CGMS XXVIII
USA-WP-12
Agenda Item: H.2

SEARCH AND RESCUE INTERFERENCE MONITORING AND COORDINATION

Summary and Purpose of Document

To provide the Coordinating Group for Meteorological Satellites(CGMS) members information regarding U.S. 406 MHz interference mitigation efforts within the Cospas-Sarsat system.

Action Requested: None

SYSTEM DESCRIPTION

The Cospas-Sarsat(C-S) system is designed to locate and relay transmissions from distress beacons and relay the corresponding distress alert information to the appropriate notify search and rescue authorities. A typical Search and Rescue(SAR) event would evolve along the following lines:

1. A distress beacon is activated.
2. A satellite detects the beacon transmission.
3. The satellite relays the beacon signal to a Cospas-Sarsat ground station.
4. The GS ground station computes a location solution based on the beacon signal's Doppler shift and sends the solution to the Mission Control Center(MCC).
5. The MCC sends the location to the appropriate Rescue Coordination Center(RCC).
6. The RCC dispatches life saving resources to the location.

Distress beacons can transmit on three frequencies, 121.5 MHz, 243 MHz, and 406 MHz. The nature of distress beacon transmissions in the 406 MHz band allows the system to easily distinguish between interfering signals and legitimate signals. The 406 MHz beacons transmit a burst of data every 50 seconds. The 121.5 MHz and 243 MHz distress beacons transmit a CW signal and the system cannot readily distinguish between interference and legitimate beacon signals in these bands, for that reason, interference mitigation in the these two bands will not be discussed further in this paper. Figure 1 contains a description of the SAR process.

