RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

APPLICATION NOTE No.108
November 13, 1940

EFFECT OF TEMPERATURE ON FREQUENCY OF 6J5 OSCILLATOR

Oscillator frequency stability becomes increasingly important as utilization of short waves is increased. The reason is that while factors tending to change the frequency of an oscillator act for the most part to cause small percentage changes, the tolerable frequency variation in a receiver or transmitter is generally expressible as a definite number of kilocycles which is independent of the oscillator frequency. For example, the frequency band which is passed by the i-f system of an "all-wave" broadcast receiver is the same whether the frequency of the receiver signal is 500 kilocycles or 20 megacycles. A five-kilocycle change in the frequency of the oscillator would have the same effect in either case. Since the oscillator frequencies for these two cases would be approximately 1000 kilocycles and 20 megacycles, a five-kilocycle deviation would represent 0.5 per cent of the operating frequency for the 500-kilocycle signal, and 0.025 per cent for the 20-megacycle signal. For equal effect, therefore, the frequency variation for the short-wavelength signal should be one-twentieth of that for the longer-wavelength signal.

Television and frequency-modulation services employ wide bands, and, consequently, do not require quite the high degree of oscillator frequency stability of the above example. The tolerance for frequency-modulation has been estimated to be five to twenty kilocycles, and that for television reception, twenty to fifty kilocycles. These tolerances, when applied to frequency-modulation signals at 50 megacycles and television signals up to 100 megacycles, indicate permissible oscillator-frequency deviations in the range of 0.01 to 0.05 per cent. Receivers for such services must be capable of tuning to this order of accuracy, and of maintaining their oscillator frequency, thereafter, within the tolerance considered to be acceptable.

Factors tending to change the oscillator frequency are:

1. Temperature variations affecting the mechanical and electrical properties of the oscillator circuit.

2. Voltage variations.

3. Structural changes of circuit elements produced by shock, vibration, etc.

Measurements of Temperature Rise and Frequency Drift

This Note deals primarily with frequency change due to temperature variation. Preliminary results were obtained in a series of tests with a television receiver altered to use the oscillator circuit shown in Fig. 1-A. The change was made to facilitate testing procedure, and not because it offered any advantages in practice. These tests showed that:

1. With the oscillator operating at 58 megacycles, its frequency decreased 150 kilocycles in an hour, and was still decreasing slowly at the end of that period.

2. The temperature of the chassis at a point near the oscillator tube increased approximately 15°C during the hour. The temperature of the air increased about 13°C, and that of the top of the oscillator tube (6J5, a metal type) increased by approximately 50°C. The temperature between the base of the tube and the socket increased 30°C.

3. Changes in the socket material affected the amount of frequency drift appreciably, but the differences between the frequency drifts observed with wafer-type sockets and sockets of the molded ceramic type were small in comparison with the total drift. Curves showing frequency drift vs time are given on Fig. 2.

Further tests were made by first operating the receiver for at least an hour to allow the frequency to reach (approximately) its equilibrium value, then quickly changing the oscillator tube and observing the frequency change as the fresh tube heated. In these tests, the maximum frequency change observed was never more than one-third of the change observed in the preliminary tests. When ceramic-type sockets were used, the changes were still less. The curves of Fig. 3 show results of tests made in this manner. An immediate conclusion is that for the receiver used the oscillator tube does not account for more than a third of the observed frequency change. Actually, the fraction chargeable to the tube is less than this, because insertion of a cold tube in a hot socket cools the socket to an undetermined degree. Thus, part of the observed frequency change is due to the change in socket capacitance as the socket temperature again rises to the equilibrium level.

It will be noted that the ordinates of Figs. 2 and 3 are given in terms of change in capacitance as well as in kilocycles. The capacitance corresponding to a given change in frequency can be determined readily when the operating frequency and the total capacitance of the circuit are known. The relation is

$$\Delta F/\Delta C = -500\ F/C$$

where F is frequency in megacycles
ΔF is frequency change in kilocycles
C is total circuit capacitance in $\mu\mu f$
ΔC is the change in circuit capacitance in $\mu\mu f$

The negative sign indicates that an increase in circuit capacitance causes a decrease in frequency, and vice versa. In the receiver used for the tests described above, the total capacitance was 58 $\mu\mu f$ and the operating frequency was 58 megacycles; consequently, a capacitance change of 0.002 μμf would cause a frequency change of one kilocycle, and the 150-kilocycle change observed (see Fig. 2) would correspond to a capacitance change of 0.3 μμf. It should be mentioned that the original oscillator circuit had twice the total capacitance of the circuit used in this test, and included a compensating condenser. For these reasons, the frequency shift of the unaltered receiver was very small in comparison with the 150-kilocycle change noted above.

