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A DECADE FREQUENCY GENERATOR FROM A SINGLE FREQUENCY ORIGIN

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ABSTRACT

Development is in progress on a technique and an equipment which will derive, from a single fixed frequency source, an output which is variable in decade steps of one cycle through 10 Mc over the frequency range of one cycle to 100 Mc. The system herein described synthesizes this output by the multiplication, selection, mixing, and successive division of a fixed 100-kc frequency. Uniqueness and simplicity are achieved by the fact that the 1-cycle, 10-cycle, 100-cycle, and 1000-cycle control units are of identical operation and construction and can be used interchangeably. Additional identical units may be added to produce increments to as low an order as desired (0.1, 0.01, 0.001 cycles, etc.). The configuration of the system is such that no adjacent signals requiring filtering lie closer than 5 percent. The lowest fixed frequency generated is 10 kc.

A unit covering the range of 1 cycle to 300 kc was constructed in semifinal form and found to operate satisfactorily, indicating that the techniques involved in producing the lower order of increments are sound.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R10-07
RDB Project NR 510-070

Manuscript submitted October 15, 1952

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A DECADE FREQUENCY GENERATOR FROM A SINGLE FREQUENCY ORIGIN

INTRODUCTION

The purpose of this project is to develop techniques which will make possible the construction of equipment which will produce, from a single 100-kc input frequency, an output frequency which is variable in one-cycle steps over a range of 1 cycle to 100 Mc by means of eight decade units. This output must be completely dependent upon and must maintain the original accuracy of the input. Extraneous signals and sidebands must be sufficiently low that harmonics of the output can be used in frequency measurements and control.

For a system of this nature to operate satisfactorily it is necessary that the arrangement of the frequencies used in the synthesization be such that the extraneous beats or modulations produced can be easily filtered. In the past this has been a major drawback due to filtering limitations when small incremental changes are required. In other systems, an additional variable oscillator is added to produce the low order increments (usually from 1 kc down to 1 cycle). At high frequencies, the errors in the variable oscillator, which are always added, are small compared to the lowest frequency increment. However, as the frequency is decreased, the percent error becomes more and more appreciable. By using the equipment shown in Figure 1, the output is not only variable in one-cycle steps, but can be decreased to any desired increment merely by the addition of an extra interchangeable digit control section (Figure 1c). Also the output frequency retains the same percentage accuracy as the driving frequency, and at no point in the system is a sideband generated which cannot be filtered. The equipment itself is constructed of small individual plug-in chassis or digit control sections which can easily be replaced and four of these are directly interchangeable. In the final equipment, the control knobs will be arranged as shown in Figure 1d and, in addition, indicators for the frequency controls will be placed at the top right-hand side of the equipment in a row so that the output frequency can be read directly. In addition to the ten positions in each decade, one more position will be provided which will overlap the next decade. This feature should prove quite useful when determining selectivity curves. At the top left-hand side of the equipment, a comparison oscilloscope will be provided by which proper operation of the equipment can easily be determined. Also, a band switch may be required.

SYNTHESIZATION

The synthesization system, shown in block diagram in Figure 2, consists of eight decade sections, each of which controls one digit in the output frequency. A block of 10-kc harmonics from 100 to 200 kc is generated from the basic 100-kc source and fed simultaneously into the inputs of the first five sections. The first four of these sections are of identical construction and operation.

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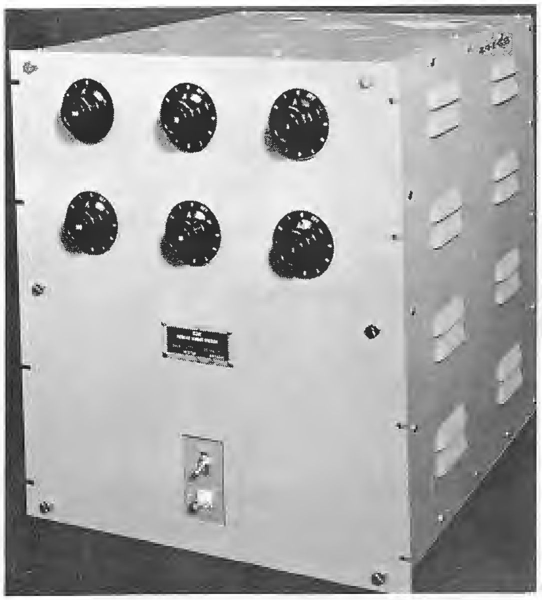

