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THE DANGER OF INTERMODULATION GENERATION BY RF CONNECTOR HARDWA--ETC(U)

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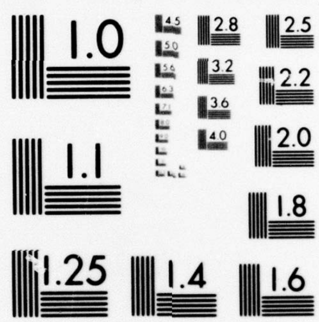
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NRL Prob R01-58

(9) Technical memo.

22 SEP 1975

AD A061500

From: Director, Naval Research Laboratory, Washington, D.C. 20375
To: Commander, Naval Electronic Systems Command (PME106-13)

Subj: (6) The Danger of Intermodulation Generation by RF Connector Hardware Containing Ferromagnetic Materials.

Encl: (1) NRL Tech Memo 5430-180A CEY:lg of 16 Sep 1975 (14) NRL-TM-5430-180A (11) (12) 12p.

1. Mr. W.R. Coffman (PME106-11) requested that information be provided in advance of a Naval Research Laboratory (NRL) memorandum report on the radio interference to weak signal system that is caused by hardware containing ferromagnetic materials. This information has been prepared and is contained in enclosure (1).

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By direction

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16 September 1975

TECHNICAL MEMORANDUM

Subj: The danger of intermodulation generation by RF connector hardware containing ferromagnetic materials.

Background

1. This technical memorandum is presented in advance of formal reporting on the in-depth study of mechanisms and means for reducing intermodulation generation (IMG) in passive radio frequency (RF) hardware, presently under way at the Naval Research Laboratory (NRL). It is imperative that the communication community be again and quickly alerted to the harmonic and IMG interference danger of RF connectors and associated components which contain ferromagnetic materials (iron, nickel, cobalt, and their alloys).

2. In a recent search for improved RF connector designs it became evident that the body structure of many of the newer type coaxial connectors and adapters are being manufactured from stainless steel, type 303, a low permeability (<2) ferromagnetic alloy. That such a material could be considered for fabricating RF connectors is difficult to understand because of the known non-linear effects of even small quantities of ferromagnetic contaminants in RF systems. To cut cost, nickel plating, another ferromagnetic material, is apparently also being widely substituted for previously used silver or gold plating of brass stock connectors. If satellite or other weak desired signal communication systems (utilizing multicarrier transmitters) are to succeed and/or survive, such interference generating materials must be eliminated in all transmission elements of the systems.

3. To reverify the ferromagnetic threat and establish the magnitudes of interference, IMG tests of sample RF coaxial hardware were undertaken using the NRL IMG test facility.[1]

[1] The IMG test facility, as presently configured tunes the 240 to 310 Megahertz (MHz) frequency range. Six tunable cavity resonators are utilized to form a high isolation two transmitter multicoupler which in turn feeds the transmit port of a diplexer, utilizing fixed tuned interdigital resonators. The transmitter powers may be independently varied from 0 to 100 watts (W). The receive port of the diplexer feeds a high gain low noise receiver/spectrum analyzer. The device under test (DUT), transmission line hardware in the subject tests, is placed between the common junction port (normally the antenna port) of the diplexer and 500 feet of RG-214/U coaxial cable which approximates an infinite transmission line and ideal termination. For two 30 W carriers (one at 250 MHz and the other at 270 MHz) from the common junction port, the reflected internal 3rd order IMG ($2f_2-f_1$ = 290 MHz) of the test set, DUT terminals bypassed, generally measures $\leq$ - 140 decibels referred to one milliwatt (dBm). This represents a test set residual 3rd order intermodulation conversion $\leq$ - 185 dB relative to either carrier output, or $\leq$ - 188 dB relative to 60.W., the total power from the diplexer. With 10 dB reduction in each signal (output) power, the residual 3rd order IMG is well below the receiver noise floor, approximately -150 dBm in 100 hertz (Hz) bandwidth. Ideally, decreasing each signal 10 dB should drop the 3rd order IMG by 30 dB.

