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Project 1177-32

FINAL REPORT

For

Analysis of Signal-to-Noise Enhancement Using a Highly Selective Modulation Tracking Filter

June 1, 1972

by

C.R. Haden and C.W. Alworth

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Department of Electrical Engineering
Texas A&M University

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Abstract

Experiments are reported which utilize photodielectric effects in semiconductor loaded superconducting resonant circuits for suppressing noise in RF communication systems. The superconducting tunable cavity acts as a narrow band tracking filter for detecting conventional RF signals. Analytical techniques have been developed which lead to prediction of signal-to-noise improvements. Progress is reported in optimization of the experimental variables. These include improved Q, new semiconductors, improved optics, and simplification of the electronics. Information bearing signals have been passed through the system and noise has been introduced into the computer model. Recommendations for further study are made in this report.

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Results

During the year, a mathematical model was developed for the cavity, and considerable computer runs were made. The results of the computer runs were given in the monthly reports. The concept of the mathematical model is summarized below. In an RF cavity partially filled with a semiconductor, photon excitation of the semiconductor results in a change of both the energy storage and energy dissipative qualities of the system. This is externally manifested by both a frequency change and an amplitude change in the natural response. An electrical lumped-circuit equivalent of the filter is shown in Figure 1.

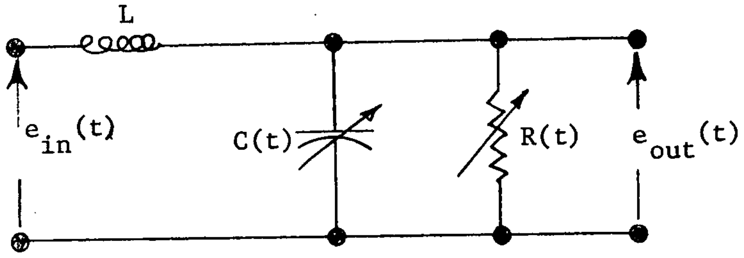

Figure 1, Lumped Circuit Model

The relationship between the input and output voltages may be simply expressed as

$$L\frac{d}{dt}\left[\frac{d}{dt}\ C(t)e_{out}(t) + \frac{e_{out(t)}}{R(t)}\right] + e_{out}(t)=e_{in}(t) \qquad (3)$$

The relationships for C(t) and R(t) may be found from photodielectric theory, and are given by

$$C(t) = C - n(t)A \qquad (4)$$

$$R(t) = B/\{n_0 + n(t)\} \qquad (5)$$

Where A and B are constants determined by the semiconductor size and cavity geometry, n(t) is the time varying portion of the free carrier charge density, n_0 is the thermal equalibrium value of free charge carrier density, and C is the constant value of capacitance which includes the non-charge carrier dependent portion. In order to obtain a solution of (3), some of the physical parameters must be empirically defined. For the system used, these parameters were calculated and found to be:

$L = (1.5)(10^{-9})$ henry

$C(t) - (2.231)(10^{-11})[1.0-0.016\alpha(t)]$ farad

$R(t) = (8.56)(10^{6})[1.0 -78.4\alpha(t)$ ohms

$\alpha(t) = (\text{Scale})(1.0-\cos\omega_m t)$

where "Scale" is the modulation intensity factor and ω_m is the modulation frequency in radians/second. For these parameter values the Q of the system will be 800,000.

No closed form solution is available for equation (3). This equation has been solved by numerical techniques and the modulation frequency was recovered, both with and without white gaussian noise. A portion of the computer results are shown in Figure 2. (next page)

The modulation frequency was 8.7 MHz, the cavity carrier frequency was 870 MHz. The system Q was 8000, which gives a bandwidth of approximately 108 KHz for the 3db down points. This proves that the concept of the tracking filter works mathematically, since the signal which was passed through the model and recovered was greater than the system bandwidth. This is due to the enhancement of the nondissipative effect in the complex photodielectric constant, and is a direct result of energy exchange between the capacitive and inductive properties of the cavity, while the resistive property is very small.

With the exception of the light diode and focusing system (the optical subsystem), the system is complete, and has been tested with a 6 milliwatt argon laser as the light source, with an electro-optic modulator intensity modulating the laser output, which is not adequate. The system does indeed track the signal, but as yet no data has been taken to show the improvement or prove the mathematical model.