Figure 1a - Panel of equipment completed at present

Figure 1b - Side view

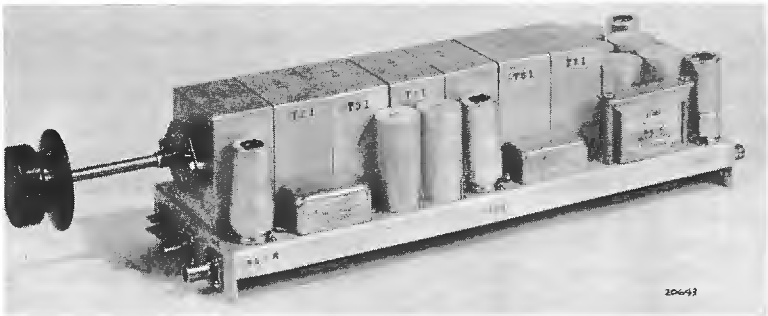

Figure 1c - Single digit control section

Figure 1d - Sketch of panel as it will appear when completed

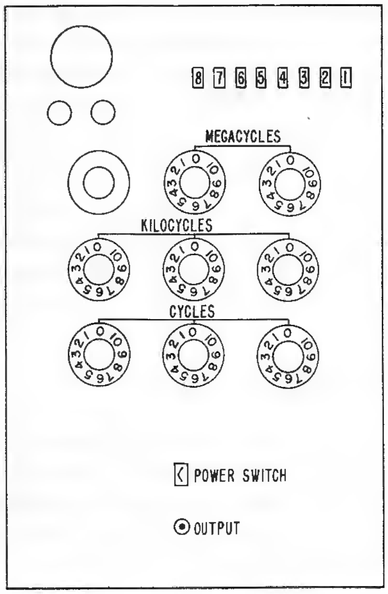

Figure 1 - The decade frequency generator

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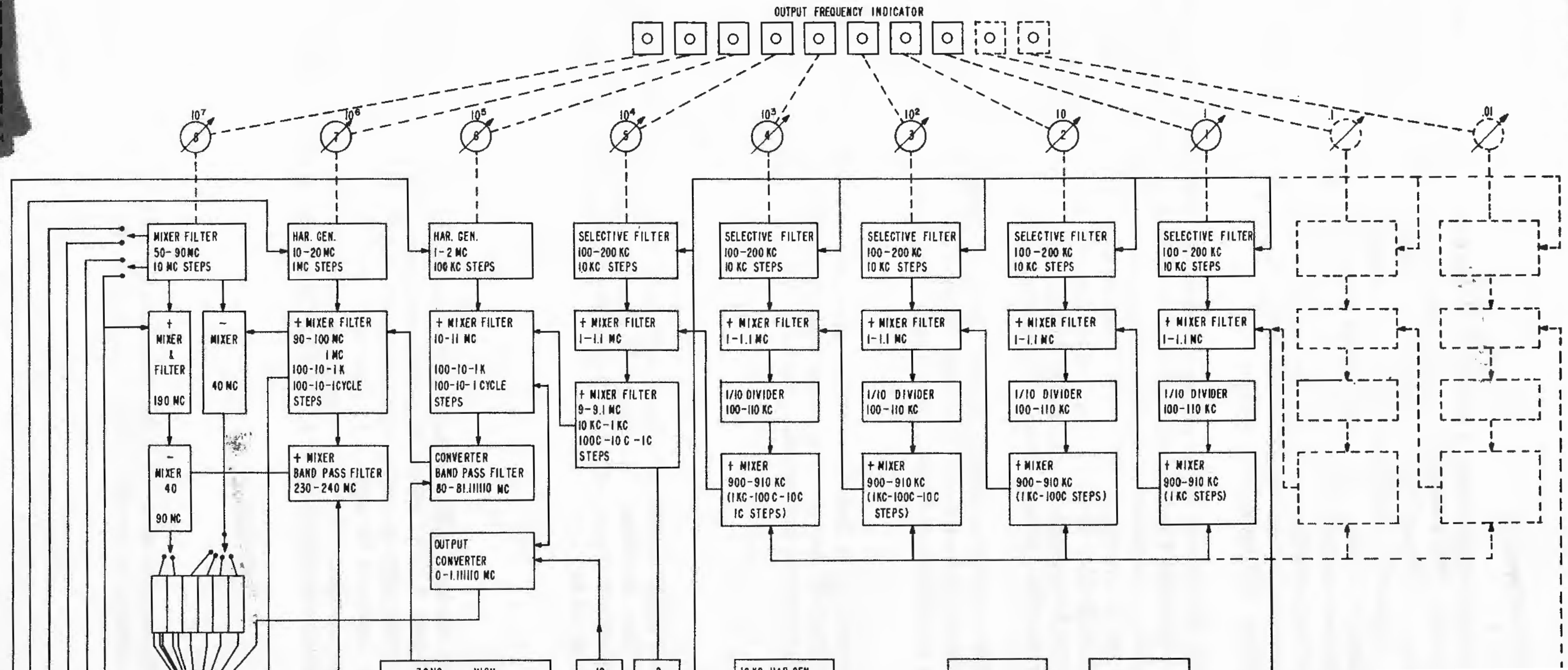

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First Four Digit Control Sections

In the first block of the first digit control section, individual frequencies from the input block are selected and filtered. The lowest frequency selected is 100 kc and is raised in increments of 10 kc to 200 kc. A fixed 900 kc generated from the 100-kc driving source is added in the second block. Since the increments are not changed, the frequency varies from 1000 to 1100 kc in steps of 10 kc. The third block consists of a ten to one divider which divides both the frequency and the increments so that the lowest frequency is again 100 kc but is now raised in increments of 1 kc to an upper frequency of 110 kc. In the last block a fixed 800-kc, derived from the 100-kc driving source, is added, thus making the output variable from 900 to 910 kc in 1-kc steps.

The second digit control section is identical in construction and operation to the first, except that, instead of the fixed 900 kc, the output of the first section is added. The frequency at this point is therefore variable in 10-kc increments by the input selector and by 1-kc intermediate steps from the variable 900- to 910-kc output of the first section. When the signal passes through the divider of the second digit control section both sets of increments are divided, making the frequency at this point 100 kc plus 1-kc increments controlled by the second section and plus 100-cycle increments controlled by the first section.