Determination of equivalent capacitance is useful in two ways; first, it enables us to extend the interpretation of our results to other frequencies and other operating conditions, and second, it suggests the nature and magnitude of corrective measures to be applied.

The stating of frequency variation in terms of capacitance change does not necessarily imply that the frequency change is entirely due to a change in circuit capacitance. An increase in circuit inductance, caused by mechanical expansion of coils and leads with increasing temperature, also causes a decrease in frequency. Hence, it is possible that under some conditions an inductance change could account for a major part of the frequency drift.

Discussion of Drift Components

A curve showing temperature rise vs time for the television receiver given is shown on Fig. 2. Only part of the heat causing increases in receiver temperature comes from the oscillator tube itself. Quite different temperature-rise curves should be expected with receivers of other design or application. Accordingly, in order to obtain a better determination of the performance of the tube itself, a special chassis containing only the oscillator circuit and a little auxiliary equipment to facilitate drift measurements was constructed. Drift measurements taken with this special chassis are shown on Figs. 4 and 5. With this chassis, the operating frequency was 52 megacycles, and the circuit capacitance was 26 μμf. Hence, a frequency change of one kilocycle corresponded to a capacitance change of 0.001 μμf.

Fig. 4 shows data obtained with each of the two oscillator circuits of Fig. 1 for a wafer socket. This socket was fastened directly to the chassis. Since a possible objection to this arrangement was that the aluminum chassis might conduct heat away too rapidly, a special socket mount, consisting of a steel plate suspended from the chassis by rubber grommets, was also used for these tests. These results are shown on Fig. 5 for the "grounded-grid" circuit of Fig. 1-A.

It is at once apparent that the drift (expressed as capacitance change) is less under these conditions. The change in ten minutes, with a wafer socket, is 0.06 μμf for the special chassis with the rubber-mounted socket, and 0.095 μμf for the television receiver. The temperature rise between tube base and socket was approximately 30°C in the receiver, and from 10°C (near the edge) to 20°C (near the center) in the special chassis. These differences are of the correct order of magnitude to correspond to the differences in results. The temperature difference in the two cases corresponds roughly to the increase in air and chassis temperatures in the receiver. Consequently, it is reasonable to conclude that approximately two-thirds of the socket temperature rise in the receiver is due to heat from the tube, and that the remainder is due to heat from other sources. The temperature rise of other parts, which accounts for two thirds of the total drift, is almost entirely the result of heat from other sources.

A comparison of Figs. 2 to 5 leads to an approximate analysis of the sources of frequency drift, as shown in the following table.

Part	Temp. Rise (receiver)	Capacitance Change	Temp. Coeff.
	°C	μμf	μμf per °C
Tube (internal structure)	-	0.03	-
Tube base	30	0.03	0.001
Socket (wafer)	30	0.03	0.001
Other circuit elements	15	0.20	0.017
Total		0.29	

For the special chassis, the results on the basis of the same coefficients are as follows:

Part	Temp. Rise	Capacitance Change	Temp. Coeff.
	°C	μμf	μμf per °C
Tube (internal structure)	-	0.03	-
Tube base	15	0.015	0.001
Socket (wafer)	15	0.015	0.001
Total		0.06	

If it is assumed that the ceramic socket used in the receiver and the low-loss plastic socket used with the special chassis contribute negligible amounts to the frequency drift, the predicted changes with these sockets are 0.270 μμf for the receiver, and 0.045 μμf for the special chassis. Observed values are 0.261 μμf and 0.047 μμf, respectively. For these tabulations, the tube capacitance change has been separated into "internal structure" and base components, because it has been assumed that only the base is affected by changes in external temperature.