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Two simple experiments were made to determine the level of non-linear IMG introduced by suspect RF connector hardware. Test "A" was conducted with two 30 watt (W) carriers to simulate the typical small ground or shipboard terminal and measure the resultant IMG interference at the diplexed receiver input. Test "B" determined the approximate maximum permissible carrier levels which would create connector IMG interference equal to the noise in the terminal receiver 25 kilohertz (kHz) bandwidth (BW). Nominally the IMG level would be about -126 dBm for this noise level. It should be noted however, that threshold for a 75 bit per second phase shift keyed signal will have a carrier to noise density ratio of about 30 dB. This signal level is about 14 dB lower than the -126 dBm test level or -140 dBm, an extremely severe requirement. External magnetic fields positioned near connector samples were employed as diagnostic aids to verify that effects were "ferromagnetic" and not "metal-oxide-metal contact" problems, also a possible IMG contributor. It is worth noting that, experimentally, contact and ferromagnetic IMG effects can be made similar in magnitude. However, the ferromagnetic interference effects are generally larger, more persistent, easier to repeatedly measure and identify for elimination.

4. Standard silver plated brass type "N" or "BNC" connector/adaptors used as the device under test (DUT) appear quite linear providing the devices are clean and the contact surfaces are well aligned, typically allowing IMG measurements to -140 dBm. As a further test, connectors such as the UG-29B/U double female and the UG-57B/U double male type N adapters were interconnected in groups up to sixteen adapters (all that were immediately available) as the DUT. IMG degradation was still quite low, being equal to or less than 4 dB relative to the basic test set IMG level of -140 dBm, just noted. Multiple BNC type adapters were only slightly worse. Linear adapters required to interconnect the test samples were frequently rechecked during the tests to verify low residual IMG.

5. To prove that high measured IMG of suspect connector hardware was in fact due to the use of ferromagnetic materials, external magnetic fields were placed parallel with and perpendicular to each DUT. Conceptually, IMG in a ferromagnetic substance is reduced because of the reduction in incremental permeability while being subjected to a large steady magnetic field. Ideally, the material should be magnetically saturated to reduce the permeability to unity (air). This is not practical, however, with materials and air gaps involved in normal RF connector design. (An early suggestion to purposely make connector parts from magnetic material is seriously questioned).

6. Several IMG spectrum characteristics are experimentally evident when the DUT containing ferromagnetic material is subjected to a sufficiently large alternating magnetic field. If negligible residual magnetism[2] exists in the device, IMG depression will be maximum at both the positive and negative peaks of the magnetic field and thus at twice the magnetic field frequency. The resultant RF spectrum will therefore contain sidebands spaced at twice

[2] Magnetization is a more precise term for residual magnetism used in this report.

the magnetic signal frequency from the IM carrier. If residual magnetism is present, a relatively smaller ac field will modulate the residual field and form sidebands spaced at the magnetic frequency from the IM carrier. If the ac field is increased beyond a critical magnitude, the spectrum will suddenly flip to predominantly frequency doubled sidebands (the demagnetized state) and will remain in this state at higher and lower drive levels until remagnetized by a large dc field. Such characteristics result in hysteresis effects which will be discussed with the RF hardware data.

Hermetic Seal Non-Linear Effects

7. Hermetically sealed RF feedthrough (bulkhead) connectors and adapters, sometimes mistaken as linear connectors because of their similar external appearance, have long been known to be highly non-linear and are to be avoided wherever possible. These devices are non-linear because a portion of the center conductor through the glass seal and the metallic rim around the glass seal are made of "kovar" or similar ferromagnetic alloy. Kovar is used because it is a nearly perfect "match" to the thermal coefficient of glass "7052".

8. Two very common types of hermetically sealed RF connectors widely used in the Navy are the bulkhead UG-30C/U and UG-30D/U type N double female adapters. Using either adapter as the DUT and test A (60 W drive), the IMG level typically measured -85 dBm, an interference increase of 55 dB over the -140 dBm linear device reference. Such adapters may thus be characterized as having a non-linear conversion of about -133 dB, greatly inferior to the -188 dB achievable with the non-ferrous UG-29B/U or similar adapter.

9. To verify that the above measured high IMG level was a function of the kovar (ferromagnetic) material, a solenoid dc magnetic field of approximately 700 gauss was applied coaxially to the adapter. The initial IMG level of -85 dBm decreased to -105 dBm, a reduction of 20 dB. Removal of the external magnetic field caused the IMG level to again return to -85 dBm. The repeatability of these measurements indicates that negligible change occurred to the residual magnetic field of the kovar material resulting from application of the relatively large 700 gauss external field; a characteristic not shared by the stainless steel and nickel plated RF connectors, described later.

