DOMSAT CW Transmission Bent Pipe Investigation: Initial Phase Noise Measurements via RCA SATCOM Link

M. H. Brockman
Telecommunications Science and Engineering Division

C. E. Jones
Radio Frequency and Microwave Subsystems Section

A preliminary investigation of a DOMSAT link using a SATCOM stationary Earth satellite and ground station has provided initial phase noise data for continuous-wave radio frequency transmission which is applicable to a bent pipe technique.

I. Introduction

An initial phase noise investigation has been made for continuous wave (CW) transmission from the RCA SATCOM station at Goldstone, California, up to a SATCOM stationary Earth satellite and retransmission back to the same Goldstone station. This investigatory test was conducted to provide initial information for a study for a proposed bent pipe concept for Galileo mission support.

II. Configuration for Phase Noise Investigation

A. General

The test configuration used for the CW phase noise investigation is shown in Fig. 1. For this investigation, a 73-MHz CW signal was provided to the RCA SATCOM ground station which resulted in an uplink CW signal at 6208 MHz to the SATCOM Earth satellite. The downlink signal (6208 minus 2225 MHz) transmitted from the Earth satellite provided an output CW signal from the SATCOM ground station at approximately 73 MHz. Bandpass filters with 1-MHz half-power bandwidths were utilized at the input to and output from the SATCOM ground equipment to effectively eliminate any interference to and from other users. Uplink power was set by RCA so as to provide a downlink nominal carrier-to-noise power ratio of +11.4 dB in the 1-MHz half-power bandwidth for the ~73-MHz output signal.

Operating frequencies for the elements of the test configuration shown in Fig. 1 were chosen so as to make use of available hardware as described later in this report. Translation of the ~73-MHz signal to 9.56 MHz provides a carrier-to-noise power ratio of +33.8 dB in a 6-kHz noise bandwidth at the output of the bandpass filter shown in Fig. 1 due to receiver noise. This 9.56-MHz signal plus noise provides an input to a sinusoidal phase detector which is an element of the phase-locked-loop shown in Fig. 1. The phase-locked-loop provides a means for comparing the phase of the ~73-MHz output signal from the SATCOM ground equipment with the 73-MHz signal provided for uplink transmission. The receiver noise discussed above, which is input to the sinusoidal phase detector, appears as 0.83 degrees rms at baseband in a 3-kHz noise bandwidth at the output of the phase detector. The widest closed loop bandwidth of the phase-locked-loop is chosen so that any effect introduced on the 0.83 degrees rms due to receiver noise is small (about 0.5%). Any phase differences due to frequency translation, oscillator instability, and intermodulation effects in the SATCOM link will then appear at the output of the phase detector in a 3-kHz noise bandwidth superimposed on the receiver noise discussed above. These phase differences, if present, will represent those components that the phase-locked-loop cannot follow (track out) and consequently will be a function of the closed loop noise bandwidth. For this initial investigatory test, the phase-locked-loop shown in Fig. 1 had three selectable bandwidths with two-sided design values of 10, 50 and 250 Hz. The actual measured two-sided closed loop noise bandwidths were 9.3, 47, and 267 Hz.

B. Equipment Description

To minimize hardware and engineering costs the test equipment used for the SATCOM phase stability measurements consisted of, for the most part, commercial equipment and components available at JPL. The uplink 73-MHz signal and the 63.44-MHz used within the phase-locked-loop were generated by Hewlett-Packard 5100A frequency synthesizers (refer to Fig. 1). The 24-MHz VCO used within the loop was a Block III receiver type. The reference frequency used for translating the downlink 73 MHz to 9.56 MHz was generated by a Fluke 644A synthesizer. All mixers were commercial double-balanced mixers including the loop phase detector.

