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Quarterly Progress Report No. 1  
October 1, 1962 to December 31, 1962  
Report No. 1

# Study of Phase-Shift Amplifier Techniques

D. K. Adams

## COOLEY ELECTRONICS LABORATORY

Department of Electrical Engineering  
The University of Michigan



# 407172

Department of the Army Task No. 2244-731-17  
Contract No. DA-36-039 AMC-00059(E)  
U. S. Army Electronics Research and Development Laboratory  
Fort Monmouth, New Jersey

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STUDY OF PHASE-SHIFT AMPLIFIER TECHNIQUES

by

D. K. Adams

Approved by   
B. F. Barton

for

COOLEY ELECTRONICS LABORATORY  
Department of Electrical Engineering  
The University of Michigan  
Ann Arbor

The object of this study is to conduct a theoretical  
and experimental investigation of phase-shift amplifier techniques.

Department of the Army Task No. 2Z44-031-17  
Contract No. DA-36-039 AMC-00059(E)  
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## 1. PURPOSE

1. 1 Continue and extend basic study of the phase-modulation technique to obtain low-noise, broadband, RF amplification. This work includes but is not limited to examination of existing limitations and how best to pair off these limitations to optimize the over-all amplifier.

1. 2 Study the use of subharmonic and multiple pumping to obtain improved characteristics.

1. 3 Study the use of electron beams as a modulating component for extension of the technique to microwave frequencies.

1. 4 Study use of other nonlinear storage media such as plasmas, ferrites, or other possible devices for unique characteristics, advantages, or disadvantages.

1. 5 Study use of the phase-shift techniques to enable design of mixer assemblies with broadband, low-noise gain.

## 2. ABSTRACT

Progress has been made in studying simple-varactor, multiple-varactor and ferrite-core phase-shift amplifiers. A single-varactor amplifier has been built in an optimum structure. The latter operates in the reflection mode with a circulator. The principle weakness of this structure was the diode detector, so considerable study has been made of this detector. Efficiencies in excess of 50 percent have now been measured.

Study has also been made of a transmission line periodically loaded with varactors to see what benefits this technique will provide. A suitable structure has been designed and is being tested.

Also described are ferrite core techniques, which are being used to investigate phase-shift amplifiers with multiple pumping. A related effect, employing subharmonic oscillations to increase gain, is also discussed.

**3. PUBLICATIONS, LECTURES, AND CONFERENCES**

**There is nothing to report in this section for the period.**

#### 4. GENERAL DESCRIPTION OF PHASE-SHIFT AMPLIFIERS

A phase-shift amplifier is a device in which the phase of an RF wave is varied by passing the wave through an energy-storage medium whose properties vary due to a modulating signal. Gain can result when the modulated RF power exceeds the modulating power. For an ideal (i. e., lossless) medium, gain can always be obtained, but since any real medium has loss, the potential of the phase-shift principle must be examined under a variety of circumstances.

Figure 1 shows a general representation for the phase-shift amplifier. A transmission line is loaded with a nonlinear energy-storage medium (i. e., a dielectric, ferrite, plasma or semiconductor). When a modulating signal is applied to the line, its electrical length changes which phase-shifts the incident RF (i. e., pump) wave. The amount of modulated RF energy will be proportional to the incident RF power, which can be quite large in many cases. Therefore, a phase detector at the end of the line can receive an amplified version of the modulating signal, and the gain will be proportional to the incident RF level.

To form a simple analysis of Fig. 1, assume that  $V_s$  influences  $\beta$  more than  $\alpha$ , when  $V_s$  is small, so  $\alpha$  can be considered constant. Then

$$V_2 \cong V_1 e^{-\alpha l} e^{j\beta l} \left[ 1 + j l \left( \frac{\partial \beta}{\partial V_s} \right) V_s \right] \quad (1)$$

The phase detector responds to the increment

$$\left| \Delta V_2 \right| = l V_1 V_s \left( \frac{\partial \beta}{\partial V_s} \right) e^{-\alpha l} \quad (2)$$

Therefore, the maximum modulation power that can be delivered to the phase detector is

$$\frac{1}{2} \left[ l V_1 V_s \left( \frac{\partial \beta}{\partial V_s} \right) e^{-\alpha l} \right]^2 Y_1 \quad (3)$$

Since the available signal power is

$$\frac{1}{8} V_s^2 / R_s \quad (4)$$

the transducer gain is

$$G_T = 4 \left[ \ell V_1 \left( \frac{\partial \beta}{\partial V_s} \right) e^{-\alpha \ell} \right]^2 Y_1 R_s \quad (5)$$

An interesting conclusion from the above expression is the existence of an optimum line length,  $\ell = 1/\alpha$ , which yields

$$(G_T)_{\max} = 0.544 \left[ \frac{V_1}{\sigma} \frac{\partial \beta}{\partial V_s} \right]^2 V_1 R_s \quad (6)$$

A second basic characteristic of interest is bandwidth. One potential advantage of the phase-shift technique is the relative ease of obtaining large bandwidths at high RF frequencies. The main concern regarding bandwidth is that the input bandwidth be as large as the desired amplifier bandwidth. In Fig. 1, the input bandwidth is

$$B = 1/RC \text{ (radians/sec)} \quad (7)$$

where C is the total capacity of the loaded section of line. Since C is proportional to  $\ell$ , say,  $C = k\ell$ , then<sup>1</sup>

$$B = 1/R_s k \ell \quad (8)$$

and

$$\begin{aligned} B \sqrt{(G_T)_{\max}} &= 0.74 \left[ V_1 \frac{\partial \beta}{\partial V_s} \right] \sqrt{Y_1 / k} \\ &= \frac{\partial \beta}{\partial V_s} \sqrt{P_{\text{inc}} / k} \end{aligned} \quad (9)$$

<sup>1</sup>In this analysis, no attempt is made to improve the input bandwidth by a slow-wave structure. However, this is an obvious extension, which will be considered in the future.

