Standards and the Microwave Profession

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THE KEYNOTE of the 1962 PGMTT Symposium was the reciprocal dependence between the National Bureau of Standards and the microwave profession. The fact that the Symposium was held at the NBS Boulder Laboratories symbolized our mutual interest. I would like to analyze this relationship and suggest the mutual benefits to be gained by fostering it.

Consider first the size of the microwave industry. Exact figures are not available nor are they necessary to the argument, but we know that there are three to four hundred companies engaged in the manufacture and sale of microwave components, instruments and systems. Their annual product is about one and a half billion dollars. This microwave industry probably represents about 15 per cent of the total electronic industry, the annual product of which is roughly 11 billion dollars. The industry is growing several times faster than the gross national product.

The National Bureau of Standards is responsible for providing the standards and criteria for accurate, uniform, and consistent measurements for this great domestic industry, to achieve the dissemination of these standards, and to assure their proper international coordination.

In electronics its effort consists of the work of the Radio Standards Laboratory in Boulder and the Electricity and Instrumentation Divisions in Washington—an aggregate of about seven million dollars per year and 520 people. Of this effort, that devoted to microwave work can be identified as an aggregate of about two million dollars per year and about 70 people. Our budget is thus minute in comparison to the product of the industry.

Yet, by definition and by law, we are the ultimate arbiter of proper measurements. Because of this distinction, by no means an unmixed blessing to our staff, whatever competence or lack of competence we have will exert a powerful leverage throughout the industry which is quite out of proportion to the absolute number of dollars spent and people employed. This imbalance between size and responsibility emphasizes the care we must take in determining how our own dollars will be spent, and suggests immediately that intimate rapport with the profession is a must.

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Another imperative for the careful use of NBS resources is that the development of a standard is not a self-contained event, nor is it even the total extent of our responsibilities—there is more to the standards structure than just building a device. To do our job, we must achieve mastery of the principles upon which the standards rest. We must do research first to facilitate the adaption of new physical principles as improved bases of old standards and second to acquire the skill in new fields to create standards where none existed before. We must continually develop and evaluate the standards. We must then make them available to all who need them, including the standards organizations of other countries. In each of these phases of the job, NBS must again be in intimate contact with the profession.

The complexity is illustrated by the development of our present standard of microwave power. The ideas behind this standard—a calorimetric determination of the response of a bolometer mount—were formulated in 1952 by members of the Radio Standards Laboratory. Its present accuracy of 0.2 per cent at 10,000 Mc was achieved only through careful analysis, experimentation, and development. It also required parallel development of standards for other quantities such as impedance and attenuation. The first calibration service of microwave power on a routine basis was offered by NBS in 1958. Now microwave power calibrations are provided to industry and the military by the Radio Standards Laboratory in X-band from 100 μw to 100 mw, and these services will shortly be extended to other frequencies. During the past two years the standard has been internationally compared with standards of the United Kingdom and of Japan on several separate occasions. Toward the development of better standards in the future, some research has been done on the acceleration of an electron beam by a microwave field as a possible standard of power. Some thought has been given to the observation of radiation pressure in a high Q cavity or Fabry-Perot resonator, to the broadening or saturation of certain molecular resonances, and to the possibilities of the Hall effect, although we have not been able to begin experimental investigation of these topics. In the meantime, coherent power generators have arisen at infrared and optical frequencies which will shortly demand power standardization.

If the foregoing is sufficient to establish an intimate relationship between the microwave profession and the

National Bureau of Standards, we may then ask what benefits arise by recognizing and fostering a reciprocity of effort.

One basic question we both face is whether your profession is receiving adequate service from NBS so that you can make measurements of the accuracy and uniformity you require. We presently base our judgments of what is needed upon our experience, from reading the literature, and from our personal contact with other members of the profession. This knowledge is necessarily limited. What we need in addition is strong, thoughtful, and over-all feedback from the profession. Just as NBS has the responsibility to provide the profession with standards, so the profession has a reciprocal responsibility to make its needs for measurement standardization clearly known to us.

For example, in many areas, the profession seems to be doing fairly well in advancing the state of the art with only infinitesimal assists from standards of measurement. Can you indeed get along pretty well without reference to absolute standards? Can you often use relative measurements, or theory, or just plain ingenuity, to circumvent the absence of standards? Can you still make good progress with 10 per cent, 20 per cent accuracy? If so, it is our business to be aware of these areas.