Because of their inability to operate up to the required system frequencies, all synthesizers were set at one-half of the desired frequency, and then each output was frequency-multiplied, utilizing commercial frequency doublers followed by lab-constructed bandpass filters to ensure clean output spectra. Selection of 9.56 MHz for the translated downlink signal was dictated by an available narrow-band (~6 KHz) bandpass filter (FL1) centered at that frequency.

In order to duplicate the expected behavior of the test equipment using the SATCOM communication link, a lab test setup was made as shown in Fig. 2. The noise level was adjusted for a 11.4-dB signal-to-noise power ratio at the output of the 73-MHz bandpass filter (Point B); then the output spectrum of the 9.56-MHz filter (Point A) was photographed and is shown in Fig. 3. Comparison of Figs. 3 and 6 (described in Section III) shows similarity between the lab test setup and the actual SATCOM spectrum at the 9.56-MHz filter output.

Figure 4 shows the loop dynamic phase error for 267-Hz bandwidth operation when locked to a test input CW signal plus noise with a signal-to-noise ratio of +11.4 dB in a 1-MHz bandwidth. Again, a close similarity between test and SATCOM measurements is noted by comparison of Figs. 4 and 7c (described in Section III).

III. Measured Performance

Figures 5a and 5b show the ~73-MHz carrier signal plus receiver noise voltage spectrum at the output of the 1-MHz bandwidth bandpass filter for the downlink signal described in the preceding section for two different spectrum analyzer swept frequency ranges. Figure 6 shows the corresponding 9.56-MHz carrier signal plus receiver noise spectrum at the output of the 6-kHz bandwidth bandpass filter (input to the phase detector) over a smaller frequency interval. The measured values of phase noise at the output of the phase detector were 0.88, 0.85 and 0.83 deg rms respectively for the closed loop noise bandwidths of 9.3, 47, and 267 Hz. Figures 7a, 7b, and 7c are oscilloscope pictures of the phase noise at the output of phase detector for the corresponding measured 0.88, 0.85 and 0.83 deg rms values. Note that separate tests (see Section II-B) with a +11.4-dB carrier-to-noise ratio in the 1-MHz bandwidth at ~73 MHz provided the same carrier plus receiver noise spectrum as shown in Fig. 6 and a measured noise level of 0.83 deg rms at the output of the phase detector. Figure 8 shows phase noise plotted as a function of the phase-locked-loop two-sided noise bandwidth with a curve drawn through the measured data points. It is interesting to note that the measured phase noise (0.83 deg rms) for operation with 267-Hz closed loop noise bandwidth is the same as the expected value due to receiver noise as discussed earlier (Section II-A).

In explanation of this for the condition in which the 0.83 deg rms is essentially due to receiver noise, the measured 0.88 deg rms for 9.3-Hz closed loop selection includes additional phase noise of 0.29 deg rms due to the SATCOM two-way link. This results from the receiver noise and satellite link noise being statistically independent. The 0.85 deg rms measured for 47-Hz closed loop selection then includes additional phase noise of 0.18 deg rms due to the SATCOM link. If the assumption is made that the carrier-to-noise power ratio was actually 1 dB higher than described in Section II-A, then receiver noise would be 0.74 deg rms. The additional phase noise due to the SATCOM link would then be 0.48 deg rms for 9.3-Hz closed loop selection, 0.42 degrees rms for 47-Hz selection and 0.38 deg rms for 267-Hz selection.

During this CW phase noise investigation, another signal was observed in the SATCOM receiver about 1.5 MHz higher in frequency than the CW signal being observed herein. Later investigation by RCA revealed that this signal, which was transmitted from a station along the Alaskan pipeline, had its polarization (linear) improperly set and it should not have been present in the SATCOM transponder that contained the CW transmission considered here. It should be noted that subsequent polarization adjustment at the station in Alaska to orthogonal linear removed the signal from the transponder being utilized for this investigation. This signal (~1.5 MHz higher in frequency) appeared to be about 12 dB lower in peak level than the CW transmission. Observation of its on-off modulation pattern on a spectrum analyzer in the SATCOM ground station in conjunction with the phase error observed on the oscilloscope (see Fig. 7) indicated that a small portion (~1 deg peak to peak) of this modulation pattern appeared at the output of the phase detector in the phase-locked-loop discussed above (see Fig. 1).

