VI. MICROWAVE ELECTRONICS[*]

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A. NOISE

1. Noise Measurements

Both noise measuring systems were shut down for modifications and repairs; therefore no work is reported.

2. Low-Noise Traveling-Wave Tube at 500 Mc

The first tube, described in past Quarterly Progress Reports, was completed and tested. The gain is about 15-18 db, and the noise figure is 12-13 db. Some of the obvious reasons for the high noise figure are: (a) The intercepted current is 1-2 per cent. This, because of the large value of C (approximately 0.14), produces much larger excess noise than is found in conventional tubes with $C \approx 0.03$. (b) The gun is movable in the envelope, but apparently it cannot move far enough away from the helix to reach the optimum noise position.

A new tube is being designed with the same electrical parameters but with better mechanical assembly techniques.

S. Saito, L. D. Smullin

3. Noise Measure of a Transistor

Study of the noise measure of a transistor continues. The noise measure of an amplifier can be defined as

$$M = \frac{F - 1}{1 - \frac{1}{G}}$$

where F is the noise figure, and G is the available gain.

The value of M was determined for a transistor, and its behavior was studied as a function of the generator resistance and the transistor biases. In particular, the question was asked: What happens if we optimize M instead of F in order to obtain low-noise operation?

For an ideal transistor ($r_B = 0$), with only shot noise being considered, μ^2 should be made as large as possible, where

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$$\mu^2 = \frac{\alpha^2 r_c}{4r_E} = \text{maximum available gain of transistor with } r_B = 0$$

We make r_c large by making the collector voltage $|V_c|$ large (that is, if we neglect the Early effect; otherwise, r_c cannot be changed, if $|V_c|$ is greater than approximately 0.5 volt). We can make r_E small by increasing I_E, the dc emitter current.

If we take into account the finite base resistance r_B, the situation changes and there will be, in general, an optimum set of values for I_E and V_c. Finally, if we take into account 1/f noise that is proportional to some power of the collector voltage, there will be another optimum set of values for I_E, V_c.

To reduce 1/f noise we must reduce $|V_c|$. For very small $|V_c|$, the back resistance of collector diode, r_c, will become quite small and so will the gain. Optimizing the noise measure will set $|V_c|$ at a value at which the gain is small but finite. Whereas, if we adjust in order to optimize F, we may reduce the gain to unity. In any case, we shall be uncertain where to stop, since the gain is not contained in the noise figure expression.

B. W. Faughnan

B. HIGH-POWER MICROWAVE TUBES[*]

1. Multiple-Cavity Klystrons

a. Theory

A detailed analysis of the small signal gain-bandwidth relationships of stagger-tuned multi-cavity klystrons was developed. The results will be presented in a paper at the AIEE-IRE Conference on Electron Devices, at Boulder, Colorado, June 29, 1956.

A. Bers

b. Experiment

Since the theory mentioned above is entirely small-signal, an experimental study of the effect of stagger tuning on the efficiency of pulsed klystrons is being planned. Preliminary measurements were attempted on a General Electric Company Z5076 four-cavity, 20-kv tube; future measurements will be made on the Varian Associates V-87 four-cavity klystron.

Experiments were made on the General Electric Company tube to test the effectiveness of reducing collector voltage in increasing tube efficiency. Since the tube was

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not designed with this feature in mind, the results indicated only a minor change in efficiency. The body currents were relatively large under conditions of reduced collector potential; hence we cannot draw any firm conclusions. Future experiments are planned.

B. A. Highstrete

C. A SYNCHROTRON INJECTION SYSTEM

An injection system for an alternating-gradient (AG) synchrotron is being investigated in connection with the synchrotron to be built by the Cambridge Accelerator group.

1. Synchrotron Acceptance

If a procedure developed by Slater (1) and by Twiss and Frank (2) is generalized, a Hamiltonian function can be set up to describe the oscillation of particles in any synchronous machine.

$$H' = \frac{p'^2}{m'} - V(\cos\phi + \phi' \sin\phi_o) \tag{1}$$

where ϕ_o is the phase stable position, ϕ' is the deviation from this position, H' is the Hamiltonian of the oscillation, p' is the excess momentum, m' is the mass associated with the oscillation, and V is a voltage parameter that is dependent upon the particular type of accelerator used. For an AG synchrotron of the type proposed by Courant, Livingston, and Snyder (3), V is just the total gain in voltage around a single turn at maximum field; m' also varies from one type of machine to another. For the strong-focused synchrotron, we have

$$m' = \frac{p_o^2}{k\alpha E_o} \tag{2}$$

a mass reduced by the factor $k\alpha$, where k is the ratio of radiofrequency to orbit frequency, and α is the momentum compaction factor.