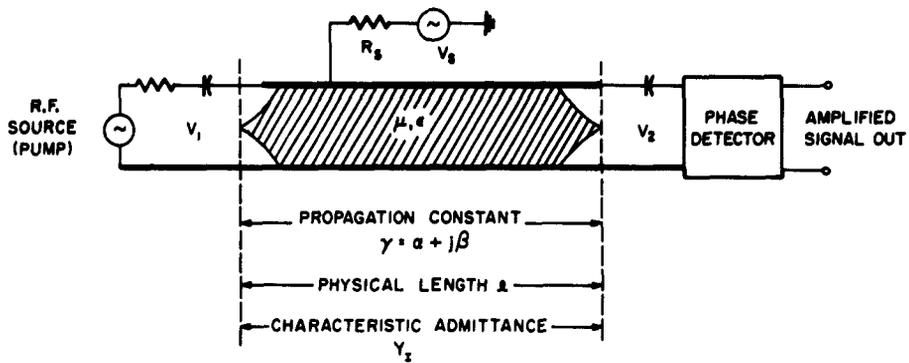


Fig. 1. General representation of a phase-shift amplifier.

where  $P_{inc}$  is the incident RF pump power. Therefore, this gain-bandwidth product is independent of the length of the line. This conclusion, of course, neglects any conditions that RF bandwidth may impose on  $\beta$ . Since the latter conditions depend more explicitly on the nature of the nonlinear medium, this effect will be taken up in greater detail later.

## 5. VARACTOR PHASE-SHIFT AMPLIFIER

To date, phase-shift amplifiers have been realized mainly with varactors. Since a varactor is a lumped element, the distributed phase-shift representation in Fig. 1 may not seem appropriate in this case. However, image parameter theory overcomes this apparent difficulty. In Fig. 2, a varactor with admittance  $Y$  is centered in a section of line whose unloaded electrical length and characteristic admittance are  $\theta$  and  $Y_0$ , respectively. The equivalent homogeneous line has electrical length and characteristic admittance  $\beta$  and  $Y_1$ , respectively, where

$$\gamma = \alpha + j\beta \quad (10)$$

$$\tanh \gamma/2 = j \frac{\left[ \frac{Y}{2jY_0} \tan \frac{\theta}{2} + \tan^2 \frac{\theta}{2} \right]}{1 - \frac{Y}{2jY_0} \tan \frac{\theta}{2}} \quad (11)$$

and

$$\frac{Y_1}{Y_0} = \frac{\tanh \gamma/2}{\tan \theta/2} \quad (12)$$

For a given varactor, these equations can be solved for  $\alpha$  and  $\beta$ , and then  $\partial\beta/\partial V$  determined from the varactor characteristic. By this procedure, the essential phase-shift amplifier characteristics for any varactor can be obtained.

The main advantage of approaching varactors in the manner of Fig. 2 is the ready extension to a cascade of varactors. The properties of a periodically-loaded line can be derived from those of the single varactor configuration, if the latter is represented as in Fig. 2. Hence, a periodically-loaded line of varactors is a logical extension of the single-varactor phase-shift amplifier.

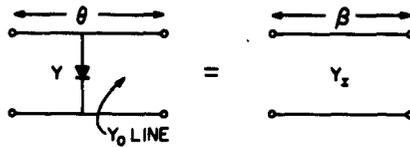


Fig. 2. The representation of a single varactor in a section of line as an equivalent transmission line, using image parameter theory.

### 5.1 Single-Varactor Phase-Shift Amplifier

Most of our work to date has been on the single-varactor version. In this case, there are two basic modes of operation, which are illustrated in Fig. 3. In both cases, a short circuit is positioned to resonate the static varactor susceptance. It is readily shown from (10) and (11) that tuning the varactor at midband gives the greatest phase-modulation sensitivity.

As drawn, the two configurations in Fig. 3 have identical performance. However, when a circulator is available, the reflection mode becomes superior. The resulting configuration is shown in Fig. 4. The analysis of Fig. 4 has been reported previously (Refs. 1, 2 and 3), but in these prior studies the most overlooked part of the system was the phase detector. The form of phase detector that has been used to date is shown in Fig. 5. There an inserted carrier is used to change the reflected signal from the varactor into an AM envelope. The question of AM detector efficiency now arises. The detection efficiency will depend largely on the diode used, which in turn depends on the pump frequency. If the detector problem is neglected, the gain-bandwidth product tends to increase with pump frequency. Therefore, high frequency detectors are of greatest interest. The results of our study of detectors are discussed in Section 3.

An experimental phase-shift amplifier employing a single varactor, has been constructed as shown in Fig. 6. The RF (pump) bandwidth of this system is determined by the varactor. It is found that the shunt conductance of a conventional cartridge-type varactor, when mounted in shunt across an X-band waveguide, approximately equals the characteristic admittance of the waveguide. Therefore, there are frequencies where reactive tuning (by a short behind the varactor) will produce a matched load. The midband reflection coefficient is

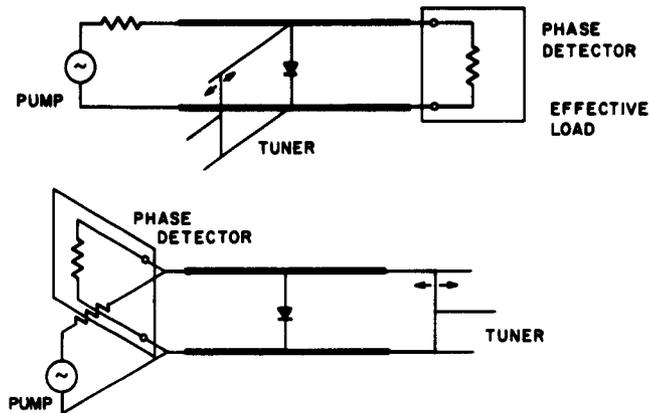


Fig. 3. Two equivalent methods of using a single varactor as a phase-shift amplifier.

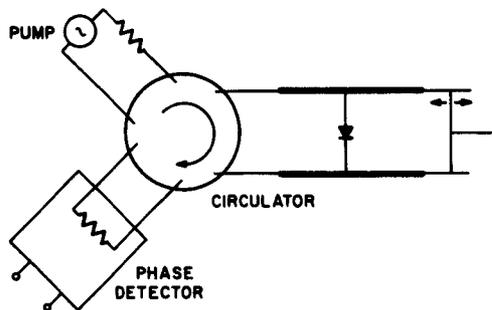


Fig. 4. The use of a circulator to improve the reflection-mode phase-shift amplifier.