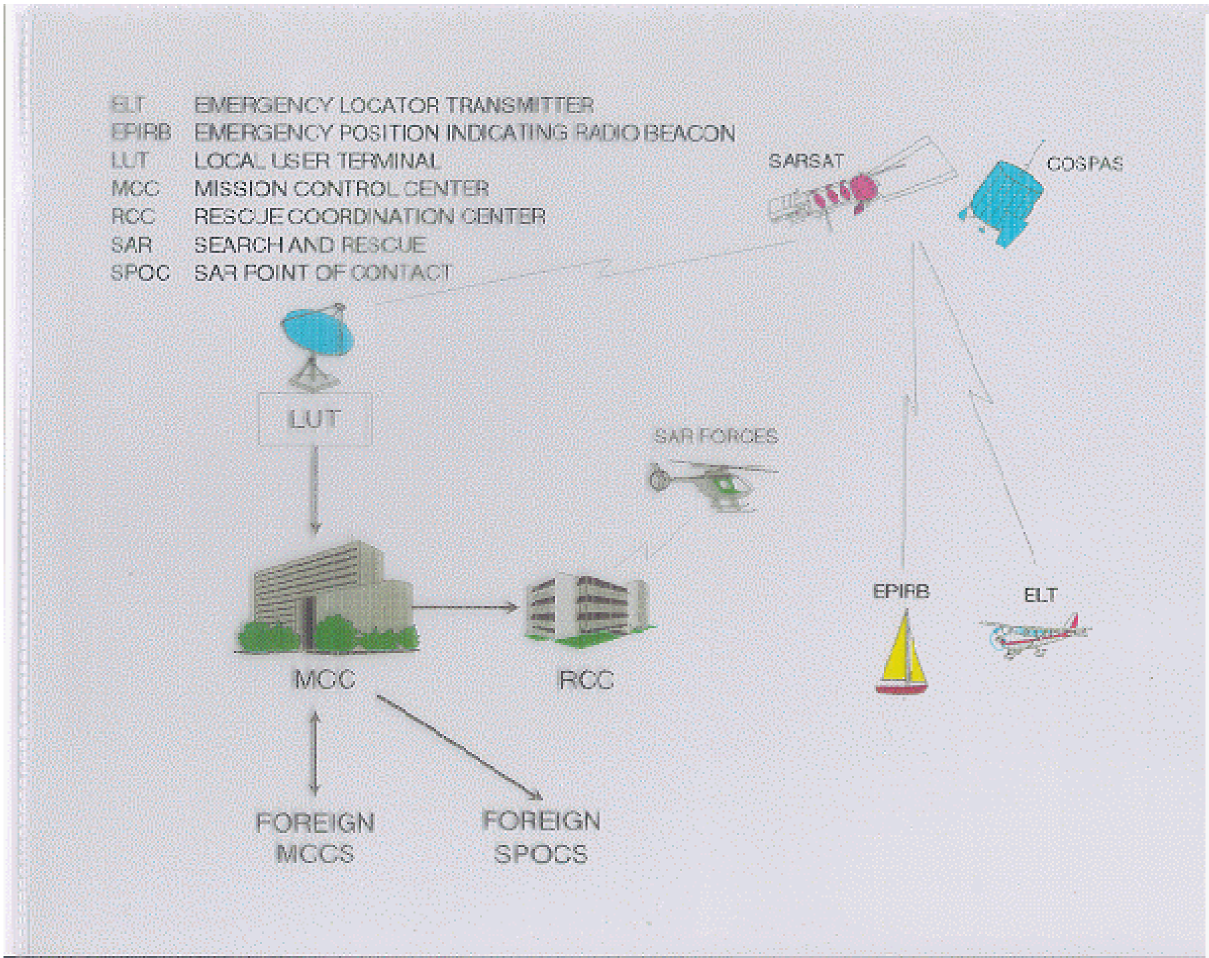

Figure 1. System diagram.

406 MHz BEACONS

A Cospas-Sarsat beacon manufacturer must submit all 406 MHz beacon design to rigorous type approval process that test the beacon model for frequency stability, ability to function in extreme temperatures, battery life, and power output. This process helps ensure that a beacon has the signal characteristics necessary for proper processing and that the beacon will not become a source of interference itself. All 406 MHz beacons are given a type approval certificate upon passing the rigorous test procedure. The United Sates requires that all 406 MHz beacons in use be Cospas-Sarsat type approved.

The 406 MHz beacons transmit a bi-phase encoded/phase modulated 112 to 144 bit message every 50 seconds. The total transmission time for a burst is approximately 500 ms. The beacon message includes such fields as:

- Country code
- Manufacturer
- Presence of homing device in beacon
- Error correction.

These fields form a unique 30 character hexadecimal ID that D. that is stored in a registration database. The database will contain a telephone number of the beacon owner and the home port of the vessel carrying the beacon. This unique beacon Id, along with the other data contained in the formatted beacon message, These characteristics allows the system to easily distinguish an interferer from a legitimate signal in this band.

SPACE SEGMENT

The space segment consists of SARR (Search and Rescue Repeater) and SARP(Search and Rescue Processor) instruments aboard Russian(Cospas) and NOAA POES(Sarsat) LEO satellites. The Cospas satellites maintain a near polar orbit at an altitude of 987 to 1022 kilometers with a period of 105 minutes +/- 30 seconds and an inclination of 83 degrees[1]. The Sarsat satellites are in a sun synchronous orbit at an altitude of 833 to 870 kilometers with a period of 102 minutes +/- 30 seconds and an inclination of around 98.75 degrees[2]. Each satellite is in a different orbital plane. There are four separate systems on board the Sarsat satellites. Each Sarsat LEO has a:

- 121.5 MHz repeater with a 25 kHz bandwidth
- 243 MHz repeater with a 25 kHz bandwidth
- 406 MHz repeater with a 100 kHz bandwidth
- 406 MHz processor with a 5 kHz bandwidth.

The repeaters are “bent pipe”, that is, they modulate the receiver input directly onto the 1544.5 MHz downlink. There is no storage or processing capability associated with the repeaters. A transmitter and a LUT Cospas-Sarsat ground station must have mutual visibility to the SARR antenna aboard the spacecraft in order for the signal to be received by a GS the ground station. The SARR instrument also contains an automatic gain control circuit that maintains constant receiver output level for modulating the downlink transmitter. Large interfering signals reduce the receiver gain such that less output power is available for beacon signals. This results in less sensitivity for beacon signals, especially those near threshold. It should be noted that the Russian(Cospas) LEOs do not posses 406 MHz or 243 MHz repeaters and are not able to relay 406 MHz interference signals to a -GS Cospas-Sarsat ground station.

The 406 MHz SARP does have memory. It stores 406 MHz beacon information and continually retransmits this information for a period of 24 to 48 hours, giving the satellites a global beacon detection capability. CW signals, like interference, are not processed by the SARP, so there is no global interference locating capability. Signals from the spacecraft's SARRs and SARP are modulated directly on to a 1544.5 MHz downlink as described by Figure 2.

