(1 + \theta_M)^2 + \theta_n^2]}$$

where:

$$\theta_n = \frac{m_{12} n_{21} + m_{21} n_{12}}{2 m_{11} m_{22}}$$

$$\theta_m = \sqrt{1 - B - \theta_n^2}$$

$$B = \frac{m_{12} m_{21} - n_{12} n_{21}}{m_{11} m_{22}}$$

1 W. W. Gartner, "Temperature Dependence of Junction Transistors," Proc. IRE, Vol. 45, P662.

The resulting power gains are:

$$G_{\max}/_{25^{\circ}\text{C}} = 17.75 \text{ db}$$

$$G_{\max}/_{150^{\circ}\text{C}} = 14.12 \text{ db}$$

Table B-I
Gain Variations

Temp.	Gain	h_{21}	m_{11}	m_{22}	$(1 + \theta_M)^2 + \theta_n$
25°C	17.75 db	0.462	172	4×10^{-6}	10.976
50°C	14.12 db	0.436	370	4.5×10^{-6}	10.138

Conclusions: h_{21} remains essentially constant over the considered temperature range. The term $[(1 + \theta_n)^2 + \theta_n^2]$ in the expression for $G_{\max}$ shows a relatively small change. The primary determining factor in gain variation is m_{11} , the real part of the input impedance. As the junction temperature increases from 25 to 150°C the $\text{Re}(h_{11})$ varies from 172 to 370 ohms. This ratio expressed in db is $10 \log \frac{370}{170} = 10 \log 2.17 = 3.38 \text{ db}$ accounting for all but a 0.25 db variation in gain.

The short-circuited input impedance is:

$$h_{11} = R_{bs} + \frac{R_e^1}{1 - \alpha}$$

A major portion of the variation in gain can be attributed to the variation of the base-spreading resistance (R_{bs}) since $R_e^1 \ll R_{bs}$. Thus a plot of Z_{in} (vs) temperature can be utilized to determine the optimum point to match an amplifier required to function over a specified temperature range.

APPENDIX C

TRANSISTOR MAXIMUM POWER OUTPUT

The theoretical maximum power output for class B operation can be achieved as a function of voltage breakdown (V_{cbo}) and peak collector current (I_{cm}).

The expression for collector current is assumed to be:

$$i_c = I_{cm} \cos \omega t \quad - \quad \frac{\pi}{2} < \omega t < \frac{\pi}{2}$$

$$i_c = 0 \quad \frac{\pi}{2} < \omega t < \frac{3}{2} \pi$$

The average value of collector current is:

$$I_c = \frac{1}{2\pi} \int_0^{2\pi} i_c d(\omega t)$$

$$I_c = \frac{I_{cm}}{\pi}$$

The fundamental component of the collector current is, from Fourier Analysis, :

$$I_{cim} = \frac{1}{\pi} \int_0^{2\pi} i_c \cos \omega t d(\omega t)$$

$$I_{cim} = \frac{I_{cm}}{2}$$

The fundamental component of voltage developed across the load is:

$$E_{cim} = I_{cim} R_L$$

The fundamental power output of the device is:

$$P_o = I_{ci}^2 R_L \quad \text{where:} \quad I_{ci} = \frac{I_{cim}}{\sqrt{2}}$$

The maximum voltage which can be applied to the device is:

$$\frac{V_{cbo}}{2}$$

The relationship between V_{cbo} and $I_{cim} R_L$ is:

$$\frac{V_{cbo}}{2} = I_{cim} R_L = \frac{I_{cm}}{2} R_L$$

Thus,
$$P_o = \frac{I_{cm} V_{cbo}}{8}$$

This is the maximum power output obtainable neglecting high frequency effects and thermal considerations. It can be utilized as a figure of merit for high-power devices when an accurate method for determining I_{cm} is obtained.

Sylvania Electric Products Inc., Amherst Laboratories, Buffalo, N. Y.
DEVELOPMENT OF C- AND X-BAND POWER GENERATORS

Rept. for 1 June - 31 Aug 62 on r-f Power Generators
by J. Kellett. 5 Oct 62, 42 p. incl. 9 illus, 7 tables, 1 ref.

(Rept. no. A35-5-5.0-10)

(Contract DA-36-039-SC90757)

Unclassified report

DESCRIPTORS: Electronic Circuits, *Microwave Networks, *Oscillator Circuits, *Tuned Circuits, *Frequency Stabilizers, *Microwave Equipment, *Radiofrequency Generators, *Microwaves, *Radiofrequency Oscillators, *Radiofrequency Power, Crystal Oscillators, *Microwave Oscillators, Oscillators, *Radiofrequency Oscillators, Radio Equipment, Radio Transmitters, Electronics, *Semiconductors, *Transistors, Transmission Lines, Waveguides.

The objective of this program is to conduct research work leading to development of C-Band, 10 w; and X-Band, 2.5 w, solid-state power generators. The "indirect" power generation technique employing a transistorized exciter and a cascaded chain of frequency multipliers was selected. The exciter output frequency was tentatively set at 156.25 mc and the multiplier chain being considered is a cascade chain of six frequency doublers. Design objectives were established and detailed investigations of oscillator stability under pulsed operation, power amplifier pulsed power gain and pulse generation techniques were initiated. An analytical treatment of oscillator load impedance variations predicts frequency stability of 1×10^{-6} for the selected configuration. The effect of junction temperature variations upon transistor power gain is treated and an expression for the maximum power output of a transistor is derived. An experimental evaluation of the pulse power gain of two transistor types was conducted and an increased power gain of 25% was observed for pulsed operation over cw operation.

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