Over-all test results with a mica-filled phenolic socket indicate a temperature coefficient of 0.0017 μμf per degree C, but tests with a cold tube inserted in a hot receiver show less change than for wafer sockets. The explanation is probably that the wafer socket is cooled almost to room temperature by the insertion of a cold tube, while the mica-filled phenolic socket retains considerable heat because of its greater mass and different structure. The apparent differences in the performance of sockets under the conditions of Figs. 2 and 3 indicate the necessity for caution in the interpretation of all data obtained by the insertion testing method.

No special significance should be attached to the use of the "grounded-grid" oscillator circuit in these tests. In this connection, the two types of circuit shown in Fig. 1 were tested on the special chassis and gave the data shown by curves 1 and 2 of Fig. 4. Since mechanical construction of both circuits was substantially alike and also typical, it is proper to point out that the difference between curves 1 and 2 (of Fig. 4) is small in comparison with the drift shown on Fig. 2.

Compensation for Drift

Since the frequency drift is in the direction that would be caused by an increase in circuit capacitance with temperature, it is possible to decrease the drift by using a fixed capacitor having a negative temperature coefficient as part of the oscillator circuit. Capacitors employing ceramic dielectrics and having negative coefficients as high as 0.0007 μμf per degree C are available, and are frequently used for this purpose.

In the receiver used for the tests described in this Note, the temperature rise of the chassis is enough to produce a considerable change in the capacitance of such a condenser. It is interesting to compute the extent of compensation by substitution of a capacitor, with a negative coefficient, for part of the total circuit capacitance. An initial computation shows that in order to obtain a capacitance change of 0.29 μμf when the temperature rise is 15°C, the compensating condenser should have a negative coefficient of 680×10^{-6} μμf per degree C and a capacitance of 28.5 μμf. If the compensating-condenser temperature is assumed to be the chassis temperature, as shown on Fig. 1, the capacitance change at any time can be computed. The net capacitance change reaches a maximum value in eight minutes, and drops back to zero in an hour. However, a mode of compensation which would cause the frequency to reach an equilibrium value more quickly might be preferable. This result is obtained with a compensating capacitance value of 19.5 μμf, and is shown by curve 2 of Fig. 6.

Further improvement in compensation can be obtained by any means which would cause the temperature of the compensating condenser to rise more rapidly during the first few minutes of receiver operation. Location of the condenser in a position to receive more heat directly from the oscillator tube would tend to produce that result. Another possibility would be the use of a heating element, of suitable characteristics, in the vicinity of the compensating condenser. In the example considered above, the heater should cause an additional temperature rise of 6°C, and the heater and compensating condenser considered alone should reach equilibrium in ten minutes.

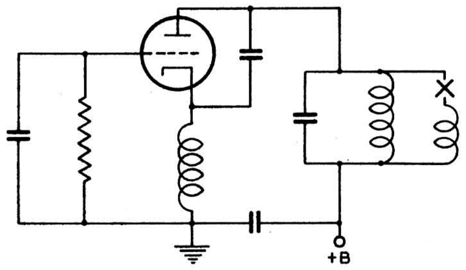
Conclusions

High-frequency oscillator circuits of typical construction give rise to considerable frequency drift during the warm-up period of the receiver, if a compensating condenser is not incorporated in the oscillator circuit.

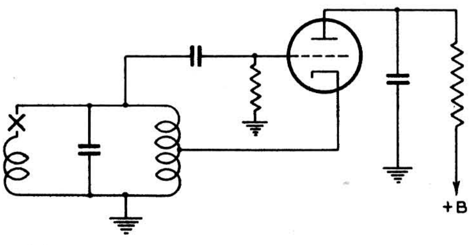
The amount of drift chargeable to the tube alone is likely to be small in comparison with the total drift of a complete receiver. Consequently, a comparison of drift data for different tube and socket combinations is not a matter of first importance. Such comparisons would be important only after a high degree of refinement had removed most of the drift not directly chargeable to the tube.

Available compensating condensers are adequate to minimize the frequency drift of typical oscillator systems to a satisfactory degree, insofar as television and frequency-modulation services are concerned.

