V-11. Improvements in Reflex Klystron Linearity with the Use of Varactor Diodes

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The reflex klystron oscillator is very widely used as a frequency-modulated oscillator in modern microwave radio links for telephone and television communication systems.

In the reflex klystron, a variable voltage V_R applied to the repeller gives rise to a frequency deviation Δf; the relation $\Delta f = \Delta f(V_R)$ can be considered linear only within a very limited range around its origin. Medium and large-transmission-capacity radio links, however, produce wide frequency swings with consequent intolerable distortion.

Generally, frequency shifts of about $1^0/00$ cause differences in FM sensitivity of approximately 5 to 6%. Modulation sensitivity variations of this range cause distortions and, therefore, intermodulation noise which exceeds the CCIR's severe values for the noise. Hence the need for an adequate linearization of the klystron, which can be obtained by the pulling effect exerted upon its oscillation frequency by a mismatched load.

This can be accomplished by inserting a device between the cavity and the matched load, i.e., a special circuit presenting to the cavity a reflection coefficient, which is suitably variable in amplitude and phase. Adjustments of these two variables allows complete control of the reactance seen at the oscillator output. The more usual linearization devices are:

a) Two-branch waveguide devices with movable shorts. The shorts are one on the broad and the other on the narrow side of the waveguide (E-H tuner or E-H "lineator"[1]).

b) Devices with variable-depth screws, which can be moved along a slot placed in the center of the broad side of the waveguide (slide screw tuner or slide screw "lineator").

c) Devices with phase-displacement plates of dielectric material and with a single stub on the broad waveguide side.

A new method of linearizing the klystron's modulation characteristic employes varactor diodes, widely used nowadays in microwave techniques. Varactors are characterized by a junction capacitance $Cg(V)$ which is a function of a voltage V applied to the diode, according to the equation:

$$Cg(V) = C_o \left(1 - \frac{V}{V_b}\right)_{-n}$$

in which:

V_b = barrier potential depending on material (Si or Ge) and equal to about 0.3 to 0.5 V at room temperature.

C_o = junction capacitance with no bias.

n = 1/2 for abrupt junctions;

= 1/3 for gradual junctions.

In practice, varactors can be mounted in an external cavity and coupled by means of an iris to the klystron's internal cavity, as shown in Fig. 1, or they can be inserted in the waveguide after the klystron cavity, without any

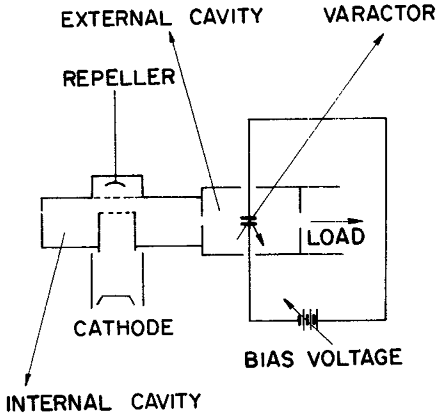

Figure 1.

special procedure. In both these cases, it is possible to vary the varactor's capacitance by exploring some of its characteristic by means of two different methods:

1) A fraction of the modulation voltage applied to the repeller is carried to the varactor by a suitable divider.
2) No voltage other than the continuous bias voltage is carried to the varactor. (In this case it is the rf field which causes the varactor capacitance automatic shift along its characteristic. The shift varies according to the rf power emitted.)

The linearization mechanism is rather complex; here and in the following notes we can give no more than a summary of the results of our analytical research.[2]

To obtain a perfect linearization ($f = K \cdot V_R$, with K constant), the varactor capacitance should be:

$$C(V) = AV + C_o$$

i.e., linear behavior vs bias voltage. Since the varactor's characteristic is not really linear, it cannot provide a perfect correction of the klystron distortion.

