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TRAVELING-WAVE TUBE AMPLIFIERS: AN S-BAND RADAR PREAMPLIFIER

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ABSTRACT

An S-band low-noise traveling-wave tube, manufactured by RCA Laboratories and designated as A4395, was tested at the Naval Research Laboratory and found to have a noise figure of approximately 9 db and a small-signal gain of approximately 26 db. This tube, with associated circuitry, was installed in the AN/MPQ-5 radar in operation at Chesapeake Bay Annex of the Naval Research Laboratory for the purpose of evaluating the effect of the addition of such a preamplifier to a conventional radar system. The improvements resulting from the addition of this tube to the AN/MPQ-5, as shown both by system measurements and comparison of display photographs with and without the preamplifier, were increased sensitivity, increased maximum range, and lower system-noise figure.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R12-02

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INTRODUCTION

The application of a low-noise traveling-wave tube as a preamplifier to an existing radar system of higher-noise figure has the effect of reducing the over-all noise figure of the system. The noise contributed and amplified by this preamplifier is the dominating factor in the over-all noise figure, since it masks to a great extent noise contributions from the rest of the system.

Laboratory tests of the series A4395 traveling-wave tube[1,2] indicated a noise figure in the region of 9 db, and a small-signal gain of 26 db. Since these tubes perform in the S-band frequency range, it seemed feasible to use one as an r-f preamplifier in the receiver of a conventional S-band radar; and, on the basis of availability and convenience, the AN/MPQ-5 was selected as the radar to which this preamplifier was to be added. If the tube exhibited the same noise figure in operation in the radar as under laboratory tests, it would in effect give the radar a noise figure of approximately 9 db. Although some S-band radars have been built with comparable noise figures, as a matter of practical experience few maintain this noise figure for very long. A consistent 9-db noise figure, if obtainable, would therefore represent a considerable improvement in almost any operating S-band radar.

NOISE FIGURE CALCULATIONS

The noise figure of a combination of preamplifier and radar receiver may be written [3] as

$$F_{PR} = F_P + \frac{F_R - 1}{G_P}, \qquad (1)$$

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[1]Kittredge, F. A., Jr., North, W. R., III, "Traveling-Wave Tube Amplifiers: RCA Low-Noise Tubes," NRL Memorandum Report No. 2[redacted]6 , January 1954

[2]Radio Corporation of America, RCA Laboratory Division, Princeton, New Jersey, "Discription of Low-Noise Traveling-Wave Tube A4395"

[3]Pound, R. V., "Microwave Mixers," Radiation Laboratory Series, Vol. 16, Page 15 (Equation 23)

where

G_P = Gain of preamplifier

F_P = Noise figure of preamplifier

F_R = Noise figure of radar receiver

F_{PR} = Noise figure of the combination of preamplifier and radar receiver

N_R = Noise figure of radar receiver in decibels

N_{PR} = Noise figure of the combination of preamplifier and radar receiver in decibels.

The instruction manual[4] specifies a 15-db receiver noise figure when the AN/MPQ-5 leaves the factory. The A4395 traveling-wave tube can be considered as having a 9-db noise figure and a small-signal gain of 26 db. Substituting these values, expressed in ratios, in Equation (1) we get

$$F_{PR} = 10^{0.9} + \frac{10^{1.5} - 1}{10^{2.6}}, \tag{2}$$

or

$$F_{PR} = 8.03. \tag{3}$$

Converting F_{PR} into decibels, where $N_{PR} = 10 \log_{10} F_{PR}$, we get $N_{PR} = 9.05$ db. Since $N_R = 10 \log_{10} F_{PR}$ we also get $N_R - N_{PR} = 5.95$ db-improvement. Variations from the original factory specifications on noise figure could give a still larger improvement.

MODIFICATION OF THE AN/MPQ-5 RADAR

A type AN/MPQ-5 radar was available on a part-time basis at the Chesapeake Bay Annex. Operating this radar with a traveling-wave tube preamplifier necessitated the following modification. The A4395 tube[5] and associated r-f circuitry were inserted between the TR cavity and the crystal mixer (Fig. 1) by removing the crystal from its integral combination with the TR cavity and inserting a matching taper from the cavity to the 50-ohm traveling-wave tube input; and the 50-ohm output of the traveling-wave tube was fed into the crystal mixer, whose input was modified to receiver the 50-ohm output of this tube. In addition, provision was made to inject the local oscillator signal at the mixer input.

In order to facilitate visual observation of the effect of the preamplifier on radar performance, magnetically controlled coaxial switches were inserted at both the input and output of the traveling-wave tube, allowing the r-f energy either to pass through the tube to the crystal mixer or to bypass the tube and go directly to the mixer. The system was retuned, and measurements made to ascertain that system conversion loss, operating without the preamplifier, was equal to system performance before modification. The oscillator was appropriately padded to prevent frequency shift and power-output variation because of load changes, enabling the crystal to operate at the same current with or without the traveling-wave tube in the circuit.

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[4] "Lark SP-1M Radar Equipment. NRL Prototype for ANA/MPQ-5 and ANA/SPQ-2 Radar," NRL Report 3584, Vols. I and II , February 1950

[5] Peter, R. W., "Low-Noise Traveling-Wave Amplifier," RCA Review, Vol. XIII, No. 3, pp. 344-368, September 1952

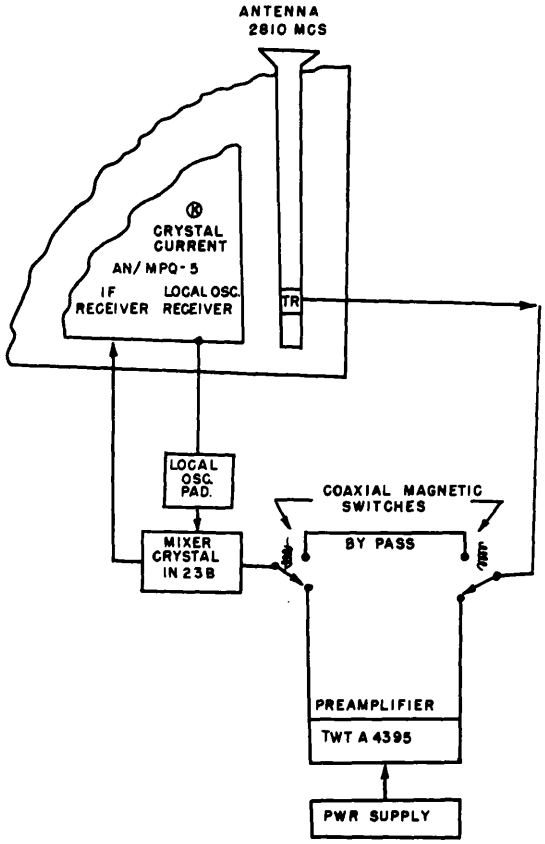

Fig. 1 - Modification of AN/MPQ-5 radar for traveling-wave tube preamplifier addition

SYSTEM MEASUREMENTS

To assure proper traveling-wave tube performance, gain and noise figure of the preamplifier were optimized utilizing laboratory techniques.[1] The receiver and detector used for these measurements were the AN/MPQ-5 receiver, of one-megacycle bandwidth, and its associated detector. The noise source was inserted directly at the TR output. The gain of the RCA tube, with the radar operating on a frequency of 2810 megacycles, was approximately 26 db.