OSCILLATOR CIRCUITS USED IN TESTS



(a) GROUNDED-GRID OSCILLATOR CIRCUIT



(b) GROUNDED-PLATE OSCILLATOR CIRCUIT

FIG.1

TEMPERATURE RISE & FREQUENCY DRIFT OF COLD TELEVISION RECEIVER

WITHOUT FREQUENCY-COMPENSATING CONDENSER

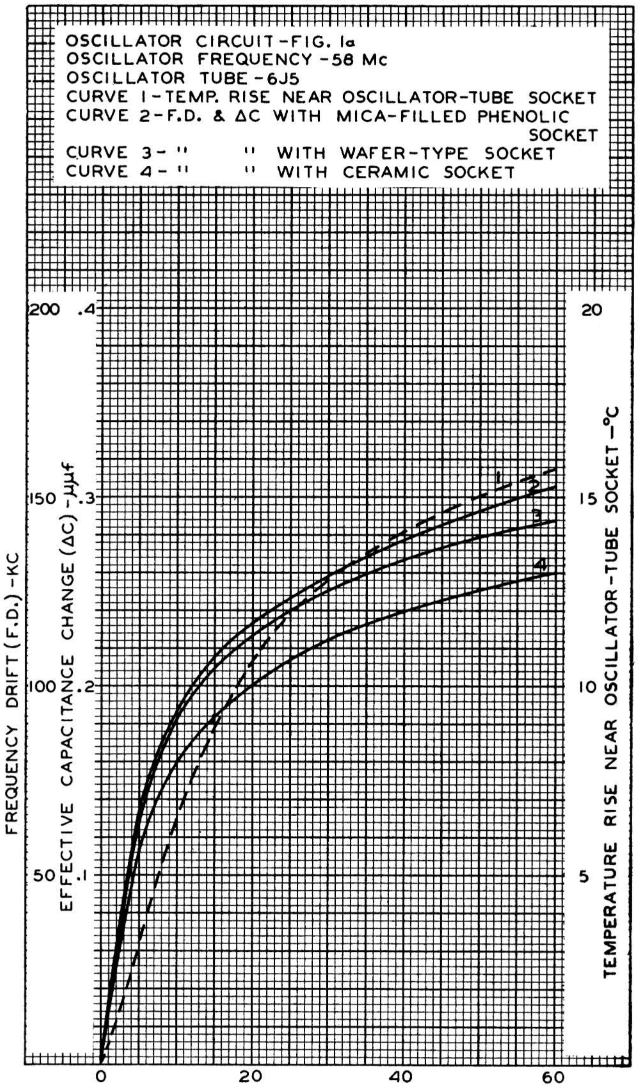


FIG.2

FREQUENCY DRIFT OF WARM TELEVISION RECEIVER FOR COLD OSCILLATOR TUBE
WITHOUT FREQUENCY-COMPENSATING CONDENSER