then essentially zero. The equivalent circuit in Fig. 7 now describes the varactor and circulator in Fig. 4. The effect of bias or modulation ( $V_s$ ) in Fig. 7 is to produce a change of capacity

$$\Delta C = \left( \frac{\partial C}{\partial V} \right) V_s \quad (13)$$

This change of capacity produces a reflection

$$\rho = jQ \frac{\Delta C}{C} \quad (14)$$

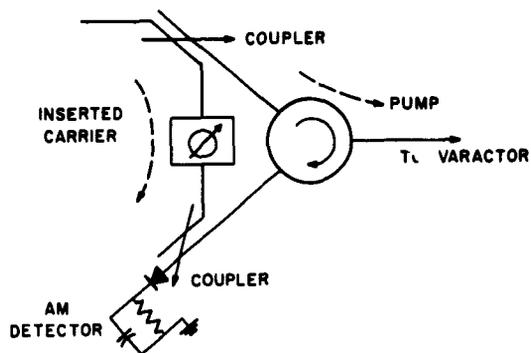


Fig. 5. A detection scheme for the phase-shift amplifier. An inserted carrier is adjusted to be in quadrature with the pump (referred to the detector). The reflected signal from the varactor now appears as an amplitude envelope on the inserted carrier.

where  $Q = \omega_p C / 2Y_0$ , and a shift in resonant frequency

$$\frac{\Delta\omega}{\omega} = \frac{\Delta C}{2C} = TV_s \quad (15)$$

where  $T$  denotes the relative tuning rate due to bias. It is thus possible to eliminate the least measurable quantities,  $\Delta C$  and  $C$ , to obtain

$$\rho = 2QT V_s \quad (16)$$

Both  $Q$  and  $T$  are easily measured, so they do not have to be calculated from the more conventional varactor characteristics, which are often incomplete.

A check on (16) has been made by measuring the quantities directly. Figure 8 shows  $\rho$  and  $\Delta\omega$  vs. bias, which by (16) corresponds to  $Q \approx 13$ . The  $Q$  can also be measured, since the reflection in Fig. 7 varies with frequency according to

$$\rho \approx 2Q \frac{\Delta\omega}{\omega_0} \quad (17)$$

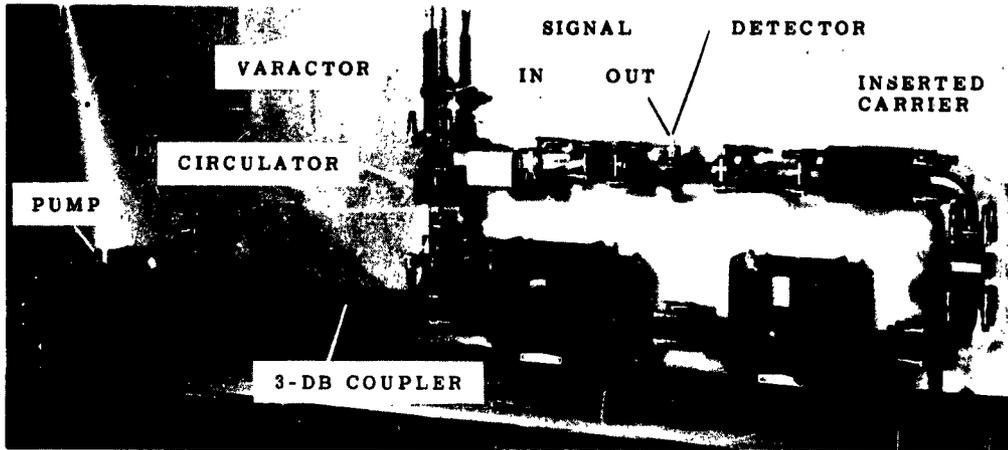


Fig. 6. A "breadboard" model of the phase modulation amplifier.  
 Pump frequency 9.4 kMc. Signal bandwidth 100 Mc.

The results of this measurement are shown in Fig. 9, which shows  $Q \approx 12$  and checks well with Fig. 8.

The total sideband power due to a low level sinusoidal modulation is

$$P_{sB} = \frac{1}{2} |\rho|^2 P_p \quad (18)$$

where  $P_p$  is the incident pump power. Therefore, using the expression in (16) for reflection coefficient, the transducer gain can be written

$$G_T = \frac{\text{detected output signal power}}{\text{available input signal power}} \quad (19)$$

$$= 4R_s (2QT)^2 \eta^2 P_p$$

where  $\eta^2$  is the detector efficiency. This expression is identical to (53) in Ref. 1, but (18) has the advantage of containing more easily measurable quantities.

Initial experiments with the circuit in Fig. 6 have produced voltage gains in excess of 20 db, as shown in Fig. 10, but the bandwidth of the output detector was rather

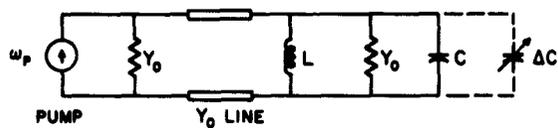


Fig. 7. The equivalent circuit of Fig. 4 when varactor loss matches the circulator.

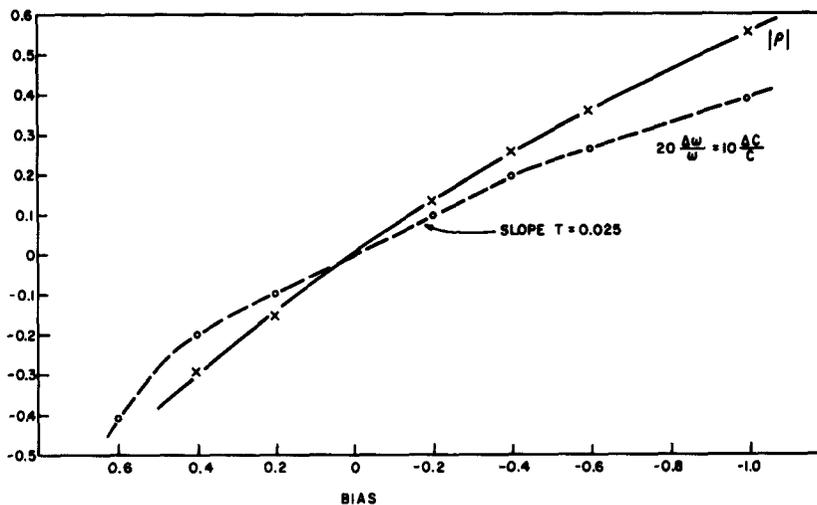


Fig. 8. The measured variation of reflection and tuning with bias for a varactor shunting an X-band waveguide. Zero bias resonance frequency 9450 Mc.

narrow in this case. At present, a more suitable detector is being developed according to the observations in Section 3. The results will be reported next quarter.