Without the preamplifier, the noise figure of the AN/MPQ-5 radar was measured as approximately 18 db, and with the preamplifier it was measured as about 9 db. It is emphasized that these measurements are approximate in the sense that an error of possibly 10 percent may exist. The radar was available for only a limited period of time; so that no elaborate measurements could be made. It is possible to say on the basis of the measurements made, that the addition of the traveling-wave tube definitely improved the noise figure of the radar system to which it was added.

PERFORMANCE MEASUREMENTS

While the system was in operation, the improvement in performance could be seen immediately by observation of the system display. Because of the obvious nature of these

improvements it was decided that the changes in system performance could most easily be demonstrated by means of photographs. A Land-Polaroid Camera was used to take comparison photographs within minutes of each other. The pictures were snapped, the preamplifier switched out of the system, and another picture taken. Both pictures were then developed.

Because of film characteristics, the improvement visible to the operator watching the display is not fully shown. The improvements shown, however, are of sufficient magnitude to warrant their inclusion.

In the first A-scan photographs (Figs. 2 and 3), a stationary target (A) near noise level in amplitude was examined. The AN/MPQ-5 automatic gain control was turned off and the gain was adjusted to keep approximately the same target amplitute in both photographs. The improvement in noise figure is readily apparent.

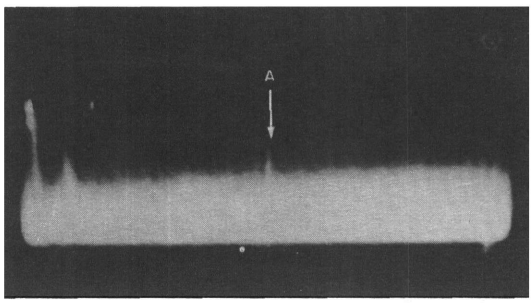

Fig. 2a - Fifty-mile range without preamplifier

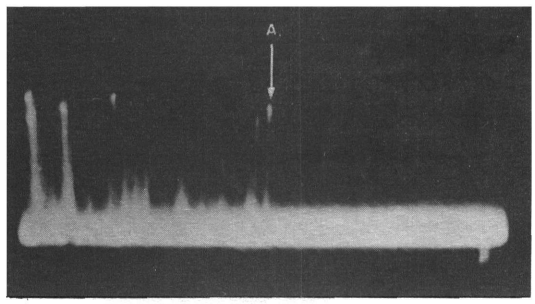

Fig. 2b - Fifty-mile range with preamplifier (manual gain reduced)

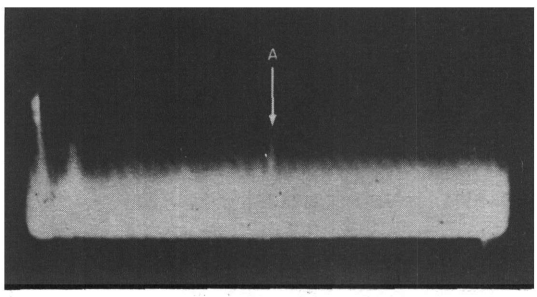

Fig. 3a - Fifty-mile range without preamplifier (high noise level)

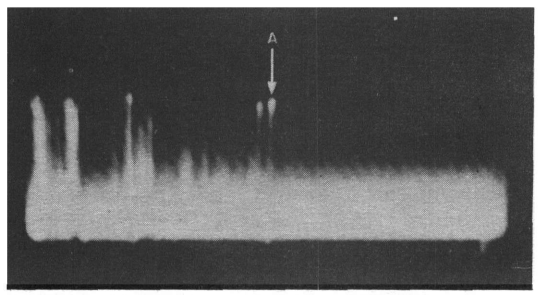

Fig. 3b - Fifty-mile range with preamplifier (high noise level)

The effect of the preamplifier addition can also be shown where the noise level is kept constant. With the preamplifier energized using the previous target and a distinct target saturation effect is immediately apparent (Fig. 3).

The PPI photographs show a still more remarkable improvement. Since so much information is available on the photographs, the improvement can best be noted by examination of the outlined blocks (Figs. 4a and 4b). A 20-mile sweep is presented, with the range measured from the center outward, and the increase in readable targets may be easily noted. The land masses also appear with greater distinctness. Figs. 5a and 5b with the same range, show system operation after the gain was raised to the point where the noise was painted on the scope. These figures also show a definite increase in target density when the preamplifier is used.

The operation of the radar on the 50-mile sweep range (Figs. 6a and 6b) presents more evidence as to comparative target readability with and without the preamplifier. The outer areas show an increase in target density, and near the extremities there is an increase in the range at which targets can be detected when the preamplifier is used. The noise level painted on the radar scope was held approximately the same for these photographs, as shown by the indication of noise at the center and edge of the scan.

It was possible to obtain better-than-normal operation during this particular experiment. The radar, located on a 100-foot cliff overlooking Chesapeake Bay at North Beach, painted targets on the scope beyond the 100-mile range marker in the Eastern Shore Virginia area (Figs. 7a and 7b). The outlined areas on the photographs show the increased detail of the land masses with the addition of the preamplifier.

In the 100-mile photographs taken of the system operating with the gain set so as to operate at a high-noise level (with corresponding obscurity of information at shorter ranges), the improvement in target readability can still be attained (Figs. 8a and 8b).

CONCLUSIONS

The addition of the RCA type A4395 traveling-wave tube as a preamplifier to the AN/MPQ-5 radar produced 9 db improvement in noise figure which resulted in corresponding improvement in system performance. This improvement was in two forms: increased range and increased target readabiltiy. It is expected that similar improvements can be achieved in other radar systems by means of this type of preamplifier.

The preamplifier had the further characteristic of retaining its optimum performance. In the tests conducted, the traveling-wave tube required only a slight adjustment in helix voltage from day to day, after initial warm-up, to duplicate the previous performances of 9-db noise figure.

