CHAPTER 6

EVALUATING, MODIFYING, AND MAINTAINING EXISTING C4ISR FACILITIES

6-1. Purpose of evaluating, modifying and maintaining existing C4ISR facilities

The purpose of this chapter is to provide guidance, steps, and procedures for verifying, upgrading, and evaluating the grounding, bonding, and shielding networks in an existing facility. The specific items to consider and inspection procedures used during the evaluation of the facility will be addressed. The procedures are directed toward verifying that the grounding, bonding, and shielding networks have not been compromised, that the basic resistance goals continue to be met, and that corrosion is effectively controlled.

6-2. Facility survey

For an existing facility with electrical wiring already installed, with an earth electrode subsystem (frequently only a connection to the water system) present, and with electrical/electronic equipment in place, the installation of the grounding, bonding, and shielding networks described in previous chapters may not be straightforward. In recognition that major retrofitting, with the attendant costs and operational disruption, may be required in order for the facility to conform to the recommended practices and procedures, it is necessary that a comprehensive grounding, bonding, shielding, and lightning protection survey be made of the entire facility. The findings of the survey should be documented on a survey form. Survey forms are DA Forms 7452-4-R through 7452-9-R as shown in figures 6-1 through 6-6. Reproducible forms can be found at the end of the manual. The results should be critically analyzed to determine the extent to which the existing system fails to conform to the recommendations set forth in the previous chapters. In areas of non-conformance, the performance history of equipment and subsystems in the facility should be examined to establish, if possible, any relationships which exist between noted deficiencies and operational problems. Then the decision to retrofit and the extent of any such retrofitting can be made based on the relative need to improve and on the overall cost of the retrofit.

a. Baseline configuration. Before upgrading, altering, or expanding the grounding, bonding, or the shielding of a facility, it is necessary to define and analyze the existing system. This definition and analysis should include drawings depicting the ground system layout of the facility; determination of the condition, integrity, and effectiveness of the existing grounding, bonding, and shielding systems; documentation of existing conditions; and a comparison of the findings with the facility requirements to determine if improvements are needed.

(1) Engineering drawings for the facility should include all structures, the configuration of the earth electrode subsystem, location of utility piping and cable systems, general landscape features, and building profiles. Drawings should also show methods of connecting to the earth electrode subsystem, methods used for structural steel assembly, locations and methods for the installation of reinforcing steel as well as metal screens or sheets. Electrical drawings should show wire sizes, breaker sizes, as well as cable type, routing and enclosures utilized, the lightning protection subsystem, with heights and locations of air terminals, down conductor sizes and routing, fasteners, guards, and connections to the earth electrode subsystem.

(2) Compare the drawings with the existing configuration. If the drawings do not match the configuration, review available maintenance and change records to confirm the changes made where acceptable. Update the drawings as needed to reflect additions or modifications that have been made but not entered on the drawings. If new drawings must be prepared, be sure they include all elements of the structure. It is very important that an accurate representation of the existing configuration be used in determining what changes are required to the grounding system.

EARTH ELECTRODE SUBSYSTEM CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY *Fort Tank*		2. DATE *(YYYYMMDD)* 20020228	
3. LOCATION *Building 1929*		4. INSPECTOR *Andre Ampere*	
5. SKETCH THE LAYOUT OF THE EARTH ELECTRODE SUBSYSTEM *(Or attach an up-to-date engineering drawing)* *See attached drawing 001-51-7, 30 April 2001*			
6. SOIL CONDITIONS *(Type)* ☐ LOAM OR HUMUS ☒ CLAY ☐ SAND ☐ GRAVEL		7. EARTH ELECTRODE SUBSYSTEM RESISTANCE MEASUREMENT *1.5 ohms*	
8. LAST RESISTANCE MEASUREMENT *1.4 ohms*		9. MONTHS SINCE LAST RESISTANCE MEASUREMENT *14*	
COMPONENT IDENTIFICATION			
10. GROUND RODS			
10a. TYPE *copper*	10b. SIZE *(Diameter)* *1"*	10c. LENGTH *20 ft*	10d. PHYSICAL CONDITION *good: no corrosion, no damage*
11. GROUND CONDUCTORS			
11a. TYPE *stranded/bare*	11b. SIZE *1/0*	11c. MATERIAL *copper*	11d. PHYSICAL CONDITION *good: no corrosion*
12. INTERCONNECTING CONDUCTORS			
12a. TYPE *stramded*	12b. SIZE *1/0*	12c. MATERIAL *copper*	12d. PHYSICAL CONDITION *good: no corrosion*
13. RISERS			
13a. PHYSICAL CONDITION *good*		13b. MEASURED RESISTANCE *1.5 ohms*	
13. GROUND WELLS			
13a. PHYSICAL CONDITION *good*		13b. MEASURED RESISTANCE *1.0 ohms*	
14. WEATHER CONDITIONS *(At time of inspection)* ☐ WET ☒ DRY ☐ SNOW ☐ RAIN ☐ MIST			
15. MEASURED TEMPERATURE *80 F*		16. DAYS SINCE LAST PRECIPITATION *10 days*	