### 5.2 Multi-Varactor Phase-Shift Amplifiers

Although the simple gain-bandwidth relation in (9) is independent of line length, there are several reasons for pursuing distributed structures. First, the transducer gain times bandwidth is proportional to line length. Second, commercially available varactors in simple mounts offer only certain natural bandwidths, so distributed structures are a useful means of trading gain for bandwidth. Third, the derivation of (9) does not include effects due

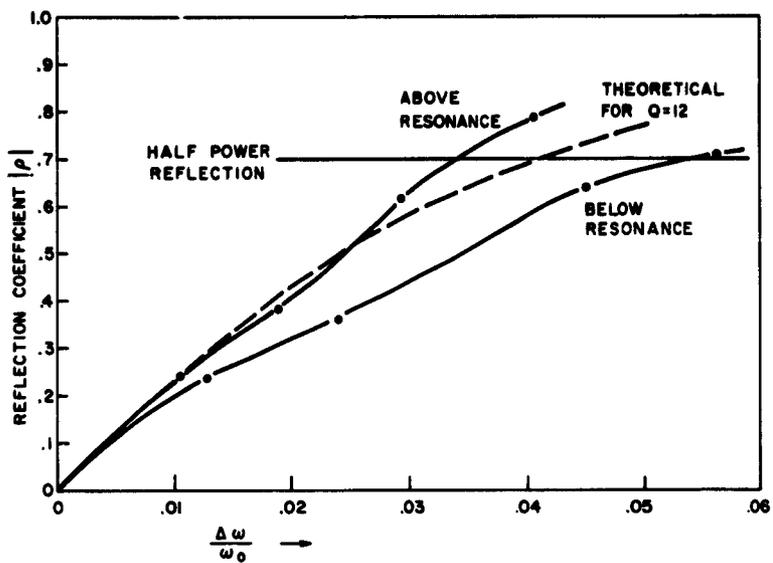


Fig. 9. Measured reflection coefficient vs. frequency shift for the same varactor as in Fig. 8.

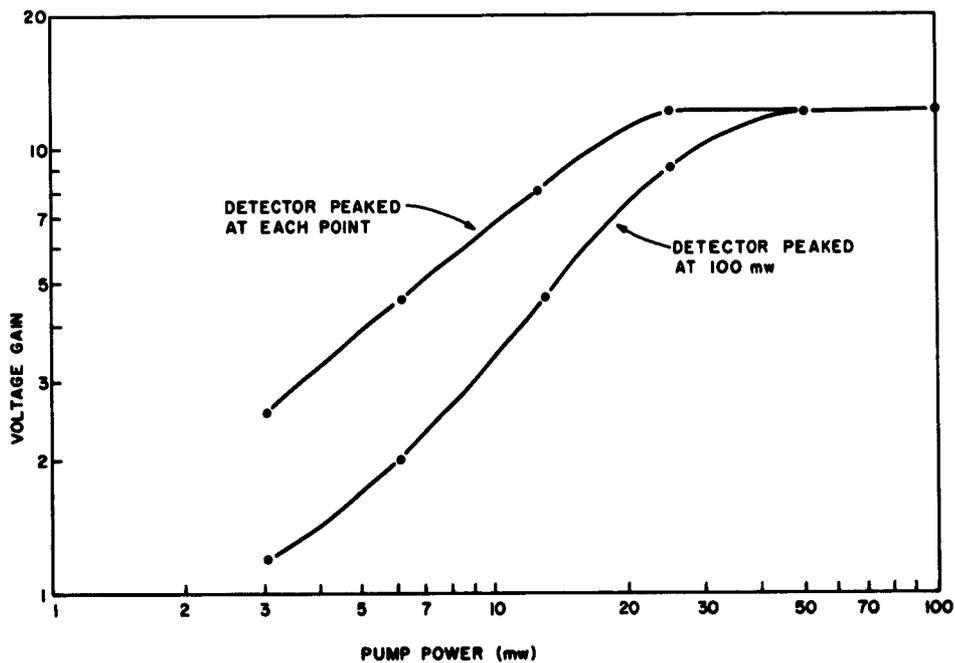


Fig. 10. Voltage gain vs. pump power for 9.5 kMc pump.

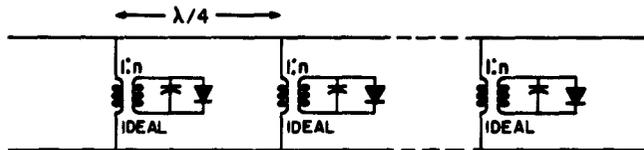


Fig. 11. The periodically loaded line of varactors presently under study for a phase-shift amplifier. Each varactor is tuned at midband and coupled to the line by a transformer. The appropriate spacing in this case is a quarter wavelength at midband.

to the extra RF bandwidth limitations that are imposed by the distributed structure. A study has been started that will evaluate these aspects of distributed varactor structure.

The distributed structure that is presently being studied is shown in Fig. 11. With this structure, we are seeking 20 db gain from dc to 1000 Mc. An optimum structure has been designed, but the results will be given further checking before they are reported. Also, some supporting experimental work is planned for the next quarter.

## 6. MICROWAVE DETECTOR EFFICIENCY

The basic principle of the phase shift amplifier is modulation followed by demodulation, but only the former is capable of gain. Therefore, care must be taken that the efficiency of the latter is as large as possible. A suitable definition of detector efficiency is (Ref. 4).

$$\eta^2 = \frac{\text{detected ac power}}{\text{sum of all sideband powers}} \quad (20)$$

For a given diode and frequency, this efficiency tends to vary with the detector load, the carrier power, and the impedance the diode presents to the sidebands. A circuit for measuring detector efficiency is shown in Fig. 12. With this circuit, the efficiency at X-band of 1N23B and 1N23B has given the best results and these are shown in Fig. 13. It is of interest that efficiencies in excess of 50 percent have been obtained. However, the highest efficiencies occur for low carrier powers and large detector loads, where the detector bandwidth is small. For the 1N23B, a good operating point from the standpoint of bandwidth is at about 20 mw carrier power and a 200 ohm detector load.

Similar measurements to these in Fig. 13 have been made on 1N263 diodes and the results are plotted in Fig. 14. The latter show a lower output impedance (about 50 ohms), but less efficiency (about 14 percent). Further measurements will be made on both diodes with external bias to see what improvements are possible. Also measurements of efficiency vs. bandwidth are planned.