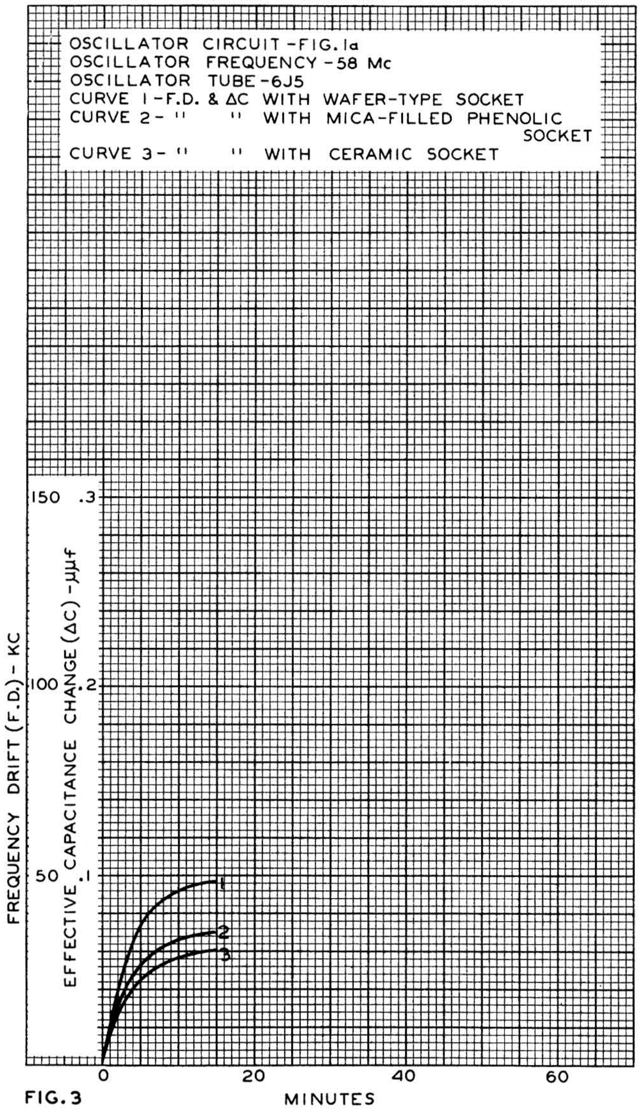


FIG. 3

OCT. 14, 1940

RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY, INC.

92C—6231

EFFECTIVE CAPACITANCE CHANGE OF COLD OSCILLATOR TUBE IN WARM SPECIAL CHASSIS WITH WAFER-TYPE SOCKET MOUNTED ON CHASSIS

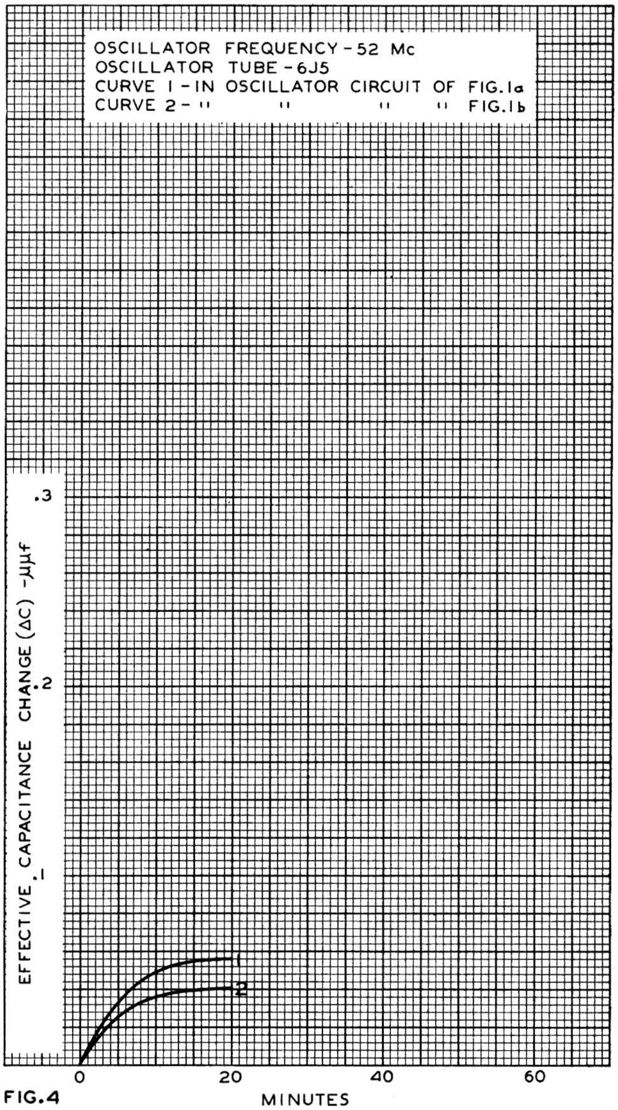


FIG. 4

OCT. 14, 1940

RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY, INC.