IV. Summary and Conclusion

This initial phase noise investigation with CW transmission indicated that phase instabilities due to the SATCOM link are at relatively low frequencies about the radio frequency carrier. Providing that a phase noise investigation over wider bandwidths that will accommodate a telemetry modulation spectrum confirms this, a bent pipe technique utilizing such a link should introduce a very small telemetry signal-to-noise degradation for operation into a DSN station facility operating with radio frequency closed loop noise bandwidths of 10 Hz or greater. The test configuration described in this report can be expanded to include telemetry modulation which encompasses a correspondingly wider bandwidth. With such a configuration, a simulated telemetry transmission test conducted in conjunction with a facility such as CTA-21 would provide initial data on telemetry signal-to-noise ratio loss due to phase noise for a bent pipe technique.

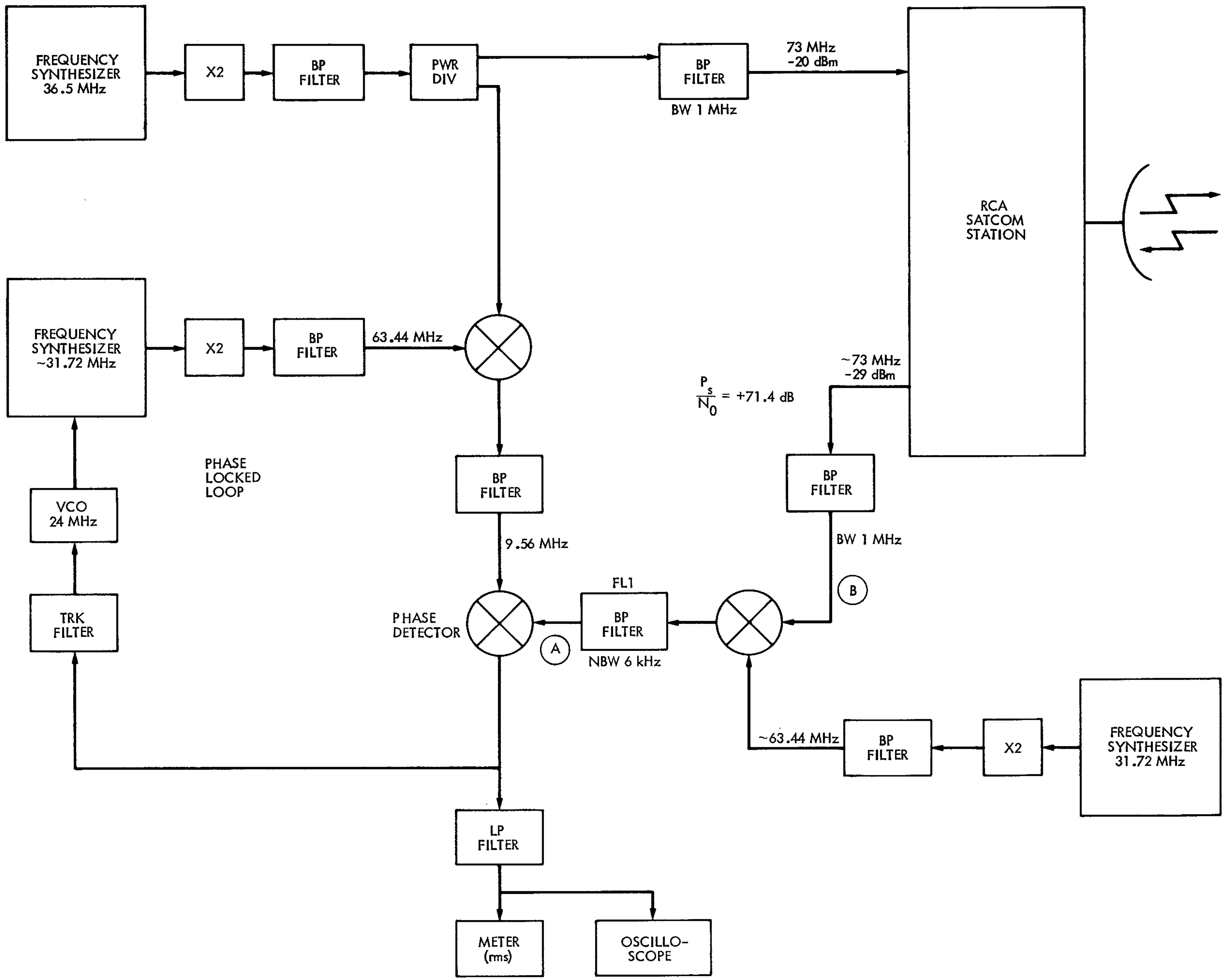

Fig. 1. Test Configuration for initial phase noise measurement CW transmission via SATCOM link