A given set of input conditions of phase and energy will correspond to a particular Hamiltonian function H'. The orbits of H' that are closed curves in phase space will represent values at which particles will be accepted into stable orbits. From the Hamiltonian function, we can also find the extent of the radial oscillation in the synchrotron from the relation

$$\frac{\Delta r}{r_o} = \alpha \frac{p'}{p_o} \tag{3}$$

The quantity V will be so chosen that it accepts most of the input beam for a given energy and phase spread at injection. This energy and phase spread must then be limited in order not to exceed the radial oscillations allowed by the width of the vacuum chamber.

2. The Injection System

The injection system, besides limiting energy and phase spread, must also inject the particles at a fairly high energy, of the order of 20 mev. This requirement is necessary because of remnant magnetic fields in the synchrotron. Using a linear accelerator is probably the most convenient way of achieving the required energy with the necessary beam current.

In a linear accelerator with a bunching section, as described in the Stanford Accelerator Report (4), both phase and energy spread at the output can be controlled to some extent. In the bunching section, these quantities vary reciprocally, although they vary together in the relativistic section. The linear accelerator can be operated either at the fundamental frequency of the synchrotron or at some higher harmonic. If a harmonic frequency is used, the output of the linear accelerator will have a number of pulses of output for each synchrotron cycle that corresponds to the harmonic number used. Since this would be equivalent to a large phase spread at injection, it must be used with a supplementary bunching system. If a current grid or cavity prebuncher is operated at the synchrotron frequency, most of the charge can be concentrated in a single linear-accelerator cycle for each synchrotron cycle. With such a bunching system, the phase spread at injection becomes negligibly small. The problem then becomes one of reducing the energy spread as much as possible.

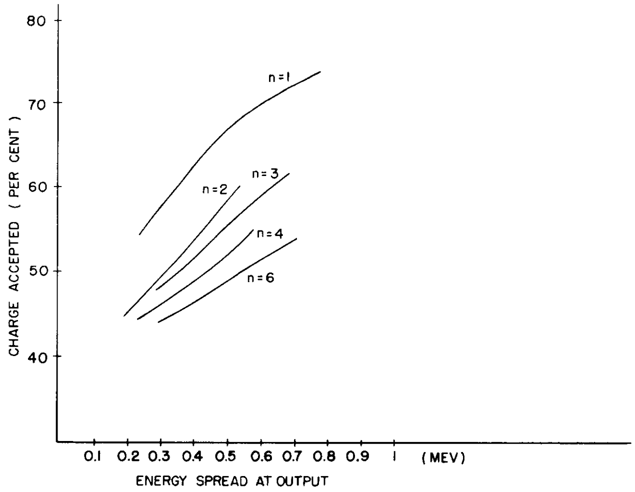

Fig. VI-1. Charge accepted versus energy spread for different harmonic numbers of the linear accelerator.

If we use a Hamiltonian formulation similar to the one given in Section VI-C. 1, a general expression for the energy spread can be derived. From this expression, a study of any given parameter can be made while the others are held fixed, in order to minimize the output energy spread — subject to practical limitations. One study was made to compare the operation of the linear accelerator at various harmonic frequencies from one to six. A cavity prebuncher was used. The following buncher parameters were chosen:

Total energy, 4 mev	Injection field, 0.5 mev/meter
Injection velocity, 1/3 C	ϕ_o at injection, 15°
Maximum field, 5 mev/meter	ϕ_o at exit, approximately 80°

The total linear-accelerator energy was 20 mev. The percentage of charge accepted with a given energy spread was plotted for various harmonic numbers between one and six. See Fig. VI-1.

A. J. Lichtenberg

References

1. J. C. Slater, Revs. Modern Phys. 20, 473 (1948).
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4. M. Chodorow, E. L. Ginzton, W. W. Hansen, R. L. Kyhl, R. B. Neal, and W. K. H. Panofsky, Rev. Sci. Instr. 26, 134 (Feb. 1955).

D. TECHNIQUES

In order to insure a high vacuum in the low-noise traveling-wave tube, the collector is made of titanium; by means of a bias resistor it is run about 20-50 volts below the helix. In this way, we use the principle of the titanium vacuum pump.

The same technique is most readily applied to the reflector of a reflex klystron. This should allow very high vacua to be attained, thus reducing ion-oscillation modulation products.

L. D. Smullin