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# Multi-Stage Depressed Collectors (MDC) For Efficiency Improvements of UHF Broadcast Klystrons

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# MULTI-STAGE DEPRESSED COLLECTORS (MDC) FOR EFFICIENCY IMPROVEMENTS OF UHF BROADCAST KLYSTRONS*

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Depressed collectors are passive converters of kinetic energy into potential electric energy thus reducing the consumed primary power and raising the efficiency of electron beam devices. Well performing, scientifically designed Multi-stage-Depressed Collectors (MDC's) have been introduced, designed, improved and successfully applied over the last ten years to numerous Traveling Wave Tubes (TWT's) fitting the requirements of high efficiency wide band counter measures, radars and ground air space communications.



The principle of operation of a depressed collector may be explained from Fig 1. This collector is free of competing lens effect and provides a smooth diverging force on the electrons. Application of similarly built collectors to TWT's led to very impressive improvements in the overall efficiency of TWT's that were operated both at saturation and in the linear level as shown in Fig. 2. In TWT's we were thus able to keep the efficiency constant within a 3 dB range while the output power varied by 10 dB, an improvement of 7 dB that was accomplished without changing dc voltages and without using any mod-grids. The problem to be solved is thus to transfer this technology to UHF klystrons. We will see that this task is more difficult to accomplish than in TWT's, but judging from our successful klystrons experiments an acceptable solution appears to be likely.

Let us now return to some basic considerations in order to gain a deeper understanding of the problem and its implications.

Fig. 3 shows a normalized energy distribution curve in the spent beam of a UHF-TV klystron at saturation. The ordinate is the percentage of electrons in the beam with a normalized kinetic energy of more or equal to $V/V_0$, where $eV_0$ is the starting kinetic energy of all electrons prior to RF interaction. The area under the curve represents the kinetic energy left over in the spent beam past the output cavity. When the drive level is reduced below saturation the distribution curves assume the form indicated, for example, by the 3 dB and 6 dB curves. Notice the fact that klystrons create an electron energy spectrum that extends from almost zero minimum energy to about 1.5 times the dc energy. Now let us compare this with the electron energy spectrum of a typical TWT, Fig. 4, and we notice that TWT's have a substantially narrower energy spectrum than klystrons which - translated into the collector design - implies a more difficult problem to be dealt with in klystron MDC's. But this is not the only difficulty associated with collecting spent beam electrons

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from a klystron output: Returning again to Fig. 1 we recollect that in order for the electrons to penetrate deeply into the potential field of the collector the injection angles must not be too large. The magnitude of these angles is shown in Fig. 5. Since it is very difficult and time consuming to measure individual angles Fig. 5 gives a statistical integration of angles within $8^o$, $11.7^o$, and $15^o$ at saturation and 3 dB down for a 1 kW klystron with 35 percent efficiency and $\mu$perv = 0.6.

When klystron efficiency and the perveance are increased, as in the case of modern TV klystrons, the output angles would be much larger (approx twice as large) than as shown in Fig. 5 and without corrective measures an efficient collector would be virtually impossible to design. Fortunately, an effective, though not perfect remedy, exists in the method of beam reconditioning as shown schematically in Fig. 6: The magnetic focusing field in the klystron is permitted to decrease and the beam to expand to a larger radius. Fundamental theorems of physics show that such an expansion leads to a reduction of exit angles as shown in Fig. 6 on the lower line. This method was successfully tested and developed by myself and coworkers at LeRC in the very early 1970's, mainly for TWT's but also for two klystron cases. Thus, with a significant reduction in angles one may hope to develop an acceptable collector efficiency even for modern design TV klystrons, though the degree of improvements will not be as high as that shown before for TWT's. Fortunately, the mode of operation of TV klystrons, that is its operation way below saturation over a large fraction of time will mitigate somewhat the adverse effects that we discussed before.