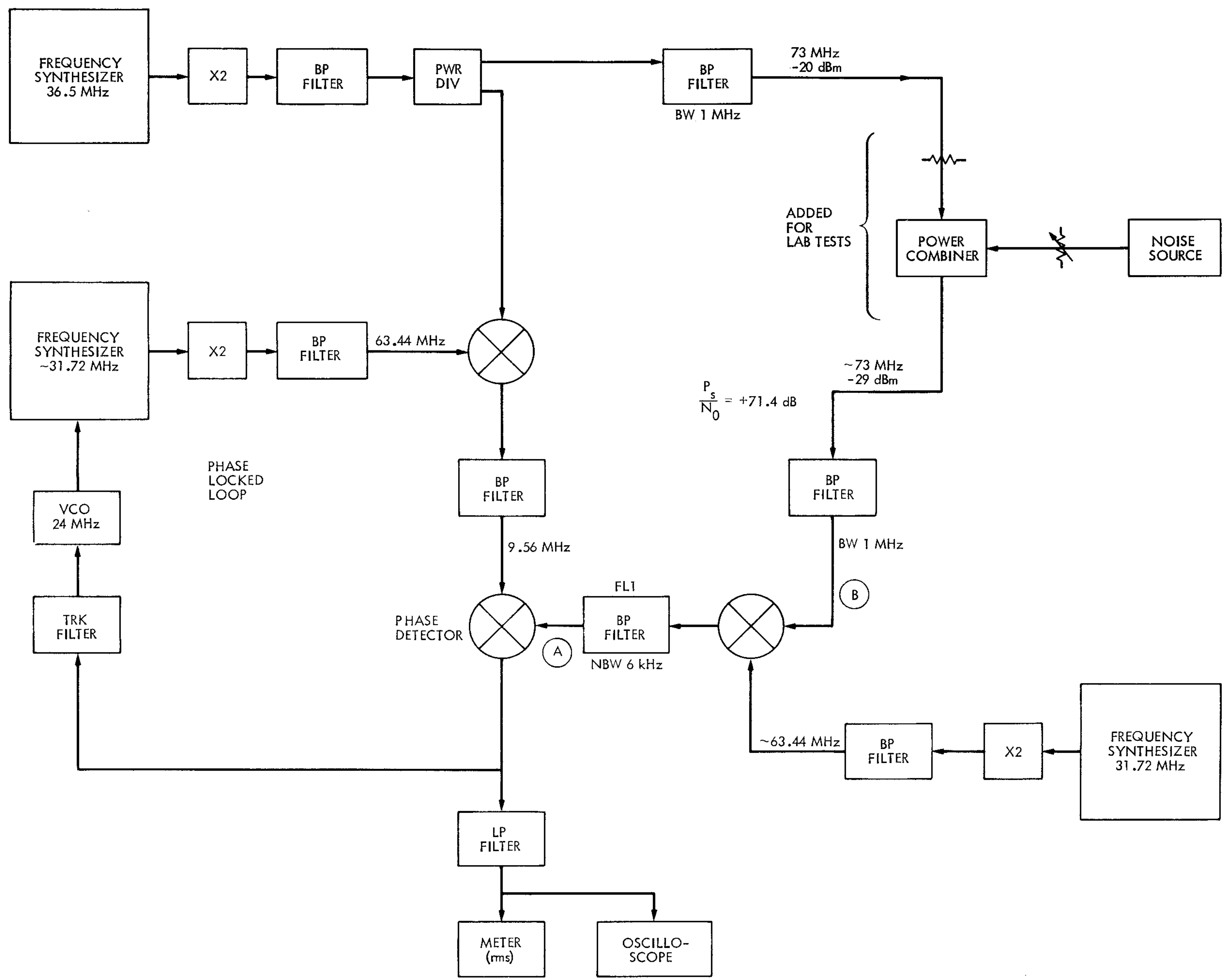

Fig. 2. Equipment configuration for laboratory calibration

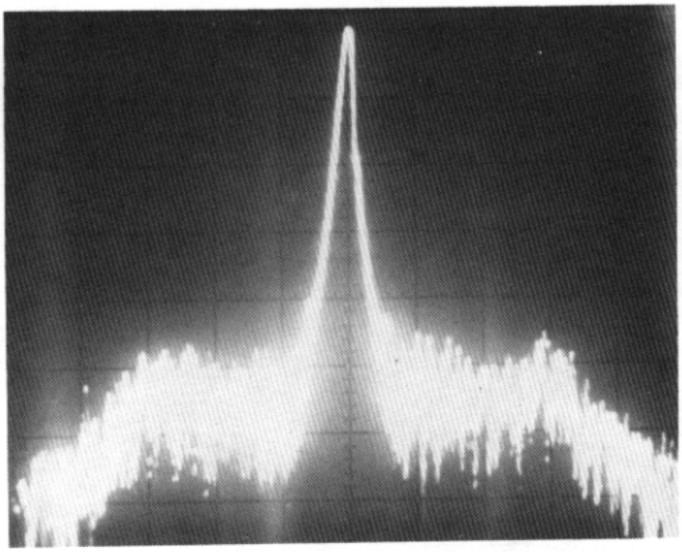

Fig. 3. 9.56-MHz lab calibration spectrum at 6 kHz-bandwidth filter output. Horizontal scale = 1 kHz/div; vertical scale = 10 dB/div (SNR) = +33.8 dB)

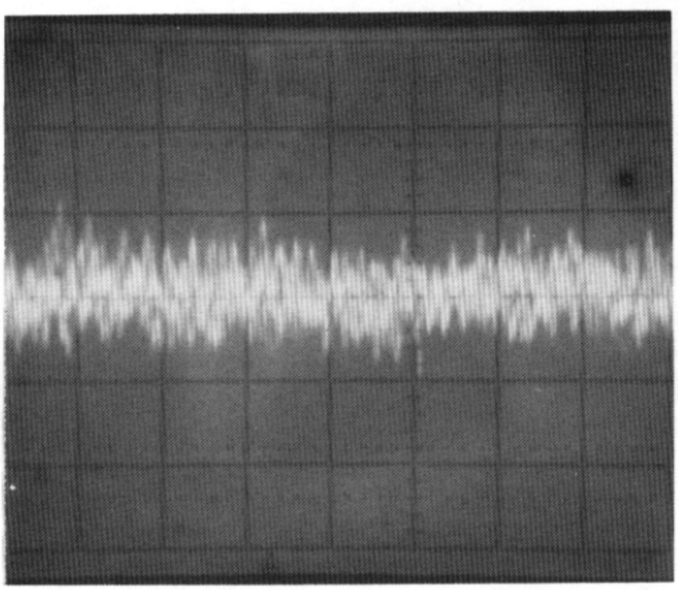

Fig. 4. Lab calibration 3-kHz bandwidth baseband noise. Horizontal sweep = 2 ms/div; vertical scale = 1.5 deg peak/div