DA FORM 7452-4-R, FEB 2002 USAPA V1.00

(2) Figure 6-1. Sample of completed DA Form 7452-4-R

GROUNDING AND BONDING CONNECTION CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY	2. DATE *(YYYYMMDD)*
Fort Tank	20020328
3. LOCATION	4. INSPECTOR
Building 316	*Lou Swire*

5. GENERAL CONDITION

☐ EXCELLENT ☒ GOOD ☐ POOR ☐ UNACCEPTABLE

6. SPECIFIC DEFICIENCIES

LOCATION	DEFICIENCIES
1. Service entrance raceway	*The metallic raceway is not bonded*
2. Service entrance panel (2000A)	*Bonding jumper is undersized (#2 AWG Cu)*
3. Distribution panel D-1	*Neutral bus is bonded to ground bus*
4. Raceway between panel D4&D5	*Connector (fitting) is non-metallic*
5. Panel DP-7	*No ground bus. Neutral bus is used for both neutral and ground conductors*

7. RESISTANCE *(Use double balanced dc bridge or approved bond resistance meter and identify those bonds whose resistance is greater than 1.0 milli-ohm)*

LOCATION	DEFICIENCIES
1. Raceway between panels D-3	
and D-7	*High resistance is due to non-metallic fitting*
2. Between panels D-7 & D-9	*Metallic raceway is not continuous*

8. INEFFECTIVE BONDING JUMPERS

LOCATION	MATERIAL	LENGTH	SIZE	DEFICIENCIES
1. Service entrance panel (2000A)	*copper*	*10"*	*#2 AWG*	*undersized*
2. Distribution panel D-6 (300A)	*copper*	*7"*	*#6 AWG*	*undersized*
3. Distribution panel D-9 (150A)	*copper*	*24"*	*#2 AWG*	*too long*

DA FORM 7452-5-R, FEB 2002 USAPA V1.00

Figure 6-2. Sample of completed DA Form 7452-5-R

LIGHTNING PROTECTION GROUNDING SUBSYSTEM CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY *Fort Tank*	2. DATE *(YYYYMMDD)* 20020330
3. LOCATION *Building 358*	4. INSPECTOR *Joe Sparks*

5. SKETCH THE LAYOUT OF THE ACTUAL LIGHTNING PROTECTION SUBSYSTEM *(Or attach an up-to-date engineering drawing if it exists)*

See attached drawing 001-50-09, 12 December 2001

6. ALL LIGHTNING PROTECTION EQUIPMENT UL LABELED [X] YES [ ] NO	7. UL MASTER LABEL ISSUED AND PROPERLY ATTACHED TO THE BUILDING [X] YES [ ] NO

8. AIR TERMINALS

8a. HEIGHT *2 ft*	8b. MATERIAL *copper*	8c. SIZE *(Diameter)* *5/8"*
8d. PROPER BASES/FITTINGS [X] YES [ ] NO	8e. PROPERLY INSTALLED [X] YES [ ] NO	8f. LOCATED AND SPACED AS SPECIFIED [X] YES [ ] NO
8g. DOES THE HEIGHT OF AIR TERMINALS PROVIDE PROPER CONE OF PROTECTION [X] YES [ ] NO	8h. PHYSICAL CONDITION *well maintained*	

9. ROOF CONDUCTORS

9a. TYPE *stranded*	9b. SIZE *2/0*	9c. MATERIAL *copper*
9d. BEND RADIUS ACCEPTABLE [X] YES [ ] NO	9e. SECURELY FASTENED [X] YES [ ] NO	9f. PROPER FITTINGS [X] YES [ ] NO
9g. PROPERLY BONDED TO AIR TERMINALS AND OTHER METAL OBJECTS ON ROOF [X] YES [ ] NO		
9h. PROPERLY INTERCONNECTED TO OTHER CROSS ROOF CONDUCTORS [X] YES [ ] NO	9i. PHYSICAL CONDITION *good*	