Each digit control section which is added reduces the increments by a factor of 10. Therefore to produce one-cycle increments, four digit control sections are required. If increments of a fraction of a cycle are needed, additional digit control sections may be added.

To provide complete coverage in decade relation nine equal increments (ten frequencies) are required for each digit control section. However ten increments (eleven frequencies) are used in this equipment to provide an overlap position for each digit control section.

Fifth Digit Control Section

The first part of the fifth digit control section, including the 1- to 1.1-Mc timed filter, is identical to that of the first four sections. As shown in Figure 2, this 1 to 1.111110 Mc signal is added to 8 Mc in the third stage of the fifth section to produce 9 to 9.111110 Mc variable in steps of 1 cycle to 10 kc.

Sixth Digit Control Section

In the sixth digit control section, 100-kc steps are obtained by selecting individual 100-kc harmonics between 1 and 2 Mc. When this frequency is added in the second stage to the 9 to 9.111110 output of the fifth section, a frequency is produced which is variable in steps of 1 cycle to 100 kc between 10 and 11.111110 Mc. The filter in this stage is varied in 100-kc steps by the ganged switch. A 70-Mc signal is added in the third stage to produce an output, through a bandpass filter, of 80 to 81.111110 Mc variable in steps of 1 cycle to 100 kc.