The installation of a traveling-wave tube as a preamplifier to an existing radar, such as the AN/MPQ-5, is a rather simple modification. The advantage of the modification could be further enhanced by the replacement of the traveling-wave tube electromagnet by a permanent magnet, effecting a considerable reduction in size and weight.

ACKNOWLEDGMENTS

The author extends his thanks to Mr. L. F. Gilchrist and his associates of the Equipment Research Branch of the Naval Research Laboratory for the loan of the AN/MPQ-5 radar and for their aid in its operation.

Acknowledgment is also made to the members of the High Resolution Branch of the Naval Research Laboratory, especially Mr. G. P. Ohman for his technical guidance and to Mr. F. A. Kittredge for his assistance in traveling-wave tube operation.

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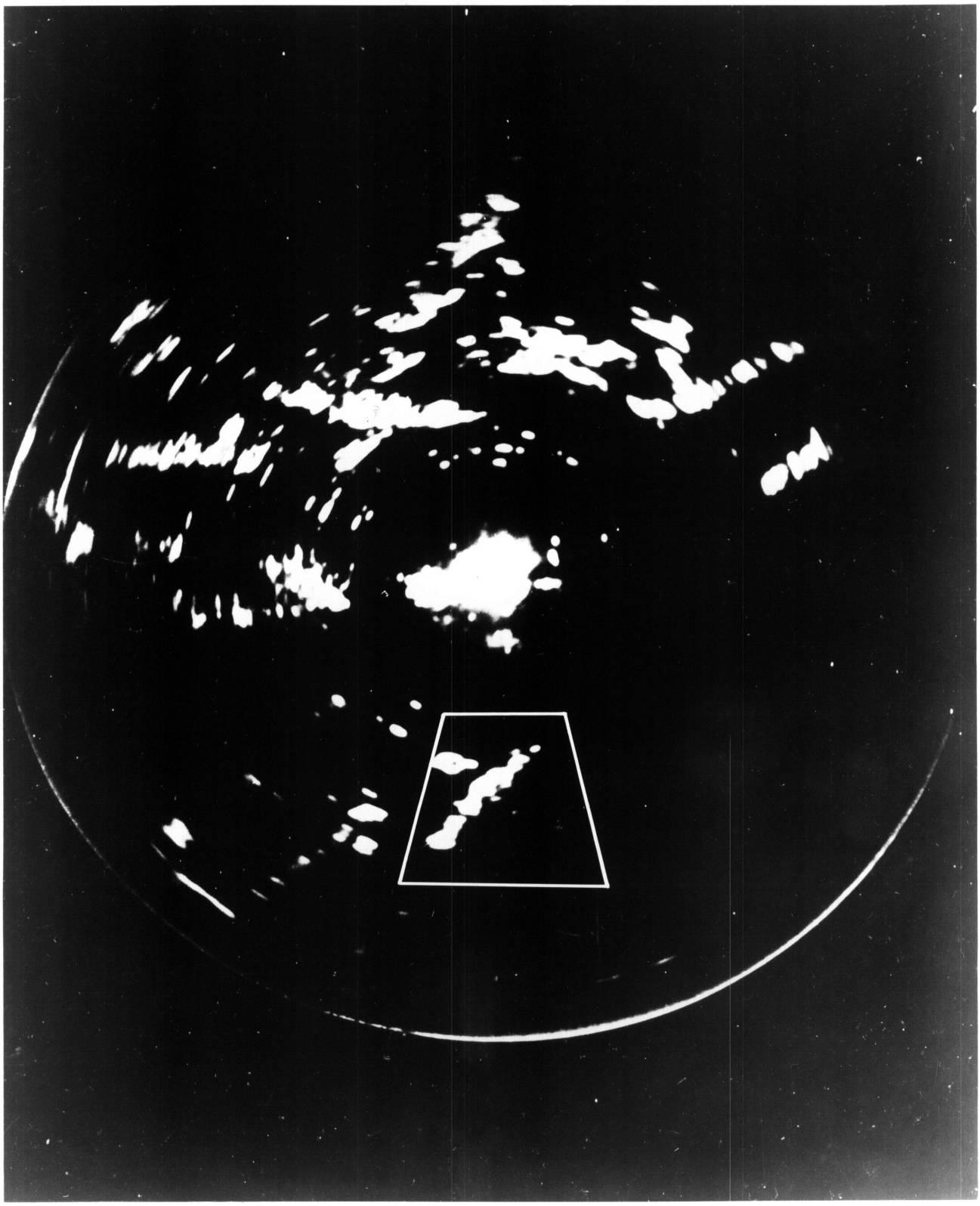