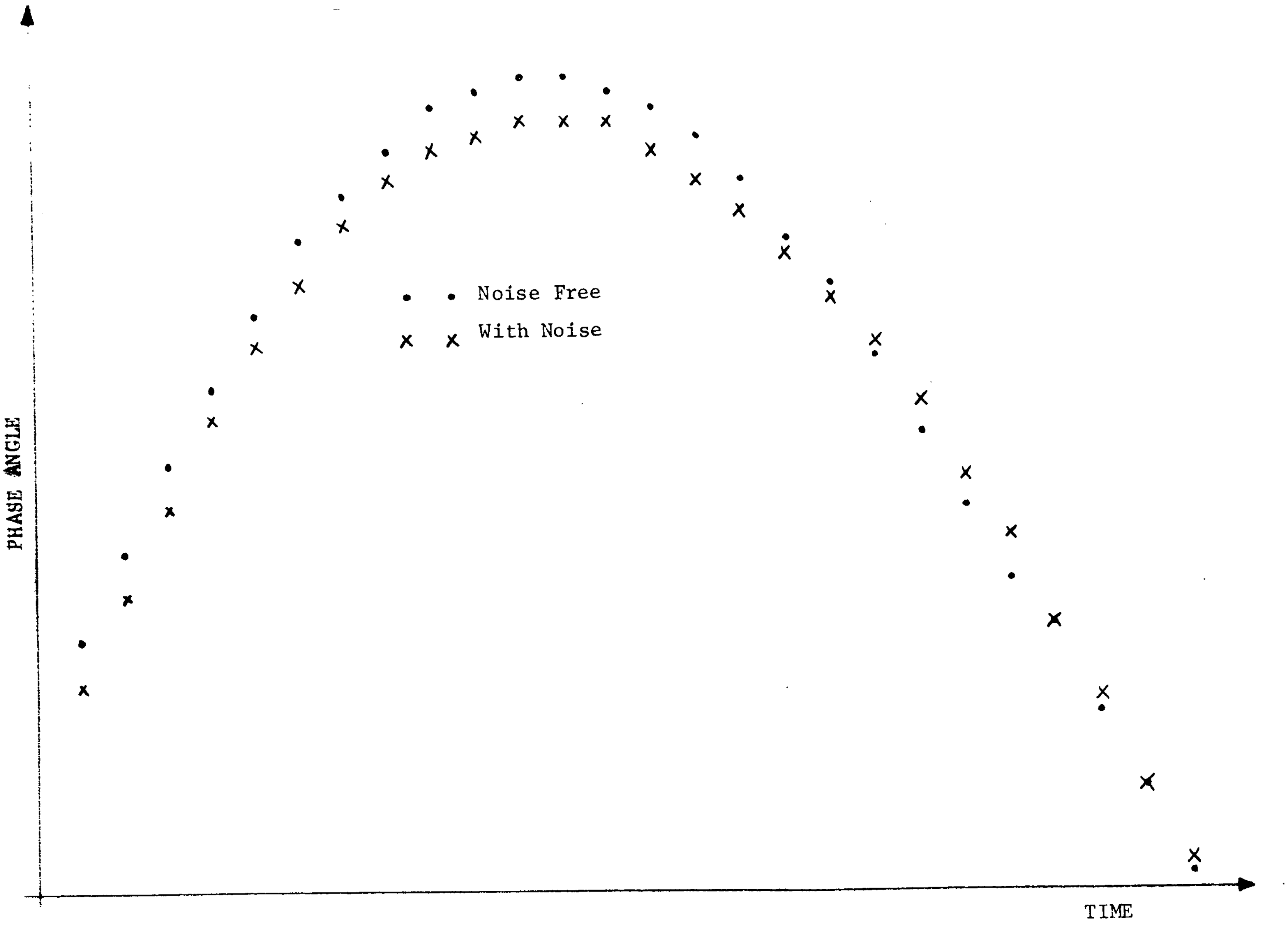

Figure 2 - Mathematic Model Results

Difficulty has been experienced in obtaining a high Q from the cavity. This is caused by poor lead plating in the cavity, but this can be corrected. The system currently has a bandwidth of 100KHz and has passed good quality audio signals.

Conclusions

Computer runs show that a narrow band filter can indeed pass a wide band signal; furthermore, preliminary experimental results show that the filter is passing a signal that is wider than the filter bandwidth. This means that the concept behind the modulation filter is valid, and is worth the effort to produce a prototype.

Recommendations

The recommendations for further work are as follows:

1. Use of a niobium cavity should be introduced to improve the Q of the cavity at 5.9°K.
2. Development of a technique for analytically extracting signal-to-noise ratio from the computer results is a necessity.
3. Bandwidths of the experimental cavity and the model should be determined and correlated.
4. Various types of signal forms should be used at different noise levels to determine optimum signal format for this system.
5. Further work with sample optimization is needed. Samples are already available.