Seventh Digit Control Section

The seventh digit control section selects 1-Mc harmonics between 10 and 20 Mc and adds the output of the sixth section to produce 90 to 101.111110 Mc variable in steps of 1 cycle to 1 Mc.

[redacted]

Eighth Digit Control Section and Output

The eighth digit control section is somewhat more involved since it not only must introduce the 10-Mc increments but must also convert the output so that the increments begin at zero. Individual harmonics of 10 Mc between 50 and 90 Mc are generated by mixing 20, 40, 50, and 100 Mc in the following sequence:

90 = 50 + 40

80 = 100 - 20

70 = 50 + 20

60 = 100 - 40

50 = 50.

These signals are then presented simultaneously to two mixers. In the first mixer a direct beat is obtained against the 90 to 101.111110 Mc output of the seventh section producing the following outputs:

90 to 101.111110 - 90 = 0 to 11.111110 Mc

90 to 101.111110 - 80 = 10 to 21.111110 Mc

90 to 101.111110 - 70 = 20 to 31.111110 Mc

90 to 101.111110 - 60 = 30 to 41.111110 Mc.

These are presented to the appropriate output filter. In the second mixer the selected 50- to 90-Mc signal is added to 100 Mc to produce 150 to 190 Mc in 10-Mc steps. After amplification this signal is mixed with 230 to 241.111110 Mc to produce the final output. This latter variable frequency is obtained by adding the 90 to 101.111110 Mc output of the seventh section to a standard 140-Mc signal. The following outputs are produced:

230 to 241.111110 Mc -190 = 40 to 51.111110 Mc

230 to 241.111110 Mc - 180 = 50 to 61.111110 Mc

230 to 241.111110 Mc - 170 = 60 to 71.111110 Mc

230 to 241.111110 Mc - 160 = 70 to 81.111110 Mc

230 to 241.111110 Mc - 150 = 80 to 91.111110 Mc.

These outputs in turn are fed into the appropriate output filters. The output switch, ganged with the 10-Mc switch, selects the output from the appropriate filter. In the 90- to 100-Mc position the output of the seventh unit is fed directly to the final output. Provision is made in the first position of the output switch for obtaining 0 to 1 Mc without using the high order decade sections since it is not necessary to use the upper decade ranges when an audio output is desired and since it is unlikely that both the very low and very high frequencies will be used at the same time. This is done by making a special conversion at the sixth digit control section by beating the 10- to 11.111110-Mc signal with the standard 10-Mc signal to

[redacted]

produce an output essentially flat from 1 cycle to 1.111110 Mc, variable in decade increments of 1 cycle through 100 kc.

Special 0- to 300-kc Converter

In order to prove the feasibility of the system and to obtain an equipment useable at lower frequencies, an alternate fifth decade section as shown in Figure 3 was made at the addition of the 10-kc steps, in the fifth section, so that an output could be obtained from 0 to 300 kc. The signal as it comes from the second stage of section five is variable in steps of 1 cycle through 10 kc from 1 to 1.111110 Mc. When this signal beats against a standard 1-Mc signal, the final output will be 0 to 111.110 kc; against 900 kc, 100 to 211.110 kc; and against 800 kc, 200 to 311.110 kc. Standard frequencies of 800 and 900 kc are used because they are needed previously in the equipment. Since the mixing signals are still present, the output is fed through a low-pass filter which has a cutoff frequency of approximately 330 kc.

