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EMI SURVEY FOR MARITIME SATELLITE, L-BAND, SHIPBOARD TERMINAL

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Summary

The United States Lines 15,690-ton commercial-container ship, "American Alliance," was selected as lead ship for an onboard EMI survey prior to installation of L-Band Shipboard Terminals for operation with two, geostationary, maritime satellites.

In general, the EMI survey revealed tolerable interference levels onboard ship: radiometer measurements indicate antenna-noise temperatures less than 70 K, at elevation angles of 5° and greater, at 1559 MHz, at the output terminals of the 1.2-m-diameter, parabolic-dish antenna for the L-Band Shipboard Terminal. Other EMI measurements include field intensity from 3 cm- and 10 cm-wavelength pulse radars, and conducted-emission tests of primary power lines to both onboard radars. This information should be helpful to designers of maritime, L-Band Shipboard Terminals.

Introduction

Two, geostationary, maritime satellites, one over the Pacific and one over the Atlantic Ocean, will make available high-speed communications and navigation services to ships at sea [1]. A satellite, L-Band Shipboard Terminal [2] - [4], operating within the 1636.5 - 1645.0 MHz maritime band, will allow ships to transmit voice, teletype, facimile and digital data messages, etc. via relay satellites to shore stations with a high degree of reliability. Similarily, a reverse, shore-to-ship communications link will transmit from satellite-to-ship within the 1535.0 - 1543.5 MHz maritime band.

There is an interest in determining the magnitude and extent of electromagnetic interference (EMI) in terms of its relationship to the successful operation of an onboard, L-Band Shipboard Terminal. Sources of shipboard EMI include: receiving antenna noise (e.g., galactic and tropospheric) from mainlobe and sidelobes of the shipboard terminal antenna; near-zone field intensity from onboard 3 cm- and 10 cm-wavelength, high-power (40 kW) pulsed radars; and conducted radio-frequency (RF) emissions along shipboard primary power lines.

The United States Lines 15,690-ton, commercial-container ship, "American Alliance," was selected as lead ship for an EMI survey prior to installation of experimental, L-Band Shipboard Terminals on ships of this general class [3]. Such an EMI survey was conducted from June 16-20, 1974, onboard the "American Alliance," while berthed at Port Elizabeth, New Jersey (USA), and at sea while enroute from Port Elizabeth to intermediate ports along the Eastern Coast of the United States (see map, Fig. 1). The ship maintained a minimum of 20 miles distance from the shoreline, along its southerly route, so that interference from the shore would be beyond line-of-sight. A description of the EMI survey is given as follows, including test results. Additional experimental data and design information is available in Ref. [5].

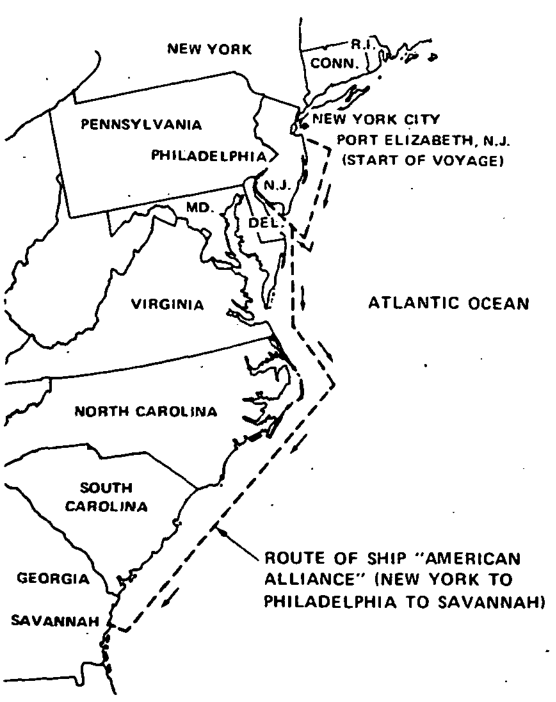


Fig. 1. Route of ship along East Coast USA.

