F.C.C. 76-101

BEFORE THE

FEDERAL COMMUNICATIONS COMMISSION

WASHINGTON, D.C. 20554

In the Matter of	
AMENDMENT OF PART 73 OF THE COMMISSION'S RULES AND REGULATIONS TO ESTABLISH STANDARDS FOR THE DESIGN AND INSTALLATION OF SAMPLING SYSTEMS FOR ANTENNA MONITORS IN STANDARD BROADCAST STATIONS WITH DIRECTIONAL ANTENNAS.	Docket No. 19692

REPORT AND ORDER

(Proceeding Terminated)

(Adopted: February 4, 1976; Released: February 12, 1976)

BY THE COMMISSION:

1. This proceeding, instituted by a *Notice of Inquiry and Notice of Proposed Rulemaking,* adopted February 21, 1973, is an outgrowth of the proceeding in Docket No. 18471, which promulgated rules governing the type approval of antenna monitors, and established a schedule for their installation at all standard broadcast stations using directional antennas.

2. The above mentioned rule amendments insure the eventual substitution at broadcast stations of modern, accurate and stable monitors for obsolete equipment whose performance has never been required to meet any uniform standard. However, the ability of any antenna monitor to reflect accurately the phase and amplitude relationships of the currents in the elements of a directional array is limited by the quality of the system used to convey samples of these currents to the input terminals of the monitor. Comments submitted in Docket No. 18471, in many cases by consulting engineers having familiarity with the antenna systems of numerous stations, suggested that many existing sampling systems are of poor design, or have deteriorated badly since they were first installed. If the potentialities of the new monitors were to be fully realized, the opinion was expressed by a number of parties that some program for the upgrading of existing sampling systems should be instituted.

3. In this proceeding, therefore, the Commission undertook to determine what constitutes the basic elements of an adequate sampling system, and the feasibility of promulgating minimum standards for its design and construction. As a basis for discussion, it offered a tentative list of specifications, formulated largely on the basis of information on this subject submitted in Docket No. 18471. The list is included as Appendix A to the instant document. We indicated that the second stage of the proceeding might be either a *Further Notice of Proposed Rulemaking* in which specific rules were proposed, or, after an examination of the comments filed, if a reasonable consensus appeared pos-

sible as to the content of such rules and the procedure for their implementation, a *Report and Order* might be issued adopting appropriate rule amendments.

4. The deadlines for filing comments and reply comments in this proceeding were originally set as May 7 and May 21, 1973, respectively, but were extended repeatedly, by appropriate *Orders*, to final dates of October 30, 1973, for comments and November 30, 1973, for reply comments.

5. Thirty-one comments and three reply comments were timely filed. Appendix B is a list of participants in the proceeding. Nearly one-half of the total are firms of consulting engineers who practice before the Commission, and whose combined experience in the matter here under consideration can only be described as vast. Generally, it is their attitude that the objectives sought to be achieved in the proceeding are necessary and laudable. In furtherance of those objectives, they have supplied a wealth of technical material pertinent to sampling system construction, operation and maintenance. Engineering personnel of individual stations, and the engineering departments of group owners also contributed much useful information, although, in general, these parties were more conservative in their opinions of how generally any new rules should be applied.

6. While many of the parties agree that the meeting of any new requirements would impose little hardship on new stations, or on stations authorized to make major changes, there is concern with the expense visited on existing stations whose sampling systems fail to meet, in one or more respects, such new standards as the Commission might adopt. With respect to these stations we have suggestions that (1) existing stations be "grandfathered" or (2) that a long period be provided in which to achieve compliance, or (3) that, on the basis of a satisfactory showing that the present monitoring system is stable, the station be excused from complying with the new rules or (4) that the installation of an approved sampling system, together with a type approved antenna monitor, be tied to a relaxation of certain existing monitoring and inspection requirements, thus providing an incentive for voluntary improvement of individual systems.

7. There are several suggestions that any sampling system specifications which the Commission may adopt be offered only as guidelines. NAB states that "any criteria looking toward standardization of sampling systems should not be part of the Commission's rules but should be included in a companion document to the Rules, depicting operating practices and procedures." NAB further avers that looking toward adoption of rules in this area, we are moving in a direction counter to our present re-regulatory efforts to eliminate "meaningless rules and rules of questionable need." The selection and installation of specific types of sampling systems, urges NAB, should be made by the station licensee and his engineering consultant. Holding that "few sampling systems may be considered unreliable" it suggests that the standardization of the design and installation of such systems is no guarantee of improved performance, as all systems will have a tendency to deteriorate with time. It suggests, as an alterative, a method of testing sampling lines should be considered "so that each licensee could perform such tests to assure non-degradation of the system. Those few sampling systems that are considered unreliable could be dealt with by

existing rules, administrative procedure, and the Commission's Field Engineering Bureau inspectors." Finally, NAB is of the opinion that even if we decide that rules are required, any action to finalize such rules is premature, and does not afford all interested parties "the fullest opportunity to participate in the rule drafting procedure."

8. Assuming that NAB's comments represent a consensus of the opinions of many broadcast station licensees, it behooves us, before going further into the consideration of the technical submissions herein, to reexamine critically the basic premises on which this proceeding was instituted, both as to the reasonable need for the remedies here under consideration, and the procedure and occasion for their application. We are contemplating adoption of new regulations governing aspects of station construction over which we presently exert no control, at a time when we are making a major effort to simplify the broadcast regulatory structure. This, in itself, poses a philosophical conflict.

9. In contrast to NAB's opinion that there is no general problem with existing sampling systems, the general tenor of other comments suggest a much more extensive need for system upgrading exists. We know that, in connection with the license renewals of a considerable percentage of stations using directional antennas the Commission has occasion to question the antenna performance and to require corrective action. To what extent these difficulties may have been generated, at least in part, because particular licensees placed undue reliance on inaccurate antenna monitor readings we, of course, can only guess, but it is reasonable to believe that this has been a not inconsiderable contribution to their difficulties.