Fig. 4a - Twenty-mile range without preamplifier

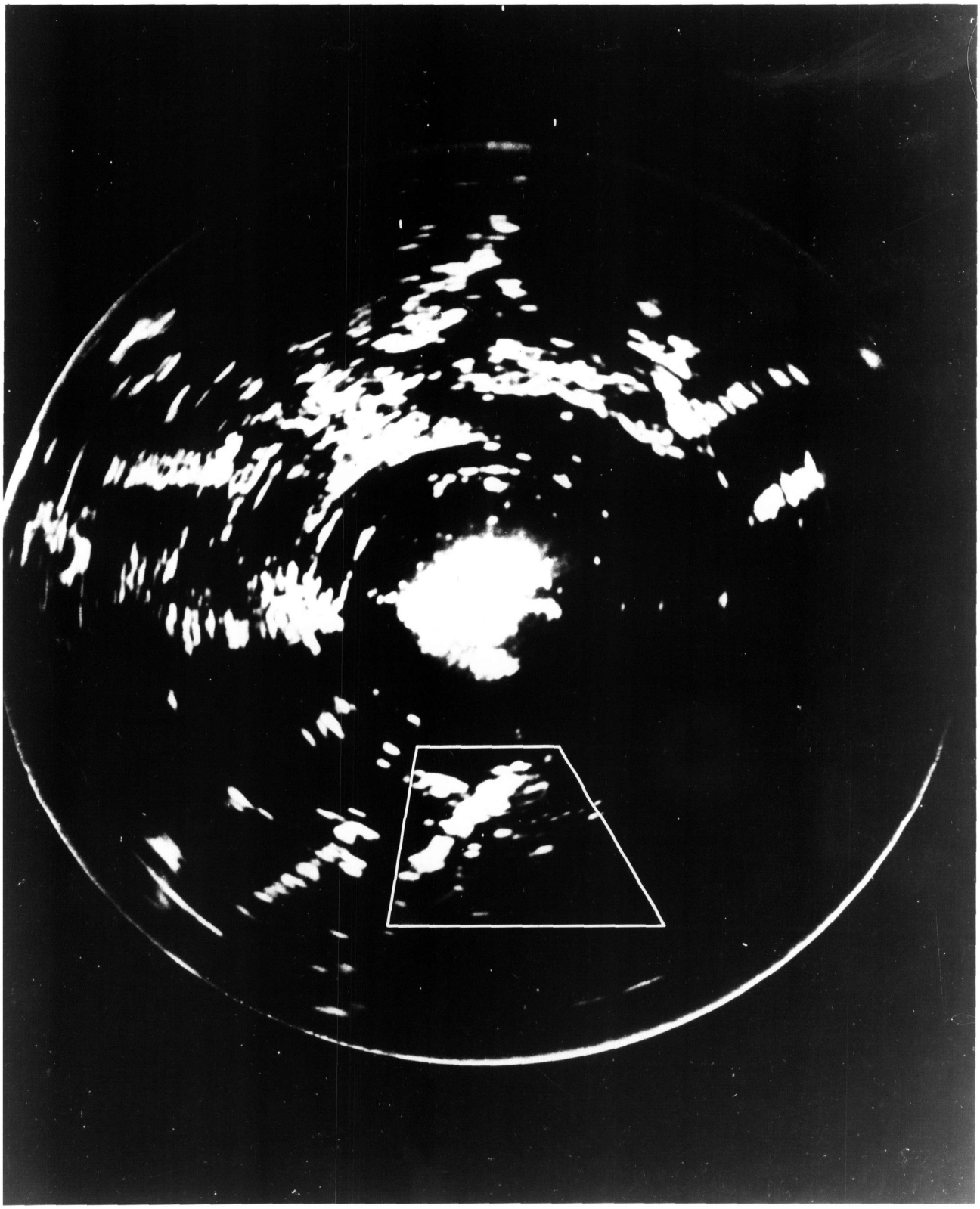

Fig. 4b - Twenty-mile range with preamplifier

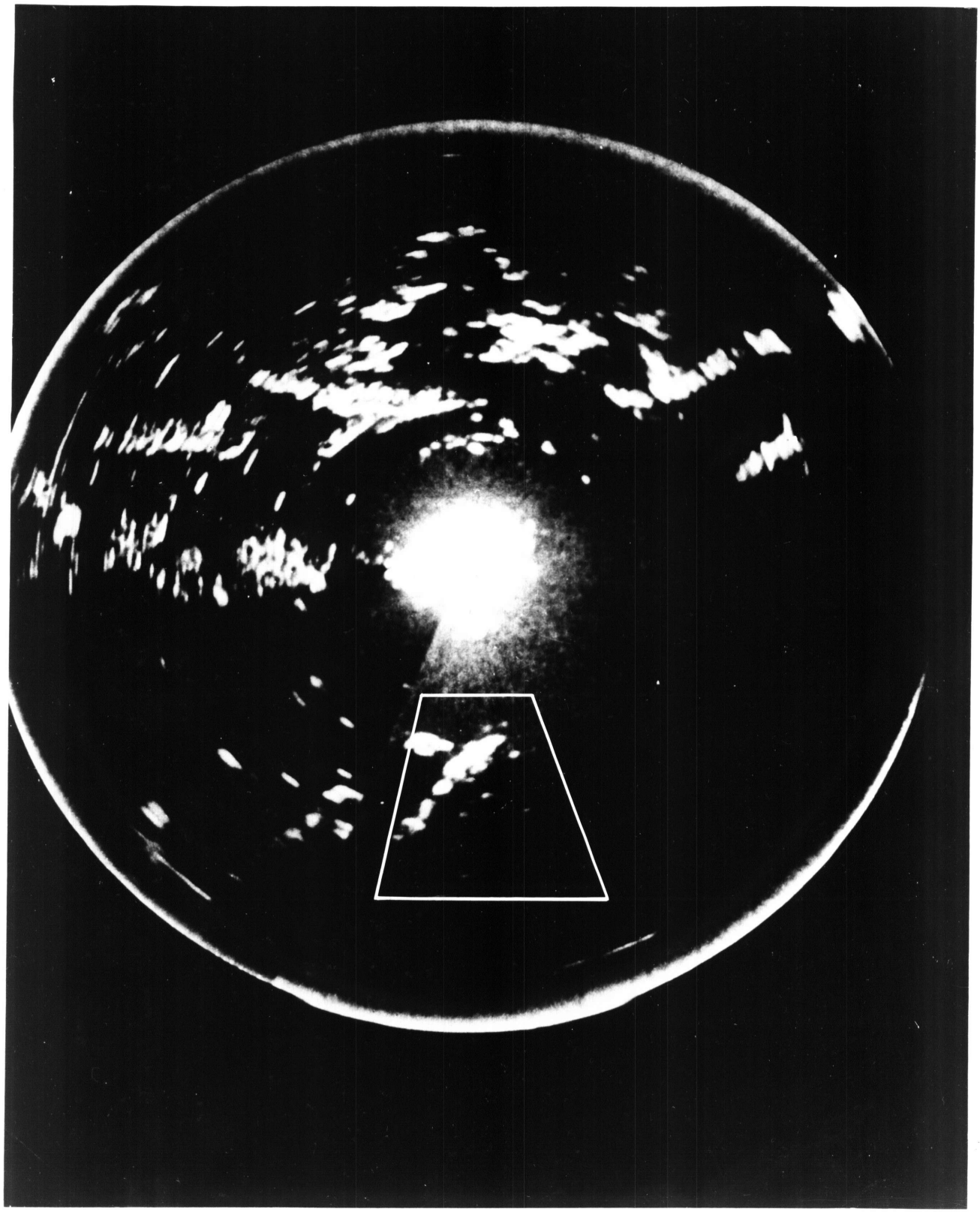

Fig. 5a - Twenty-mile range without preamplifier (high noise level)