On the other hand, NBS is capable of making many highly accurate measurements. We can measure microwave attenuation to a ten thousandth of a db if pressed. Is that good enough for you? Or do you have to have it to a hundred thousandth, and if so, please, why? We can measure microwave frequencies to a part in 10^{11}. We can measure the temperature of a noise source to a few hundredths of a db. We can measure reflection coefficient to 0.001. Are these good enough? If not, why not? Or do any of these capabilities go the other way and exceed all reasonable requirements? You see, it must be our business to know both sides of the accuracy question.

We do not offer a measurement service for microwave phase shift, but we could. How badly do you need it? We could have standards for microwave antenna gain in 18 months. How bad is the need? What do you need in the way of reflection and transmission properties of nonconventional waveguides? What ferrite properties do you have to know and how well? It is our business also to know what wants still go unsatisfied.

A second basic question is the necessity of NBS to optimize its effort—small compared with the vast size of the industry—so that it best matches your wants. Since we cannot be all things to all people, we postulate a reciprocal responsibility of the profession to provide information which assists us in this optimization.

The techniques for optimizing the NBS program are twofold. First we must identify that minimal set of quantities, frequencies, magnitudes, and accuracies which are of fundamental importance or convenience in allowing sufficiently accurate measurements of all other quantities to be derived. As an obvious example, it is in principle unnecessary to provide a separate power standard at 10 watts if a standard of power at 10 mw and also a standard of attenuation of 30 db exist. Second, in our goals we must mingle realism with perfection; we assign priorities in order to concentrate effort at the top of the list and to avoid the pursuit of accuracy for accuracy's sake. You can see that we must continually check with the profession as to the composition of our minimal set and as to the priorities involved.

A third benefit from tight reciprocal contact with the industry is that we learn what new developments are important so we can respond to those developments. For example, we naturally are now concerned with ferrites, parametric amplifiers, millimeter waves, masers, and lasers. In the near future, pending advice from the profession, we may well be concerned with the characteristics of cryogenic microwave devices and with phenomena involving microwave phonons.

Still another reciprocal benefit is the opportunity to arrive at an orderly state of the definition and usage of microwave quantities. Take, for example, noise factor. There have been conflicting definitions in the use of noise factor ever since it was first conceived. Or take insertion loss, which numerically means different things depending upon the various conditions of match at the generator and load sides of the reference planes. Improvement here would be welcomed by all.

I have previously alluded to the international responsibilities of NBS. These are particularly apparent in connection with the Consultative Committee on International Radio (CCIR) and the International Scientific Radio Union (URSI). These bodies are concerned with reaching as close an agreement as possible in the various radio measurements, and in recommending areas of emphasis to the various participating countries. The NBS is also interested in a possible extension of the work of the International Bureau of Weights and Measures into the radio field. That international bureau devotes itself now chiefly to mass, length, temperature, dc electrical quantities and ionizing radiation. Extension of its interest to the field of radio quantities would be a major international innovation. The NBS is also presently collaborating toward a new definition of the unit of time in terms of atomic standards. As the profession gains by NBS contributions to international uniformity of measurement and international exchange of information, so also the international responsibilities of NBS would be aided by increased professional involvement.

As to specific recommendations, at the very least, I believe that the problem of the quantities, the ranges of frequency and magnitude, and the accuracies that are to receive our attention is one requiring collective ac-

tion. Since the IRE Professional Group on Microwave Theory and Techniques is an organization highly representative of, and responsive to, the affairs of the microwave electronics profession, I have approached this group with the following proposal:

> That the IRE Professional Group on Microwave Theory and Techniques establish a Microwave Measurement Survey Group (or equivalent) with the continuing duty of evaluating and reporting on the state of the art in microwave measurements. Attention should be given especially to the microwave quantities in use, their ranges of magnitudes and frequencies, and the accuracies dealt with. Estimates as to various classes (*i.e.*, research, developmental, industrial) and relative extent of use both now and in identifiable future trends should be made.

This activity can be a useful report to the profession itself in summarizing and publicizing its own ability to make measurements, and a good index of technical progress from year to year.

As to conformity of definition and usage, the noise factor clinic held by PGMTT at its 1961 symposium was an excellent step. I hope this problem is further pursued, and I suggest that a suitable topic for another clinic may be insertion loss and related quantities. As to international activity in microwaves, PGMTT has effectively used and can continue to use its own journal and allied publications to report international developments in microwave theory and techniques, frequency standards, measurements of physical constants by microwave methods, and the status of agreement among the various national standards.

In summary, there exists a mutual dependence between the profession and NBS. We must rely upon you for important feedback information to help govern our activities and to better meet our national and international responsibilities. In turn, you, the profession, have to rely on us when your measurements must be accurate and uniform rather than semiquantitative and relative. The 1962 National Symposium was therefore a happy event in bringing together the microwave profession and the National Bureau of Standards.