Final Report - Period 4/1/71-4/1/72

A. Background

Prior to the current contract period, the status of the project could be summarized as follows: The refrigerator system for the cavity had finally been put in operational condition. The computer analysis program was still in initial form, but progress had been made and work in conjunction with NASA-MSC computing personnel had begun.

A re-statement of the goals and technical requirements for this contract period are given as follows:

3.2 ANALYSIS REQUIREMENTS

The analysis requirements for this study are both experimental and analytical in nature.

3.21 EXPERIMENTAL STUDY

The objectives of the experimental study to be performed during the coming contract period are as follows: Continuation of experimental program currently underway. Optimization of experimental parameters and procedures. This includes choice of cavity coating material. Experimental verification of analytical results.

3.22 ANALYTICAL STUDY

The objectives of the analytical study to be performed during the coming contract period are as follows:

a. Verify the model for the superconducting time-variant filter by comparing computer results with laboratory experiments. Using the verified mode, determine the response to signal and noise inputs. Also determine the bandwidth of the superconducting, time-variant filter.

b. Using knowledge of response and bandwidth, determine expected signal-to-noise improvements for the presently planned time-variant filter system configuration and other system configurations which may use the narrowband tracking filter properties of the time-variant filter to advantage.

c. Investigate performance for baseband digital signals, narrow baseband analog signals, wideband video signals, and subcarrier signals. Consider the optimal signal design problem for the various system configurations. Determine maximum data rates as imposed by the time-variant filter bandwidth.

d. Investigate feasibility of using the modulation tracking filter principle on spaceborne vehicles. This includes using the filter for demodulation subsequent to remodulation on a relay link.

3.23 SUBTASKS

a. Continuation of cutting of semiconductor samples for optimum specimens.

b. Continuation of analytical study and comparison of computer results and laboratory experiments.

c. Refinement of experimental procedures.

d. Continuation of experiments under noisy and noise-free conditions. Determination of filter bandwidth through theoretical analysis and experimental verification. Consideration of the optimum signal design problem, i.e., what type of signal would be optimum for the filter?

e. Investigation of performance for all digital signals, narrow base band signals, and/or wideband video signals as deemed appropriate from the analysis.

f. Determination of maximum data rates as imposed by the time variant filter bandwidth.

g. Correlation of final experiments.

h. Update to refrigerator operating manual.

i. Preparation of troubleshooting guide for refrigerator subsystem.

j. Reevaluation of optimum semiconductor samples and cavity design.

B. Current Progress and Status

A summary of the current experimental status is that the year's work has put the entire system into operational condition. Prior to the current contract period, the refrigerator only was operational. During the period, the electronic system had been completed, verified, and modified to achieve this operational status. Also, considerable effort has been made to improve the cavity Q and control its frequency. Problems encountered with getting adequate signal light into the cavity have been overcome. Semiconductor samples have been purchased, cut, and polished and tested. Finally, experiments where information signals were transmitted through the system were performed.

The analytical or theoretical problem was attacked with both numerical computer analysis and an attempt to obtain a closed-form solution. This latter attempt proved unsuccessful in that an unwieldy result, at best, was obtained even with drastic limiting assumptions and approximations. The results of this attempt were of little use, except to demonstrate that a numerical approach is preferable. The numerical solution did yield much more satisfying progress, however. After considerable refinement of the computer program, and only few model simplifications, it was found that the math model cavity would indeed track the carrier as expected. Also techniques for introducing random noise into the model were developed and calculations made. As yet, however, the signal-to-noise ratios have not been extracted.

In all, considerable progress has been made during this period, but not all goals have been met as will be seen in the following section.

C. Response to Initial Objectives

3.2.1 EXPERIMENTAL STUDY

1. The experimental program has been continued.

2. Many of the experimental parameters and procedures have been optimized.

(a) The cavity coating material of lead has proven only partially satisfactory. Its ease of application makes it attractive, but its low critical temperature (7.2°K) makes the cavity Q values only marginally high enough at the refrigerator minimum of 5.9°K. It is recommended that a niobium cavity be used in future tests.

(b) The cavity frequency was initially very difficult to pre-determine because of the unpredictable loading of a given semiconductor sample. After some empirical calculations and cut-and-try, a cavity frequency in the range of 1 GHz was achieved. The primary technique was use of an insert cap which could be mechanically shortened.