10. DOWN CONDUCTORS

10a. TYPE *stranded*	10b. SIZE *2/0*	10c. MATERIAL *copper*	10d. BEND RADIUS ACCEPTABLE [X] YES [ ] NO
10e. SECURELY ANCHORED [X] YES [ ] NO	10f. PROPER FITTINGS [X] YES [ ] NO	10g. LOCATED AND SPACED AS SPECIFIED [X] YES [ ] NO	
10h. PROPERLY BONDED TO ROOF CONDUCTORS/AIR TERMINALS AND GROUNDING ELECTRODES [X] YES [ ] NO			
10i. PHYSICAL CONDITION *good*			

11. GUARDS

11a. TYPE *PVC*	11b. SOLIDLY ANCHORED [X] YES [ ] NO	10c. PHYSICAL CONDITION *good*

12. GROUNDING ELECTRODES

12a. TYPE *copper clad*	12b. SIZE *5/8"*	12c. LENGTH *(Each)* *20 ft*	12d. FORM COUNTERPOISE LOOP [X] YES [ ] NO
12e. DISTANCE BELOW GRADE LEVEL *2 ft*	12f. DISTANCE FROM OUTER WALL *6 ft*	12g. PROPERLY INSTALLED [X] YES [ ] NO	
12h. PROPERLY CONNECTED TO OTHER GROUNDING SYSTEMS OF THE BUILDING [X] YES [ ] NO			
12i. PROPERLY CONNECTED TO DOWN CONDUCTORS [X] YES [ ] NO	12j. GROUND RESISTANCE MEASUREMENT *10 ohms*		

DA FORM 7452-6-R, FEB 2002 USAPA V1.00

Figure 6-3. Sample of completed DA Form 7452-6-R

GROUND FAULT PROTECTION SUBSYSTEM CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY	2. DATE *(YYYYMMDD)*
Fort Tank	20020301
3. LOCATION	**4. INSPECTOR**
Building 1929	*Max Drain*

5. CHECK THE GROUNDED (Neutral) AND GROUNDING CIRCUITS FOR PROPER INSTALLATION, CONNECTION, AND BONDING FROM THE SERVICE ENTRANCE PANELS TO THE DISTRIBUTION PANELS. VERIFY THAT THE GROUNDED AND GROUNDING CONDUCTORS ARE LOCATED IN THE SAME CONDUIT AS THE LINE (Hot) CONDUCTORS. RECORD THE DATA AND ALL DEFICIENCIES.

LOCATION	MAIN BREAKER RATING	GROUNDED CIRCUIT		GROUNDING CIRCUIT		PROPER INSTALLATION		PROPER BONDING		LOCATED IN SAME CONDUIT	
		SIZE	MATERIAL	SIZE	MATERIAL	YES	NO	YES	NO	YES	NO
Main panel MP-1	*1000A*	*(2) 500*	*copper*	*4/0*	*copper*	X		X		X	
Distribution panel DP-1	*225A*	*4/0*	*copper*	*#2*	*copper*	X		X		X	

6. MEASURE THE LINE-TO-NEUTRAL VOLTAGES, LINE-TO-GROUND VOLTAGES, AND NEUTRAL-TO-GROUND VOLTAGES AT ALL PANELS AND DISCONNECTED SWITCHES

LOCATION	LINE-TO-NEUTRAL VOLTAGES			LINE-TO-GROUND VOLTAGES			NEUTRAL-TO-GROUND VOLTAGES
	$V_{(A-N)}$	$V_{(B-N)}$	$V_{(C-N)}$	$V_{(A-G)}$	$V_{(B-G)}$	$V_{(C-G)}$	$V_{(N-G)}$
Main panel MP-1	*418V*	*480V*	*481V*	*480V*	*480V*	*481V*	*0.2V*
Distribution panel DP-1	*480V*	*480V*	*481V*	*479V*	*480V*	*481V*	*0.5V*

7. MEASURE THE LINE (Hot) CURRENTS, NEUTRAL CURRENTS, AND GROUND CURRENTS

LOCATION	LINE CURRENTS			NEUTRAL CURRENT	NEUTRAL CURRENT
	$I_{(A)}$	$I_{(B)}$	$I_{(C)}$	$I_{(N)}$	$I_{(G)}$
Main panel MP-1	*650A*	*630A*	*595A*	*150A*	*1.5A*
Distribution panel DP-1	*110A*	*100A*	*115A*	*52A*	*2.0A*