NOAA GOES spacecraft also have 406 MHz repeaters on board. Since there is no Doppler shift associated with signals received on a geostationary satellite, they cannot produce locations on interference. Techniques exist for using a signal's time difference of arrival to determine the location of an interferer that is in the mutual view of two geostationary satellites, but Sarsat does not employ this type of interference processing.

In summary, only the bent pipe repeater on board the Sarsat POES satellites are used for interference monitoring and locating in the 406 MHz band.

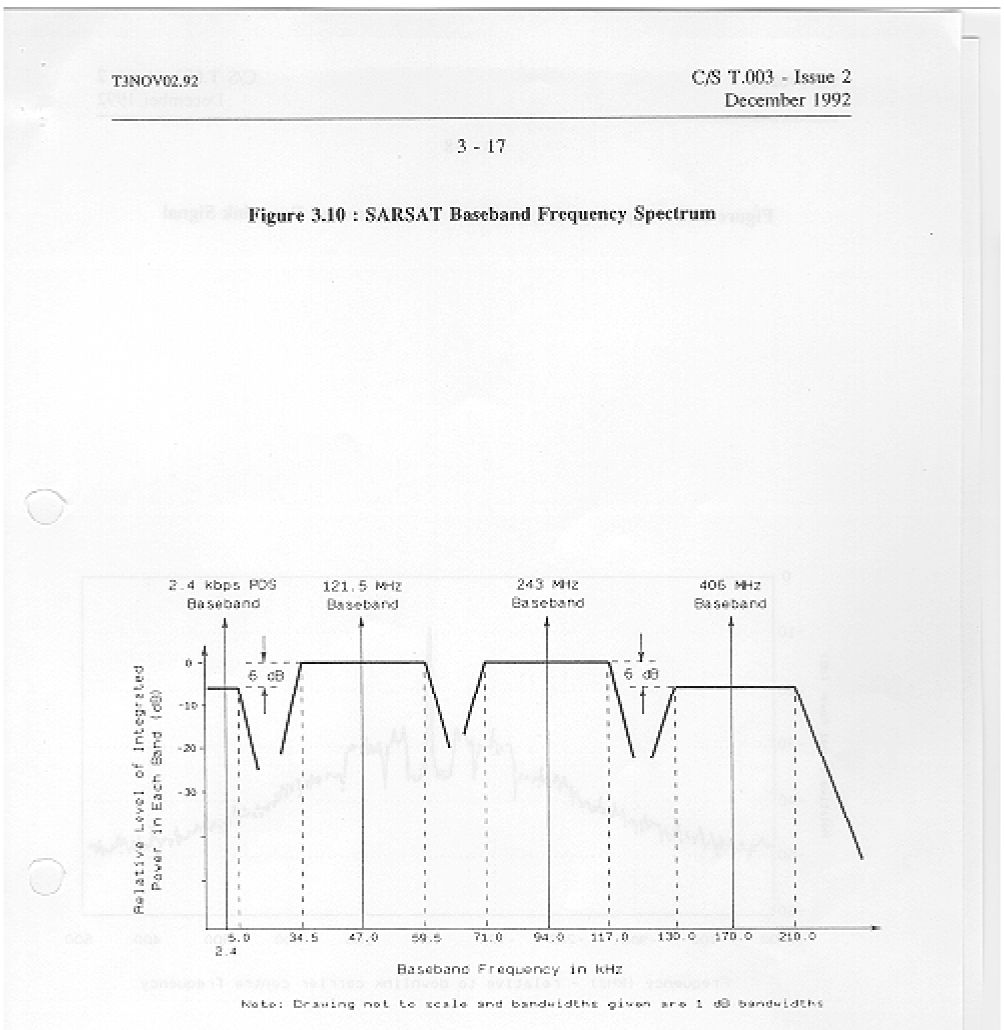

Figure 2. Sarsat downlink base band.

GROUND SEGMENT

The U.S. maintains and operates fourteen SARSAT GSs Cospas-Sarsat ground stations at seven different sites. Each site contains two ground stations, each GSs capable of tracking and processing data from two satellites independently simultaneously. A GS The U.S. ground stations are programed to will only track satellites that are greater than 5 degrees above the radio horizon which would allow for a pass duration of approximately eight minutes. The maximum pass duration of 17 to19 minutes occurs when a satellite passes directly over the GS. ground station.

