Letters to the Editor

Microwave Frequency Dividers

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IN order to extend the range of application of microwave techniques it is becoming more and more important to be able to carry out the operation of frequency division in the microwave region just as at lower frequencies. Such needs are felt, particularly, in connection with spectroscopic or atomic clocks and frequency standards which usually use spectrum lines in the neighborhood of 3000–20,000 Mc or higher.[1] It is therefore necessary to look for a frequency division principle which uses components and techniques that are practicable in the microwave range.[2]

One could inject a signal to be divided into an oscillator operating at a sub-multiple of the injected frequency and lock it in.[3] This well-known principle has obvious disadvantages. If control is lost the lower frequency oscillator will run free. A frequency divider which avoids this difficulty and which is widely used at low frequencies, e.g., in precision quartz-crystal clocks, is the regenerative modulator type.[4] This circuit also works well even in the presence of high noise levels and distorted input signals. It can be designed so that the output will be linearly dependent on the input and maintain a constant phase angle with respect to it. It can generate both sub-multiple and other fractional frequency ratios. Such a circuit to divide down from 9300 Mc to 3100 Mc has been built and tested.[5] A block diagram is shown in Fig. 1. Here it is seen that the 9300 Mc signal is applied to a mixer; to the mixer is also applied a signal at 6200 Mc. This may be a noise component or transient generated by turning the circuit on. The 6200 Mc signal beats with the 9300 Mc input signal to give an output of 3100 Mc. This is amplified by means of the Sperry 2K35 klystron amplifier tubes, and then fed to a Sperry 2K46 klystron multiplier which is tuned to double the input signal to 6200 Mc. After multiplication the signal is amplified at 6200 Mc by means of a Sperry SAC-19 klystron amplifier and fed back to the mixer. If the gain around the feedback loop is great enough, the output signal at 3100 Mc will be maintained independently of the phase shift in the feedback loop. No output will appear unless there is an input signal since the 3100 Mc beat note can only be obtained in this way. If the gain is not high enough in the regenerative circuit it may be necessary to start the operation by injecting some sort of transient. In the circuit shown this was not necessary. Since no attempt was made in this first circuit to design a very efficient mixer, it may not be necessary to use all of the amplification shown in Fig. 1. In principle, the 2K46 frequency multiplier could be replaced by any nonlinear modulator device, such as a crystal rectifier if enough gain were available and the signal level high enough.

Among numerous tests conducted, the input, intermediate, and output frequencies were measured and found to track each other and it was also shown by the insertion of wave-guide filters that no other output signals were present except those in the 3000 Mc range. The output signal was taken from the middle cavity of one of the 2K35 tubes. A definitive test of the accuracy of frequency division was made as follows. The 9300 Mc input signal was fed to a spectrum analyzer where it was viewed on the scope as a pip. The output signal was monitored by means of a frequency meter and second spectrum analyzer. In addition it was fed to a crystal multiplier which multiplied by three and then fed to the same spectrum analyzer as the input frequency. If the output frequency times three is exactly equal to the input frequency, the two pips on the scope should coincide. The two individual pips could be identified by first displaying one and then the other by control of their intensities by means of attenuators. When the two pips were superimposed they blended smoothly into one larger pip; this was done under conditions of highest dispersion in the spectrum analyzer. No beating of the two signals whatsoever could be discerned nor any shift or change in shape of the pulses. If it is assumed rather arbitrarily that a beat note of approximately one cycle per second could be observed, this means that the output frequency times three was equal to the input frequency with an accuracy of at least one part in 10^{10}. In this type of test no difficulty results if the input-oscillator-frequency slowly drifts back and forth since the output frequency drifts with it. It is clear that direct frequency calibrations of extreme accuracy would be necessary to obtain a test with the sensitivity of the one just described.

Since another klystron multiplier tube, the Sperry 2K47, is commercially available and multiplies from approximately 270 Mc up to the 3000 Mc range, frequency dividers could be built to go down to as low a frequency as desired. It is important to note that in this type of circuit it is not necessary to have amplifiers available at the input frequency but only at a lower frequency, essentially a divided frequency. Since klystron multipliers are very efficient and much easier to make than amplifiers, a multiplier tube and frequency divider dividing down from the 24,000 Mc region, rich in spectrum lines, should be possible.