8. RECORD ALL NATIONAL ELECTRIC CODE (NEC) AND NATIONAL ELECTRIC SAFETY CODE (NESC) VIOLATIONS

LOCATION	VIOLATIONS
Distribution panel DP-2	*Neutral bus is bonded to ground bus*
Distribution panel DP-5	*No ground bus. All ground conductors are connected to neutral bus*

DA FORM 7452-7-R, FEB 2002 USAPA V1.00

Figure 6-4. Sample of completed DA Form 7452-7-R

SIGNAL GROUND REFERENCE SUBSYSTEM CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY *Fort Tank*	2. DATE *(YYYYMMDD)* 20020304
3. LOCATION *Building 358*	4. INSPECTOR *Al Volta*

5. SKETCH THE LAYOUT OF THE EXISTING SIGNAL GROUND REFERENCE SUBSYSTEM OR ATTACH AN UP-TO-DATE ENGINEERING DRAWING

See attached drawing 001-50-4, 20 December 2001

6. VISUALLY INSPECT THE EXISTING SIGNAL GROUND REFERENCE SUBSYSTEM FOR SIGNS OF DETERIORATION, BURNING, CORROSION, OR DAMAGE. RECORD ALL DEFICIENCIES.

LOCATION	GROUND COMPONENTS	DEFICIENCIES
Tower antenna #3	*Ground conductor*	*corrosion*
Battery set #3 (Room 12)	*Ground bus*	*corrosion*

7. CHECK THE CONTINUITY OF THE GROUNDING CIRCUITS. CHECK ALL CONNECTORS, JOINTS, BONDS, AND FITTINGS FOR PROPER INSTALLATION, CRACKS, AND TIGHTNESS. RECORD ALL DEFICIENCIES.

LOCATION	DEFICIENCIES
Computer room (Room 2)	*Bond between the server #2 frame and raised floor frame was broken*
Telephone room (Room 3)	*Battery rack is not grounded*

8. MEASURE THE RESISTANCE BETWEEN CONNECTORS, JOINTS, BONDS, AND FITTINGS USING DOUBLE BALANCED DC BRIDGE. RECORD ALL MEASUREMENTS.

LOCATION	CONNECTIONS	RESISTANCE
Computer room (Room 2)	*Bond between ground plate and raised floor*	*0.2 milliohms*
DCO	*Bond between ground bus and phone rack*	*.03 milliohms*

9. MEASURE THE EARTH TO GROUND RESISTANCE OF THE SIGNAL GROUND REFERENCE SUBSYSTEM USING THE FALL OF POTENTIAL METHOD. RECORD THE MEASUREMENT.

RESISTANCE *1.5 ohms*

DA FORM 7452-8-R, FEB 2002 USAPA V1.00

Figure 6-5. Sample of completed DA Form 7452-8-R

SHIELDING SUBSYSTEM CHECKLIST FOR EXISTING FACILITIES

For use of this form, see TM 5-690; the proponent agency is COE.

1. FACILITY	2. DATE (YYYYMMDD)
Fort Tank	20020227
3. LOCATION	**4. INSPECTOR**
Building 358	*Lou Scable*

5. VISUALLY INSPECT THE EXISTING SHIELD NETWORK FOR PROPER GROUNDING AND SIGNS OF DAMAGE, CORROSION, AND LOOSENESS

LOCATION	DEFICIENCIES
Service entrance point	*Corrosion at point of bonding to the shield*

6. CHECK SHIELDING ON ALL DOORS, WINDOWS, VENTILATION PORTS, VISUAL ACCESS OPENINGS, AND WALLS FOR PROPER INSTALLATION AND BONDING

LOCATION	DEFICIENCIES
Ventilation port	*No bonding screen wire applied*

7. CHECK ALL UTILITY LINES, ELECTRICAL CONDUCTORS, AND DATA CABLES FOR PROPER BONDING AND SHIELDING	YES	NO
a. UTILITY LINES, ELECTRICAL CONDUCTORS, AND DATA CABLES ARE PROPERLY BONDED TO THE SHIELD AT THE POINT OF ENTRANCE	X	
b. ALL ELECTRICAL GROUNDED AND GROUNDING CONDUCTORS ARE IN THE SAME CONDUIT AS PHASE CONDUCTORS	X	
c. ALL ELECTRICAL FILTERS AND CONDUCTORS ARE PROPERLY ENCLOSED INSIDE METAL (STEEL) CASES/CONDUITS	X	
d. ALL METAL OBJECTS/CASES/CONDUITS ARE PROPERLY BONDED TO GROUND	X	
e. DATA CABLES ARE PROPERLY BONDED TO THE SIGNAL GROUND FEFERENCE SYSTEM	X	