The circuit device used is shown in Fig. 2: The varactors, mounted on fingers, have been arranged in the center of the waveguide, so that they are exposed to the maximum rf field. A double coaxial stub and sliding rf chokes enable the varactors to be continuously biased and the shorts to be shifted at the same time. The latter factor is essential, since by regulating the short circuits' position in the stub, one eliminates hysteresis phenomena, frequency jumps, and oscillation gaps, which arise if the varactors are placed in the waveguide without any compensation. In choosing the varactors, preference was given to those with high Q (to load the klystron cavity

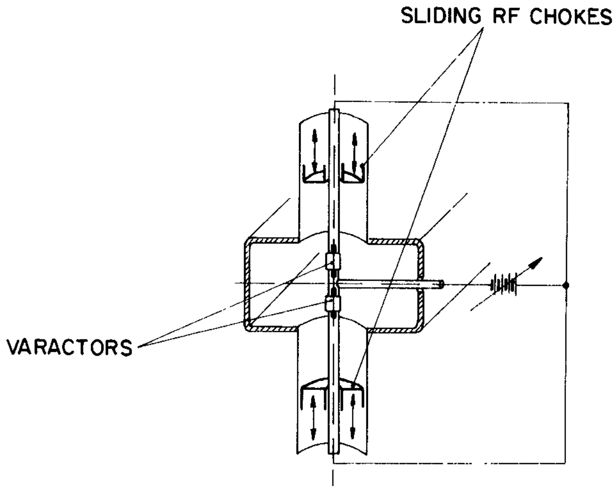

Figure 2.

with minimum additional losses) and with high breakdown voltage, for reasons not explained here. To verify experimentally what has been stated above, static and dynamic tests were taken.

In the static measurement, carried out in the 7 Gc range, the VA–225 C klystron was used, with its cavity coupled directly to the waveguide by a rectangular iris. The varactor was an MA 4344 A with a breakdown voltage of −24 V. From the graphs obtained (Fig. 3 and Fig. 4) the linearization effect of klystron characteristic is obvious after the introduction of the varac-

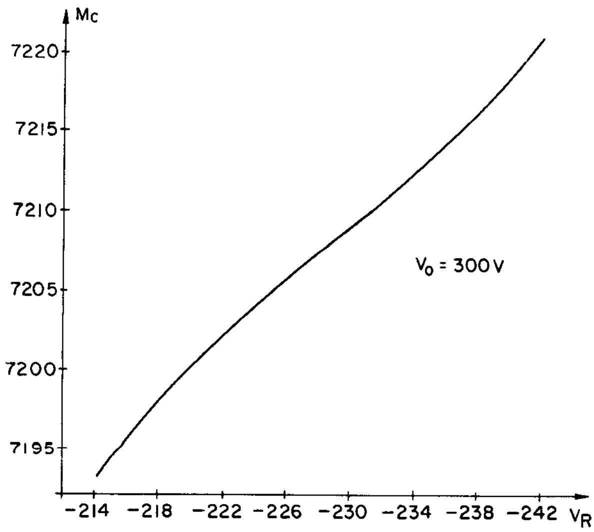

Figure 3.

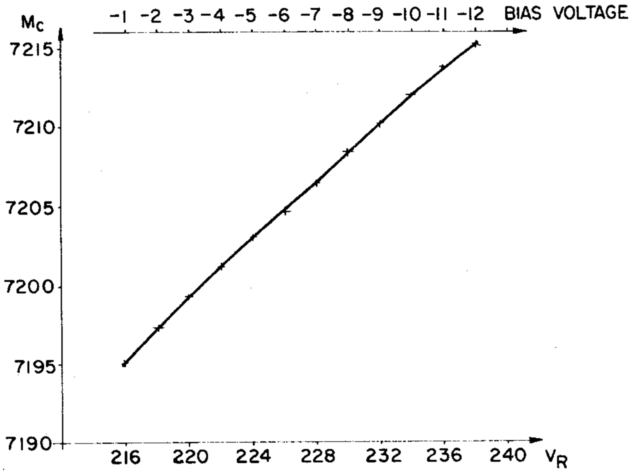

Figure 4.

tor, whose bias was varied according to the repeller voltage. The dynamic as well as the static measurements were taken in the 7 Gc range, varying, however, klystron and varactor.