To illustrate the potential, consider Fig. 7 that shows the overall klystron efficiency and that of the collector as function of the drive level over a range of 3 dB. As the power output is reduced by 3 dB the efficiency drops only by 1.1 dB. A substantial part of the losses has, thus, been recovered by the collector. The results shown in Fig. 7 can certainly be improved some what with the klystron work expected to be done presently because of availability of analytical tools and more mature development. We show in Fig. 8 results obtained with TWT's at very low drive levels, down to zero drive. Here one has achieved a better than tenfold improvement in the overall efficiency when the TWT is operated 10 dB down from saturation. Similar, though not as good results may be expected from TV klystrons such that the present power consumption in TV klystrons will be reduced by a factor of two to three and this improvement achieved without the deleterious effects of back-streaming electrons that cause noise and other distortions in the output signal.

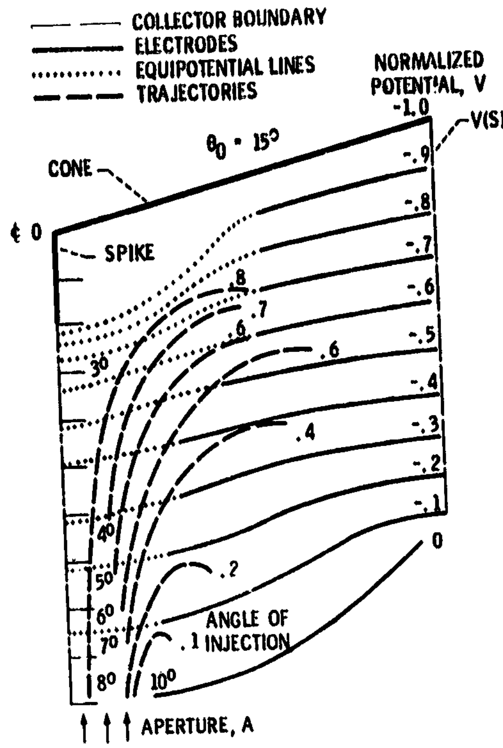


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Figure 1. - Depressed collector for a tv klystron.

| TWT MODEL | MICROPER-VEANCE | ELECTRONIC EFFICIENCY, % (EXPERI-MENTAL) | OPERATION MODE | MDC STAGES | COLLECTOR EFFICIENCY, % COMPUTED | COLLECTOR EFFICIENCY, % MEASURED | OVERALL EFFICIENCY, % MEASURED |
|---|---|---|---|---|---|---|---|
| TMEC 5897C | 0.47 | 17 | SATURATION | 5 | 84.9 | 84.2 | 41.6 |
| TMEC 5897 | 0.47 | 17 | SATURATION | 3 | 81.6 | 81.9 | 39.0 |
| TMEC 5897C | 0.47 | 3.7 | LINEAR | 5 | 89.7 | 87.4 | 18.6 |
| TMEC 5897C | 0.47 | 7.7 | LINEAR | 5 | 86.7 | 86.4 | 30.1 |
| TMEC MTZ 7000 | 0.49 | 19.5 | SATURATION, HIGH MODE | 5 | 81.4 | 84.3 | 48.0 |
| | 0.40 | 16 | SATURATION, LOW MODE | | 84.4 | 85.5 | 47.6 |
| TMEC MTZ 7000 | 0.49 | 19.5 | SATURATION, HIGH MODE | 5 | 70.4 | 77.6 | 42.0 |
| | 0.40 | 2.4 | SATURATION, LOW MODE | | 91.8 | 91.9 | 18.5 |
| TMEC MTZ 7000 | 0.40 | 16 | SATURATION, LOW MODE | 4 | 83.8 | 81.7 | 42.7 |
| TMEC MTZ 7000 | 0.40 | 3.6 | LINEAR | 5 | 88.7 | 90.4 | 25.5 |
| VARIAN VTG 6336 A1 | 1.23 | 24.4 | SATURATION | 4 | 78.4 | 76.1 | 45.8 |

Figure 2. - Verification of computational design procedure analytical versus experimental mdc/twt performance.