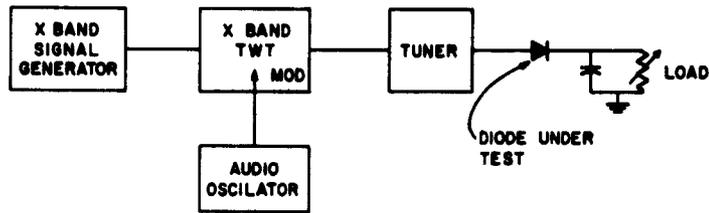


Fig. 12. The circuit used for measuring detector efficiency. The sideband power is determined by accurate measurement of the percentage modulation. The load resistance is varied, and the diode tuned for a maximum ac output with each load resistor. The curves in Figs. 13 and 14 were obtained in this way.

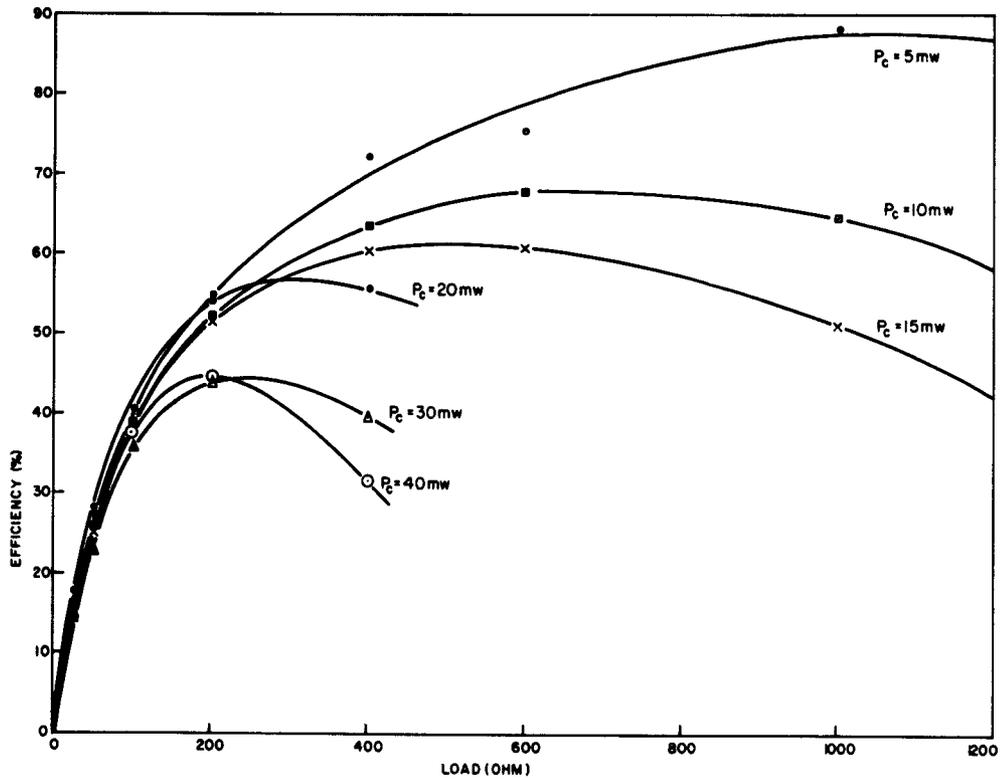


Fig. 13. Peak detector efficiency vs. load for a 1N23B diode detector with various carrier powers (frequency 9 kMc).

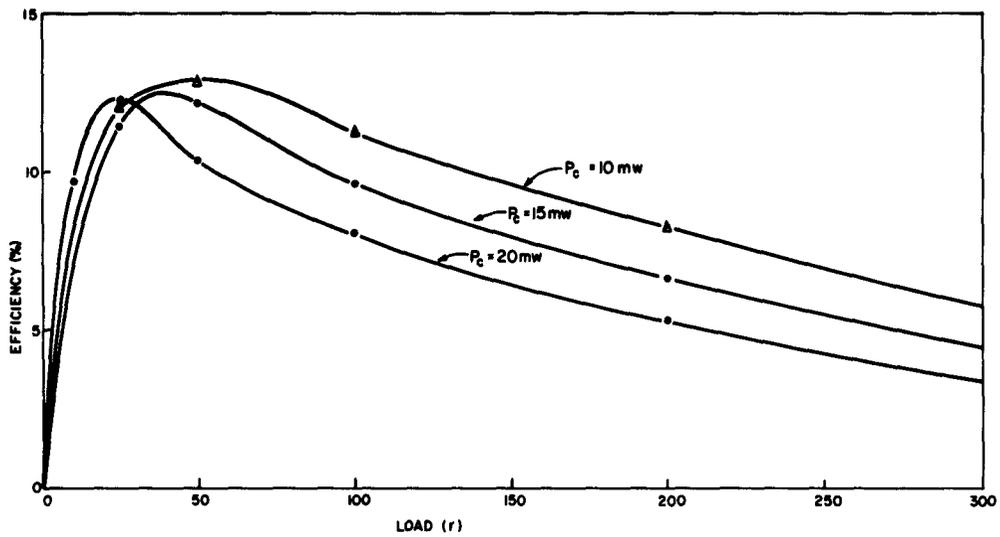


Fig. 14. Peak detector efficiency vs. load for a 1N263 diode detector with various carrier powers (frequency 9 kMc).

## 7. MAGNETIC PHASE-SHIFT AMPLIFIERS

It has been found that some magnetic amplifiers operate on the phase-shift amplifier principle. Therefore, a study of phase-shift techniques with ferrite cores has been initiated. Ferrite cores offer several advantages over varactors. One advantage is an inherently symmetrical characteristic which enhances temperature stability. A second advantage is complete dc isolation. The principle disadvantage of cores is their limited frequency range. Nevertheless, cores can be used to test various phase-shift amplifier techniques.

One new technique that is being studied with magnetic amplifiers is multiple pumping. The spectrum involved in this case is shown in Fig. 15. Phase modulation sidebands are produced by the mixing of  $\omega_s$  and  $\omega_p$ . However these sidebands are in a degenerate parametric amplifier relationship with  $2\omega_p$ . Therefore, by maintaining a proper phase relationship between  $\omega_p$  and  $2\omega_p$ , the sidebands can be enhanced.

An alternate viewpoint of this system is that the pump harmonic acts like a Q multiplier in the original pump tank. An analysis of this effect has been completed (Ref. 3) and two basic results obtained:

1. A 60 percent increase in gain-bandwidth product can be obtained by harmonic pumping.
2. By virtue of the Q multiplying feature, harmonic pumping offers a convenient method for trading bandwidth for gain.