Shipboard Installation

Various subsystems of an operational L-Band Shipboard Terminal, supplied under a U.S. Maritime Administration contract [2], provided essential equipment for this EMI survey, including a 1.2-m-dia. paraboloidal (dish) reflector, without radome, with 24 dB gain above isotropic at 1559 MHz. Receiver subsystems resulted in a system noise figure of 5.9 dB. The 1.2 m antenna contained, a right-hand circularly polarized, prime-focus RF feed for 1535 - 1660 MHz (transmit and receive) operation.

A make-shift antenna stand, and tripod mount with azimuth-elevation swivel axes, were used to position the dish antenna centerline approximately 2.8 m above the deck of the Flying Bridge for antenna mainlobe clearance. The above-deck configuration for the vessel, "American Alliance" is given in Fig. 3. The antenna stand was positioned on the starboard side of the ship's "Flying Bridge" (Fig. 4), in the approximate location selected tentatively for an operational L-Band Shipboard Terminal. A 12-m-length, low-loss coaxial cable ran from the output terminal of the 1.2 m dish antenna to EMI test equipment located in the ship's Wheelhouse immediately below the "Flying Bridge." Additional EMI test equipment was operated also in a below-deck Storage Room containing S-Band (10 cm) and X-Band (3 cm) navigation radar cabinets.

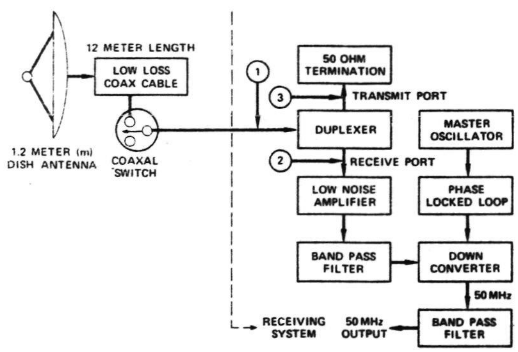


Fig. 2. Simulated L-Band Shipboard Terminal.

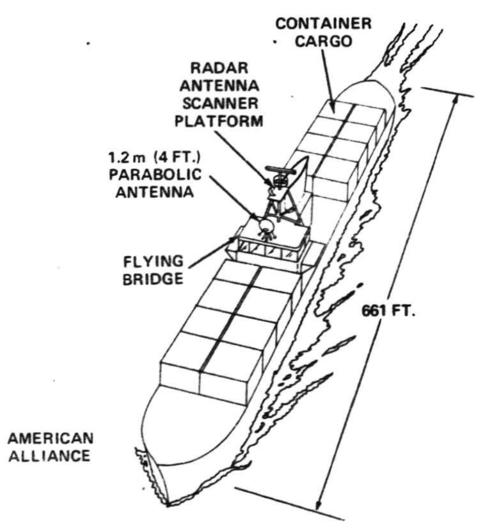
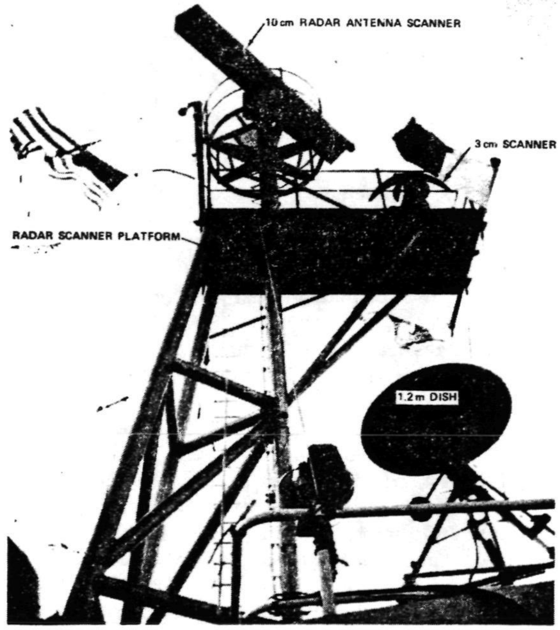


Fig. 3. Above-deck configuration of vessel, "American Alliance."