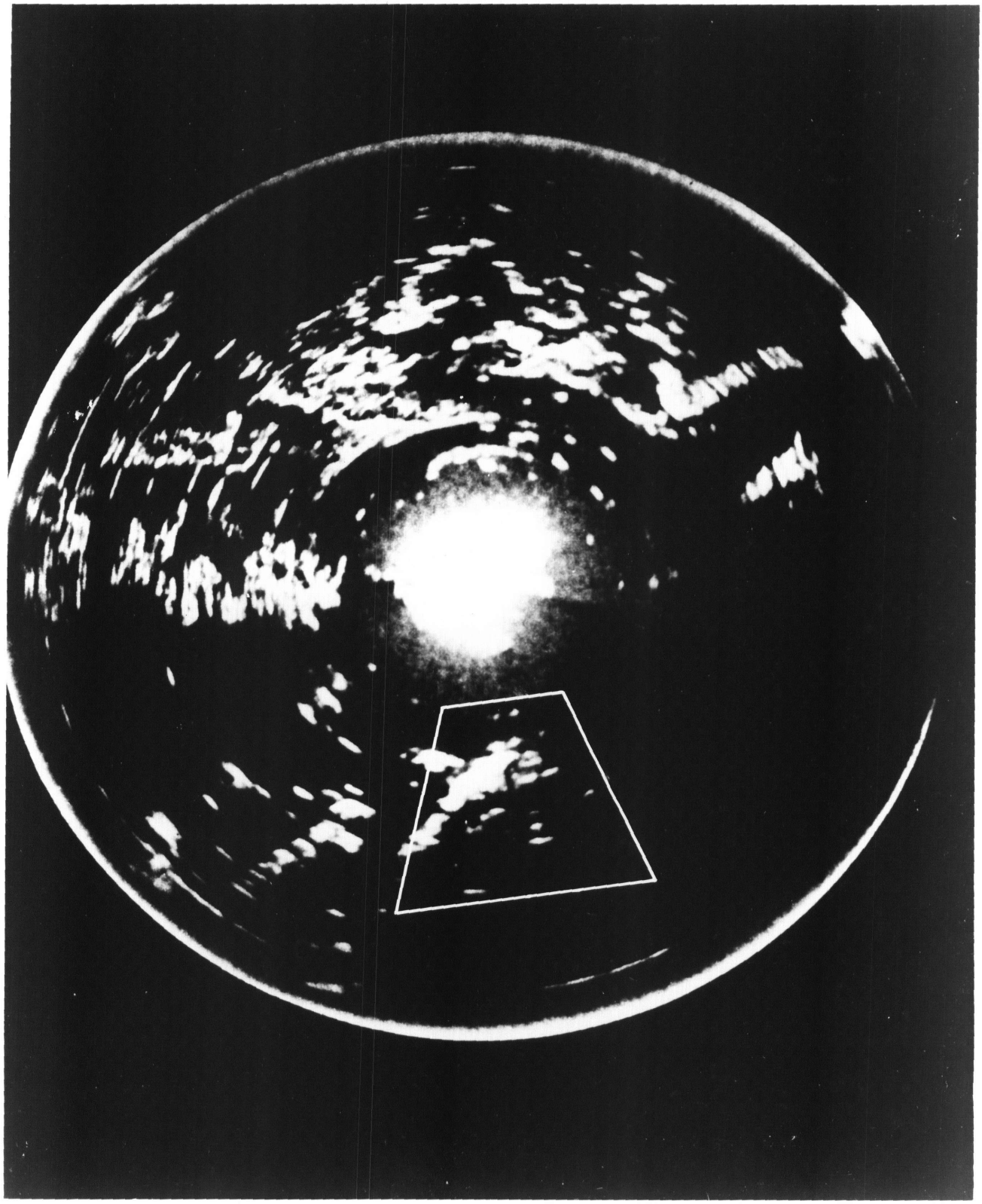

Fig. 5b - Twenty-mile range with preamplifier (high noise level)