10. Many existing sampling systems evidently were installed without proper attention being given to the use of components and constructional techniques which contribute to the stability of the system, and minimize both short and long term environmental effects. In many instances, while such systems presumably were designed as a result of decisions made by licensees and their engineering consultants, it seems likely that the licensee's interest in minimizing immediate costs, rather than the engineer's aim toward maximizing long term performance, may have exerted a predominant influence on the system design. While subsequent experience with such systems may have reinforced the engineer's opinion as to the need for adequate sampling system design, in the absence of any required standards for such systems, cost may continue to remain a major determinant of the kind of system installed.

11. It should be observed that in monitoring observations aimed at maintaining the essential parameters of a transmitting system, it is only in the observation of the relative phases of the fields of the elements in a directional system is the operator required to place total reliance on the accuracy of samples delivered at the end of long transmission lines. For instance, when remote reading of antenna currents is undertaken, periodic calibration of the remote meters against base current meters is required. Such a verification of phase relationships is, of course, not practicable.

12. The contrast between the heavily built transmission system used to feed power to the antenna, and the light, almost flimsy construction

of many of the systems used to monitor the performance of the antenna has frequently been cited.

13. In the light of all the above, we believe that a unique case exists for extending the Commission's regulatory control into this area.

14. It has been suggested that such standards as the Commission might wish to adopt be established only as general guides, perhaps compiled as a body of standards of good engineering practice. This proposal has a certain appeal, particularly since the material submitted in this proceeding, in addition to providing recommendations as to the major components of a stable sampling system, also contains a great deal of information on constructional techniques which, if adopted, obviously contribute importantly to the overall quality of the system. While we believe this material is useful, and should be made generally available, it would hardly be feasible to adopt rules containing the mass of detail required.

15. On the other hand, it is not clear how the adoption of a "general guide" would be helpful in upgrading deficient sampling systems. There is a certain degree of unanimity among engineers on the general characteristics of a good sampling system, and such a guide would serve simply as a compendium of what they already know. To the extent that inadequate systems presently exist because of licensees' reluctance to undertake needed improvements, the situation is unlikely to be altered by the adoption of what, at most, can be considered as recommendations, to be adopted or ignored, as the individual may elect.

16. Standards of good engineering practice, if consistently applied, become *de facto* rules. If they are not invoked, they remain no more than the kind of general guides discussed above which, as we have indicated, we believe would be generally ineffective.

17. Accordingly, we believe our aim should be toward the adoption of rather broadly drawn rules, but to include in this *Report and Order*, in considerably more detail than is necessary to support these rules, a discussion of other relevant aspects of sampling system design. In this way, the total effort may serve both to establish basic requirements for such systems, and, at the same time, provide such guidance as may be desirable in the details of system installation.

18. We agree with those commenting parties who urge that in the formulation of rules for sampling systems, the required constructional features should only be those reasonably necessary to promote stability and repeatability in the antenna monitoring system, and thus its ability to reflect accurately deviations from licensed operating parameters.

19. NAB states that the performance of all sampling systems deteriorate with time, and apparently advances this as a reason why upgrading of systems may be fruitless. We believe that a properly constructed system deteriorates much more slowly than one of poor design, and, in looking at the requirements for an adequate sampling system, those constructional details which contribute to long term stability are considered as of primary importance.

20. NAB assumes that the Commission, by means of the rather infrequent inspections of standard broadcast stations which its limited corps of field engineers are able to perform, can detect unreliable sampling systems, and on this basis may require corrective action.

Certainly, if the sampling system is visibly in an advanced state of physical deterioration, this fact may be evident. However, in many instances, electrical deterioration may occur which may not be discovered in the kind of inspection the engineer has the opportunity to make. A study of the station's operating and maintenance logs may reveal that the performance of its directional antenna is not satisfactory, but the reasons for its departure from proper adjustment may not be evident. Excessive phase and current deviations not reflected in abnormal monitoring point readings would tend to indicate trouble in the phase monitoring system, but monitoring points have their own vagaries. Thus, the station operator must rely on both antenna monitoring and field monitoring for a reasonably complete picture of directional operation. It seems not unreasonable to expect that the antenna monitoring system be so installed that it can be relied on to give accurate information to the operator.

Sampling System Design and Installation

21. In this section, we will review the engineering material submitted in this proceeding, and, in some instances, draw tentative conclusions as a result of our study of this material. Under the heading *Sampling Lines* we consider as the first of the two major components of a sampling system, the design and disposition of the coaxial cable which delivers the sample currents from each tower of the array to the antenna monitor, and under *Coupling Elements*, the apparatus used to extract samples of the tower currents to be fed into the sampling lines. In the section *Maintenance of Sampling System Performance* we discuss measurement procedures which may be used to detect any deterioration in system performance, and under *Other Considerations* outline other minor details of system design which appear of sufficient importance to record for general guidance, but, in many instances, seem inappropriate for inclusion in rather broadly drawn rules.

Sampling Lines

22. A point on which there is almost entire agreement is that sampling lines should have a solid outer conductor—braided or foil wrapped lines afford insufficient shielding against unwanted fields, are subject to moisture contamination, and are probably the weakest component in many older sampling systems. Also, there is near unanimity as to the necessity for all lines in the system to have identical physical and electrical characteristics.[1] While most comments assume that the outer conductor will be of copper, aluminum cable is also available. While its electrical characteristics are apparently satisfactory, some of the comments cite difficulties in achieving satisfactory bonding and terminations when this material is used as an outer conductor. In addition to being less expensive than copper line, aluminum appears to have one possible long-term advantage—the outer conductor is usually seamless, while the copper version has a welded seam. However, there was no indication that rupture of this seam is a frequent occurrence.