Antenna-Noise Temperature Measurements

With the 1.2 m antenna positioned on the Flying Bridge (Fig. 4), antenna-noise temperature at a center frequency of 1559 MHz was measured using an Airborne Instruments Laboratory Type 2392B Radiometer [6], and cold-load reference temperature (liquid nitrogen, 77 K) located in the Wheelhouse (Fig. 5). A continuously-variable precision attenuator (ARRA* Type 5614-60 L) was adjusted to obtain an equal output reading on the X-Y Recorder for both switch positions A and B. Measurements were made



(a) 1.2 m dish antenna on Flying Bridge.

(b) 1.2 m dish, tripod and stand.

Fig. 4. L-Band Shipboard Terminal, 1.2 m antenna on Flying Bridge.

*Calibrated at 1559 MHz both before and after sea tests using calibrated standard signal generator and RF power meter.

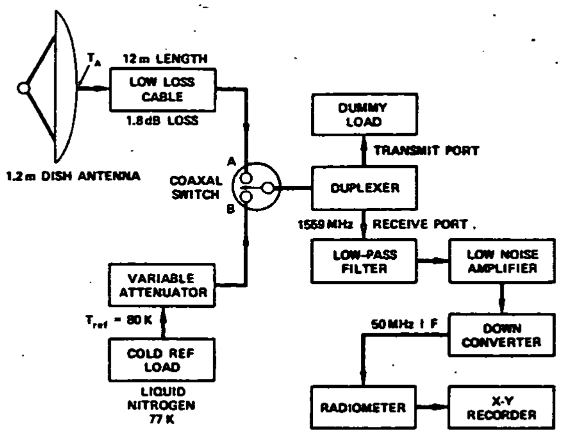


Fig. 5. Radiometer for antenna-noise temperature measurements.

then for the 1.2 m antenna azimuth angles from 0° - 360°, in 20° increments, and for elevation angles from 0° - 90°, in 5° and 10° increments.

Since an apparent antenna-noise temperature was measured at the output end of the 12 m coaxial cable (switch terminal A, Fig. 5), it was necessary to compute antenna-noise temperature T_A considering the fixed 1.8 dB transmission cable loss. Two methods [7] were necessary: Method 1 was used for computing values of T_A less than, or equal to the cold-load reference temperature, T_{ref} = 80 K; Method 2 was used for values of $T_A > T_{ref}$ = 80 K. A description of each method follows.

Method 1

The apparent antenna-noise temperature T'_A, measured at switch terminal A, is expressed as

$$T'_A = T_A\,\omega + (1-\omega)\,T_0 \text{ degs Kelvin (K)} \qquad (1)$$

for $0 \leq \omega \leq 1$ (dimensionless). Similarly at switch terminal B,

$$T_\alpha = T_{ref}\,\alpha + (1-\alpha)\,T_0 \text{ degs K} \qquad (2)$$

for $0 \leq \alpha \leq 1$ (dimensionless) where

ω = antenna transmission line attenuation power loss

α = total attenuation (power loss) of variable attenuator, including miscellaneous losses

T_{ref} = cold-load reference noise temperature = 80 K

T_0 = 300 K = ambient physical temperature of all transmission lines

Setting $T'_A = T_\alpha$ from (1) and (2), and solving for T_A gives,

$$T_A = T_0 + \frac{\alpha}{\omega}\,(T_{ref} - T_0) \text{ degs K} \qquad (3)$$

lim $(\alpha/\omega) \to 0$, $T_A \to T_0$, max. Furthermore, (3) is used only for computing values of $T_A \leq T_{ref}$, corresponding to lower scale readings on the variable attenuator.

Method 2

On the other hand for higher scale readings of the variable attenuator, corresponding to values $T_A > T_{ref}$, T'_A at terminal A is expressed in terms of the noise temperature of the attenuation [7] as,

$$T'_A = T_A + (L_\omega - 1)\,T_0 \text{ degs K} \qquad (4)$$

for $1 \leq L_\omega < \infty$. Similarly at terminal B,

$$T_\alpha = T_{ref} + (L_\alpha - 1)\,T_0 \text{ degs K} \qquad (5)$$

for $1 \leq L_\alpha < \infty$ where

L_ω = antenna transmission line loss power ratio

L_α = total attenuation power loss ratio for cold-load reference arm

Again setting $T'_A = T_\alpha$ in (4) and (5), gives a value of T_A as,

$$T_A = T_{ref} + T_0\,[L_\alpha - L_\omega] \text{ degs K} \qquad (6)$$

Note that when $L_\alpha = L_\omega$, $T_A = T_{ref}$. Whereas Method 1 is used only for values of $T_A \leq T_{ref}$, Method 2 is used only for values of $T_A > T_{ref}$.