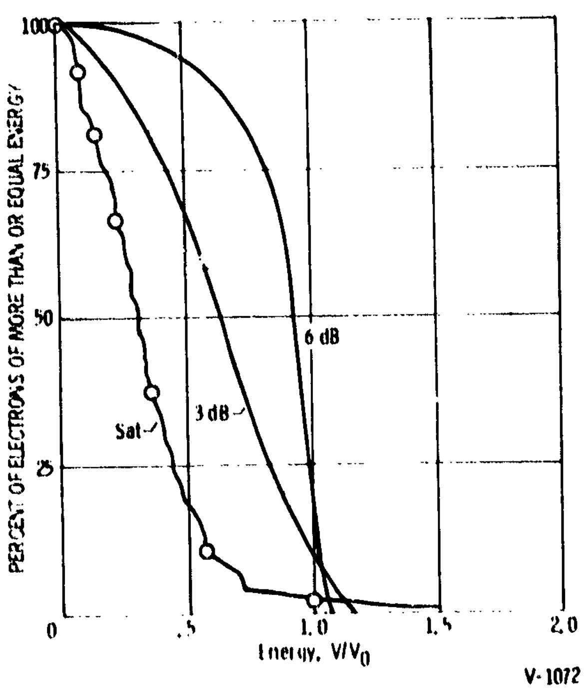


Figure 3. - Energy distribution in the spent beam. Saturation, 3dB, 6dB of a uhf-tv klystron; measured efficiency, 61 percent, perveance, 1.2 μperv; $V_0$ = 29.2 kV.

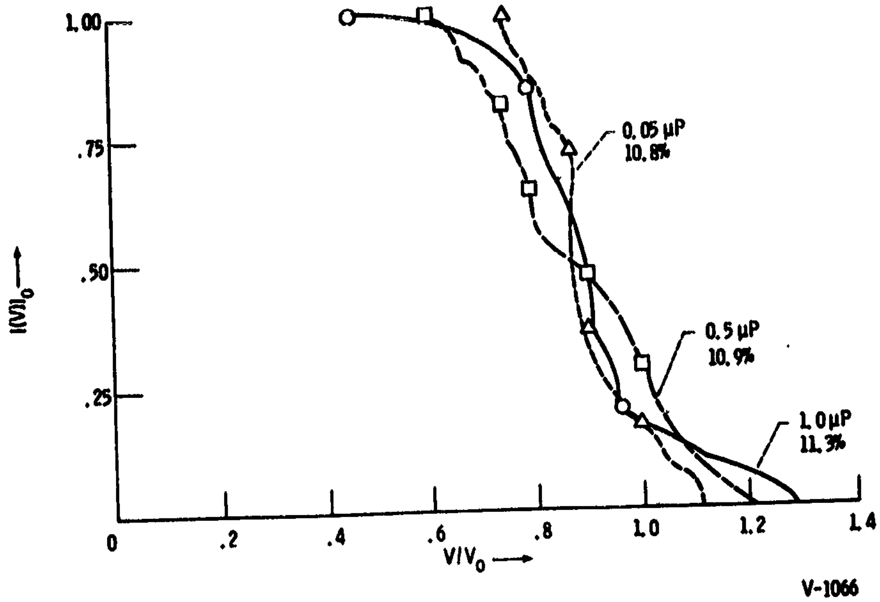


Figure 4. - Comparison of energy spread for tubes of same efficiency as function of perveance in a TWT.

[μPERV = 0.60; ηRF ≈ 35%.]

| | BEAM ANGLE, deg | | | | | |
|---|---|---|---|---|---|---|
| | 8.0 | | 11.7 | | 15.0 | |
| | SATURATION | 3 dB BELOW SATURATION | SATURATION | 3 dB BELOW SATURATION | SATURATION | 3 dB BELOW SATURATION |
| | PERCENT OF BEAM POWER WITHIN AN ANGLE | | | | | |
| NO RECONDITIONING | 67.5 | 92.5 | 83 | 94 | 91.5 | 96 |
| RECONDITIONING | 94.5 | 96.5 | 97.5 | 98.5 | 97.5 | 98.5 |

Figure 5. - Effect of reconditioning on the spent beam dispersion in a klystron output at saturation (sat) and 3dB below saturation.