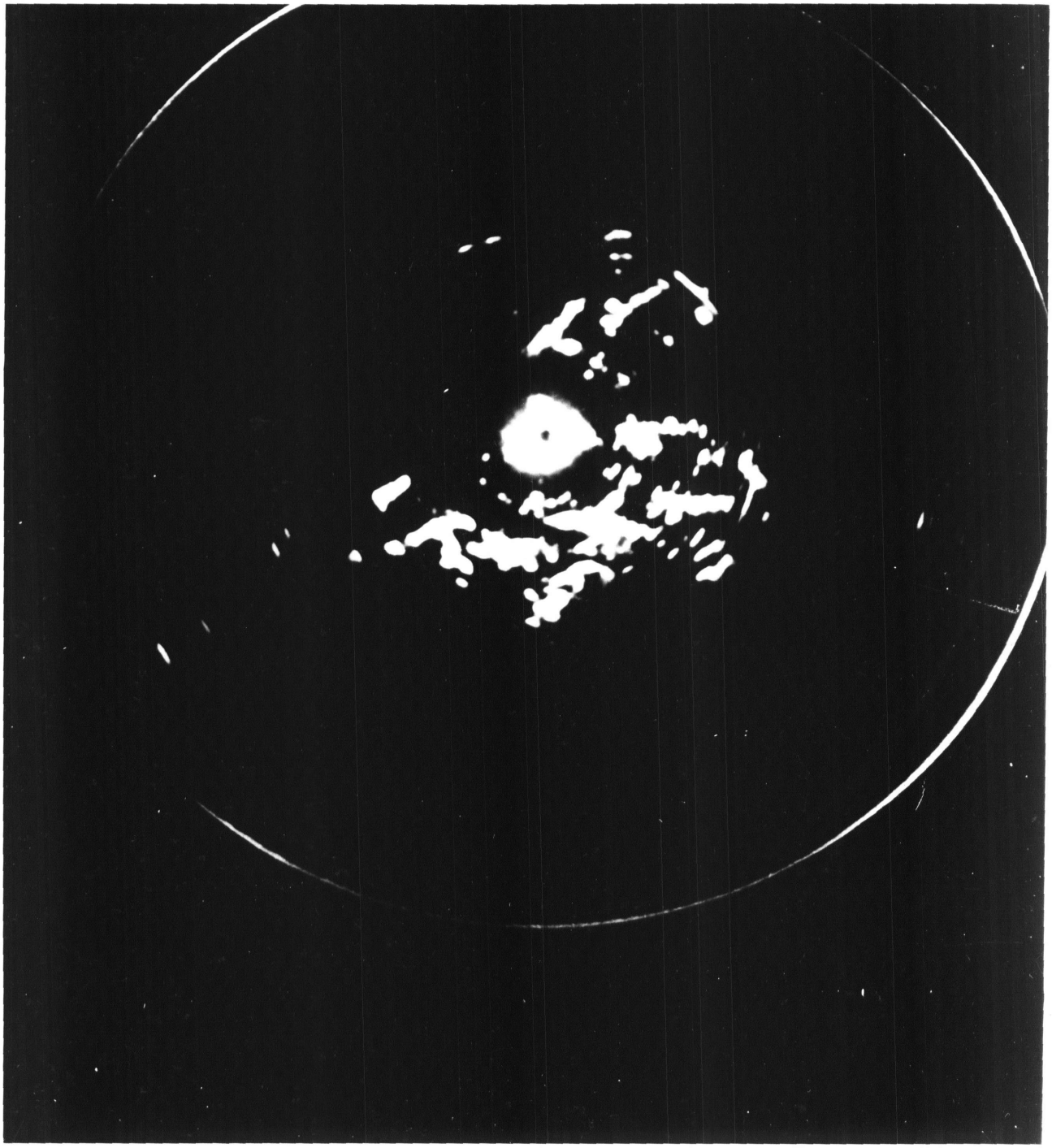

Fig. 6a - Fifty-mile range without preamplifier

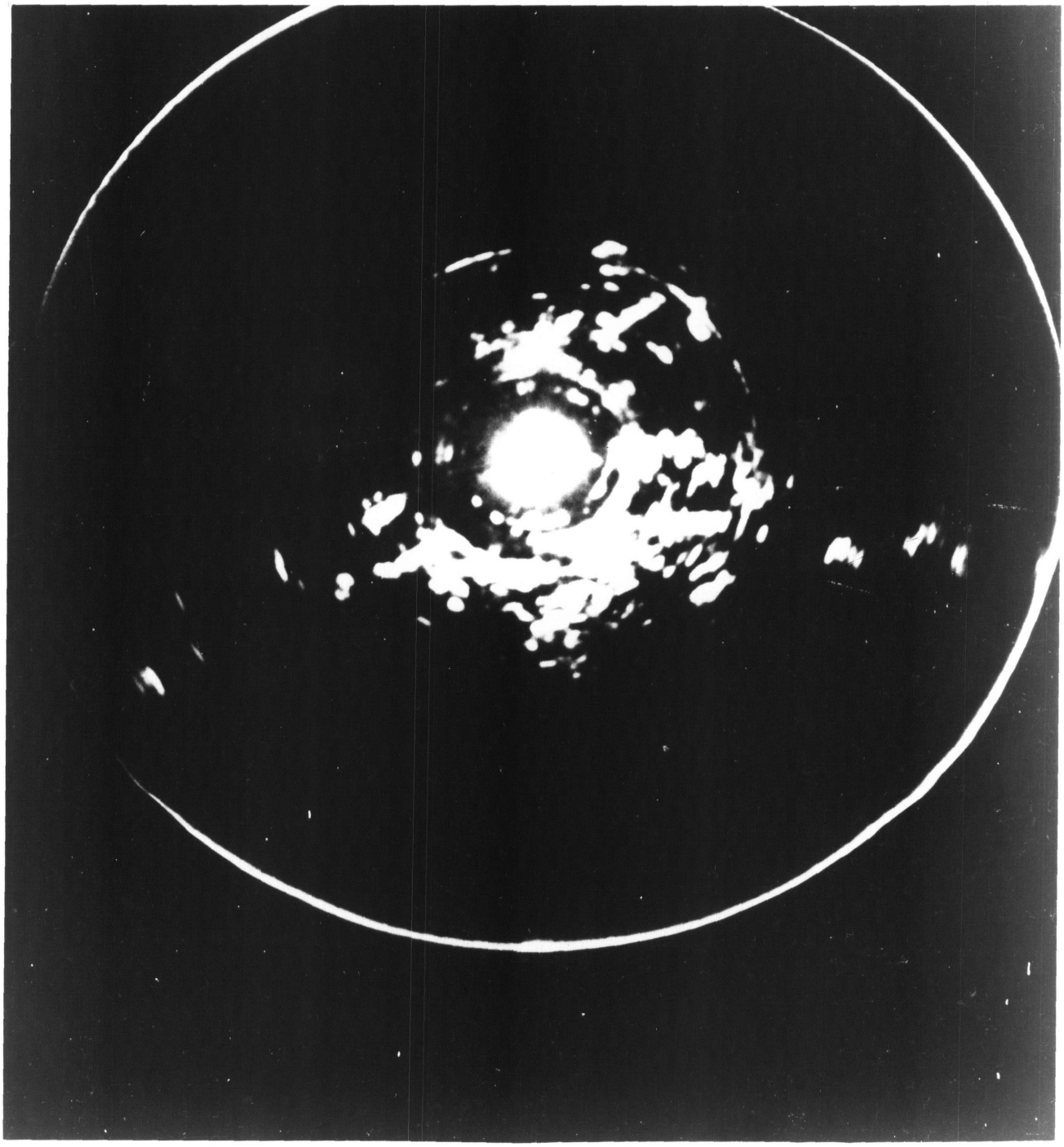

Fig. 6b - Fifty-mile range with preamplifier