An extreme case of harmonic pumping occurs when the pump harmonic cause the pump circuit to undergo subharmonic oscillations. In this case a modulating signal ( $\omega_s$ ) can be used to vary the phase of the subharmonic oscillation, which would be a sensitive means of amplification. In addition, the subharmonic oscillation could be operated in a quenching mode for still greater sensitivity. The over-all system is shown in Fig. 16.

The system in Fig. 16 is being studied with magnetic cores. A special feature of cores that will be employed in this case is core symmetry, which produces only

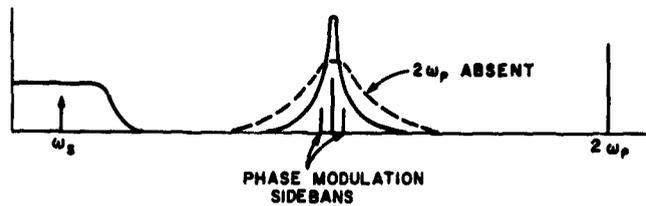


Fig. 15. Spectrum of phase modulation spectrum with harmonic pumping.

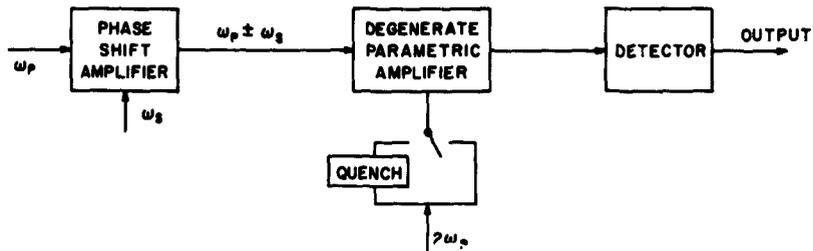


Fig. 16. A particular realization of Fig. 15, where the degenerate parametric amplifier acts as an active filter. Both superregenerative and continuous modes are possible.

odd pump harmonics in the absence of a signal. Only when a signal is applied do even harmonics appear, so a second harmonic output device would be very temperature stable. This mode of operation is very similar to the basic phase shift amp, but with a second harmonic output the circuit in Fig. 16 must be modified slightly. The degenerate parametric amplifier will now operate at  $2\omega_p \pm \omega_s$ , and its pump will be at  $4\omega_p$ . Further study of this principle is scheduled for the next quarter.

## 8. CONCLUSIONS

At this time, our conclusions are incomplete because they reflect only one quarter's work. However, the following facts are noteworthy at present:

1. A phase-shift amplifier can be modeled in a general way so the many possible phase-shift techniques can be related and compared. An appropriate model is that in Fig. 1.
2. The performance of a single varactor phase-shift amplifier can be predicted from simple measurements on a varactor. However, these measured quantities differ from the conventional ratings given by varactor manufacturers, so a correspondence is still required.
3. Multiple varactor structures can improve phase-shift amplifier characteristics by allowing greater flexibility in impedance level and hence bandwidth.
4. The efficiency of the detector in a phase-shift amplifier has been measured and can exceed 50 percent.
5. Multiple pumping adds another useful degree of freedom to phase shift amplifier design. At present, superregenerative detection appears to be the most useful multiple pumping effect.

### 9. PROGRAM FOR THE NEXT INTERVAL

During the next quarter emphasis will be placed on the following phases of this project:

- a. Further study of single varactor circuits with improved output detectors will be made.
- b. The design of a multiple varactor phase shift amplifier will be completed and initial experimental tests performed.
- c. The study of multiple pumping techniques with magnetic core, phase-shift amplifiers will be continued.

10. KEY TECHNICAL PERSONNEL EMPLOYED ON PROJECT AND MAN-HOURS WORKED  
DURING QUARTER

<u>Name</u>	<u>Title</u>	<u>Total Hours</u>
Dr. B. F. Barton	Laboratory Director	52
Dr. D. K. Adams	Research Engineer	280
Mr. J. L. Cockrell	Associate Research Engineer	320
Dr. A. B. Macnee	Faculty Consultant	37
Mr. W. B. Ribbens	Assistant Research Engineer	44

Background Information on Key Technical Personnel

Ben F. Barton, Director, Cooley Electronics Laboratory

PRESENT RESPONSIBILITIES

Supervisor of the research effort of the Cooley Electronics Laboratory.

EDUCATION

B. S. E. E. , The University of Michigan, 1947  
M. S. E. E. , The University of Michigan, 1952  
Ph. D. , The University of Michigan, 1957

TECHNICAL EXPERIENCE

Engineer, General Motors Corporation, automotive testing, 1947-48.  
Engineer, MC Mfg. Company, 1948-51, pneumatic compressor development.  
Student, 1951-57.  
Teaching Fellow, Electrical Engineering Department, The University of Michigan, 1957-58.  
Research Engineer, Cooley Electronics Laboratory, The University of Michigan, electronic countermeasures research, 1951-61.  
Director, Cooley Electronics Laboratory, 1961-.

PUBLICATIONS

Analysis of a Mechanically-Tuned Resonator for Use in Frequency Range 100 to 1000 Mc.  
The University of Michigan, Electronic Defense Group, Technical Report No. 6,  
August 1952, (Unclassified).

Analysis of a Mechanically-Tuned Resonator for Use in Preselector and Converter Applications, with L. S. Jimerson, The University of Michigan, Electronic Defense Group, Technical Report No. 21, October 1953, (Restricted).

The Design of Efficient Coupling Networks, The University of Michigan, Electronic Defense Group, Technical Report No. 44, March 1955, (Unclassified)

The Design of an Efficient Wideband Antenna System, The University of Michigan, Electronic Defense Group, Technical Report No. 45, August 1955, (Unclassified).

An Evaluation of a Special Broadband Receiver Input Circuit, with D. Hamburg, The University of Michigan, Electronic Defense Group, Technical Report No. 67, November 1956, (Unclassified)

"Some Useful Techniques for Overcoming the Broadband Limitations of Conventional Distributed Amplifiers," IRE Convention Record, Professional Group on Circuit Theory, Part II, 1957, with L. A. Beattie and P. H. Rogers.

"Interstage Design with Practical Constraints," IRE Convention Record, Professional Group on Circuit Theory, Part II, 1957.

Synthesis of Multi-Channel Amplifiers, The University of Michigan, Electronic Defense Group, Technical Report No. 70, May 1957.

"The Synthesis of Multi-Channel Amplifiers," WESCON Convention Record, Professional Group on Circuit Theory, Part II, 1958.

A Modification Study of the AN/MIQ-8(XE-3), The University of Michigan, Electronic Defense Group, Technical Report No. 91, May 1959, (Secret).