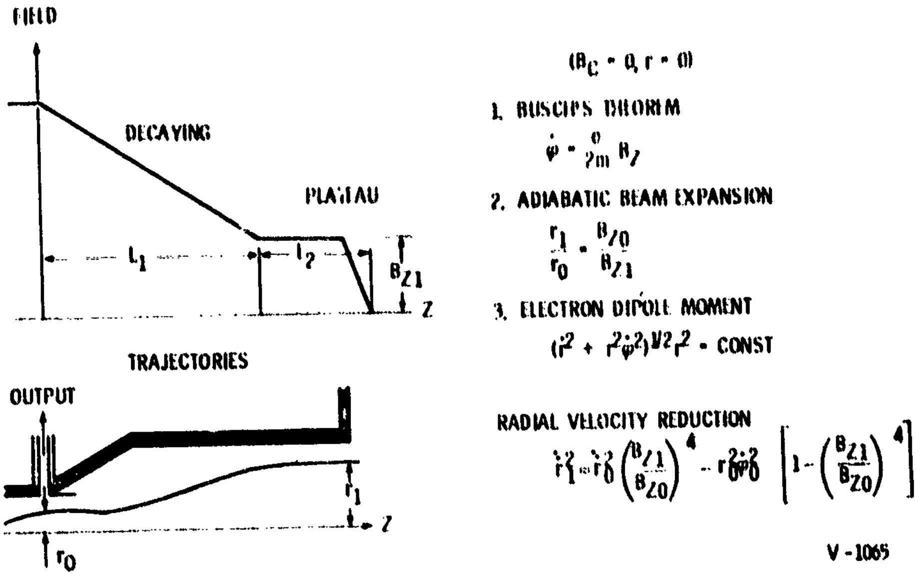


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Figure 6. - Schematic of reconditioning.

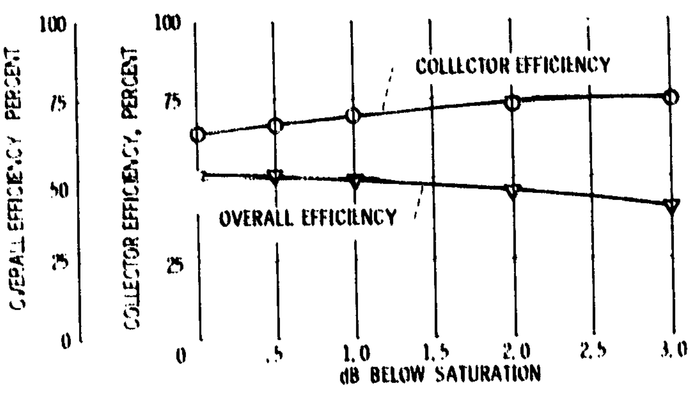


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Figure 7. - Performance of the LeRC 10-stage 'dispersive lens' collector with the 1-kW, 0.6-uperv rca klystron f = 4.65 GHz (1971).

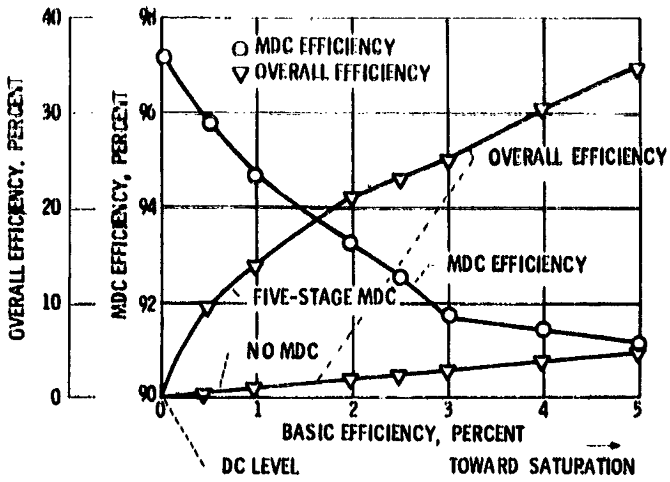


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Figure 8. - The efficiency of the mdc vs the intrinsic twt efficiency in the linear small signal region, measured at 6.4 GHz; and overall TWT efficiency.