The klystron was now replaced with the VARIAN VA 222 A and C, whose working characteristics are

Resonator voltage	$V_o = 750$ V
Reflector voltage	$V_R = -1100$ V
Output power	$P_{out} = 1$ Watt
Average modulation sensitivity	So = 300 kc/V.

The varactors were the MA 4345 C type. The breakdown voltage in this type (silicon) is −48 V. Various linearizations were obtained for bandwidths of ±4, ±5, and ±6 Mc (peak-to-peak). The residual nonlinearity was never

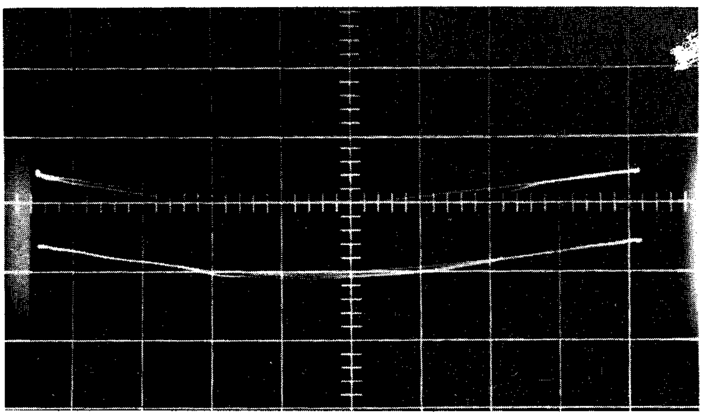

Fig. 5 $\Delta f = \pm 6$ Mc p.p. Variation in slope = 5%.

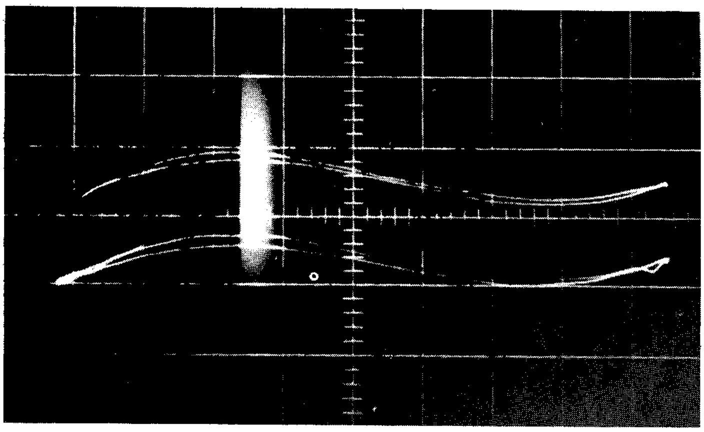

Fig. 6 $\Delta f = \pm 5$ Mc. Variation in slope = 4%.

greater than 7 $^0/_{00}$ and was often in the range of 4 to 5 $^0/_{00}$, as illustrated in the attached photos (Fig. 5 and Fig. 6). By varying the continuous bias at the varactor terminal edges, variations in modulation sensitivity (which is always greater than that of the klystron) and different slope, i.e., different harmonic content, can be obtained.

CONCLUSIONS

1. The tuning range the varactor device affords is at least as wide as the conventional passive "lineators."

2. The new varactor "lineator" takes up less room than the passive ones.

3. No great degree of stability is required for the varactor's bias voltage, especially when biasing towards breakdown, where the characteristic is flatter. The stability is not superior to the voltage stability required by the klystron. The theoretical and experimental research outlined here has demonstrated the possibility of improving klystron linearity by means of varactors.

FOOTNOTES

1. As far as we know, there is not in the Anglo-Saxon technical literature a specific and explicit word (except for "tuner," which is not a specific word) to indicate a linearizing device. In the present case we suggest the use of the neologism "lineator," by which we mean a special circuit or device which makes the frequency deviation-repeller voltage characteristic of the reflex klystron more linear.
2. See paper presented at the 64th Annual Meeting of the A.E.I., Stresa, Italy, 22–26 Sept., 1963. Volume of reports: Paper 36, pp. 1–15: A. Pistilli, V. Possenti, "A new varactor application to improve the reflex Klystron linearity."

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