8. MEASURE STRAY CURRENTS ON THE GROUND CIRCUITS

LOCATION	GROUND CIRCUITS	CURRENT MEASUREMENTS
Service entrance	*Electrical ground conductor*	*0.5 amps*
	Data cable shield	*0.1 amps*

9. MEASURE THE BOND RESISTANCES

LOCATION	BOND CIRCUIT	RESISTANCES
Service entrance	*Data cable to shield*	*0.1 ohms*

DA FORM 7452-9-R, FEB 2002 USAPA V1.00

Figure 6-6. Sample of completed form 7452-9-R *b. Field inspections*. After the drawings are obtained or prepared, conduct a comprehensive survey of the grounding, bonding, shielding, and lightning protection practices throughout the facility. This survey should cover all the major elements of the fault protection subsystem, signal reference subsystem, bonding (both in current paths and between structural elements), lightning protection for the structure, and shielding for both electromagnetic interference (EMI) [and electromagnetic pulse (EMP), if required] and personnel protection.

(1) Visual observations should be concisely documented and related to the engineering drawings for the facility. Measurements performed and data collected should be accurately documented on the survey form. The steps of the inspections are as follows.

(a) Analyze the earth electrode subsystem and measure its resistance to earth (figure 6-1).

(b) Inspect a representative number (5 to 10 percent) of the bonds throughout the facility (figure 6-2).

(c) Inspect and evaluate the lightning protection subsystem (figure 6-3).

(d) Inspect fault protection subsystem; make spot checks of stray current levels (figure 6-4).

(e) Wisp out and describe the signal grounding networks (or systems) present in the facility (figure 6-5).

(f) Perform a ground system shielding survey (figure 6-6).

(g) Evaluate (if applicable) the electromagnetic (EM) shielding of (or in) the facility (figure 6-6).

(h) Before leaving the facility, review the survey forms for accuracy and completeness.

(2) A comprehensive survey of the earth electrode subsystem should include the following items.

(a) Determine the configuration of the earth electrode subsystem for the facility. Sketch the conductor layout on the survey form or on an attached sheet. Engineering drawings may be attached in lieu of the sketch. Corrections or additions should be made to the drawings as appropriate (figure 6-1 #5). Identify the type of earth electrode subsystem present, i.e., rods, ring ground, grid, grid with rods, plates, horizontal radials, utility pipes, etc. (figure 6-1 #10 through #13). Note all interconnections between the earth electrode subsystem and other conductors such as water pipes, buried tanks, structural columns, underground guard cables, antenna counterpoises, and power grounds (figure 6-2).

(b) To the extent that information is available, determine the composition (copper, copperclad steel, steel, solid, hollow, etc.), diameter, and length of ground rods, as well as the size, depth, and composition of the ring ground. If horizontal rods or ribbons are used, record the dimensions; likewise, record the physical dimensions and composition of plates, cylinders, or other types of electrodes (figure 6-1 #10 through #13).

(c) Examine the conductor or conductors used to ground the power system neutral in the first service disconnecting means (i.e., main power switch or breaker for the facility), the power transformers, or other elements of the power distribution system to the earth electrode subsystem. Record the size or sizes on the survey form. Using a clamp-on ammeter, measure the ac current in each of these conductors and record the value on the survey form (figure 6-4).

(d) Inspect those bonds associated with the earth electrode subsystem carefully for evidence of looseness, corrosion, electrolysis, and lightning or mechanical damage (figure 6-2).

(e) Make a general classification of the type of soil at the site. If the site possesses unique properties (i.e., located on a mountaintop, in a swamp, on a coral reef), appropriately indicate the unusual features (figure 6-1). Also generally describe the weather conditions existing at the time of the survey, particularly if the earth resistance measurement described in the next step is performed. If known, indicate how recently rainfall totaling at least 0.01 inch has occurred. State if any soil treatment or enhancement procedures have been utilized (figure 6-1).

(f) Measure the resistance to earth of the earth electrode subsystem using the fall-of-potential method (figure 6-1).