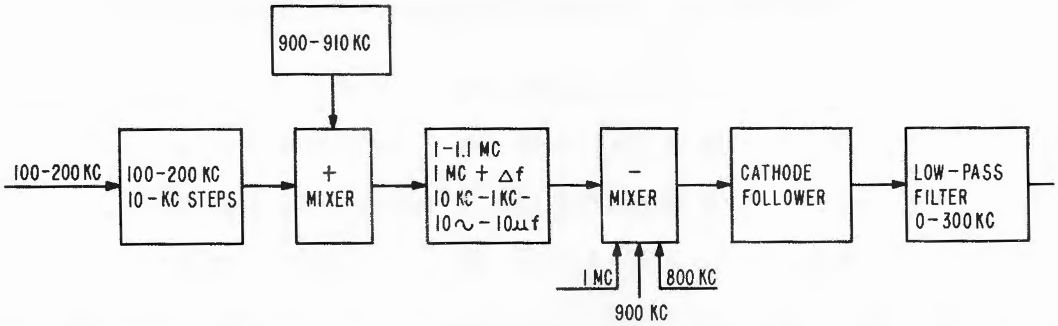

Figure 3 - Block diagram of 0-to 300-kc converter (alternate fifth digit control section)

DESIGN

10-kc Harmonic Generator (100 to 200 kc)

Originally the band of 10-kc points between 100 and 200 kc was to have been obtained by mixing 20 or 40 kc with 100, 150, or 200 kc as follows:

100 + 0 = 100
150 - 40 = 110
100 + 20 = 120
150 - 20 = 130
100 + 40 = 140
150 + 0 = 150
200 - 40 = 160
150 + 20 = 170
200 - 20 = 180
150 + 40 = 190
200 + 0 = 200.

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This arrangement has considerable merit in that the nearest sideband which appears in the mixing is 20 kc removed. The worst condition exists at 180 kc where the sideband is 200 kc, or 11 percent removed. The major drawback of this system was the large variation in voltage between the various mixed voltages and those at 100, 150, and 200 kc where no mixing occurs. Also several switch sections are necessary to select the proper mixing signals.

Since the selecting system has to be repeated in each of the first five synthesizing sections it is advisable to combine as many of the operations as possible. In view of this fact it was decided to produce the entire block of 10-kc harmonics between 100 and 200 kc and arrange the synthesizing sections to select the desired frequencies. In this case the nearest sideband would be 10 kc removed or at the worst condition, where 190 kc must be filtered from 200 kc, it would still be 5 percent removed. This separation is sufficient to permit good filtering.

In the analysis of a pulse it is found that the length of the pulse determines the relative level of the higher order harmonics. Figure 4 shows the relative strength of the harmonics produced by a 5-μsec pulse formed from the tip of a 10-kc sine wave. The purpose of the 10-kc harmonic generator (100 to 200 kc) (Figure 5) is to produce, from the 100-kc standard, a 10-kc pulse sufficiently short to have harmonics of relatively even amplitude between 100 and 200 kc and to filter the output so that only this block of harmonics appears.

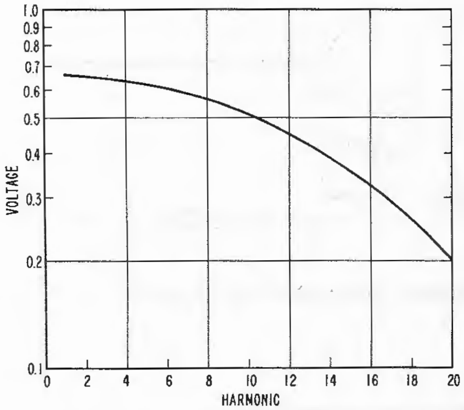

Figure 4 - Relative amplitude of harmonics present from the 5-μsec tip of a 10-kc sine wave

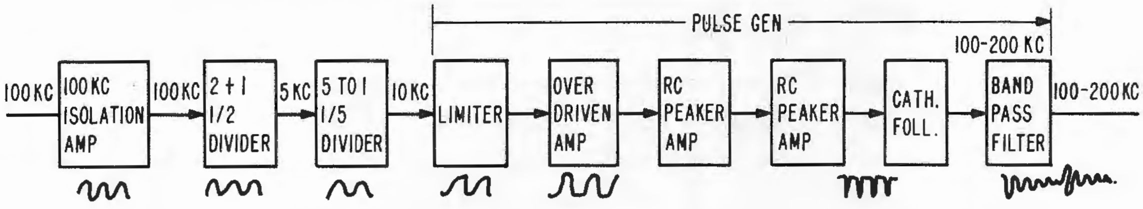

Figure 5 - Block diagram of the 10-kc harmonic generator for frequencies between 100 and 200 kc