10. IMG reduction as a function of applied magnetic field was initially studied by observing the interference level as a function of the applied field. It was soon evident, however, that the relationships between the IMG and magnetic field were too complex and non-linear (interdependent in some devices) to fully explore experimentally at this time. As an example, the subject adapter IMG actually increased with increasing field, from -85 to -82 dBm at about 350 gauss, passing through a broad maximum before decreasing to -105 dBm at

700 gauss. When a sinusoidal voltage (~2kHz) was applied to the solenoid, fundamental as well as harmonic modulation sidebands were produced on the IM carrier. This is an indication of residual magnetism in the kovar elements. A transverse dc field (perpendicular to the connector axis) of approximately 1000 gauss had essentially no control over the IMG level, apparently a result of the kovar element shapes and RF current paths.

11. IMG tests were conducted with modified UG-58/U type N female panel receptacles assembled to simulate a UG-30C/U adapter, with and without the kovar (ferromagnetic) pieces. Using 60 W drive (Test A), the simulated adapter with the kovar pieces measured -83dBm; without the kovar pieces, -137 dBm. The need to remove kovar in seals is unmistakable.

12. In test B, the total power to either the UG-30C/U or UG-30D/U adapters had to be decreased to 0.2 watts to reduce IMG to approximately -126 dBm, the typical terminal receiver input signal threshold for 0dB C/N in 25 kHz BW. Device non-linear conversion of -149 dB at only 0.2 W drive indicates the possibility of interference generation even in a receiving antenna system as the result of radiated pickup of nearby transmitted antenna signals. At 0.2 W drive, the 700 gauss axial dc field only reduced IMG about 2 dB and the 1000 gauss transverse field, as before, had no effect.

13. Hermetic seals were one of the IMG contributors in the first FLTSATCOM spacecraft system. Interference was reduced by changing the original diplexed signal design to the current dual antenna design. Initially, removal of all kovar-glass seals was contemplated. The number of hermetic seals remaining in the current spacecraft design is not known. Final IMG evaluation will be required as part of the Qual Model Spacecraft performance. It is believed that some of "Gapfiller's" IMG problems may be due to hermetic-seals.

14. The many hermetically sealed connectors used in Navy ground and shipboard terminals are evidently still contributing to ambient IMG problems. Interference reports on hermetically sealed connectors are documented as early as 1966[3]. Tests aboard the USS Bunker Hill indicated that third harmonic distortion from Navy high frequency (HF) transmitters increased about 20 dB when hermetically sealed adapters were employed.

[3] NELC LTR SER 3250-14 of 3 Mar 1966 (Information Bulletin) and Final Report for Electrical Hull Interaction, pp 12-15, contract No. 123 (953) 55012A IITRI Project E6062 of 28 Feb 1967.

15. Theoretically, 3rd order IMG , ·›duced by 2 equal carriers in a two-port device (an over-simplification in practice) should be 9 times the 3rd harmonic power of either carrier. This would imply a projected IMG contribution by the hermetically sealed adaptors at HF of 29.6 dB, considerably less than the 55 dB IMG contribution at UHF indicated by NRL tests. The difference may possibly be due to high residual transmitter 3rd harmonic distortion even without the hermetic seal connectors in the shipboard tests and frequency resonance effects not accounted for in either test.

16. Many later reports by the Naval Electronic Laboratory Center (NELC) and the IIT Research Institute (IITRI) have continued to warn of the hermetic-seal harmonic and IMG interference problem from HF through UHF. Unfortunately, these devices are still in Navy stock and widely used. Dr. Smith of Code 5207S at NRL has been consulted on the hermetic-seal problem and is currently looking for possible substitutes for the usual ferromagnetic materials employed.

17. Recent conversations with Mr. Kerr of ELEX-50452 indicate that the commercially available UG-30/U or its equivalent, which employs a gasket seal construction (in place of the glass-kovar hermetic seal), good for pressures to perhaps 50 psi, may soon be made available as Navy stock. Several "castoff" silver plated brass UG-30/U adapters were located, cleaned and checked in the IMG test set. These units, after some rework, were very close in performance to the silver plated brass UG-29B/U adapters, namely -140 dBm at 60 W drive. Pressurized connectors and adapters should be used as an interim solution replacement for many of the presently used hermetically sealed (ferromagnetic) devices; providing of course, that the pressurized adapters are not made of stainless steel and do not use nickel plating or other ferromagnetic materials.