(3) A comprehensive survey of the lightning protection subsystem should include the following items (figure 6-3).

(a) Make a sketch of the lightning protection network for the facility or compare the system as installed with the engineering drawings. Indicate the location of air terminals (lightning rods), the routing of roof and down conductors, connections to the earth electrode subsystem, and the location and size of bonding jumpers.

(b) Document the Underwriters Laboratories (UL) listing of the system if available.

(c) Record the height (above the roof) and material of the air terminals. Inspect for evidence of burning, pitting, or melting of a degree that seriously weakens (physically) the air terminals. Identify other metallic extensions (railings, antenna masts, etc.) extending above the air terminals or outside the 150-foot radius of protection.

(d) Record the cable sizes and materials used for roof and down conductors. Examine both types of conductors for unnecessary length, sharp or unnecessary turns [radii less than 20 cm (8 inches)], corrosion, and mechanical damage.

(e) Check fasteners and mounting hardware for secure mounting, looseness, corrosion, and mechanical damage. Verify that fasteners for connecting dissimilar metals (e.g., copper to aluminum) are of UL approved bimetallic construction.

(f) Ensure that interconnections between the lightning protection subsystem and the earth electrode subsystem, structural metals, utility lines, etc., are recorded.

(g) Inspect the guards that provide mechanical protection for down conductors. Note any down conductors in areas with public access or subject to contact by equipment or machinery. All such down conductors must be guarded with metallic or non-metallic (preferably) guards to a height of at least 2.7 meters (9 feet) from grade or floor level. Such guards must be securely fastened in place and not show appreciable physical degradation. Metal guards to include electrical metallic tubing (EMT) and conduit must be bonded to the down conductor at the top and bottom.

(4) A comprehensive survey of the fault protection subsystem should include the following items (figure 6-4).

(3) *(a)* Inspect the fault protection subsystem for conformance with the requirements of MIL-STD-188-124B and the National Electrical Code (NEC). Specifically, all equipment

supplied with electric power and other electrical apparatus falling within the jurisdiction of the standard or the NEC, must be grounded in accordance with the standard or the code. Inspect the facility and the equipment associated with the facility to see that grounding (green) conductors are present and record the sizes of the conductors. See that all connections are tight and well made.

(b) Verify that color continuity is maintained from the breaker panels to the equipment. In particular, be alert for white wire/green wire reversals.

(c) Verify that the neutral white wire (or other designated conductor) is not grounded at intermediate distribution panels, at switch boxes, or inside equipment. The grounded conductor (neutral white wire) shall be bonded to the earth electrode subsystem only at the first service disconnecting means. Facilities which can be temporarily removed from service should be de-energized and the main power switch locked or otherwise secured open. With electrical power removed, disconnect the neutral from ground at the first service disconnecting means and check for continuity between the neutral and the grounding conductor. A low resistance reading (<10 ohms) indicates that the neutral is connected to ground somewhere other than at the first service disconnect. This ground connection must be located and removed. Under normal operation, a one megohm resistance should easily be attained.

(d) Measure for stray currents using a clamp-on ammeter in the safety ground network at selected points throughout the facility. Choose a sufficient number of points to give an indication of the relative stray current level in the facility. In facilities containing electronic equipment, record and take action to correct all levels greater than 0.1 ampere.

(5) A comprehensive survey of the signal reference subsystem should include the following items (figure 6-5).

(a) Prepare a general description of the methods, techniques, and practices of signal grounding in the facility. Determine if an identifiable, dedicated signal grounding network is present. Note the equipment served by the network. Include the description of this network and record the location and size of wires or buses used as signal conductors. Also determine the existence of an equipotential plane.

(b) Using a double balanced bridge or a four-terminal milliohmmeter, measure the resistance between selected points of the signal ground network. Where lower frequency ground networks exist, measure the resistance between those points on the network where equipment interconnections are made. Measurements between equipment cabinets should not exceed 20 milliohms. Measurements between the cabinet and ground or the cabinet and the structure should be no more than five milliohms.

(6) A comprehensive survey of the bonding subsystem should include the following items (figure 6-2).