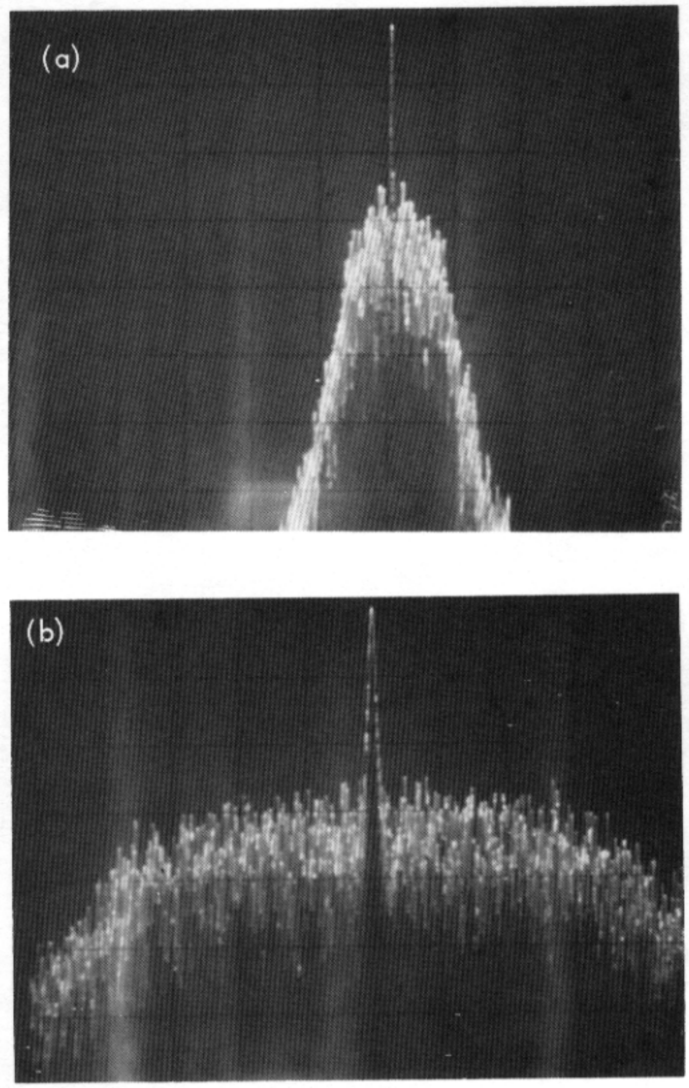

Fig. 5. 73-MHz received spectrum at 1-MHz bandwidth filter output (SNR = +11.4 dB)
(a) Horizontal scale = 1 MHz/div; vertical scale = 10 dB/div
(b) Horizontal scale = 0.2 MHz/div; vertical scale = 10 dB/div