Stainless Steel Non-Linear Effects

18. Comparitive IMG tests between typical stainless steel connectors and physically identical devices made from non-ferromagnetic materials (such as brass, beryllium copper, phosphor bronze or aluminum, as specified in MIL-C-39012B) were initially planned. Although many companies indicate such connector availability, the non-ferromagnetic substitute devices are apparently not "off-the-shelf" items.

19. The Americon Model 3080-0000 precision "N" double jack (female) adapter was selected for IMG testing because its passivated stainless steel body, which serves as the coaxial outer conductor, could be readily duplicated from other materials. The passivation process is a metallurgical surface treatment, forming a non-ferrous protective coating to reduce chemical

activity and rust. The adapter center contacts are made of beryllium copper, gold plated. The precision construction is to provide minimum VSWR, contact resistance and generally higher performance than its counter part, the standard UG-29B/U adapter.

20. Each of the six 3080 stainless steel adapters purchased for the test measured from -85 to -90 dBm IMG in test A (60 W drive). It is thus evident that the so-called nonmagnetic (permeability < 2, MIL-C-39012B) connector/adapter is extremely non-linear. At best it generates only 5 dB less interference than that created by the non-linear ferromagnetic (hermetic-seal) adapter, which was discussed earlier. This high level of non-linear conversion, is typical of all stainless steel RF connector/adapters tested to date, regardless of manufacturer. To verify that the non-linearity was in fact due to the two stainless steel outer conductor elements of the 3080, identical structural elements were machined from brass and assembled with the original gold plated beryllium copper inner contact element. With this change the intermodulation component levels were measured from -137 to -140 dBm in test A. The 3 dB variation experienced at times is believed to have been a contact problem with the unplated brass elements. The urgency to replace stainless steel RF connectors with linear devices is clear.

21. Reassembling the 3080 with the original stainless steel body elements, again produced the previously measured high IMG levels of -85 to -90 dBm when 60 watt drive was applied. Application of the 1000 gauss transverse field typically reduced IMG by 20 to 25 dB and the 700 gauss axial field reduced IMG 10 to 15 dB.

22. Stainless steel RF connector/adapters typically exhibit small residual magnetic effects not discussed in the above measurements. Nickel plated devices also exhibit these effects, as shown later. This is perhaps best demonstrated by an example. Maximum IMG is generally found after subjecting the device to a large ac magnetic field which has been slowly removed to minimize residual magetism. For example, IMG for one 3080 adapter measured -86 dBm in test A (60 W drive) following the degaussing treatment. Negligible residual magnetism was verified by observing that the RF spectrum contained only sidebands spaced at twice the magnetic signal frequency from the IM carrier with the 2kHz (~ 50 gauss peak-peak) test signal. Next, a dc transverse field of 1000 gauss was applied. With this steady dc field, IMG was reduced to -112 dBm, an indicated reduction of 26 dB from the initial measurement. Removing the dc Field resulted in an IMG level of -88 dBm, a reduction of 2 dB from the initial degaussed maximum IM level. Reapplying the dc field again reduced the IMG level to -112 dBm, which was the level found after the dc field had first been applied. The dc

field measurements were repeatable, providing the DUT was not subjected to a large ac field. Using the small 2 kHz ac test signal as before revealed that sidebands were spaced at the 2 kHz magnetic drive frequency from the IM carrier. This indicates a restoration of the residual magnetism, as discussed earlier. When the ac field was increased somewhat beyond a critical magnitude (~280 gauss peak-peak for this device), the IM carrier spectrum reverted back to sidebands spaced at twice the magnetic signal frequency. After a moment at this level, the magnetic drive signal was slowly reduced to zero whereupon the ambient IMG level was again -86 dBm, the initial value measured with minimum residual magnetic field. Such a sequence of measurements has been found to be repeatable over a reasonable period of time. There is evidence, however, from measurements, that a device shelved for some time loses or gains residual magnetism. This perhaps is dependent upon its surroundings during storage and handling. Hence, measurements are more reproducible after an initial degaussing operation.

23. In test B, the total power to a 3080 adapter had to be decreased to 0.5 watts (both input signals equal) to reduce IMG to approximately -126 dBm (the terminal receiver input signal threshold for 0dB C/N in 25 kHz BW). The 1000 gauss transverse field reduced IMG approximately 14 dB but the 700 gauss axial field was no longer effective. The fields at the 60 W drive level were considerably more effective being 20 to 25 dB reduction for the transverse field and 10 to 15 dB reduction for the axial field. The stainless steel adapter non-linear conversion of -153 dB at 0.5 W drive (an improvement of about 4 dB over the non-linear kovar hermetic-seal adapter) still represents a real possibility of interference generation in a receiving antenna system as the result of radiated pickup from nearby transmitted antenna signals.