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The 100 kc from the standard is fed into a tuned 100-kc isolation amplifier. This amplifier prevents any feedback of unwanted signal on the 100-kc line and also insures that enough voltage is present to establish a firm "lock" in the locked oscillator dividers which follow. The 2 to 1 and 5 to 1 dividers are tuned-plate, shunt-fed impedance-stabilized locked oscillators which will be discussed later. The dividers used in this unit will remain in lock with as low as 0.025 v of 100 kc on the input of the amplifier and will remain in lock with a supply voltage variation of 50 to 300 volts.

The sine wave output of about 10 volts from the divider stages is fed into the first half of a twin triode which acts as a limiter, flattening the top of the sine wave. The second half which is an overdriven amplifier flattens the bottom of the wave. This square wave is fed through two RC peaker and amplifier stages to the grid of a cathode follower output stage.

Analysis of the pulse thus obtained (Figure 6) shows that it contains all the 10-kc harmonics between the tenth and the twentieth at approximately the same amplitude. The total drop in voltage between the 100-kc point and the 200-kc point is only 1.12 db. A bandpass filter is placed in the output to pass only the desired block of harmonics (Figure 7).

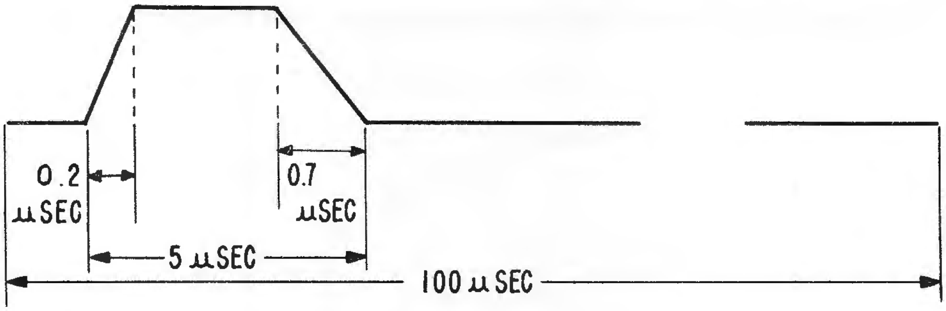

Figure 6 - Pulse obtained from pulse generator in 10-kc harmonic generator

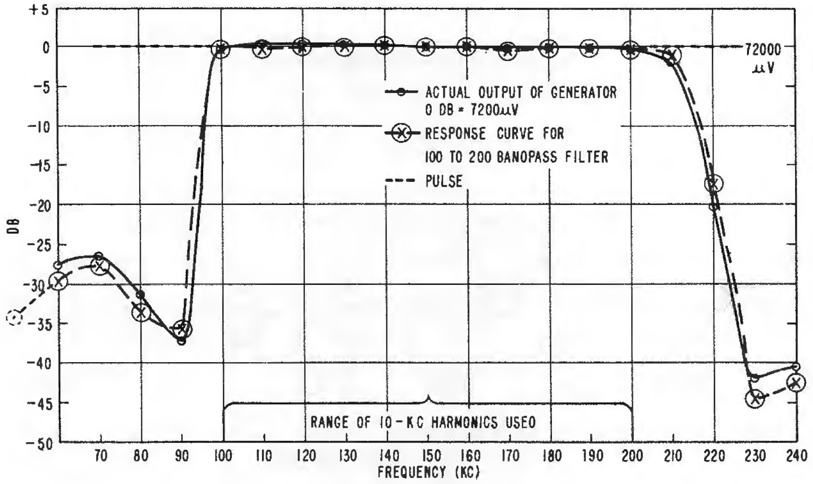

Figure 7 - Output and filter characteristics of 10-kc harmonic generator

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800-kc, 900-kc, and 1-Mc Generators

The 800-, 900-, and 1000-kc generators, except for the tuning of the filters, are of identical construction and operate in essentially the same manner. Each unit, as shown in Figure 8, consists of two harmonic generators with triple-tuned filters in their plate circuits and a tuned output amplifier with a low impedance output coupling coil.

