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THE STATUS OF MICROWAVE INTERFEROMETRY

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THE STATUS OF MICROWAVE INTERFEROMETRY

Part I

From an earlier demonstration in 1959 of a 35 gigacycle microwave-measuring system, considerable progress has been made in many areas. Mention will be made today of one area: in particular, the solid-block construction eliminating wave guides in the open air. With a first introduction to microwave equipment, it was not uncommon to see long and various shaped wave guides. Wave guides are defined as the medium through which microwaves can travel, often referred to in microwave jargon as "plumbing."

Figure 1 will show a proposed concept of a prototype microwave interferometer and I would like to point out that the prime considerations were concerned with a gage for measuring roundness.

If you will observe closely, you will see a dial indicator mounted on the top. This was used as a reference for calibration. In front and toward the viewer is a null meter to indicate the position of the wave pattern. At the rear of the gunlike microwave device is another null meter for tuning purposes.

Figure 1A will show a comparison being made between microwaves and a standard feather-touch indicator using micrometrical-roundness measuring and recording equipment. The comparison data are shown in Figure 2.

In Figure 3 is shown some of the methods for use of the prototype device in the shop. Please note that the use of machine screw and slides were thought of as some standard to compare, using the graduations on the machine slide as reference.

The microwave-measuring device can also be used for determining coating thickness on metal, paint, plastics, porcelain, rubber, etc., or any such dialectic materials. A logic diagram, Figure 4, shows the first concept for the circuitry of a 35Gc microwave-measuring system.

Thermal coefficients of expansion were one of the new problems to be considered. Perhaps the word "new" seems misleading, but in truth, this problem was once completely ignored and not considered, mainly because such accuracy as we now talk about and work with cannot tolerate the smallest fraction of a degree without a complete loss of integrity in a measurement.

Long-term stability in electronic components is another problem. Solid state electronics however are bringing this problem back within reach of some goals. As usual, heat and cold have effects that are sometimes quite obvious and other times not so obvious.

To bring the present state of the art of Microwave Interferometry up to date, let us examine the features inherent, both good and bad.

A logic diagram of the circuit is given in Figure 5. The microwave interferometer includes crystal detectors, circulators, difference transformer, and a 100 kilocycle generator.

The transmission cavity determines frequency of input pulse to first hybrid junction. We can orientate the components given in Figure 6 by comparing the picture with the logic diagram.

Basically, the microwave interferometer consists of five parts: a radio-frequency signal source, phase comparator, transmitting and receiving antenna, and a reference path and micrometer-driven phase shifter.

Figure 7 shows the reference path. This is the standard against which are measured phase changes along the path between the source and the target and then back to the phase discriminator. The phase change depends upon the targets position; therefore the interferometer can sense and measure small movements of the target.

The phase shifter was intended to provide a method for calibration of the instrument. It was thought that the motion of the target in microinches could then be read out visually on the meter.

The operator would use the shifter, which is a variable short circuit, acting electrically as the target to alter the incoming signal to correspond to a change in the distance to the target.

The phase shifter is actuated by a micrometer which indicates in divisions of 0.001 or 100 microinches. Allowance must be made for the different phase velocity of the microwave signal in air, as compared with that within the waveguides. The constant, k , is a fixed value dependent on frequency. At 35Gc, k is 1.2525. Since the phase velocity is faster within the wave guide by this factor, adjustment of the phase shifter will proceed faster than adjustment of the head-target distance (air) by a factor of k . This must be considered whenever a measurement is made by adjustment of the phase-shifter micrometer.

The function of the crystal controlled 100kc sawtooth generator is to sweep the 35Gc klystron. Thus stabilization is achieved across the resonance of a transmission cavity. The input to the first hybrid junction therefore is a narrow pulse whose frequency can be determined entirely by the transmission cavity.

Frequency stability is of course, an important factor when measuring to such close tolerances. The refinements of this unit represent the advanced state of the art to date in microwave interferometry.

Perhaps it would be helpful to numerate what advancements are known to date:

1. The interferometer sensing-head construction that eliminates open wave guides. Figure 8 shows the construction and the reason why the wave guides are mechanically and electrically equal, since they are milled out of a solid block of special invar.
2. The klystron is attached to the input port by an especially designed wave guide that is a poor heat conductor.
3. The free-space antenna is directly fastened to the sensing head, also the close proximity antennae are mounted the same way. Refer to Figure 9 and 10.
4. New designs in klystrons give long life, and a reliable source of 35Gc in microwaves.
5. Advanced circuit design that gives frequency stability, low electronic noise, and a minimum of long-term drifting.

Part II

Principles and Applications

Perhaps a short description of the principles in circuitry and the resolution for periodic displacements would be in order.

The resolution for fixed targets; i.e., targets varying at displacement rates up to about 10 cycles per second is 10 microinches. For displacement frequencies between 10 and 100 cps, the resolution is less than 10 microinches. For displacement frequencies between 100 cps and 20 kilocycles per second, the resolution is one microinch provided that suitable band-pass filtering is used to narrow the band width around the frequency of interest.

We have found the long-term stability of the instrument to be about 10 microinches.