(a) Visually check a representative number (5 to 10 percent) of the various types of bonds in use throughout the facility. Welded, brazed, or silver soldered connections should be examined for broken or cracked seams, presence of voids, size of filler deposit length and number of deposits (if discontinuous), and evidence of corrosion. Soft soldered bonds should be inspected for broken connections, evidence of cold solder joints (crystalline, grainy appearance), and signs of overheating. Soft solder should only be used to improve conductivity at load bearing joints; it should not be required to provide mechanical restraint. There shall be no solder joints in either the fault protection subsystem (this includes the green wire network) or in the lightning protection subsystem. Bolted joints should be checked for looseness, inadequately sized fasteners, corrosion of either the fastener or main member, improper use of washers and locknuts, absence of or inadequate coverage with protective coatings, damaged or missing hardware,

and improperly cleaned mating surfaces. Be particularly thorough in the inspection of bolted connections in areas open or exposed to the weather. Joints using rivets, clamps, and other type fasteners should generally be examined for looseness and corrosion.

(b) Record the location and nature of specific bond deficiencies.

(c) Concurrently with or following the visual inspection of the bonds, perform bond resistance measurements. Select five to ten bonds that visually appear tight, well made, and corrosion free and measure their resistances. The sampling should include structural bonds, equipment-to–structure bonds, connections between safety ground wires, conduit-to-conduit or conduit-to-cabinet joints, bonds in lightning down conductors (to include structural columns if used for lightning discharge paths), and others as appropriate. Measure all bonds exhibiting visible defects. These measurements indicate the actual resistance between the two measurement points and also include the effects of any paths in parallel with the bond under test.

(d) For every bond exhibiting a resistance greater than one milliohm, check for looseness; if the connection is loose, tighten the fastener. Measure the resistance again after tightening. If the resistance is still greater than one milliohm and the joint can be readily disassembled, disassemble the joint and check for corrosion, debris, paint, or other non-conductive materials. Remove the material, reassemble the bond, and re-measure the resistance. If the resistance is still greater than one milliohm, note on the survey form the location of the bond and indicate the type of corrective action needed.

(e) Bonding jumpers using wires, cables, or wide metal straps are frequently used for fault grounding, signal grounding, and lightning grounding. Fault protection jumpers should conform to Article 250 of the *NEC*®. If they do not conform to Article 250, the jumpers should be replaced with cables or straps of the sizes specified by the *NEC*®. Signal grounding straps should be only as long as needed to bridge the physical distance and should exhibit a length to width ratio of not greater than 5 to 1. Lightning bonds should be restricted to not more than 1.8 meters (6 feet) and should only be used to interconnect lightning down conductors to nearby metallic objects. In addition to these requirements, examine the end connections at the end of the straps or jumpers for looseness, corrosion, and mechanical damage as described above. Any bond jumper not conforming to these requirements should be documented in the survey form. Note the specific location and indicate the type of corrective action needed.

(7) A comprehensive survey of the shielding subsystem should include the following items (figure 6-6).

(a) Identify the presence and nature (or type) of shields at the facility. (Recognize that shielding may be incidentally provided by a wall, screen, or other type of barrier that is primarily intended for a different purpose.) Record the description of the type of shields on the survey form.

(b) Inspect screens, shielded cabinets, doors, covers, etc., of all designated RF barriers for wear, damage, corrosion, broken bond straps, broken or damaged bonds, and loose gaskets. Observe equipment operation for evidence of interference, noise, or malfunctions. Record deficiencies on the survey form. Ensure that grounding conductors passing through a designated RF barrier are bonded.

(c) Be sure that the bonds and bonding inspection include the shields.

(d) Examine cables and connectors for broken or frayed shields, improper mounting, and evidence of corrosion. Check to see if the termination of cable shields is properly performed.

6-3. Performance evaluation program

Use the information available from the corrected drawings and the facility survey to determine if modification or upgrading of the facility is necessary. Compare the grounding, bonding, shielding, and lightning protection networks and practices with the recommendations contained in the previous chapters of this manual. While making these comparisons, be particularly alert for indications of operational, installation, or maintenance problems (either with a system or with a piece of equipment) which may be directly or indirectly related to a noted deficiency. Where a need for upgrading is indicated, determine what retrofit steps would be necessary and estimate the costs. If the operational mission of the facility justifies the cost, proceed with the implementation.

6-4. Upgrades

The following guidelines may be used to help evaluate the survey findings and to help define the retrofit steps which should be taken. This set of guidelines is not to be considered as all inclusive. Specific situations can be expected to arise that will not be adequately covered by the guidelines. These situations must be recognized and dealt with on an individual basis.

a. Earth electrode subsystem. If the measured resistance of the earth electrode subsystem is greater than 10 ohms, identify the reason for the high resistance. Review the past record (if available) of earth resistance measurements for signs of gradual increases in resistance as well as sudden resistance changes. (Discard from consideration "zero" resistance reading and other similarly unobtainable values.) Examine the resistance readings for possible correlation with site changes.