Test Results

Antenna-noise temperature measurements were made both at sea and in the harbor; in general, antenna-noise temperatures were lower at sea (Figs. 6, 7). This is especially true of "hot spot"* noise temperatures resulting from harbor-generated EMI (e.g., loading cranes, dock rotating machinery, etc.). Also, a series of "hot spots" were identified as 1559 MHz signals from the NASA Applications Technology Satellite (ATS-6), currently in geostationary orbit at 94 W. longitude (Fig. 6).

The majority of the "hot spot" noise temperatures, above 5° elevation angle, disappeared as the "American Alliance" went to sea (Fig. 7). Exceptions are the two "hot spot" noise temperatures resulting when the 1.2 m antenna mainlobe pointed toward the radar-scanner platform on the mast (65° elevation angle, Figs. 6 and 7), and when the Sun entered the mainlobe at 75° elevation angle (Fig. 7).

In general, the measured steady background noise temperature increased sharply below 5° elevation angle (Figs. 6, 7). However, at angles greater than 10°, the steady component remains fairly constant vs. elevation angle from 10° - 85°. The average background noise temperature varies, within this range of angles, from 50 K to 60 K, at sea; and from

*Noise temperatures greater than steady background noise temperature.

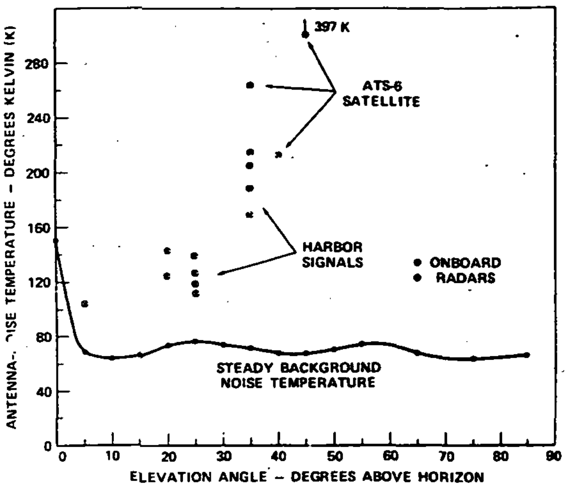


Fig. 6. 1.2 m (4 ft) dish antenna-noise temperature vs. elevation angle in harbor 1559 MHz data "American Alliance."

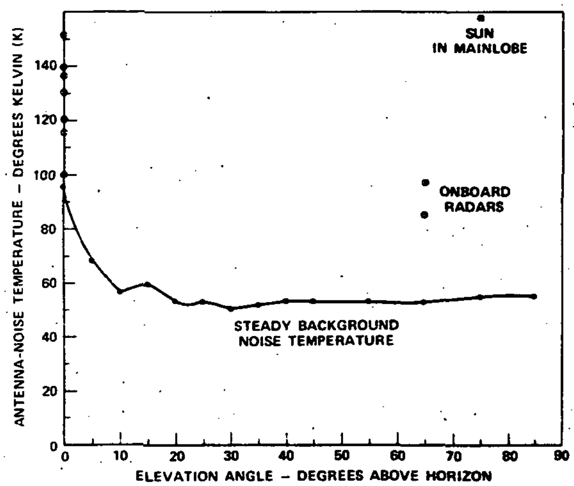


Fig. 7. 1.2 m (4 ft) dish antenna-noise temperature vs. elevation angle at sea 1559 MHz data "American Alliance."

65 K to 75 K, in harbor. Each data point (dot), in general, represents 18 independent measurements, obtained at azimuth angles from 0° - 360°, in 20° increments. Antenna-noise temperatures not averaged include all "hot spot" noise temperatures identified by circled X's.