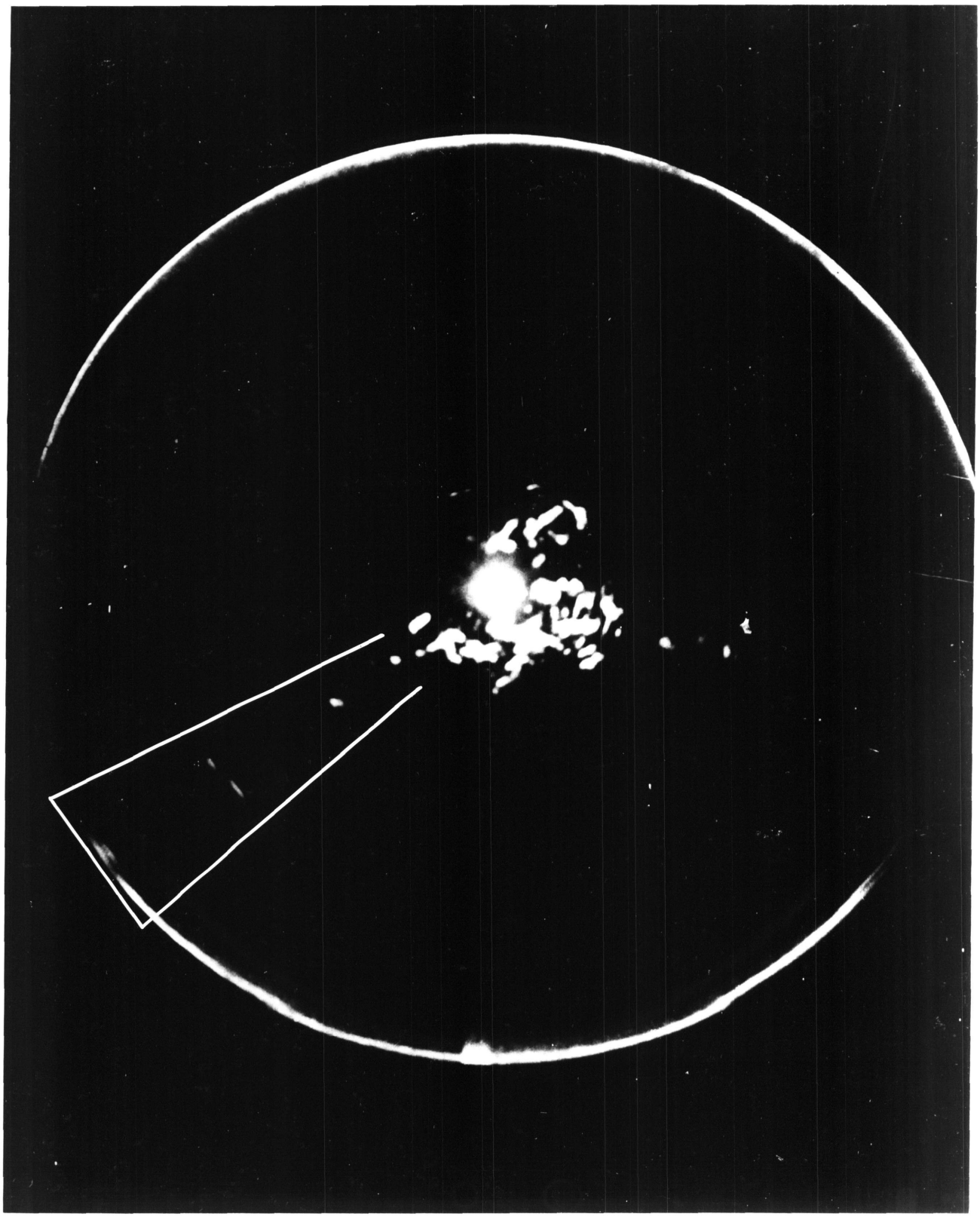

Fig. 7a - One-hundred-mile range without preamplifier

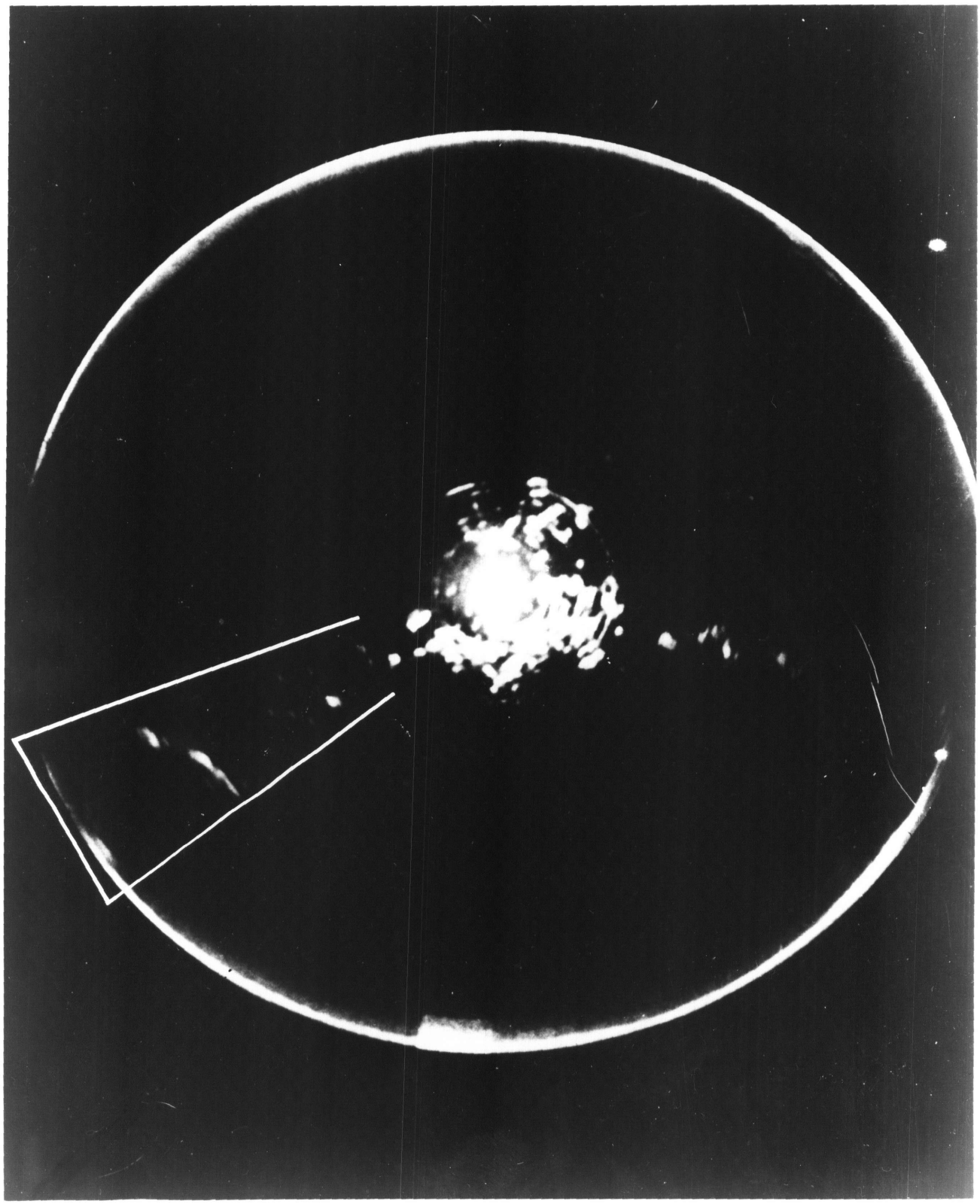

Fig. 7b - One-hundred-mile range with preamplifier

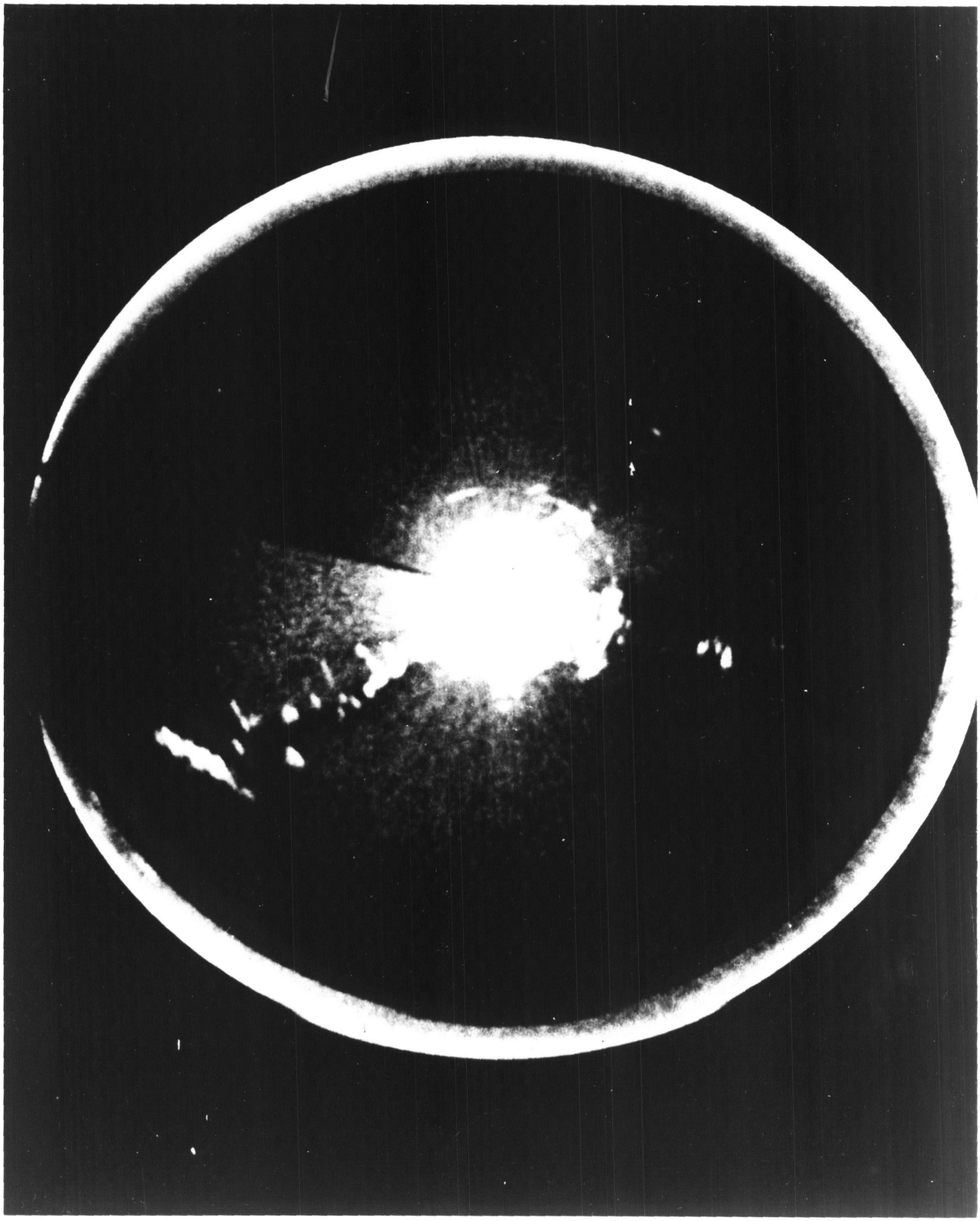