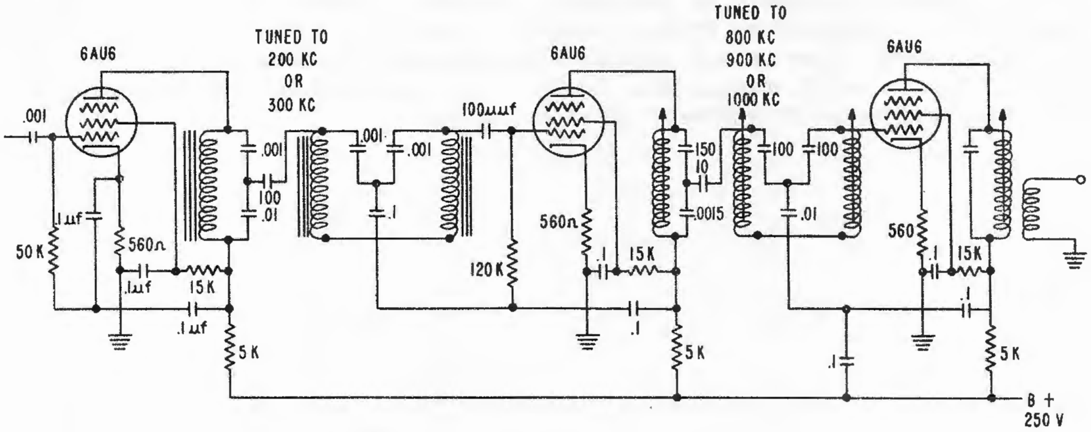

Figure 8 - Circuit of the 800-kc, 900-kc, and 1-Mc generators

The filter of the first harmonic generator is tuned to 200 kc in the 800- and 1000-kc units and to 300 kc in the 900-kc unit. This filter consists of three identical coils wound on toroidal dust cores. The Q's of these coils are approximately 100 and the resonant impedances are in the vicinity of 100K ohms. Each coil is enclosed in a soft iron can. Coupling between the coils is made at critical coupling. The method of coupling shown in Figure 8 was chosen because of ease of construction, impedance at the coupling elements, and the fact that additional discrimination is obtained against the lower frequency sidebands.

The second filter which is tuned to 800, 900, and 1000 kc in the respective units is of similar construction except that the coils are universal wound pi on coil forms with variable slugs. A considerable amount of variation in tuning can be obtained in this manner without disrupting the coupling. The output section of these generators is a normal tuned output amplifier with a low impedance output coupling coil. All sidebands on the output frequencies of these units are well over 100 db below the desired frequency.

Low-Frequency Digit Control Sections

The most distinctive part of the system is in the operation of the first four digit control sections. These sections are of identical construction and may be used interchangeably. Additional sections may be added to obtain smaller increments of frequency; each added section reduces the frequency increment by a factor of 10. The operation of each of these sections can be broken into four parts as shown in Figure 2.

A 100- to 200-kc block of equal amplitude 10-kc harmonics from the harmonic generator unit is fed into the input amplifier. Selection of individual frequencies is made by a triple-tuned switched section which consists of three identical tuned circuits. The coils are wound of litz wire on a μ 14 toroidal dust core. Variation in inductance is obtained by tapping the lower end of the coil. In the actual construction the taps are physically spaced around the toroid to correspond to the position on a switch wafer. The wafer then is mounted very close to the coil and actually acts as the coil support.

The switch shaft extends through the center of the toroid. This type of construction allows the unit to be built very compactly, and, with soft iron shield cans around each tuned circuit, affords little chance for extraneous couplings. Coupling between the coils is made capacitively, at slightly over critical coupling, resulting in a flattening of the top of the selectivity curve. Some misadjustment in the placement of the taps is therefore permissible without a drop in output voltage from the filter. A representative selectivity curve for the 10-kc harmonic selector section is shown in Figure 9.