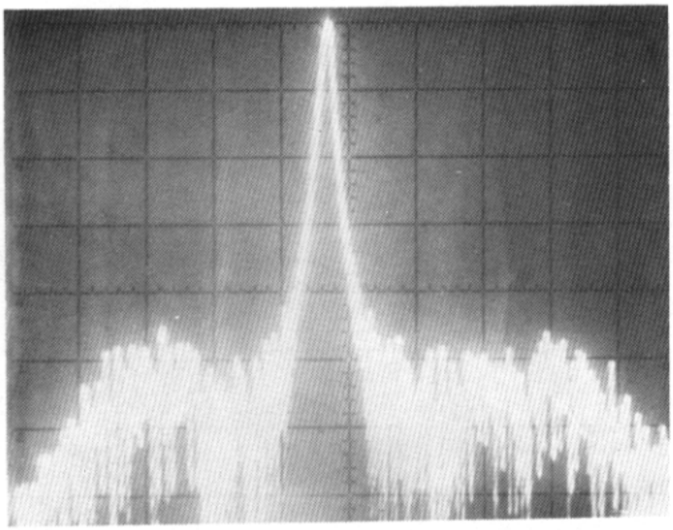

Fig. 6. 9.56 MHz received spectrum at 6 kHz bandwidth filter output. Horizontal scale = 1 kHz/div; vertical scale = 10 dB/div (SNR = +33.8 dB)