"Fuze and Communication Repeaters," Electronic Countermeasures, Chapter 16, Institute of Science and Technology, The University of Michigan, 1961, (Secret).

A Study of Proximity Fuzes and Their Electronic Countermeasures, with F. N. Bailey, E. L. McMahon, A. W. Naylor, V. L. Wallace and F. M. Waltz, The University of Michigan, Cooley Electronics Laboratory, Technical Report No. 127, January 1962, (Secret).

#### HONORS AND AFFILIATIONS

Member of Sigma Xi, Institute of Radio Engineers, and The University of Michigan Science Research Club.

David K. Adams, Research Engineer

#### PRESENT RESPONSIBILITIES

Conducting research on solid-state microwave devices and antennas.

#### EDUCATION

B. A. (Physics) 1952, Reed College, Portland, Oregon  
M. A. (Physics) 1953, University of British Columbia, Canada  
Ph. D. (Electrical Engineering) 1963, The University of Michigan

#### TECHNICAL EXPERIENCE

Teaching Assistant (Physics) Reed College, 1951-1952.  
Teaching Assistant (Physics) University of British Columbia, 1952-1953.

Instructor in Atomic Weapons and Nuclear Physics while serving in  
U. S. Army, 1954-1956.  
Staff member, Sandia Corporation, Albuquerque, New Mexico, 1956-1957,  
atomic weapons tests.  
Graduate Research Assistant, Cooley Electronics Laboratory, The University  
of Michigan, 1957-1959.  
Research Associate, Cooley Electronics Laboratory, 1959-1960.  
Instructor in Electrical Engineering and Faculty Consultant 1960-.

#### PUBLICATIONS

Some Considerations of Four-Frequency Nonlinear Reactance Circuits, Technical Report  
No. 96, Electronic Defense Group, The University of Michigan, September 1959.

"Circuit Properties of a Double-Sideband, Doubly-Pumped Nonlinear Reactance Modulator,"  
Proceedings of the National Electronics Conference, 1960.

"An Analysis of Four-Frequency Nonlinear Reactance Circuits," IRE Transactions on Micro-  
wave Theory and Techniques, May 1960, pp. 274-283.

A Study of Traveling-Wave Directional Filters with Wideband Ferrite Tuning, Technical  
Report No. 106, Electronic Defense Group, The University of Michigan, April 1961.

An Analysis of the Brett Ultra-Wideband Video Amplifier, Technical Report No. 122, Cooley  
Electronics Laboratory, The University of Michigan, July 1961.

"Parametric Amplification by Phase Modulation," Proceedings of the National Electronics  
Conference, 1962.

"Power Interference Levels of Rectangular Slots Antennas in a Common Ground Plane by  
Simplified Analysis and Tests," with R. B. Harris, Y. K. Kwon and J. A. M. Lyon, 12th  
Annual U. S. Air Force Antenna Symposium, 1962.

A Study of Double-Sideband Reactive Mixers, Technical Report No. 134, Cooley  
Electronics Laboratory, The University of Michigan, December 1962, (Also published  
as the author's doctoral dissertation in The University of Michigan).

#### HONORS AND AFFILIATIONS

Member of Sigma Xi, Member of Institute of Radio Engineers.

James L. Cockrell, Associate Research Engineer

#### PRESENT RESPONSIBILITIES

Conducting research on parametric amplifying devices.

#### EDUCATION

B. S. (Electrical Engineering) University of Wisconsin, 1943  
M. S. E. (Electrical Engineering) The University of Michigan 1951

#### TECHNICAL EXPERIENCE

Production Engineer, Cathode Ray Tubes, RCA Victor, Lancaster, Pa.  
1943-1944.  
Radar Officer, Electronic Field Service Group, USNR, 1944-1946.  
Electronics Engineer, Magnetic Recording, National Standard Co.,  
Niles, Michigan, 1946-1950.

Instructor (Electrical Engineering), The University of Michigan, 1950-1951.  
Assistant Professor (Electrical Engineering), Michigan State University,  
1951-1956.  
Research Scientist, Nuclear Reactor Control Group. Leads and Northrup  
Company, Philadelphia, Pennsylvania, 1956-1962.  
Associate Research Engineer, The University of Michigan, Cooley Electronics  
Laboratory, 1962-.

#### PUBLICATIONS

"Modular Concepts in Reactor Control Instrumentation, with D. F. Ryan and J. H. Magee,  
AIEE Transactions, Part I (Communications and Electronics), Vol. 77, November 1958.

"Variation of the Trip Point in the ORNL-Type Safety System," with C. W. Ricker, AIEE  
Transactions, Part I (Communications and Electronics), Vol. 77, November 1958.

"The Application of Transistors, Magnetic Amplifiers, and Vacuum Tubes in Power Plant  
Instrumentation," with E. W. Voorhoeve, ISA Proceedings of 4th National Power  
Instrumentation Symposium, May 1961.

"Nuclear Protective Systems Design for Reliability," with V. S. Underkoffler and J. H. Magee,  
IRE Transactions on Nuclear Science, Vol. NS-8, October 1961.

#### HONORS AND AFFILIATIONS

Member of Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, AIEE, Senior Member  
IRE.

Alan B. Macnee, Professor of Electrical Engineering

#### PRESENT RESPONSIBILITIES

Teaching Consultant for Cooley Electronics Laboratory.

#### EDUCATION

S. B. (Electrical Engineering), Massachusetts Institute of Technology, 1943.  
S. M. (Electrical Engineering), Massachusetts Institute of Technology, 1943.  
Sc. D., Massachusetts Institute of Technology, 1948.

#### TECHNICAL EXPERIENCE

Staff member, receiver group at the MIT Radiation Laboratory, 1943-46,  
specializing in the noise performance of intermediate-frequency amplifiers.  
Staff member, MIT Research Laboratory of Electronics, 1946-49, research  
on high-speed electronic computation.  
Research Associate, Chalmers Institute of Technology, Gothenburg, Sweden,  
1949-50, developed electronic differential analyzer.  
Assistant Professor of Electrical Engineering, The University of Michigan,  
1950-51.  
Task Engineer, Cooley Electronics Laboratory, 1951-53.  
Associate Professor of Electrical Engineering, The University of Michigan,  
1951-59.  
Faculty Supervisor and Consultant, Cooley Electronics Laboratory, 1953-present.  
Professor of Electrical Engineering, The University of Michigan, 1959-present.  
Guest Professor of Applied Electronics, Chalmers Institute of Technology,  
Gothenburg, Sweden, 1961-62, engaged in research on network synthesis and  
gave lectures on computer technology and electronic circuits.