The GS ground station computes location solutions based on the signal's Doppler shift. The Doppler shift is the change in a signal's frequency caused by the motion of the spacecraft relative to the transmitter. See Figure 3. Two solutions are produced for every signal processed by the GS ground station. One solution is real and the other is an image. The solutions are symmetrical about the satellite's ground track. Two satellite passes over an emitter are required to resolve this ambiguity.

The real solutions from both passes will agree with each other; while the image solutions will not because the satellite's ground track will not be the same for two passes. After more than one pass over the emitter, the solution becomes composite, that is, each location that matches a previous one is averaged with the previous one. The average is weighted by the number of solutions making up the composite.

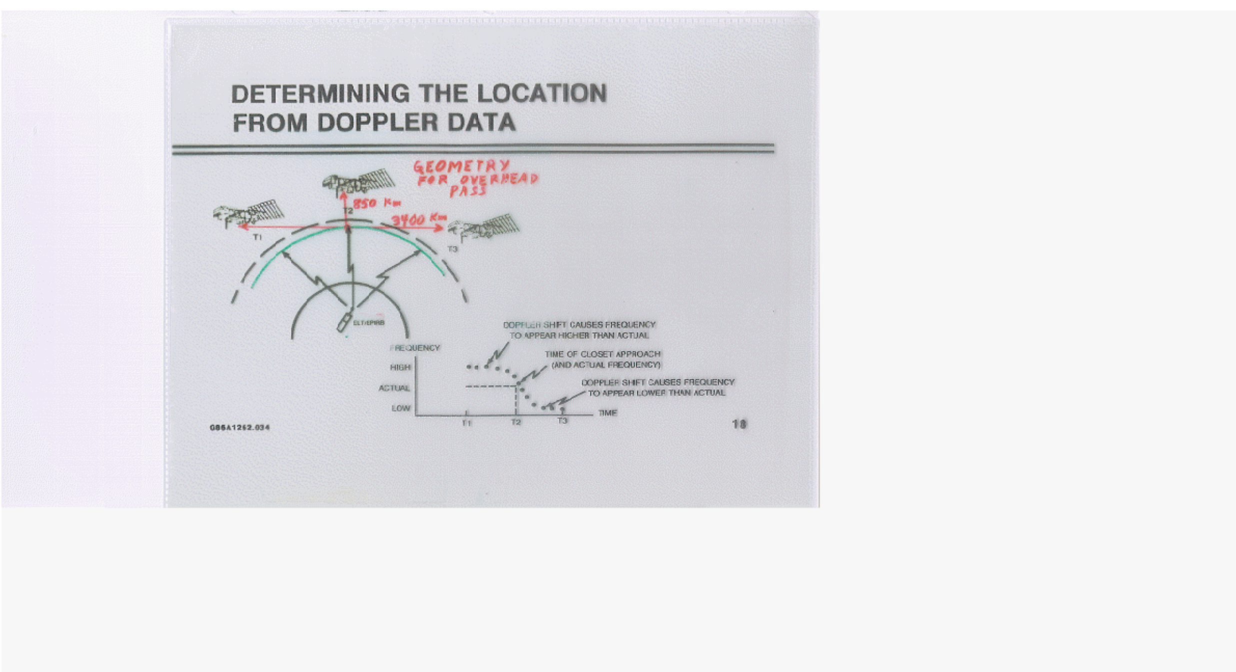

Figure 3. The Doppler Shift.

There are several factors that affect the quality of Doppler solutions such as the coherency of the signal, the duration of the signal, the frequency stability of the signal, and the satellite cross track angle relative to the transmitter. In general, the longer the duration of signal, the more accurate the solution will be, however, it is possible to produce a poor solution with a long duration signal. The interference signal with the best chance of producing an accurate location will meet the following conditions:

- The duration of the signal is at least four minutes long
- The solution includes data from both before and after the time of closest approach.
- The cross track angle between the satellite and the transmitter is between |1| and |20| degrees.

All other solutions are considered marginal.

Upon completion of a pass, the GS ground station transmits solution data to the MCC, where further processing is done. The MCC will match like solutions from different passes and different LUTs ground stations t to create composite solutions.

INTERFERENCE

The International Telecommunications Union (ITU) defines harmful interference as an interference signal that exceeds -190 dBW/m^2/Hz at the satellite antenna (at 850 km) which increases the background noise level by 0.3 dB. This corresponds to an emitter on the earth having an e.i.r.p. of -60 dBW/Hz for broadband noise or -40 dBW for a cw signal[3].