(1) Once the reason for the high resistance and local climatic conditions is established, determine the most appropriate method in terms of cost and ease of implementation for reducing the resistance. Typical alternatives include the use of more or longer ground rods, the installation of horizontal grids or wires, chemical salting, or the drilling of wells down to the permanent water table.

(2) Carefully review the building drawings to insure that proper connections to the earth electrode subsystem are provided for all elements of the facility.

(3) All specific earth electrode subsystem installation deficiencies such as grounding conductor sizes not in conformance with MIL-STD-188-124B requirements or maintenance deficiencies such as loose or corroded bonds and fasteners should be corrected as soon as possible.

b. Lightning protection subsystem If no lightning protection subsystem exists for the structure, determine if one is needed.

(1) Where a structural lightning protection subsystem exists, all deficiencies noted during the survey should be corrected.

(a) All seriously degraded damaged air terminals should be replaced.

(b) Air terminals should be relocated as needed so that they are the objects of highest elevation on the structure and where they provide a 1:1 cone of protection for the antennas without affecting their operation.

(c) Down conductors should be rerouted or additional down conductors added where more direct paths to the earth are needed.

(d) If not already provided, the lightning protection network should be interconnected with the earth electrode subsystem, electrical ground, utility pipes, equipment grounds, and with the building ground to provide common grounding for all.

(e) All corroded and mechanically damaged connectors and fasteners should be replaced with UL-approved devices.

(f) Missing and severely damaged guards should be replaced.

(g) If the structure is used as a lightning down conductor or as an electrical safety grounding conductor, see that all joints are effectively bonded.

(h) If more than 25 percent of the bonds measured exhibit a resistance greater than one milliohm then all bonds throughout the facility should be inspected carefully, and the resistance measured. Each one found deficient should be redone.

(2) The lightning protection subsystem should be expanded as needed to provide protection for those parts of the facility extending outside the established cones of protection.

(3) At those facilities where the lightning outage history indicates a need for surge protection on either signal or power lines, appropriate lightning and surge protectors should be installed. Insure that the protectors are adequate for protecting the type of equipment on which installed.

c. Coupling path analysis. Review electrical wiring diagrams and the electrical equipment distribution within the facility to determine possible direct or indirect coupling paths between noisy equipment and susceptible electronic apparatus. Apply corrective measures such as relocating equipment, redistributing the electrical load so that potentially interfering equipment are served by separate feeders, installing electrical feeders in steel conduit or raceway to reduce magnetic fields, and relocating signal lines to sensitive equipment at the maximum possible distance from power conductors feeding noisy equipment.

d. Equipment malfunction analysis. Correlate, if possible, any evidence of equipment malfunctions due to electrical noise on signal or control cables with the measured values of stray currents or voltages on grounding conductors and on cable shields. If such correlation exists, determine as best as possible the probable cause of such noise voltages. Perform corrective actions as necessary to bring the noise levels to acceptable values.

e. Signal grounding analysis. Carefully review the drawings of the facility to identify the type of signal grounding employed throughout the facility. If operational experience as indicated by maintenance logs or outage reports and operator comments reveal problems with system noise and interference attributable to grounding deficiencies, determine the severity of the problems and remedy them if necessary.

f. Shielding analysis. Where shielding deficiencies exist, determine if the need is for additional shielding or for improved maintenance of the existing shields. If no shielding is present, design and install shields as needed. If the existing shields have simply degraded through poor aperture control and poor bond or seam maintenance, implement corrective measures immediately.

g. Facility "as-built" documentation. Indicate all changes made during the upgrading process on the facility drawings.

6-5. Expansions

As operational requirements change, expansions of the grounding and shielding networks in a facility will be necessary. The added elements must maintain the philosophy and integrity of the existing networks. When making additions or modifications to shielded areas, the original level of shielding integrity must be maintained. Particular attention must be directed to the careful bonding of connector shells, the installation of filters, and other practices which may drastically degrade tile shielding effectiveness of a housing or other enclosure if not controlled. Following major additions to the facility, the facility should be resurveyed. Any deficiencies in the installation or compromises to the original networks should be corrected. File a copy of all survey results in the maintenance file for the facility to provide the initial starting point for the maintenance history. Finally review all drawings to verify that they are complete and accurately reflect the actual installation.