(c) It was discovered early in the period that the sample was receiving inadequate light from the signal diode, thereby drastically reducing the system sensitivity. After the light emitting diode was shown to be in good condition, a calculation showed that the angular output of the diode and the aperature restrictions were responsible. Two solutions were offered in the form of appropriate lens, or in the form of a collection mirror and telescope (in-house). Decisions have been made to go to a coaxial system for the electromagnetic drive of the diode to facilitate use of lenses and also to use the collecting mirror approach. The necessary equipment has already been received. Also, improved performance, higher-power diodes have been obtained.

(d) Simplifications in the electronic detection system have been made. In particular, a simple mixer-phase detector combination has been shown effective.

3.2.2 ANALYTICAL STUDY

(a) Verification of the model by comparison with experiment: This has been accomplished in part. The model and actual cavity have been shown to track carrier signals alone and with information in the same manner. Actual bandwidths have not been determined.

(b) Determination of expected signal-to-noise improvements: This has not been finished. However, techniques for putting noise into the model have been developed and used. All that remains is development of a technique for extracting signal-to-noise ratio from the data.

(c) Investigate performance for various types of signals: On the experimental side, both F-M signals and television signals have been used. However, in the analytical side, only sinusoidal A-M and square-wave signals have been used.

(d) Investigate feasibility of using modulation tracking filter on spaceborne vehicles: Little progress has been made toward this goal. However, new developments in cooling techniques are being made which reduce weight and power requirements. This improves the chances that this approach can be used.

3.2.3 SUBTASKS

(a) Cutting of semiconductors has been continued. Also several of the more exotic materials, including InSb have been obtained.

(b) See response to 3.2.2.

(c) See response to 3.2.1.

(d) See response to 3.2.1 and 3.2.2.

(e) See response to 3.2.1 and 3.2.2.

(f) Same

(g) Correlation of final experiments: These will be proposed for the next contract period.

(h) Update to refrigerator operating manual. This has been done continuously through use of the refrigerator log and laboratory manual.

(i) Troubleshooting guide for refrigerator: See next full section.

(j) Reevaluation of samples and cavity design. The latter of these two has been accomplished, but insufficient data are available for sample reevaluation.

D. Troubleshooting Guide for Refrigerator Subsystem

1. Addition of Gas to System

Never add gas to the system such that the pressure in the system exceeds 280 psig. The system is usually operated between 200 and 240 psig. It is usually best to start with about 220 to 240 psig and reduce the pressure when near the normal operating temperature. The best results are obtained with 200 psig and ΔP equal to 10 psig.

Procedure

(a) Connect charging line to gas regulator-light.

(b) Connect other end of charging line to refrigerator charging adapter. [There are two adapters and charging is usually done on the return side, although charging may be done on the supply side. The adapters are usually tied in next to the compressor.] Do not tighten the nuts.

(c) Purge charging line with helium gas. While the line is charging, tighten the nuts. Bring the line pressure to about 240 psig.

(d) Run the crosshead.

(e) Crack the valve on the charging adapter and bring the pressure to the desired valve. Using the J-T Circuit Pressure guage.

(f) Allow the crosshead to run for several minutes to equalize system pressure.

(g) Start the compressor.

2. Overheat Shutdown

If the compressor shuts itself off, this is usually caused by a high temperature condition in the compressor itself. This condition may be caused by several combinations of conditions.

(a) If the system is started from room temperature with no precooling, the compressor may overheat and shut down. If this occurs, two hours of precooling with liquid nitrogen is necessary and additional air flow through the compressor heat exchangers is also necessary. Note. In a properly air conditioned room, overheating will <u>not</u> take place.

(b) If no oil reaches the compressor head and valves, the head will overheat and cause the compressor to shut down. The no oil condition is caused by two separate and distinct causes:

1) Oil level in sight glass above sight glass, and

2) Oil level in sight glass normal, or below sight glass.

Condition 1) means that the 0.018" Make Up Orifice is plugged. If this orifice is plugged the oil filter between the oil pump (on the compressor) and the oil heat exchanger will be found to be clogged. The filter should be replaced, and the 0.018" orifice must be cleaned. See the CTi Manual for the correct procedures.

Upon restarting the system, the oil level in the compressor should drop almost immediately, and then come back up to 1/2 full.

Condition 2) means that the number 1 oil separator is not working properly and is trapping oil. The separator must be cleaned and drained according to CTi's procedures. It is also advisable to check the 0.028" Oil Injection Orifice. Note. Oil should not be added to the system until the cautionary note on page 7-5 of the CTi Operating Manual is read and understood!

Other troubleshooting procedures are listed in the CTi manual.