There are several methods for detecting 406 MHz interference in the U.S.. The primary method is the Doppler solution, since it is the only method available that can produce an accurate location. It is Doppler solutions that are reported to the FCC, ITU, or other appropriate authority to aid them in getting the interference turned off. In general, the longer the interference is on, the better the composite location solution will be, however, as few as eight solutions can produce a composite solution accurate enough to be useful.

Other tools that are useful in characterizing the interfering signal are the Dot plot and the AGC plot. The Dot plot is a time vs frequency plot that is generated by the GS ground station for every pass. Dot plots can be used to determine the presence of interference, the number of sidebands of the interference, and often how many beacon bursts were not received as a result of the interference. The location of interference cannot be determined from Dot plots. Automatic Gain Control(AGC) plots are AGC response in dBm vs time plots. The AGC plots provide a rough idea interferer locations, some idea of relative signal strength of the interference, and some idea of the persistence of the interferer. Typically, 24 hours of AGC data is collected and analyzed three or four times a year. The AGC plots are particularly useful in providing information on interference that is out of range of U.S. GSs ground stations. Table 1 provides a summary of the system's interference mitigation tools.

Table 1. Three useful interference mitigation tools.

	Presence of Interference	Precise Location	Rough Location	Emitter and LUT Require Mutual visibility to Satellite	Estimate of Signal Strength	Persistence
Doppler Solution	YES	YES	NO	YES	NO	YES
AGC Plot	YES	NO	YES	NO	YES	YES
Dot Plot	YES	NO	NO	YES	NO	NO

CHRONIC PROBLEM

There are many sources of 406 MHz interference. Out of band emissions from radars accounts for a significant amount of the problem, but there are many other sources, such as:

- Wireless modems.
- Malfunctioning telephone equipment.
- Remote control systems.
- Telemetry systems.

Analysis of satellite telemetry, specifically the 406 MHz repeater Automatic Gain Control(AGC) response, reveals that any given satellite can expect to spend 25% to 35% of the time in the presence of harmful interference. A rough idea of the locations of interference can be obtained by using satellite tracking software in conjunction with the AGC data times. Figure 3 contains a fairly typical example of an AGC plot, showing interferers located in China, Russia, and South East Asia. Appendix 1 contains a table showing the results of AGC analysis over a period of four years.