There is much to be learned about the instrument's linearity and dynamic range. However, I could quote from the specifications, although it will be quite obvious later in this paper that we have not proven the data. It is the intention of the group in charge of this project to find the answer which we believe to be in the design of antennae. The specifications given to us for output voltage versus displacement characteristics are essentially sinusoidal having a period equivalent to 0.17 inches of displacement. The output characteristic is linear within 1 percent over a displacement range of 0.016 inches, and is linear within 10 percent over a range of about 0.048 inches. The total useful dynamic range without resetting the standard phase shifter is about 0.080 inches.

The perfect wave form shown here (Figure 11) is of course, the perfect theoretical formula, but generally not found this way in practice. Good examples are illustrated in the next two slides. The first one (Figure 12) shows the experimental set up used to obtain the graph.

Note the large thimble of the micrometer is driven by a small motor. The micrometer head operates a limit switch that reverses the motion at the end of its 0.750 inches of travel. Note also that we are using the open-end standard wave guide for 35Gc frequency.

On the slide of the graph in Figure 13, one can observe that as the micrometer-phase shifter is moved in increments of 0.010 inches, each overlaying sinusoidal wave shows a change in linearity; a small amount by the slope of the line from each wave length to the other, and one wave length being equal to 0.3372 inches in air to the other. Note the gradual loss of signal strength also as the micrometer

anvil is moved away from the wave guide. As you will note, the total travel recorded is 0.750 inches.

The close proximity antenna, of course, is made for a much closer look at its object. Stand-off distances not more than 0.003 inches are standard practice. Perhaps it should be mentioned that the wave guide is a very small, coaxial copper-shielded cable 0.020 inches in diameter.

Figure 14 shows an antenna tipped with Teflon plastic being evaluated. It had a resolution of 10 microinches, a diameter of 0.250 inches, and a range of 0.050 inches. With this arrangement, it is possible to check the radial motion of a part. However, the large spot diameter makes it impossible to accurately measure scratches, but at a sacrifice of range, linearity and displacement from the target.

The free-space antenna has a focal length of 22.8 inches from the bottom of the dish. The zone of influence is about 0.250 inches at that distance. There are some side effects however from any object that might move close to the zone of influence.

There are many applications for the microwave interferometer; some are of the usual everyday type, whereas others can be considerably complex and different.

A few examples of the ordinary applications would be of interest no doubt; for example, the detection of surface finish and roundness, as shown in figure 15 on a Moore-Measuring Machine. Vibration analysis of machine tools; grinding wheels; and spindle motions are shown in Figure 16 on a Cincinnati Monoset.

Another view of the microwave unit being used to measure vibration is seen in Figure 17. This setup is at right angles to the spindle. Of course, measuring vibrations in

either case is not all that can be done at one time, since radial motion of the spindle can be measured at that particular point. In Figure 16, we are looking at the end of the spindle. Therefore axial motion of the spindle could be detected, also any fundamental vibration frequencies.

One example of interest is that all these motions could be observed through glass, plastic, or ceramics. Materials with metal bonds or metal would be the only limiting factor.

Measuring thermal expansion of hot materials or even measuring and recording vibration displacements and frequencies under inaccessible or dangerous environments is quite possible and practical. The use of the microwave interferometer, combined with a good oscilloscope, will cover frequencies of vibration that are often out of the range of the best accelerometer.

A special project to investigate, possibly one especially adapted for microwaves, is some shock work requiring accelerations of 10,000 to 50,000 g's or higher. It is extremely difficult to obtain a platform subjected to these extremely high accelerations and to know the exact acceleration level at every instant. It is thought that a dual-beam scope could be used with one beam showing displacement. Mechanically, the system would consist of a pendulum-type system with the accelerometer attached to the pendulum and the microwave target at the back of the pendulum. It would be necessary to differentiate graphically or electrically twice in order to obtain the acceleration. The pendulum would be activated by means of a fast moving hammer or second pendulum striking the first pendulum at the center of percussion. This is only at the idea stage and has not been done yet. No method is known at present to do this calibration work.

Part III

Problem Areas in Need of Further Research and Development

Discussed has been the state of the art of microwave interferometry in the current stage^{and} for new applications. Areas that need further development are given for consideration:

1. The graphs illustrated here show certain conditions of nonlinearity that must be resolved.
2. The use of the phase-shifting micrometer as a standard calibration and measuring device would be sufficient if the divisions were divided into increments of 0.000010 inches. Added to this is the problem that the micrometer does not read directly in comparable proportional readings, but a k-factor of 1.2525 must be applied for every measurement taken. Work is being done now in this area to find solutions to the problem.
3. Research and development is required in antenna design, especially at very close range with frequencies from 35Gc to 120Gc's
4. Research to control the zone of influence and confine it to a considerably smaller area.
5. Solid-state circuitry for the entire electronic system.
6. Find if possible, a new source of microwave energy to reduce or eliminate the last source of heat.

ILLUSTRATIONS TO ACCOMPANY

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Figures 1 through Figure 17
(Pages 11 through 19)

Fig. 1

Fig. 1A

Fig. 2

Fig. 3

Figure 1 - Block Diagram of Engineering Prototype Model of Microwave Interferometer

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Figure 2 - Microwave Interferometer Output Voltage

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17