23. The question of the amount and kind of dielectric, and the initial processing of the cable is rather intimately related to the question of

[1] Except for short lengths of more flexible cable needed to connect the sampling lines from their transmitter house termination to the antenna monitor.

whether equal length sampling lines should be required in any or all systems. The considerations are as follows. When the ambient temperature of a coaxial line is raised, the metal in the cable expands, causing an increase in the physical length of the cable. For any given length of cable, this effect, alone, results in increase in the phase delay in the cable. However, a temperature change in the same direction affects the constant of the dielectric in the cable so as to produce a counter effect—tending to reduce the phase delay when temperature increases. If a solid dielectric is employed, the latter effect is predominant, and lines with such dielectric exhibit a rather large negative phase/temperature characteristic. On the other hand, lines in which the dielectric is principally air or other inert gas exhibit a very much lower coefficient, generally in the positive direction. Cable with foamed polyethylene dielectric has a temperature/phase characteristic which, while inferior to air line, is much better than that exhibited by cable with solid dielectric.

24. The phase of the current sample presented to the antenna monitor is delayed by its transmission over the sampling line. If this delay varies with temperature, obviously it is a possible source of error in the monitor indication. If all sampling lines are of equal length, and exposed to the same environmental conditions, the error is cancelled, since we are concerned with the relative phases between towers, and a comparable change in the electrical length of lines leaves the relative phase indication unchanged. While, therefore, the employment of equal length sampling lines insures that temperature changes will have the least effect on the stability of the system, this expedient is quite expensive, necessitating, in many instances, the addition of hundreds of feet of sampling line only to achieve this end. It may also be an unnecessary refinement for those directional antenna systems which are not required to be held to very close operating tolerances. However, even in such cases, the effect of temperature variations on cable characteristics cannot be ignored. If unequal length lines are installed, good quality sampling line with a reasonably low temperature/phase coefficient should be employed.[2]

25. Generally, for stations not required by their authorizations to hold phase and current variations within restricted and specified limits, we believe that the decision as to whether to limit the differences in the relative length of sampling lines may be approached on the following basis. For the average array, the relative phases should be held within ±3 degrees (approximately equivalent to a ±5% variation in current ratio, which is a tolerance specified in our rules (§ 73.52(b)). Assume that, to maintain the relative phases within this tolerance, a

[2] Equal length sampling lines, of course, offer another advantage, which, alone, may recommend their installation in particular situations—that, when they are used, the antenna monitor can be made to reflect closely the relative phases of the fields actually existing in the elements of the array. This can simplify the initial adjustment of an array, and the subsequent monitoring and maintenance of its performance. The advantage may be sufficient to justify the extra expense of equal length lines, particularly for multielement systems. Many of the engineers who commented in this proceeding apparently consider this to be the case, and a number of consulting engineers regularly install lines of uniform length for monitoring directional systems which they design. In some cases, extreme care is exercised by engineers to adjust the various lines to precisely the same electrical length. If a primary aim is to reproduce, at the monitor, the specific phase relationship existing in the array such precision may be desirable. However, when equal length lines are used solely to minimize temperature/phase differentials, it seems unnecessary—nominal differences in length would normally introduce negligible errors.

monitoring accuracy of one-half this tolerance, or ±1.5 degrees represents good engineering practice. The repeatability of the type approved monitor is ±1 degree (§ 73.53(c)(13)(ii)). The permissible variation in samples presented to the monitor, caused by temperature variations, should therefore not exceed 0.5 degree. Accordingly, we believe, a reasonable basis for determining the tolerable difference in the length of lines is to ascertain, considering the phase/temperature characteristic of the line employed, and the temperature variation to which the line would be subject on a diurnal and seasonal basis, that, as between the longest and the shortest sampling lines proposed, a temperature/phase differential in excess of 0.5 degrees will not occur.

26. The following table, based on a study of material supplied by manufacturers of cable for sampling systems, gives a general idea of the magnitude of changes in phase delay occurring in two different types of cable, for different lengths of cable.

Change in delay in degrees for cables of specified lengths over a temperature range of −20 to +140 degrees F

	Frequency kHz	Cable Length		
		100 feet	500 feet	1000 feet
Dielectric	550	0.016	0.08	0.16
Primarily	1000	0.03	0.15	0.29
Air	1600	0.05	0.24	0.47
Foamed	500	0.09	0.45	0.89
Polyethylene	1000	0.17	0.83	1.7
Dielectric	1600	0.27	1.32	2.65

These figures are representative for phase-stabilized cable of the types shown. Solid dielectric cable may have a phase/temperature coefficient as much as three times as great as cable with foamed polyethylene dielectric, and its use obviously would present problems in many cases.

27. While it is obvious that air dielectric line has much the better temperature/phase characteristic, such line is considerably more expensive than line with a dielectric of foamed polyethylene. Also, because air dielectric line must be pressurized with dry air or other inert gas, auxiliary apparatus is required for this purpose. Finally, if the performance of such line is not to deteriorate, it must be subject to careful maintenance procedures. Several consulting engineers who comment discourage the use of such line for the latter reason—they have found a number of instances where maintenance has been neglected, and antenna monitoring systems have become inaccurate or inoperative primarily because moisture has penetrated improperly scavenged and pressurized lines.[3]

[3] Older types of semi-flexible air line, such as used in sampling systems, had another frailty—the inner conductor was supported by solid dielectric beads or washers, spaced at intervals along the conductor. Such lines were prone to "shorts" in handling, during which the inner conductor might be displaced between supporting beads sufficiently to contact the outer conductor. Modern semi-flexible air line has the solid dielectric material disposed in continuous helical fashion along the conductors, and apparently does not suffer this weakness.