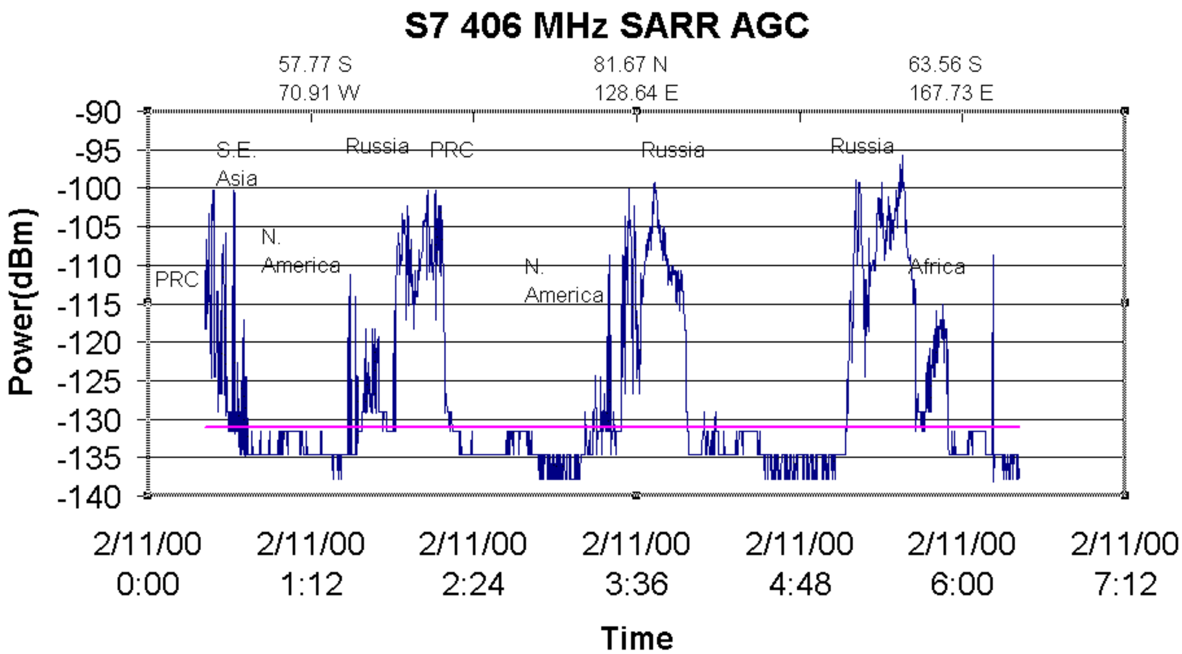

Figure 4. S7(NOAA-15) 406 MHz Repeater AGC Plot

The Russian interference visible on the AGC plot is in range of U.S. LUTs ground stations located in Alaska, so it produces Doppler solutions and is visible on Dot plots from the Alaskan GS ground station. See Figure 4 for a Dot plot of this interferer. This particular interferer is a Russian radar site and has been radiating from that location for years. Figure 4. Dot plot of Russian radar site located at 71 degrees north and 128 degrees east.