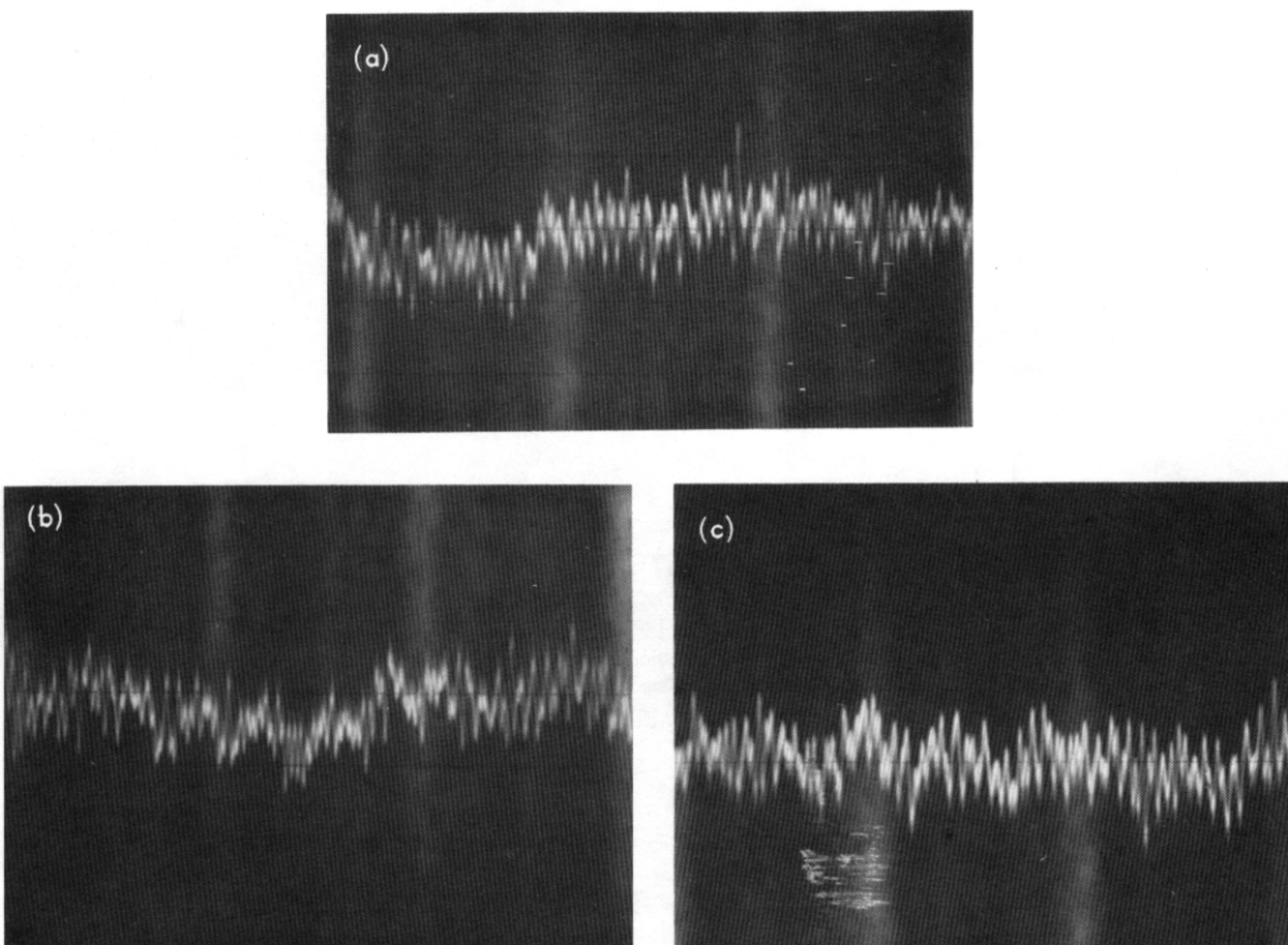

Fig. 7. Received 3-kHz bandwidth baseband noise. Horizontal sweep = 2 ms/div; vertical scale = 1.5 deg peak/div
(a) 9.3-Hz phase-locked-loop bandwidth (b) 