28. The majority of engineers appear to favor line with foamed polyethylene dielectric. It has fewer maintenance problems, and has a reasonably good phase/temperature characteristic. It seems entirely satisfactory for the majority of installations, and is probably adequate for even the most critical uses, if measures are taken to minimize phase/temperature differentials to a degree commensurate with the monitoring accuracy required for the particular array.

29. As we have pointed out previously, the employment of lines of precisely equal length seems unnecessary, in most cases, to insure adequate monitoring accuracy. It actually may be undesirable if the result of such a procedure is to present to the monitor, as between pairs of towers phase differences at or near zero or 180 degrees. Monitors are ordinarily less accurate at these extremes, and near these points it may be difficult to resolve ambiguities in the sign of the phase difference. To avoid such situations, sufficient extra cable may need to be added to one or more lines to displace the presented phase differences by several degrees.

30. Potomac, a manufacturer of type approved antenna monitors, points out that it is also desirable to avoid line lengths approximating 1/4 wavelength (and presumably odd multiples thereof), since a line of this length, driven by a low impedance high Q loop may produce a high voltage when unterminated. Should an open terminating resistor occur in the monitor input, severe damage may be caused to the monitor.

31. Phase-stabilized line is coaxial line which, on order by a customer, and, of course, subject to an additional charge, has been heat cycled by the manufacturer to reduce semi-permanent stresses produced in line manufacture. Such stabilized line has an initial phase/temperature coefficient much lower than line not so treated.[4] Unstabilized line, subject to normal temperature cycling after installation, eventually becomes stabilized. We had raised the question in our *Notice* as to the circumstances in which phase-stabilized line should be required. Generally, this would appear to depend on design considerations. If sampling lines are to be substantially equal in length, and so disposed as to be subject to equivalent environmental conditions, prestabilization would appear to be unnecessary—since all lines presumably will change equally to the same final condition. However, if lines have lengths that differ greatly, the possibility exists that as the lines approach a stabilized condition, phase indications may drift from those established in the initial adjustment of the array. For this reason, we believe phase stabilized cable should be required for any sampling system in which the sampling lines are not of approximately equal length.[5]

32. It is apparent that if the lengths of cable between each tower base and the transmitter building are buried, not only are these portions of the sampling system subject to less extremes in temperature, but are better shielded from troublesome ambient fields, better protected from damage, and less subject to deterioration from weather.

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[4] One comment suggests that the coiling and uncoiling of line after stabilization may create new stresses and, therefore, pre-stabilization is fruitless. However, no evidence is offered on this point.

[5] Phase-*compensated* line is air-dielectric cable in which the amount of supporting solid dielectric has been critically proportioned to yield an extremely low phase/temperature coefficient. The engineer may choose to use such line in highly critical installations. Like all air-dielectric cable, it requires careful maintenance.

Buried line should, of course, be jacketed. While it is therefore apparent that line preferably should be buried, it is emphasized by several of the commenting parties that soil conditions in particular areas, or other factors, may make this disposition of the line undesirable, and perhaps, impossible. In such cases, each cable must be run above ground between the tower and the transmitter house. It is evident that, where this is done, adequate support and protection of the cable is necessary. In addition, to avoid the build-up of troublesome currents in the outer conductor caused by the high fields to which it is subject, the cable must be tied to the station ground system at periodic intervals throughout its horizontal run.

Coupling Elements

33. The great majority of those filing suggestions on this point favor a single turn, unshielded loop as the coupling element, rigidly constructed, and mounted on a tower leg at a point near the current maximum, but not less than about 10 feet above ground level. The usual alternative to this kind of tower coupling element is the shielded loop, in which the shield imparts rigidity, and encloses the conductor. Such a loop is usually mounted so that it may be rotated on a vertical axis (with, of course, provision for locking in any particular orientation), to adjust the degree of coupling to the tower. While the shielded loop has theoretical advantages, in that coupling to the tower field takes place only electromagnetically, the advantage is generally held to be of no practical significance, and it is outweighed by the fact that shielded loops too often have been found to accumulate internal moisture, with a consequent deterioration in performance. The comparative ease with which such loops may be rotated is seen as a liability, rather than an asset, the general opinion seeming to be that if the loop can be rotated, in the course of time it will be, either inadvertently by high winds, by workmen painting the tower or servicing its lighting, or perhaps by a misguided operator seeking to adjust his antenna monitor readings to values he considers more suitable.

34. While the great majority of engineers believe that the orientation of the loop with respect to the tower should be rigidly fixed, it is suggested that our proposed requirement that the plane of the loop in all cases include the vertical center line of the tower is too restrictive. An alternative orientation, with the plane of the loop including a tower face, should be permitted.

35. While we had proposed that coupling loops on all towers be of equal size and shape, many engineers believe that such a requirement leaves too little flexibility for adjusting the degree of coupling to each tower so that sample voltages delivered at the line terminations will be within a range of values which the antenna monitor can accommodate. The use of loops of equal size would seem to go hand in hand with the employment of sampling lines of equal length, when a primary objective in installing equal lines is to reflect at the antenna monitor, as closely as possible, the phase differences actually obtaining among the fields of the array elements. As we have pointed out previously, we believe that sampling lines of comparable length should be required only where it is necessary to hold phase/temperature differentials to extremely low values. Thus, while we believe that the loops should be of the same general construction, we will not preclude such adjustment

of the effective size of individual loops as may be necessary to establish proper coupling levels.

36. Those who favor the use of tower loops as coupling elements believe they are the best means for extracting samples from towers of any height. However, most of these parties concede that base sampling, usually with a shielded current transformer, is an acceptable alternative for towers of limited height ("limited," in this context, includes towers of electrical heights from less than 90 up to 110 or 120 degrees). Outside this general body of opinion are a few parties who argue either that base sampling should never be employed, or that it is entirely suitable for towers of any height.