92C—6232

EFFECTIVE CAPACITANCE CHANGE OF COLD OSCILLATOR TUBE IN WARM SPECIAL CHASSIS WITH RUBBER-MOUNTED SOCKET

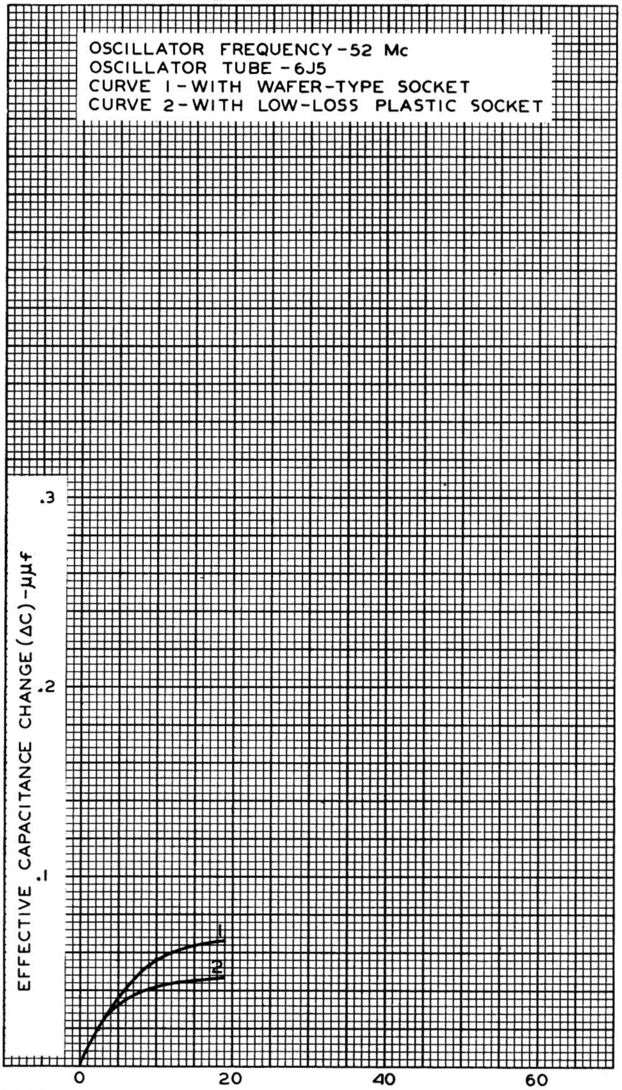


FIG.5

OCT. 15,1940

RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY, INC.

92C-6233

FREQUENCY DRIFT OF COLD TELEVISION RECEIVER
WITH AND WITHOUT FREQUENCY-COMPENSATING CONDENSER

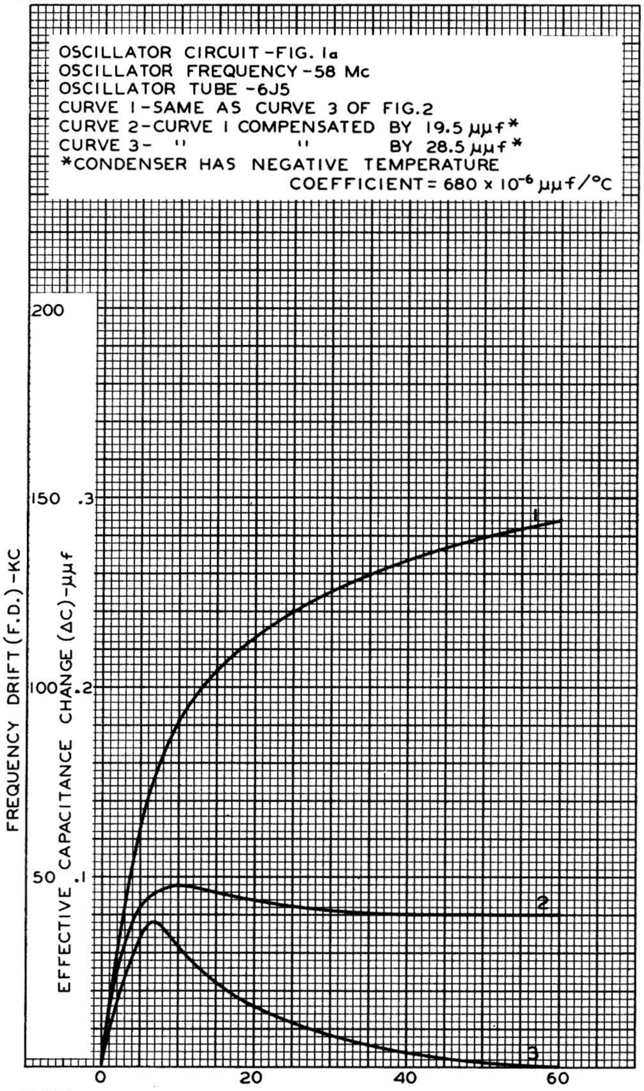


FIG.6

OCT. 15,1940

RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY, INC.

92C-6234