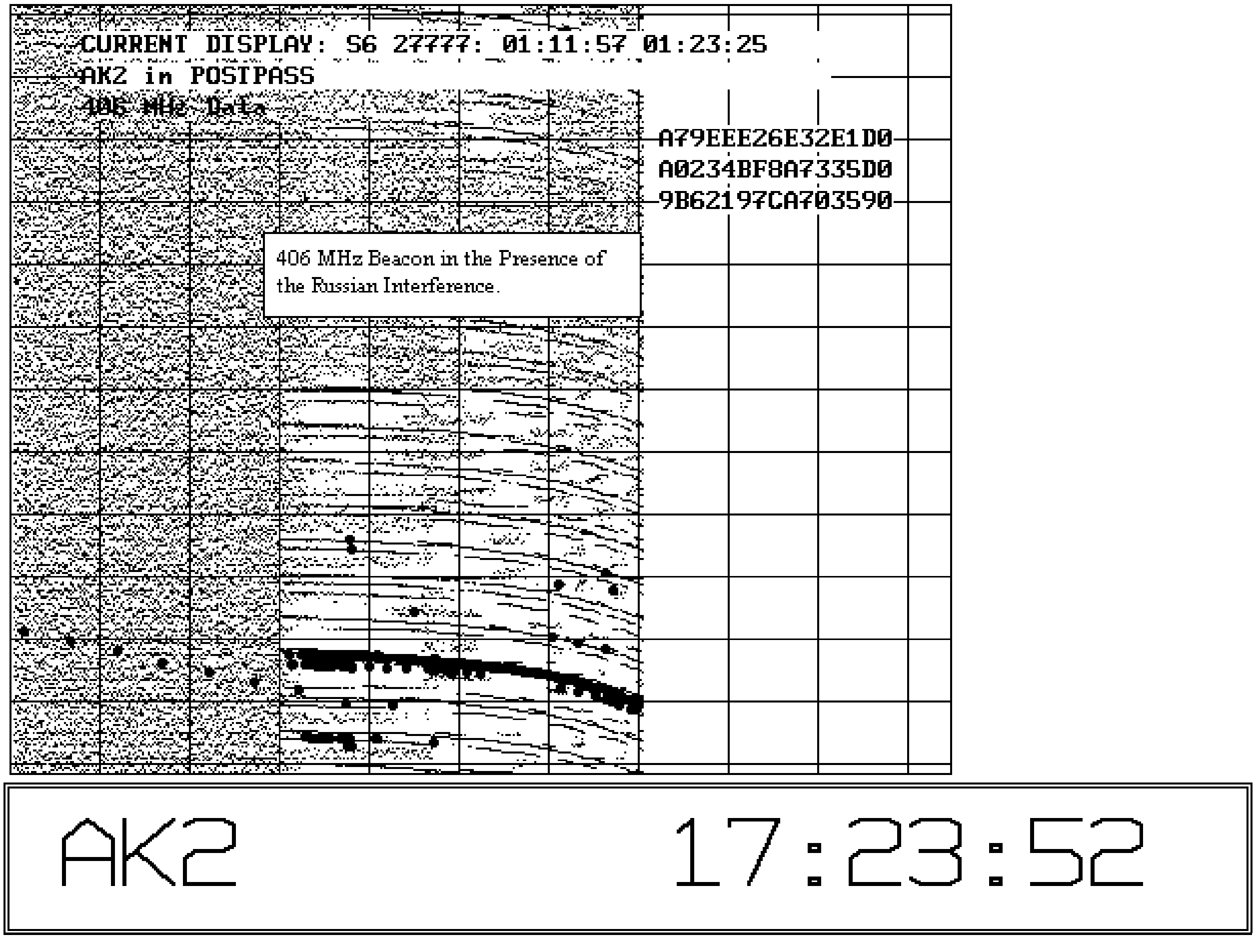

Figure 5. Dot plot of Russian radar site located at 71 degrees north and 128 degrees east.

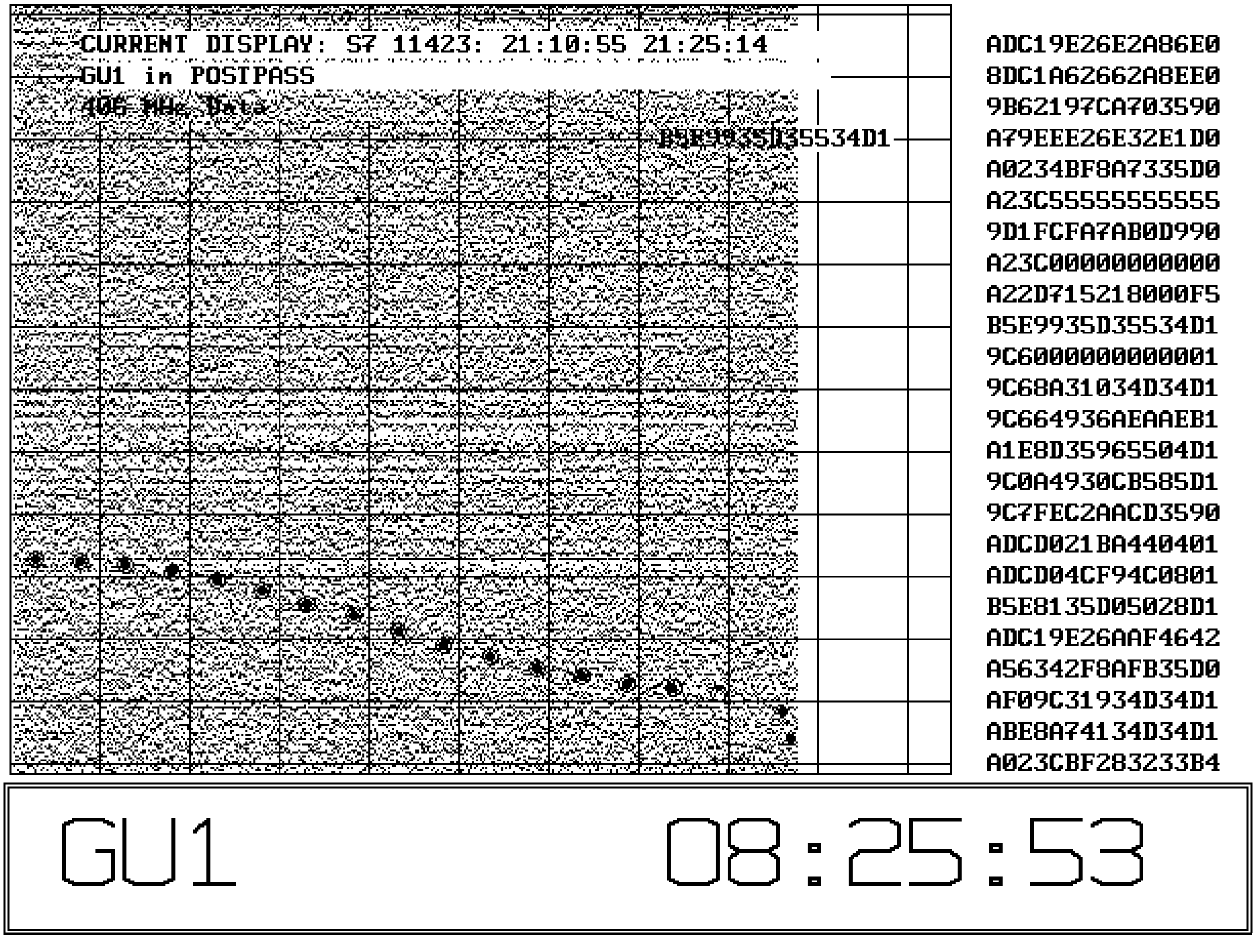

Figure 6. 406 MHz beacon Doppler curve with no interference present. Each dot is a beacon burst.