24. The stainless steel bodies of four 3080 adapters were gold plated to various thicknesses to ascertain the degree to which the adapters could be linearized. The skin depth of gold, above about 225 MHz, for simple round wire geometry (not really applicable to the connector geometry) is approximately $2(10^{-4})$ inches or less. One adapter, plated with $2(10^{-4})$ inches of gold, showed a 10 dB improvement over the unplated device, but the sensitivity to externally applied magnetic fields was essentially unchanged. This sensitivity effect indicates that the ferromagnetic effect is still dominant. Another adapter, plated with 10^{-3} inches of gold (~5 skin depths) showed only an additional 5 dB improvement (15 dB over the unplated device) and IMG reduction with external magnetic fields was as great as with the unplated device. This behavior was not anticipated. Since current density is assumed to drop to a very small value at a distance corresponding to several skin depths, the gold should essentially carry all of the current and effectively linearize the connector. Obviously, this linearization did not occur.

25. It was suggested that the above skin depth anomaly might be due to sharp internal edges of the 3080 outer conductor body elements which had not been adequately plated. Previous experiments have shown that coaxial transmission lines having steel center conductors were linearized with only about $2(10^{-4})$ inches of copper plating which is approximately one skin depth at UHF. To investigate the sharp edge hypothesis, two grooves, approximately 0.017 inches wide and 0.061 inches deep were cut into the 0.125 inch diameter steel transmission line center conductor. Before plating, the IMG level measured -75 dBm. After plating with $2(10^{-4})$ inches of gold, the IMG level measured -130 dBm. (Quieting to -140 dBm is not easily obtained with the 7 millimeter precision air line test samples, apparently because of the moveable gold plated collet, a friction contact element in the center conductor pin of each APC-7 precision adapter used at the ends of the test line). Modulation, although very evident with the unplated center conductor, was not detected after gold plating. Since sharp edged grooves were clearly a part of this experiment, it might be concluded that sharp edges were not the primary cause for the plated outer conductor non-linearity exhibited by the 3080 adapter. It should be noted however, that experimentally, IMG and modulation effects are generally more easily detected when the ferromagnetic element is part of the outer conductor of a coaxial transmission line or connector. Another possible explanation for the small improvement of the gold plated 3080 may be due to the problem of satisfactorily plating the inner surface of the outer coaxial conductor. Additional experiments and analyses of the outer conductor skin depth anomaly are in progress.

26. Arrangements were made with Dr. Schelleng of Code 6452S at NRL to accurately measure the permeability of sample devices (the 3080 and several Omni Spectra stainless steel adapters known to be non-linear). His results, which will be reported in detail separately, show that the permeability of the stainless steel used in all samples was only slightly greater than unity and hence well below the < 2 permeability specification.

27. Because of the highly non-linear RF behavior of even very low permeability stainless steel type 303, it is imperative that this material not be used in the manufacturing of RF connectors for military communication systems, where more than one transmitter will be in simultaneous operation near a receiving system. MIL-C-39012B and related specifications must be revised, prohibiting use of any ferromagnetic material. All communication centers should be alerted to the potential interference problems with currently employed and/or readily available RF connectors manufactured with ferromagnetic materials. Immediate removal of such devices is recommended.

Nickel Plating Non-Linear Effects

28. To cut cost, many "low-bid" RF coaxial connector hardware procurements are evidently being filled with so-called "non-tarnish" nickel plated connectors.

Unfortunately, nickel plated RF hardware, like the stainless steel devices, show large non-linear RF effects. Nickel is a known ferromagnetic material. Sample nickel plated brass devices tested have shown IMG degradation in excess of 10 dB and often higher than 30 dB relative to silver plated brass devices. One heavily plated device (discussed later) was essentially as non-linear as the stainless steel and hermetic-seal devices described earlier; this appears reasonable based upon the "surface current" concept. Visually, it may at times be difficult to distinguish between the nickel and silver plated devices. However, IMG measurements and/or a simple magnet attraction test of surface scrapings from the device leaves no doubt. The variability among samples tested is possibly the result of different plating thicknesses, alloys, and processing, as well as the unique geometry of each device. Further study is required to better understand the ferromagnetic IMG mechanisms, but elimination of such contaminants is of immediate importance.