37. The advantages of base sampling are that the coupling element may be enclosed in the tuning house, protected from the weather, from air contaminants and precipitation which may affect the short and long term performance of an exposed coupling loop. At the base location, furthermore, the coupling unit is readily available for testing and maintenance. Cited as another advantage (but certainly a dubious one) is the rather obvious fact that monitor sample currents, taken at the base, "track" base currents more closely than do currents obtained by tower mounted loops.

38. Those who favor tower loop sampling point out that a sample taken at or near the point where the tower current is greatest can be expected to be a more accurate reflection of the relative magnitude and phase of the field radiated by the tower than can a sample taken from the current in the antenna feed line at the tower base. The latter sample includes a reactive component primarily representing the current flow through the antenna capacitance to ground. The magnitude of this current, at any time, is affected by ground moisture content and cover and by other variable factors. Since this capacitance effectively shunts the antenna resistance, its effect on the accuracy of samples taken at the antenna base depends on the relative magnitudes of the tower capacitance and its base resistance. For towers of uniform cross section up to one quarter wavelength in height, and perhaps somewhat higher, it would appear that the antenna base resistance is sufficiently low, and the shunt reactance is sufficiently high that the error introduced by base sampling is usually small. On the other hand, self supporting towers normally have such a high capacitance to ground that some parties who would approve base sampling for uniform cross section towers of moderate heights believe it should not be employed with self supporting towers of any height. Tower base resistance increases rapidly with increases in electrical height, and, for relatively high antennas, substantial and varying errors may be involved in base sampling. That this effect is real is illustrated by the difficulty frequently experienced in maintaining adequate correspondence between base and loop current ratios in arrays having one or more tall towers.

39. Other objections raised to base sampling is that the sampling element is usually located near other components producing intense fields. The importance of adequate shielding of such transformers is emphasized, particularly the need for an electrostatic shield between the antenna feed line and the transformer secondary. There is one observation that base sampling can produce errors in a tower having a negative resistance, a situation which often occurs in multi-element arrays.

40. Assuming reasonable precautions are taken, and that well designed coupling units are employed, we believe that base sampling is an acceptable alternative to tower sampling for uniform cross section towers up to 110 degrees in electrical height.

41. A single turn, unshielded loop may be operated either at tower potential or at ground potential. When operated at tower potential, the inner leg of the loop is electrically bonded to the tower, and the cable which it feeds maintained at tower potential by electrically connecting the outer conductor to the tower at frequent points as it descends the tower. Since the point at which the cable leaves the tower is above ground potential, and the remainder of the cable run is at ground potential, a transfer device must be employed—an isolation coil, consisting of many turns of sampling cable wound on a cylindrical form. This coil may have sufficient inductance alone to present a high reactance at the station operating frequency, or it may be tuned to antiresonance at that frequency by a suitable capacity. A fixed capacitor may be employed, and tuning accomplished by shorting turns of the coil, or by a variable capacitor equipped with provision for locking its adjustment, once tuning is completed.

42. Alternatively, the loop may be mounted on stand-off insulators, and the cable insulated from the tower in similar fashion. When this type of construction is used, no isolation coil is required. Since such is the case, this type of installation is usually less costly than the one just discussed. However, many engineers consider it a less desirable type of installation, since the loop and tower cable introduce a capacitative shunt to ground. Generally, opinions as to its employment are similar to those with respect to base sampling—the insulated loop is tolerable for towers of moderate electrical height—up to about 130 degrees—but, for higher towers, all sampling loops should be installed to operate at tower potential.

43. No one commenting on our suggestion that some advantage might be gained by establishing an impedance match between the sampling element and the transmission line considered such a procedure as either necessary or desirable. We will pursue the matter no further.

44. Similarly, a proposed specification requiring that the inner conductor of the sampling line be connected to the inner leg of the loop was pointed out to be contrary to good practice in many cases, and completely infeasible when the loop is operated at tower potential.

Maintenance of Sampling System Performance

45. In our *Notice* in this proceeding, we requested suggestions as to measurement procedures which might be prescribed to determine whether the electrical performance of the sampling system remains at a satisfactory level. We envisaged the procedure as a comparative one—an initial set of measurements made and recorded when the system is first installed, would be repeated at periodic intervals, and compared with the original measurements in an attempt to detect incipient or actual deterioration in monitoring system performance.

46. It would appear that many engineers presently do conduct more or less elaborate tests of sampling systems, and we have been furnished, in some cases, with detailed descriptions of the procedures followed. Simple DC measurements of resistance at the monitor line termination, both with the line open and when terminated by the sam-

pling element are a part of virtually every test program. RF impedance measurements are also common, although the particular procedures employed differ among engineers. In one or two instances, it is indicated that such measurements are supplemented by reflectometer observations.

47. RF impedance measurements at the station's operating frequency are the easiest to accomplish, but it is pointed out that such measurements are a more sensitive indication of sampling system performance if made at a frequency at which the RF impedance of the sampling line is high.[6] However, if such measurements are to be duplicated at a later date, the frequency at which the measurements are made must be accurately known. Thus, a highly stable oscillator, with means for checking its frequency within close limits must be employed. When the system is separable into various sections (for instance where isolation coils are employed) some engineers measure the various sections separately. In addition to the tests described above, checks of characteristic impedance and the electrical length of lines may be made.

48. While we believe measurements of the nature discussed, made at the time the sampling system is first installed, and repeated at periodic intervals thereafter, are valuable in detecting the existence or incipience of conditions which may adversely affect the stability of the monitoring system, we have decided not to adopt rules which would require such measurements to be made, since their performance appears to require capability which are beyond the average licensee and his regularly employed personnel. Thus, impedance measurements require the employment of an RF bridge and associated equipment, rather expensive items of equipment which are not found in the typical station's workshop. The performance of the apparently simple DC resistance measurements, aimed at determining the insulation resistance of the sampling line, would require the periodic disconnection of each sampling element from its line, which, in the case of tower mounted loops, necessitates the disruption of carefully waterproofed connections. Moreover, on loops mounted at considerable distances above ground, the operation could be performed only by an experienced tower man, who might have to be retained especially for this purpose. These kinds of considerations generally remove periodic sampling system measurements from the "routine" category. Therefore, while we recommend that an appropriate program of measurements be adopted to establish the initial and continuing integrity of the sampling system, we will not require that such measurements be made.