Blake [8] gives theoretical values of T_A for a ground-based (approximately at sea level) antenna, at 1.6 GHz, as given in Table 1. Steady background noise temperature data points from Figs. 6 and 7 indicate close agreement, except at 0° elevation angle.

Since the antenna-noise temperature (Table 1) is only 70 K, or less, for elevation angles of 5°, and greater, it is worthwhile for equipment designers to strive for improving receiving system noise temperature. For example, modern low noise bipolar transistor amplifiers have noise figures as low as 2.0 dB at 1.6 GHz. Assuming T_A = 70 K and 1.0 dB transmission loss between the antenna output terminals and the preamplifier input terminals, gives

Table 1

Comparison of theoretical vs. measured antenna-noise temperature at 1.6 GHz

	Antenna—Noise Temperature (degs K)		
Elevation Angle	Blake's [8] Theoretical Value	In-Harbor Data (Fig. 6)	At-Sea Data (Fig. 7)
0°	125 K	150 K	96 K
5°	70 K	68 K	68 K
10°	62 K	64 K	56 K
90°	55 K	65 K*	55 K*

*Actually @ 85° elevation angle.

a receiving system noise temperature of only 300 K — a significant improvement of 5 dB in received carrier-to-noise spectral density ratio compared to 950 K (noise figure = 5.9 dB).

Field Intensity Measurements

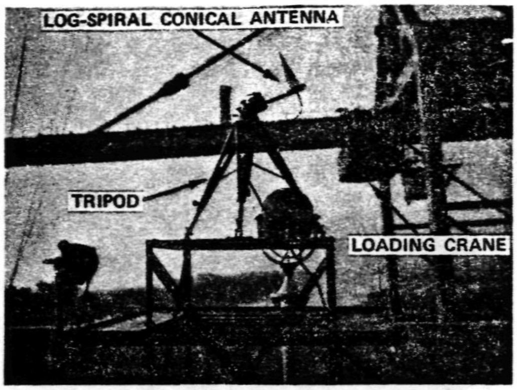
Field intensity measurements were made using a Singer-Stoddart NM-65T Radio Interference Analyzer, with standard horn antenna for L-Band measurements (1535 - 1660 MHz, in band), and a broadband log-spiral conical antenna for the 1 - 10 GHz frequency range. Measurements were referenced to several locations: at the RF feed of the 1.2 m dish antenna positioned on the starboard side of the "Flying Bridge;" at the radar-scanner platform on the mast; and in the below-deck Storage Room 1 m from the S-Band and X-Band radar cabinets (Fig. 8). Resulting broadband field intensity measurements, expressed in decibels per microvolt per meter per MHz, are given in Table 2.

Table 2 shows the lowest field intensity, in-band within 1535 - 1660 MHz, as 35 dB/μv/m/MHz for the Flying Bridge location; higher field intensities exist at the radar-scanner platform and Storage Room locations. Therefore, the Flying Bridge is a preferred location, above deck, from the standpoint of experiencing minimum field intensity from the S-Band and X-Band antenna scanners.

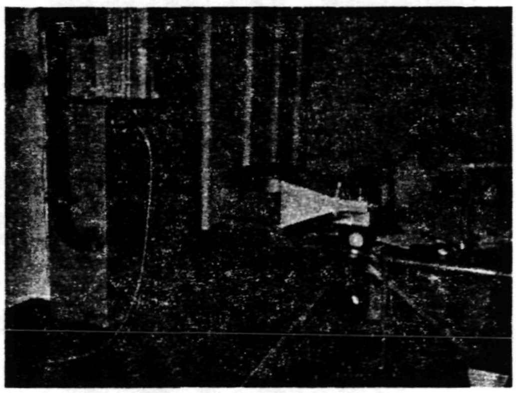
On the other hand, field intensity in-band, within 1535 - 1660 MHz, at 1-m distance from the radar cabinets in the Storage Room location, are equivalent, or greater than above-deck measurements (Table 2). This is attributed primarily to radar cabinet-case radiation.

The field intensity measurements in the L-Band, S-Band and X-Band regions are severe enough to warrant special attention to shielding requirements for L-Band Shipboard Terminal equipment that might be installed in the Storage Room, or at the radar platform on the mast.