Since amplifiers in this type of circuit are only needed at the divided frequency, some interesting possibilities are opened up by consideration of circuits of the type shown in Fig. 2. In this circuit we make the regenerative-modulator divider provide its own input by providing a second regenerative channel. In this case, if there is enough gain, the circuit should oscillate and divide in frequency at the same time. A more general arrangement allowing more flexibility in the choice of frequencies which can be used with any given set of tubes is shown in Fig. 3. Figures 2 and 3 show a proposed application to an atomic oscillator and atomic clock.[5] Here by atomic oscillator we mean a self-excited or feedback oscillator, the frequency of which is directly controlled by an absorption cell. This is in contra-distinction to the stabilized servo mechanism or frequency discriminator type of spectrum-line controlled oscillators.[1,6] To make an atomic clock it is then necessary to divide down by means of straight frequency division from the atomic oscillator to a frequency low enough to drive the usual synchronous motor type of clock. Two types of atomic oscillators in which the

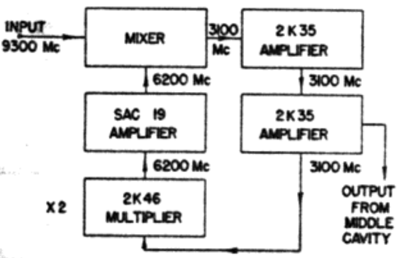

FIG. 1. Microwave regenerative modulator frequency divider, dividing 3 to 1.

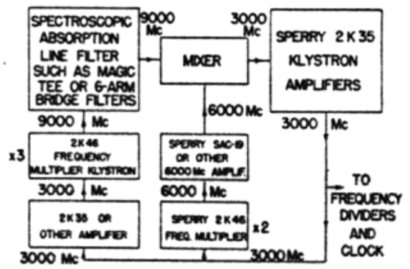

FIG. 2. Proposed combination atomic oscillator and frequency divider, using amplifiers at divided frequencies, applied to an atomic clock.

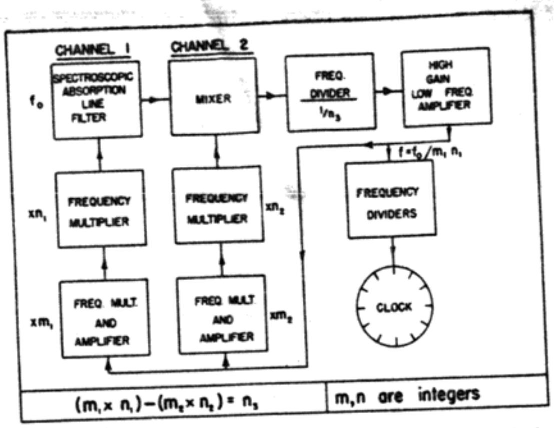

FIG. 3. General and more flexible block diagram of atomic clock using combination oscillator and divider.

feedback frequency is controlled by means of spectroscopic circuits have been described.[1,2,5] Here the spectroscopic filter is based on the use of a magic-tee or a six-arm, wave-guide Wheatstone bridge in which an absorption cell containing ammonia or other absorbing gas at low pressure determines the frequency which will be transmitted by the filter. As shown in Fig. 3, this spectroscopic filter transmits an input frequency to the regenerative modulator only at the frequency of the spectrum line used in the filter. This, therefore, controls the frequency of the oscillator and similarly that of the divided frequency. However, as compared to the atomic oscillators previously described, in this method not only is frequency division carried on simultaneously with controlled oscillation, but an amplifier at the spectrum line frequency is no longer needed.

Although it is very desirable to go back up to the 3,3 line of ammonia at approximately 24,000 Mc, and we are attempting development and procurement of suitable multiplier and amplifier tubes for this purpose, an atomic clock could be developed using a spectrum line in the 9000 Mc range using available amplifier and multiplier tubes and the circuit shown in Fig. 2. For this purpose the various deuterated species of ammonia were prepared and spectrum lines searched for in order to provide a strong absorption line at a lower frequency. Although this work is still incomplete, about 30 lines have been found in the range between 3000 and 10,000 Mc.[5] Such spectrum lines can be used to make a clock following the circuit shown in Fig. 2 or simply used in a separate atomic oscillator driving a frequency divider.

[1] "The Atomic Clock, an Atomic Standard of Frequency and Time," NBS Technical News Bulletin **33**, (February, 1949). Also, Harold Lyons, Phys. Rev. **74**, 1203 (1948).