Other Considerations

49. The loop should be mounted on the tower at a point well removed from lighting conduit. The sampling line, after being equipped with an approved waterproof end terminal or cable connector designed for use with the specific cable employed, and attached to the loop is brought down the tower inside one leg, for mechanical protection, and attached to the tower (by standoff insulators in case the loop is oper-

[6] We have one suggestion that RF impedance be made at three separate frequencies: (1) the station's operating frequency; (2) a frequency at which the impedance is high; and (3) a frequency at which the impedance is low.

ated at ground potential or by clamps electrically bonding the outer conductor to the tower, if loop is at tower potential), at sufficiently close intervals to provide substantial lateral restraint from "whipping" or displacement.

50. In critical installations, it may be desirable to employ Austin ring transformers to feed tower lighting, rather than chokes, since the ring transformer has a lower shunt capacity to ground.

51. Where feasible, the sampling line should be in a single length, without splices or connectors from the point it leaves the loop to its termination near the monitor. Short lengths of more flexible line (such as RG cable) may be used to connect the sampling line to the monitor. Where isolation coils are employed, of course, the line must be broken for its insertion, with waterproof connectors at both ends.

52. The isolation coil should be constructed of the same kind of cable which makes up the sampling line, unjacketed if tuning is to be accomplished by the inductance adjustment. The form on which it is wound should be of such construction as to provide rigid support to the coil.

53. It has been suggested that, in many cases, a better installation results if the cable manufacturer cuts the cable to length and installs the connectors. It is further suggested that isolation coils be fabricated to specifications by the cable supplier. The coil should be supported with its "hot" end well above ground level.

54. The outer conductor of buried cable should be tied to the station ground system at the tower, and at its termination within the transmitter building. Care should be taken to insure that the cable sheath and the monitor enclosure are at the same ground potential.

55. Where the sampling lines must be run above ground from the radiating elements to the transmitter house, grounding of the outer conductor of the cable at intermediate points is necessary. Recommended grounding intervals vary from 20 to 50 feet, according to the preferences of individual engineers.[7] The line must be adequately supported and protected in conduit or raceways. Generally, clamps intended for the purpose should be employed to make electrical connections to the outer conductor, to avoid possible damage to the dielectric by the heat generated in soldering.

Discussion and Decision

56. In the *Notice of Inquiry and Notice of Proposed Rulemaking* which initiated this proceeding, we stated:

> "If it appears, from a study of all comments, reply comments and information submitted in response to this Notice that rules should be established in this matter, and there is a reasonable consensus as to the content of such rules, we may adopt an appropriate Report and Order without other proceedings. Otherwise, a further notice will be issued before final action is taken."

57. In addition to a number of pertinent aspects of the matter set forth in the *Notice* on which discussion was invited, we outlined, in an Appendix, on a tentative basis, what we considered might be the gen-

[7] The approach usually employed is the "brute force" method—to add enough ground connections to preclude the possibility of trouble from ambient fields. We have noted at least one procedure, not described in this proceeding, for determining optimum grounding points—to search along the line, with a field strength meter with the loop held parallel to ground, for "hot spots"—points of standing wave maxima—where grounds should be made.

eral content of rules governing sampling system design and installation.

58. The comments submitted herein, from parties with formidable degrees of expertise in the technical area concerned, responded both directly and indirectly to the Commission's proposals. We have thoroughly considered all comments, and have been able to formulate specific standards which we believe represents a reasonable consensus of the parties.

59. While there is rather general agreement that appropriate standards should be made available, several suggestions were made that they not be embodied in specific rules, but be issued as general guides or standards of good practice. As we stated hereinbefore, it is our belief that guides or standards of this nature remain largely ineffective unless invested with some color of authority, in which case they become *de facto* rules.

60. Thus, having fully considered all aspects of this matter, we are adopting rules setting forth the basic requirements for sampling systems. These rules will appear as a new Section 73.68, and are contained in Appendix C to this document.

61. We have endeavored to include in these rules only those major constructional details which appear essential, and concerning which there is fairly general agreement among the parties to this proceeding. We have incorporated no radical ideas, and believe that many stations with sampling systems which were installed or upgraded in recent years will, without modification, fully meet the requirements we have set forth.

62. While we are convinced that the installation at all stations of sampling systems in accordance with these standards would result in a substantial improvement in the maintenance of radiation patterns within a prescribed limit, with an overall benefit to all stations operating on channels on which directional antennas are employed to limit interstation interference, we are persuaded that, because of the hardship and expense which would be imposed on many stations should we undertake to exact compliance with the rules on a general basis, a more limited approach should be taken. Thus, the rules will have immediate application only to new stations authorized after the effective date of the rules, and to stations authorized to make major changes after that date. Other existing stations will be required to meet the rules only in instances where sampling systems are patently inadequate, or where instabilities in directional operation, which may be attributed in whole or in part to inadequacies in the antenna monitoring system, are evident.

63. Suggestions have been made not infrequently that the rule requiring periodic reading of base currents in the elements of a directional array should be eliminated, on the theory that field ratios determined from these currents are less accurate than those established by loop sampling. Our response to such proposals has been to concede that while antenna monitor ratio indications have the potentiality for greater accuracy than do those determined from base current indications, in the absence of reasonable assurance that samples delivered to the monitor, in fact, consistently and accurately reflect the relative amplitudes of tower currents, we were unwilling to eliminate base currents as the primary source of information for ratio determinations.