Also, a Hewlett Packard Type 141T (8555A) Spectrum Analyzer was used to measure radar interference



(a) Field intensity measurement with log-spiral conical antenna on starboard side of Flying Bridge.



(b) Radar transmitter cabinet field intensity measurements with horn antenna (Storage Room).

Fig. 8. Field intensity measurements on Flying Bridge, Storage Room.

signals, at Test Points 1 and 2 (Fig. 2), over 1 - 10 GHz, for signals radiated by the S-Band and X-Band radar-antenna scanners. The direct-line distances from the 1.2 m dish antenna is 9.2 m to the S-Band radar-scanner, and 7.4 m to the X-Band scanner. With the mainlobe of the 1.2 m dish antenna pointing directly at each respective radar scanner, measured received signal power is shown in Fig. 9(a), (b). Fig. 9(c) illustrates the extremely effective filtering action of a bandpass filter in the Duplexer.

Conducted-Emission Tests

Narrowband and broadband conducted emissions measured on the ship's power lines at the terminals of the radar set cabinets in the Storage Room were in almost all instances higher than similar measurements in a typical commercial laboratory in the USA. The comparison was made on an octave-by-octave basis from 150 kHz to 32 MHz, the frequency range of the Singer-Stoddart NM-25T Radio Interference and Field Intensity Analyzer and Stoddart clamp-on Current Probe used. Narrowband and broadband

Table 2

Broadband field intensity levels in dB/μv/m/MHz at selected locations

Ship Location	1535-1660 MHz (In-Band)	3.1 GHz (S-Band Radar)	9.4 GHz (X-Band Radar)
Flying Bridge (Starboard Side, 2.8 m above deck)	35	125.5	125
Radar-Scanner Platform:			
Aft*	53.5	136.5	162
Starboard*	52.5	131.5	157
Storage Room:			
1 m from S-Band Radar Cabinet	77.5	104.5	-
1 m from X-Band Radar Cabinet	51	-	115

*1.2 m outboard, and level with, the radar platform.

emissions were on the order of 50 dB higher on the lower bands and 15 dB higher on the upper bands.

The broadband measurements on each shipboard power line to the S-Band and C-Band radar cabinets exceeded limits specified in MIL-STD-461A. Therefore, equipment designers should take precautions to provide appropriate power line filters for equipment operating from power lines leading to the radar sets.

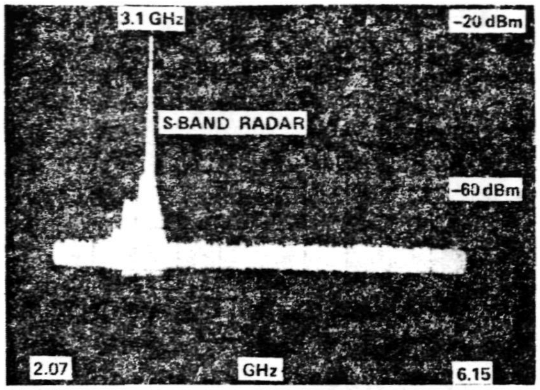
Conducted RF emissions on the radar power lines were measured also with a H-P 141T (8555A) Spectrum Analyzer, and Stoddart Current Probe. Since an IF output is typically 70 MHz, the Fig. 10 noise level at 70 MHz is equivalent to 36 dB/μA/MHz which is well below the MIL-STD-461A limit, extrapolated to 70 MHz.

Interference to Radars

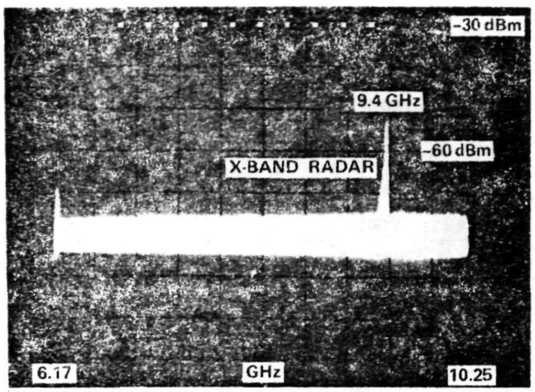
Operation of a 15-watt, 1659 MHz transmitter into terminal 3, in Fig. 2, showed that this power level did not interfere with the operation of either the S-Band or X-Band radars, even when the 1.2 m antenna mainlobe pointed directly at the respective radar-scanner antenna.