[2] "Microwave spectroscopic frequency and time standards," Harold Lyons, presented at the AIEE-IRE-NBS Conference on High Frequency Measurements, Washington, D. C., January, 1949. Also, Electrical Engineering **68**, 251 (1949).

[3] E. Norrman, Proc. I.R.E. **34**, 799 (1946).

[4] R. L. Miller, Proc. I.R.E. **27**, 446 (1939). Also, W. A. Morrison, Bur. Stand. Tech. J. **27**, 510 (1948).

[5] Harold Lyons, Phys. Rev. **76**, 161 (1949).

[6] a. Chaffee, Fletcher and Cooke, Harvard University Progress Reports on Contract N5-ORI-76, 1947–1949. b. R. V. Pound, Rev. Sci. Inst. **17**, 490 (1946); Smith, DeQuevedo, Carter, and Bennett, J. App. Phys. **18**, 1112 (1947); DeQuevedo and Smith, J. App. Phys. **19**, 831 (1948); c. W. D. Hershberger and L. E. Norton, RCA Rev. **9**, 38 (1948). d. C. H. Townes, A. N. Holden, and F. R. Merritt, Phys. Rev. **74**, 1113 (1948).

Particle Size of Evaporated Gold

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MANY observers have noted that the gold on shadowed electron micrographs granulates when exposed to an intense beam of electrons. It has been generally assumed that before electron bombardment, the gold was a smooth continuous film. Picard and Duffendack[1] published micrographs of gold evaporated at 10^{-6} mm pressure in which the gold appeared as discreet particles. From work[2] we have done on correlating electrical resistance properties of gold with microstructure, we believe that such is generally the condition of evaporated gold except when contaminated by the presence of tungstic oxide. In the usual bell jar conditions for gold shadowing electron micrographs at about 10^{-3} mm pressure, the deposit contained about five percent tungsten by analysis. This gave a characteristic matte background which was observed no matter how careful the operator was to use low beam intensity and fast exposure. When the percentage of tungstic oxide was reduced either by pumping to lower pressure or by flushing the system during evaporation with a few microns of purified nitrogen, free of oxygen, the gold appeared as discreet particles, similar to those observed by Picard and Duffendack. Such deposits showed no tungsten by chemical analysis. Figure 1 proves the existence of discreet gold particles before electron bombardment. The gold was evaporated at 10^{-6} mm pressure and then shadowed with tungstic oxide before it was placed in the microscope. The shadows could not have appeared if the granulation had taken place in the electron microscope.

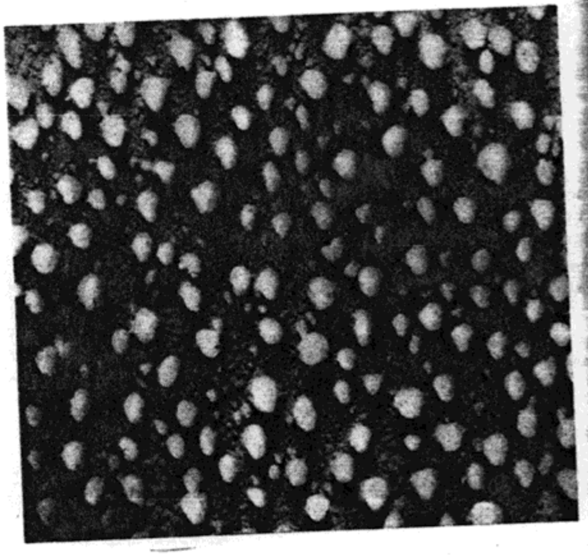

FIG. 1. Gold evaporated at 10^{-6} mm pressure and shadowed with tungstic oxide.

Figure 1 is typical of all the tungsten-free gold deposits we have observed.

[1] R. G. Picard and O. S. Duffendack, J. App. Phys. **14**, 291 (1943).

[2] P. G. Wilkinson and L. S. Birks, J. App. Phys. (to be published); P. G. Wilkinson and L. S. Birks, N.R.L. Report No. P-3443.

Energy Partition in Isothermal Fracture*

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MEASUREMENTS have been made of the elastic potential energy (e) and absorbed energy (w) associated with the fracture of four-notch specimens (0.70″×0.75″×4.6″ with 15 percent Izod notches) of a special aluminum-killed mild steel (Bethelehem), by observing for several values of deformation (s),