64. We believe such reasonable assurance would exist at a station utilizing a sampling system constructed in accordance with the rules we are adopting to feed a type approved antenna monitor. Accordingly, the new rules would provide for the exemption of stations with such monitoring installations from compliance with existing rules requiring the periodic reading and logging of base currents. However, it should be noted that, even in such cases, the amplitudes of base currents should be measured at the time the array is adjusted for proper operation, and submitted for entry into the station authorization. The capability for measuring base currents should be retained to facilitate the measurement of base currents for test purposes, or to permit the reading of these currents during any period the antenna monitor system is inoperative.

65. It also appears that stations with stable and accurate antenna monitoring systems in most cases should be able to maintain proper directional operation with less frequent monitoring point observations than are presently required. In the new rules, therefore, we are prescribing a less demanding schedule for these measurements for stations whose antenna monitoring systems meet the requirements of the rules.

66. When the antenna monitoring system is out of service due to a temporary defect, it is appropriate that alternative measurement procedures be utilized pending repair to insure that the directional antenna is functioning substantially as licensed. Section 73.69(b) of the Rules specifies the procedures to be followed when the antenna monitor is out of service for maintenance. Since a stable and properly functioning sampling system is essential to obtaining valid monitor indications, the same alternative measurement procedures should be used whenever the sampling system is out of service for minor maintenance. The rules are amended to so specify.

67. When the sampling system is being completely overhauled or components mounted on or in the vicinity of antenna towers are being replaced, it generally is not possible to maintain base current ratios, or the field strength values at monitoring points as licensed. Prior to beginning repairs affecting the antenna operating parameter, authority to operate the antenna system at variance with the license terms should be obtained, and the indirect method of determining operating power ultilized during the repair period. At the completion of a partial or complete replacement of the sample system, it is necessary to reestablish that the radiation pattern remains in adjustment. This is accomplished by conducting a partial proof of performance. A request for modification of license is to be submitted to the Commission with the measurement results and operating data obtained after overhaul of the sampling system is completed. These procedures are prescribed in the amended rules.

68. Accordingly, IT IS ORDERED, That effective March 18, 1976, Part 73 of the Commission's Rules and Regulations IS AMENDED as set forth in Appendix C.

69. Authority for the adoption of these rule amendments is found in Sections 4(i) and 303(r) of the Communications Act of 1934, as amended.

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70. IT IS FURTHER ORDERED, That this proceeding IS TERMINATED.

FEDERAL COMMUNICATIONS COMMISSION,
VINCENT J. MULLINS, *Secretary*.

APPENDIX A

1. Sampling lines:
   a. All sampling lines shall be of equal total lengths with equal portions of the lines subject to the same environmental conditions.
   b. All sampling lines shall have solid outer conductors with air/polyethylene dielectric so proportioned as to produce a minimum phase temperature coefficient.
   c. All sampling lines shall have identical electrical characteristics.
   d. Those portions of sampling lines between the towers and the transmitter house preferably should be buried. If run above ground, the lines shall be rigidly supported and positioned. Outer conductors shall be grounded at points necessary to insure that fields from the array will not induce error currents in the lines.
2. Sampling elements:
   a. Sampling elements shall be single turn, untuned, unshielded loops of rigid construction, with ample gaps at the terminals, solidly supported by nonhygroscopic insulators.
   b. Each sampling loop shall be oriented with the plane of the loop including the vertical centerline of the tower, and shall be rigidly mounted on the tower in this orientation. The center conductor of the transmission line shall be connected to the side of the loop nearest the tower.
   c. All loops shall be of the same size and shape and of identical construction, and shall be located at the same height on each tower (if the towers are of equal height) at a point close to the current maximum in the tower, but in no case less than 10 feet above ground level.
   d. For a tower of less than 1/4 wavelength in height, current samples may be obtained from the transmission line, as close to the base of the tower as possible, by a current transformer or other coupling element.

APPENDIX B

Comments

Merl Saxon, Consulting Radio Engineer
Robert Laughlin, CE, KWK
Silliman, Moffet and Kowalski (SMIC)
Sparta Electronic Corp.
Paul Godley Co.
A. Earl Cullum, Jr. & Associates (AEC)
Alan Craft, CE, KWDN
Annapolis Broadcasting Corp. (WANN)
Storer Broadcasting Co.
Potomac Instruments, Inc. (PI)
Scotts Bluff Broadcasting Corp. (KNEB)
S. & S. Broadcasting, Inc. (WTAQ)
Charles Vernon Berlin, CE, KSCO
J.G. Rountree, Counsulting Engineer
Hammett & Edison, Consulting Engineer
Valley Broadcasting Co. (KCLN)
Terrell W. Kirksey, Consulting Engineer
Benjamin F. Dawson III, Consulting Engineer
J.B. Hatfield, Consulting Radio Engineer
National Association of Broadcasters (NAB)
Clear Channel Broadcasting Service
Jansky & Bailey Telecommunications Consulting Dept.
Gautney & Jones, Consulting Radio Engineers
Frank S. Colligan
Lin Broadcasting Corp.
Association of Federal Communications Consulting Engineers (AFCCE)
Lohnes & Culver, Consulting Radio Engineers
Westinghouse Broadcasting Co., Inc.

Association for Broadcast Engineering Standards, Inc. (ABES)
Emerald Broadcasting Co. (KTHO)
Delta Electronics
Robert A. Jones, R.P.E.
Summit Radio Corporation, Group I Broadcasting Co., Inc. and Lake Huron Broadcasting Corporation

Reply Comments

Frank S. Colligan
Association for Broadcast Engineering Standards, Inc. (ABES)
Association of Federal Communications Consulting Engineers (AFCCE)

APPENDIX C

New Section 73.68 is added, to read as follows:

§ 73.68 Sampling systems for antenna (phase) monitors.