29. The standard UG-349B/U male BNC to female N adapter is one of many commonly employed "between series" adapters. Two of these devices connected via a UG-914/U double female BNC adapter (3 silver plated brass adapters in all) formed the reference DUT for the following IMG tests. The basic test set IMG reference level of -140 dBm was obtained after some rework (mainly careful cleaning).

30. The KN-99-46 adapter, built by Kings Electronics Company Inc., is structurally identical to the UG-349B/U except for the TR-5 finish (a trademark of Kings) which is visibly a nickel alloy plating. Scrapings of the finish revealed it to be magnetic. Substitution of this device for one of the standard silver plated adapters indicated it to also be very non-linear.

31. After demagnetization in a large ac transverse field, the initial IMG level of the KN-99-46 measured -89 dBm in test A (60 W drive), essentially the interference level obtained from stainless steel adapters reported previously. Application of the 1000 gauss dc transverse field decreased IMG to -109 dBm, which is a reduction of 20dB from the initial measurement. Removing the dc field resulted in an IMG level of -92dBm, which is a reduction of 3dB from the initial maximum IMG level and indicates a residual magnetism has been established in the adaptor. This conclusion was substantiated by using the small ac magnetic test signal previously described. Reapplying the dc field reduced IMG to -108 dB, essentially the level obtained when the magnetic field was first applied. The "on" and "off" dc field measurements were thereafter repeatable (within about 1dB) until the degaussing operation which again established the IMG level of -89dBm. The KN-99-46 adapter behavior with an axial magnetic field was very similar to the above transverse field data

except for a smaller effect. Replacement of the KN-99-46 adapter with a linear silver plated brass adapter again provided the basic test set IMG reference of -140 dBm.

32. Substituting any one of a number of nickel plated UG-914/U adapters (Mfg No. 74868) obtained from NRL stock for the standard silver plated DUT, typically degraded the IMG level by about 15 dB from nominal test set noise floor. Several nickel plated UG-914/U adapters (like the UG 30C/U hermetic-seal adapter discussed earlier) exhibited an increase in IMG over certain ranges of external magnetic fields. Another characteristic observed with nickel plated devices is a saturation effect which usually occurs at about 25 percent of the magnetic fields normally used for test. This saturation effect, not observed with the hermetic-seal or stainless steel devices, is probably related to the relatively thin skin of ferromagnetic material contained by the plated device. With repeated magnetic field exposures, some devices appear to suddenly "freeze" to a relatively high IMG, regardless of field and appear to return to normal operation only after a period of time. This may, in part, be due to the device heating which occurs during repeated or extended periods of exposure to the large ac degaussing field (induction heating due to eddy current flow within the device).

33. A simple experiment utilizing a standard UG-29B/U adapter was conducted to verify IMG contribution by nickel plating. Firstly, the adapter, as manufactured, measured -140 dBm IMG in test A (60 W drive). The adapter was then disassembled, stripped of the original silver plating, replated with approximately $5(10^{-4})$ inches of nickel and reassembled. In the demagnetized state IMG measured -100dBm, an interference degradation of 40 dB over that with silver plating. Obviously, nickel plating is not acceptable. Response to magnetic fields was similar to previously measured nickel plated devices. Applying a 1000 gauss transverse field, reduced IMG to -114 dBm. Removing the field indicated a small residual magnetism and IMG at -102 dBm. Similar characteristics were observed with the axial field.

34. From the above experiments it is evident that IMG interference due to nickel plating may be as intense as that due to the use of stainless steel or other ferromagnetic materials in the fabrication of RF connector hardware. Hence, it is clear that immediate action is required to: (1) prohibit the use of nickel plating as well as other ferromagnetic materials, (2) revise MIL-C-39012B and related specifications to eliminate ferromagnetic materials from all RF components where the material is subjected to effects of current flow; (3) caution all communication centers of the potential IMG interference to satellite or other weak signal reception and (4) recommend the removal of currently used or available nickel plated RF hardware.

Conclusions and Recommendations

35. The necessity to exclude use of ferromagnetic materials in the fabrication of RF connector hardware, currently an industry-wide problem, cannot be over stressed. Swift implementation of corrective measures, as outlined previously, is recommended.

Acknowledgments

Appreciation is expressed to Dr. V.J. Folen and Mr. W.E. Leavitt for their thorough review and beneficial suggestions in the above study and to my immediate co-workers, Mr. E.L. Bruns and Mr. P.W. Johnson for their assistance in conducting the experiments.

C.E. Young

C.E. YOUNG