47-Hz phase-locked-loop bandwidth (c) 267-Hz phase-locked-loop bandwidth

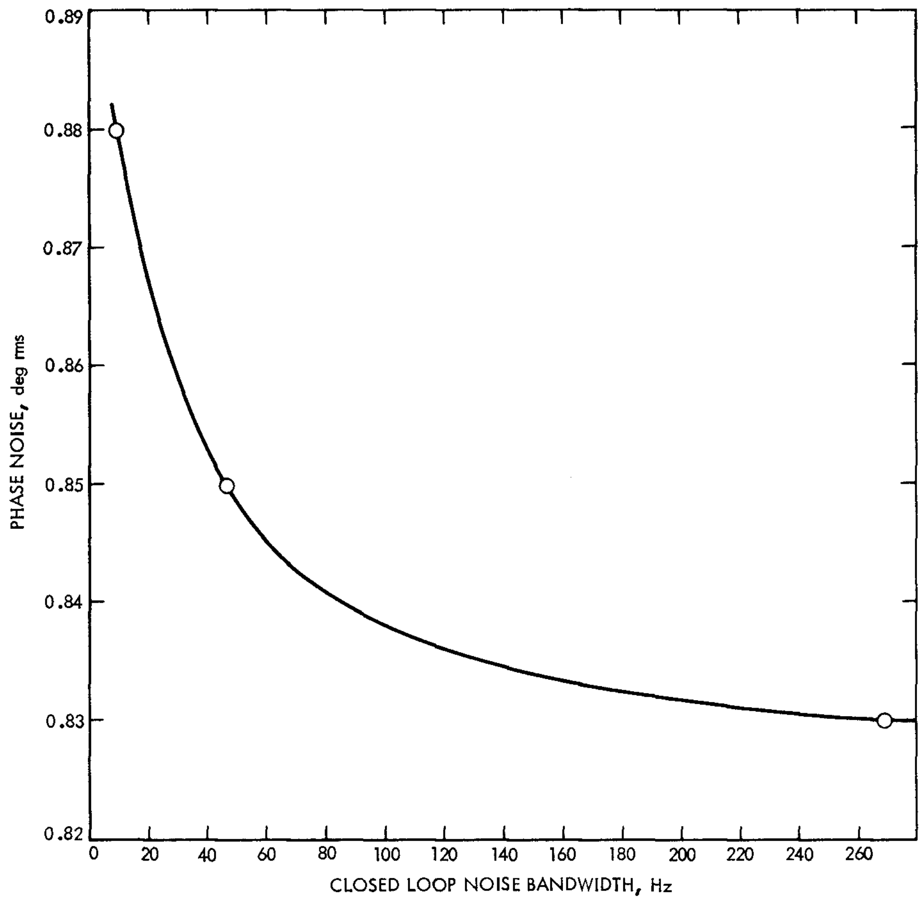

Fig. 8. Initial phase noise measurement RCA SATCOM link – CW transmission test