(a) The following requirements shall govern the installation of systems employed to extract samples of the currents flowing in the elements of a directional antenna, and to deliver these samples to the antenna monitor. After March 18, 1976, each new station issued a construction permit, each existing station issued a construction permit authorizing tower construction, and any existing station undertaking modification or reconstruction of its sampling system shall install a system meeting these requirements. The application for license or modification of license shall describe the system in sufficient detail to demonstrate its compliance therewith. In an instance where the sampling system of an existing station authorized before this date is patently of marginal construction, or where the performance of a directional antenna is found to be unsatisfactory, and this deficiency reasonably may be attributed, in whole or in part, to inadequacies in the antenna monitoring system, the Commission may require the reconstruction of the sampling system in accordance with these requirements.

(1) All coaxial cable from the sampling elements to the antenna monitor, including cable used in the construction of isolation coils, except short lengths of flexible cable connecting the transmitter house sampling line termination to the monitor, shall have a solid outer conductor and have uniform physical and electrical characteristics. The dielectric shall either be predominantly pressurized air or other inert gas, or foamed polyethylene. All sampling lines for a critical antenna array (i.e., an array for which the station authorization requires the maintenance of phase and current relationships within specified tolerances) shall be of the same electrical length with corresponding lengths of all lines exposed to equivalent environmental conditions. For other arrays, lines of differing lengths may be employed, provided that the difference in length between the longest and shortest lines is not so great that, over the range of temperatures to which the system is exposed, predicted errors in indicated phase difference resulting from such temperature changes will exceed 0.5 degree. All sampling line mounted on a tower shall be adequately supported to prevent displacement, and shall be protected against physical damage. Where feasible, sampling line sections between each tower base and the transmitter house shall be jacketed and buried; lines run above ground shall be firmly supported, and protected against physical damage, with the outer conductor strapped to the station's ground system at such points as found necessary to minimize currents induced by antenna radiation. All necessary connections, and outdoor cable terminations shall be made with waterproof fittings, designed for use with the type of cable employed.

(2) Sampling elements shall be single turn, unshielded loops of extremely rigid construction, with ample, firmly positioned gaps at the open loop end, mounted on towers at a fixed orientation, provided that, for uniform cross section towers of 110 degrees or less in electrical height, adequately shielded current transformers may be used to extract samples from the antenna feed line at each tower base. Loops shall be installed to operate at tower potential, provided that, for towers of less than 130 degrees in electrical height, loops operating at ground potential may be employed. Generally, each loop should be mounted on the tower near the point of maximum tower current, but in no case less than 10 feet above ground.

(b) Each license or modified license issued pursuant to an application containing a satisfactory showing that a sampling system has been constructed complying with the requirements set forth in subparagraphs (1) and (2) of paragraph (a) of this section, and that an antenna monitor of a make and type approved by the Commission has been installed, will be conditioned to exempt the licensee from compliance with rules which require:

(1) The routine reading and logging of base currents in the array elements.

(2) That monitoring point measurements be made more frequently than at average monthly intervals.

(c) Any existing station utilizing a type approved antenna monitor, and whose antenna monitoring system meets the specifications of subparagraphs (1) and (2) of paragraph (a) of this section, which desires to take advantage of the relaxation of logging and measurement requirements offered in paragraph (b), may file an informal request with the Commission in Washington signed by an officer of the licensee, describing the characteristics of the system in sufficient detail to demonstrate its compliance with subparagraphs (1) and (2).

(d) In the event the antenna monitor sampling system is temporarily out of service, the station may be operated without logging the monitor indications pending completion of repairs for a period not exceeding 60 days without further authority from the Commission, provided that:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the sampling system was removed from and restored to service.

(2) If remote base current indications are not available at the transmitter control position, base currents shall be read and logged at least once each day for each mode of directional operation.

(3) Field strength measurements at each monitoring point specified in the station's authorization shall be read and logged at least once every seven (7) days.

(4) If the station is operated by remote control and phase indications are read and logged at the remote control point, indicating instruments at the transmitter shall be read and logged at the time specified in § 73.114(a)(9)(ii).

(e) If the antenna sampling system is modified or components of the sampling system are replaced, the following procedure shall be followed:

(1) Temporary authority shall be requested and obtained from the Commission in Washington to operate with parameters at variance with licensed values pending issuance of a modified license specifying parameters subsequent to modification or replacement of components.

(2) Immediately prior to modification or replacement of components of the sampling system not on the towers, and after a verification that all monitoring point values, base current ratios and operating parameters are within the limits or tolerances specified in the instrument of authorization or the pertinent rules, the following indications shall be read and recorded in the maintenance log for each radiation pattern: Final plate current and plate voltage, common point current, base currents and their ratios, antenna monitor phase and current indications, and the field strength at each monitoring point. Subsequent to these modifications or changes the above procedure shall be repeated.

(3) If that portion of the sampling system above the base of the towers is modified or components replaced, a partial proof of performance shall be executed subsequent to these changes consisting of at least 10 field strength measurements on each of the radials established in the latest complete proof of performance of the antenna system. These measurements shall be made at locations, all within 2 to 10 miles from the antenna, which were utilized in such proof, including, on each radial, the location, if any, designated as a monitoring point in the station authorization. Measurements shall be analyzed in the manner prescribed in § 73.186. The partial proof of performance shall be accompanied by common point impedance measurements made in accordance with § 73.54.

(4) Request for modification of license shall be submitted to the Commission in Washington, D.C., within 30 days of the date of sampling system modification or replacement. Such request shall specify the transmitter plate voltage, and plate current, common point current, base currents and their ratios, antenna monitor phase and current indications, and all other data obtained pursuant to this paragraph (e).