DOMESTIC INTERFERENCE MITIGATION

Typically, anywhere from two to one hundred 406 MHz interference solutions are produced on locations within the continental U.S. during any given 24 hour period. Most of these are “pop ups” that only radiate for a short period. These solutions are archived, but no other action is taken.

Persistent interferers are the ones that show up in multiple satellite passes. They can last anywhere from a day or two to many years. There are several ways that domestic interference can be handled. The FCC will be called if the interferer is not located near a U.S. military or government center. The FCC has very limited resources and pursuing an interference case can require a day more of driving in a specially equipped interference locating vehicle, thus tying up the enforcement personnel for a large area while the 406 MHz interferer is located and turned off.

For this reason, care is taken to help ensure that the composite solution is accurate and that the interferer is likely to be radiating when the enforcement agent arrives on the scene.

Interference sites in Mexico can be handled through the FCC as well. The FCC will contact the Mexican frequency authorities directly. Generally, interference sites in Mexico take more time to get turned off than in the U.S..

Interference sites located near U.S. military or government installations are generally much easier to get turned off. Most military/government installations have their own frequency manager and require only a telephone call to get the interference turned off if it is indeed radiating from the facility.

INTERNATIONAL INTERFERENCE MITIGATION

Interference sites located outside of the United States, Canada, or Mexico are much more difficult to turn off. The LUTs ground stations located in Guam, Alaska, Hawaii and Puerto Rico are vulnerable to such interference from a variety of countries such as Russia, Peoples Republic of China, the Philippines, and Cuba. The official path to mitigate interference from these areas involves submitting a complaint to the ITU. The ITU then notifies the proper authorities in the appropriate country. This process is relatively slow in the best of circumstances and can be compounded by a country's internal bureaucracy and limited resources. Fortunately, many contacts are made with frequency management personnel through international meetings that sometimes allow the proper authorities to be notified informally.

AUTOMATIC INTERFERENCE MONITORING SYSTEM (AIMS)

An automatic system for reporting interference is currently in the testing phase. It will automatically track interference sites, and when certain criteria are met, it will generate a report and send it to the FCC. Currently, the requirements for automatic report generation are that the interference must be visible for 8 satellite passes within 72 hours and the search radius must be less than 12 km. The search radius is a statistical analysis performed by the AIMS computer that will give a 95% probability that the interference will fall into a given radius around a composite solution. The AIMS system will keep evolving as required to keep abreast of new developments, procedural reporting changes, and to improvements in processing. A reduction in man hours required to handle interference is expected once AIMS becomes operational.

Appendix 1.
Percentage of a 24 hour period satellite was in the presence of harmful interference.

Date	**All emitters**	**Most Active Regions(Percent)**				
	Percent I	Siberia and Russia	Far East	Africa	Mid-East	South America
1/24/96	41.0	*	*	*	*	*
3/25/97	33.4	16.5	5.4	*	*	*
6/25/97	27.5	13.9	5.2	*	*	*
7/25/97	25.5	11.2	5.5	*	*	*
8/24/97	28.2[i]	13.5	4.8	*	*	*
9/25/97	30.1	12.7	5.3	4.5	1.2	1.9
10/26/97	27.6	13.8	2.8	4.9	2.9	2.2
11/25/97	29.3	13.6	3.9	3.3	1.9	2.5
12/28/97	24.9	12.7	3.7	2.8	2.9	1.2
10/26/98	28.1	6.2	4.1	3.1	6.2	1.4
4/29/99	30.6	12.2	5.2	2.0	1.7	5.3
7/15/99	29.5	19.4	2.9	3.3	1.2	1.2
9/1/99	30.1	14.7	4.4	6.7	3	.7
2/10/00 to 2/11/00	33.2	16.4	3.8	6.6	2.3	1.7

[1]C/S T.003 p.2-6

[2]Ibid.

[3]Resolution # 205 of WARC-MOB-83

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Corrected from the 30.5% reported at the 9/10/97 meeting to remove SEDL test signal from the data.