## PUBLICATIONS

"Microwave Receivers," Chapters 5 and 16, Vol. 23, MIT Radiation Laboratory Series, pp. 122-154 and 419-439, 1948.

"A Low-Noise Amplifier," with H. Wallman and C. P. Gadsden, Proc. IRE, Vol. 37, pp. 1315-1324, 1949.

"Coupling Circuits Having Flat-Amplitude Characteristics," IRE National Convention, 1952.

"Some Limitations on the Accuracy of Electronic Differential Analyzers," Proc. IRE, Vol. 40, pp. 303-308, 1952.

The Response of a Panoramic Receiver to CW and Pulse Signals, with H. W. Batten, W. W. Peterson and R. A. Jorgensen, Technical Report No. 3, Cooley Electronics Laboratory, The University of Michigan, June 1952. Also published in Proc. IRE, Vol. 42, No. 6, pp. 148-156, June 1954.

"A High-Speed Product Integrator," The Review of Scientific Instruments, Vol. 24, pp. 207-211, 1953.

"The Nature of the Uncorrelated Component of Induced Grid Noise," with T. E. Talpey, IRE Convention, 1954. Also published in Proc. IRE, Vol. 43, No. 4, pp. 449-453, April 1955.

Extending the Transformation Ratio of a Tschebyscheff 2-Pole Matching Network, Technical Memorandum No. 13, Cooley Electronics Laboratory, The University of Michigan, January 1954 (Unclassified).

Klinkhamer's Method of Determining Filter or Amplifier Transfer Functions, Technical Memorandum No. 22, Cooley Electronics Laboratory, The University of Michigan, September 1955 (Unclassified).

"Approximating the Alpha of a Junction Transistor," Letter to the Editor Proc. IRE, Vol. 45, No. 1, January 1957.

Synthesis of Lossless Networks for Prescribed Transfer Impedance Between Several Current Sources and a Single Resistive Load, Technical Report No. 76, Cooley Electronics Laboratory, The University of Michigan, November 1957 (Unclassified). Also published in Trans IRE, Professional Group on Circuit Theory, Vol. CT-5, No. 3, pp. 168-172, September 1958.

A Wide-Band Low-Pass Amplifier Using a Pentode-to-Cathode Follower Tube Pair per Stage, with Q. C. Wilson, Technical Memorandum No. 65, Cooley Electronics Laboratory, The University of Michigan, October 1958 (Unclassified).

"Intercept Probability and Receiver Parameters," Chapter 6 in the book, Electronic Countermeasures, with D. B. Harris, Institute of Science and Technology, The University of Michigan, 1961 (Secret).

## HONORS AND AFFILIATIONS

Senior Member, Institute of Radio Engineers, Member American Institute of Electrical Engineers, Sigma Xi, Phi Kappa Phi, Eta Kappa Nu, Tau Beta Pi, IRE Browder J. Thompson Memorial Prize, 1951.

William B. Ribbens, Assistant Research Engineer

## PRESENT RESPONSIBILITIES

Investigation of ferrites as applied to microwave amplifier.

## EDUCATION

B. S. (Electrical Engineering) The University of Michigan, 1960.  
M. S. (Electrical Engineering) The University of Michigan, 1961.

## TECHNICAL EXPERIENCE

Electrical Engineering, Lear, Inc., Grand Rapids, Michigan, 1960.  
(Circuit design for proposed orbital vehicle).  
Research Engineer, Electromagnetic Materials Laboratory at the University  
of Michigan, 1961 (Boundary value problems of small ferrite samples).  
Research Engineer, Cooley Electronics Laboratory, The University of Michigan,  
1962-.

## PUBLICATIONS

"Spectral Response of Nonlinear Devices," Proceedings of the IRE, Vol. 49, p. 1700,  
November 1961.

"A Quasi Cascaded Parametric Amplifier," Journal of Applied Physics, Vol. 33, pp. 757-758,  
February 1962

"Cascading Ups Parametric Amplifier Gain," Electronics, September 1962.

"Note on the Size Independence of Magnetostatic Modes," Proceedings of the IRE, 1963.

## HONORS AND AFFILIATIONS

Member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, Student member of Institute  
of Radio Engineers, Student member of American Physical Society.

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Cooley Electronics Laboratory, The University of Michigan, Ann Arbor, Mich. STUDY OF PHASE-SHIFT AMPLIFIER TECHNIQUES, by D. K. Adams. February 1963. p. illus. (Dept. of Army Task Nr. 2244-031-17) (CEL Quarterly Progress Report No. 1, 5407-1-P) (Contract No. DA-36-039 AMC-00059(E))

Unclassified report  
Progress has been made in studying simple-  
varactor, multiple-varactor and ferrite-core  
phase-shift amplifiers. A single-varactor  
amplifier has been built in an optimum struc-  
ture. The latter operates in the reflection  
mode with a circulator. The principle weak-  
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so considerable study has been made of this  
detector. Efficiencies in excess of 50 percent  
have now been measured. (over)

1. Phase-shift amplifiers-single varactor.
2. Phase-shift amplifiers-multiple varactor.
3. Phase-shift amplifiers-ferrite core.

I. Adams, D. K.  
II. U. S. Army Electronics  
III. Contract DA-36-039  
AMC-00059(E)

Cooley Electronics Laboratory, The University of Michigan, Ann Arbor, Mich., STUDY OF PHASE-SHIFT AMPLIFIER TECHNIQUES, by D. K. Adams. February 1963. p. illus. (Dept. of Army Task Nr. 2244-031-17) (CEL Quarterly Progress Report No. 1, 5407-1-P) (Contract No. DA-36-039 AMC-00059(E))

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phase-shift amplifiers. A single-varactor  
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II. U. S. Army Electronics  
III. Contract DA-36-039  
AMC-00059(E)

Study has also been made of a transmission line periodically loaded with varactors to see what benefits this technique will provide. A suitable structure has been designed and is being tested.

Also described are ferrite core techniques, which are being used to investigate phase-shift amplifiers with multiple pumping. A related effect, employing subharmonic oscillations to increase gain, is also discussed.

Study has also been made of a transmission line periodically loaded with varactors to see what benefits this technique will provide. A suitable structure has been designed and is being tested.

Also described are ferrite core techniques, which are being used to investigate phase-shift amplifiers with multiple pumping. A related effect, employing subharmonic oscillations to increase gain, is also discussed.