Conclusions

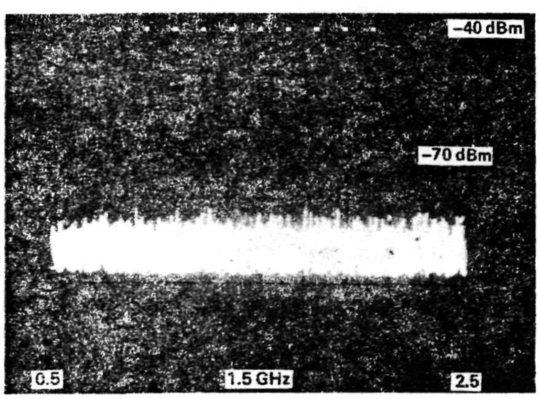
An EMI survey was conducted onboard a commercial U.S. maritime vessel to determine compatibility



(a) 1.2 m (4 ft) antenna output (Test Point 1, Fig. 2).



(b) 1.2 m (4 ft) antenna output (Test Point 1, Fig. 2).

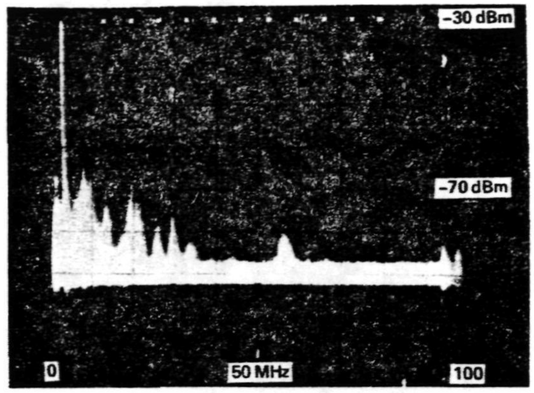


(c) Filtered Duplexer output (Test Point 2, Fig. 2).

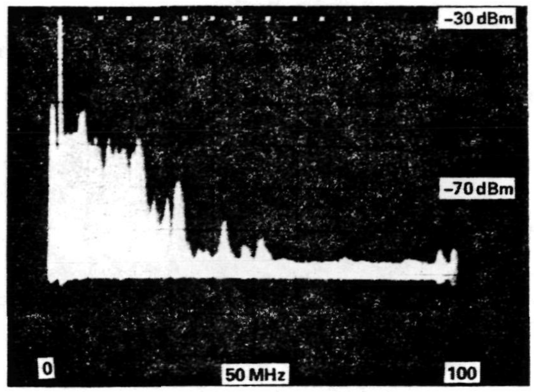
Fig. 9. Rejection of radar interference by L-Band Shipboard Terminal.

for operation of a satellite L-Band Shipboard Terminal. In general, there are no insurmountable problems. Significant aspects include:

1. Antenna-Noise Temperature Measurement: Maximum of 70 K steady background component, at 1.6 GHz, at sea, for elevation angles of 5°, and higher. This is equivalent to a ground-based antenna. Equipment designers should strive for low-noise temperature receiving systems.



(a) S-Band radar power line.



(b) X-Band radar power line.

Fig. 10. Conducted RF emission spectrum on radar power lines.

2. Field intensity measurements from 1 - 10 GHz on the ship's Flying Bridge show that an operational L-Band Shipboard Terminal can operate, simultaneously, with onboard S-Band and X-Band navigation radars.

3. Radar transmitter case radiation, below deck, in-band from 1535 - 1660 MHz, at 1 m distance from the cabinet, are equivalent, or greater than above-deck emissions in the same frequency range. Equipment designers should provide appropriate case shielding for collocated equipment.

4. Conducted-emission tests of ship's power lines to both radars show both narrowband and broadband emissions are 15 dB to 50 dB higher than equivalent USA commercial power lines, from 150 kHz to 32 MHz, thus exceeding limits of MIL-STD-461A. Equipment designers with equipment sensitive in this frequency range should provide appropriate line filters.

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