Fig. 8a - One-hundred-mile range without preamplifier (high noise level)

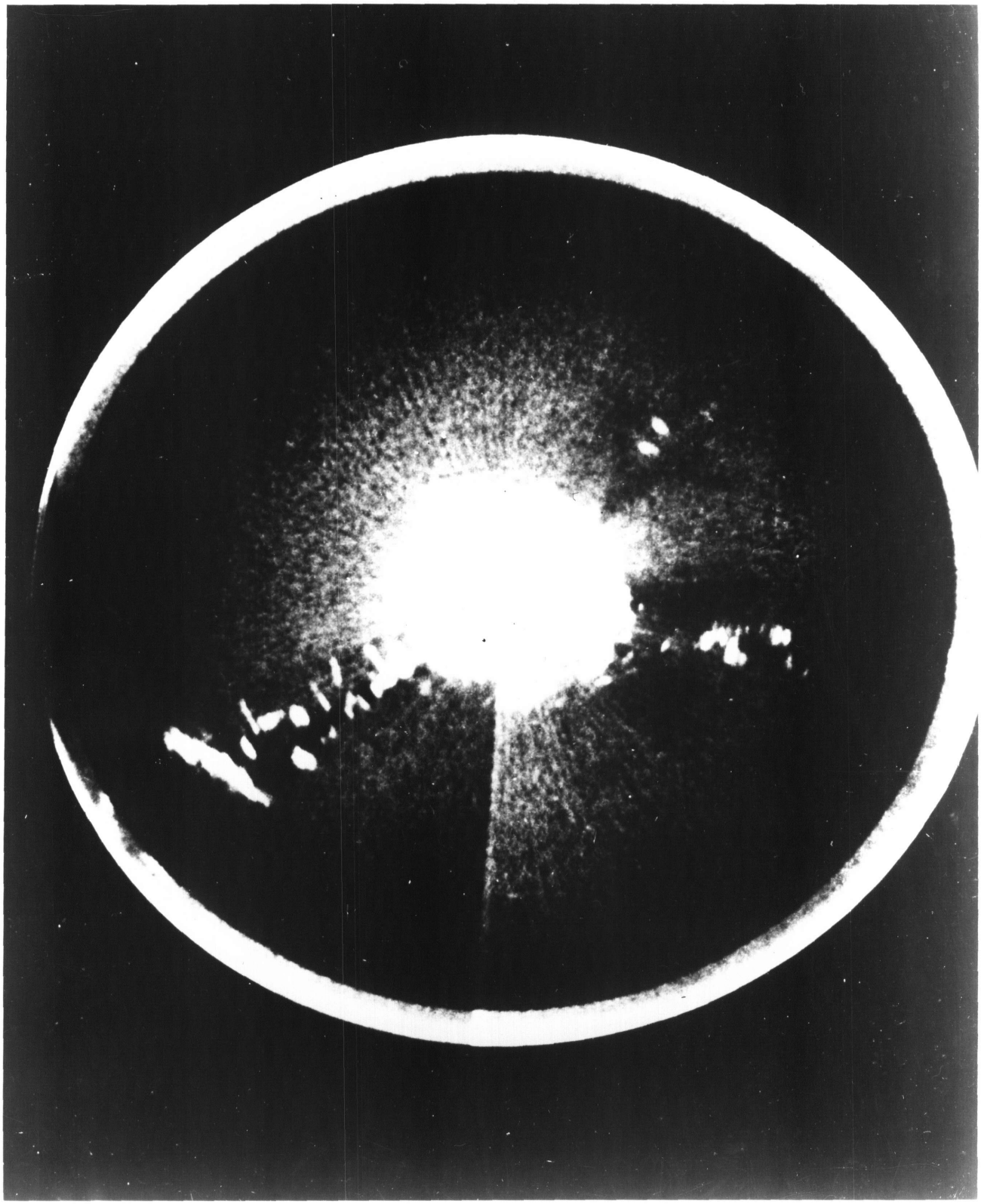

Fig. 8b - One-hundred-mile range with preamplifier (high noise level)