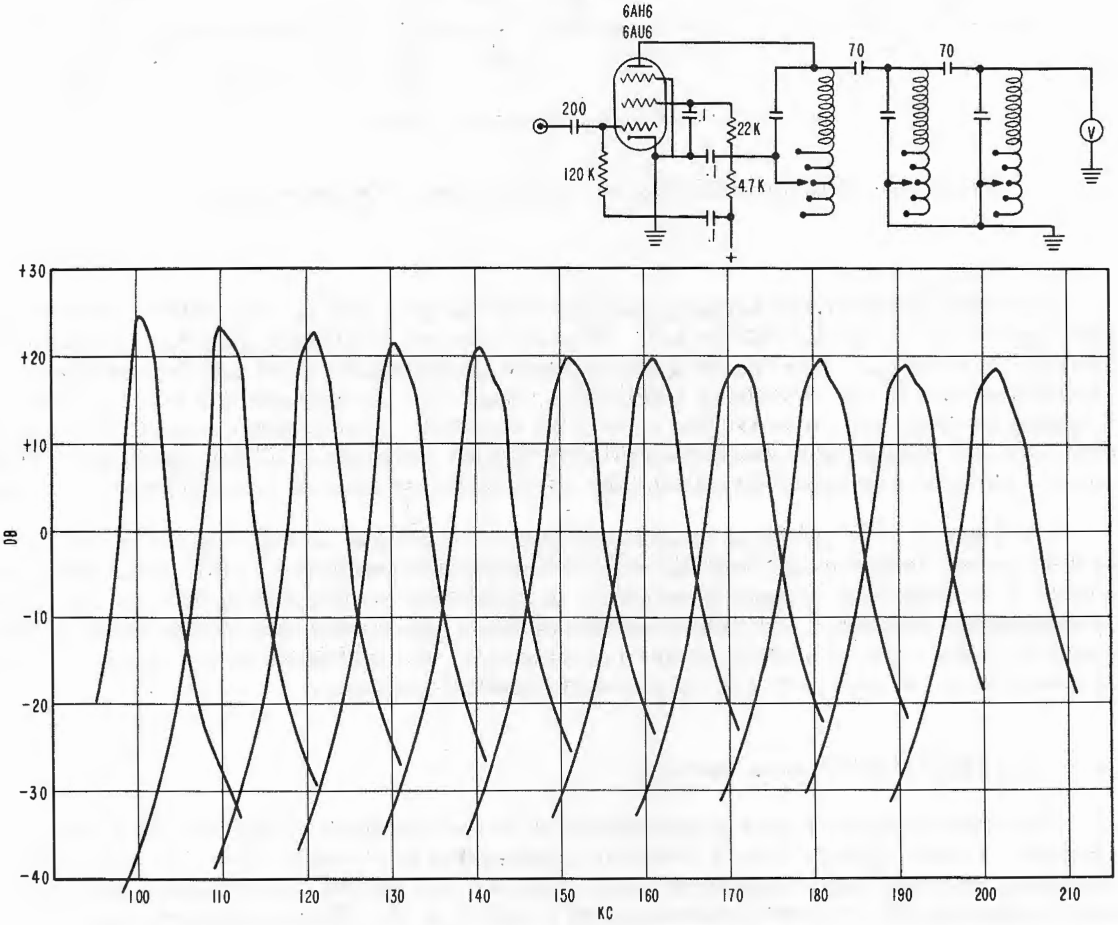

Figure 9 - Response of triple-tuned circuit used in the first four digit control sections

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The 900-kc mixer and filter (Figure 10) takes the selected 10-kc harmonic from the preceding filter and adds it to the standard 900-kc or 900-kc + Δf* signal. It also amplifies the resultant 1 Mc + Δf signal and filters out the unwanted sidebands.

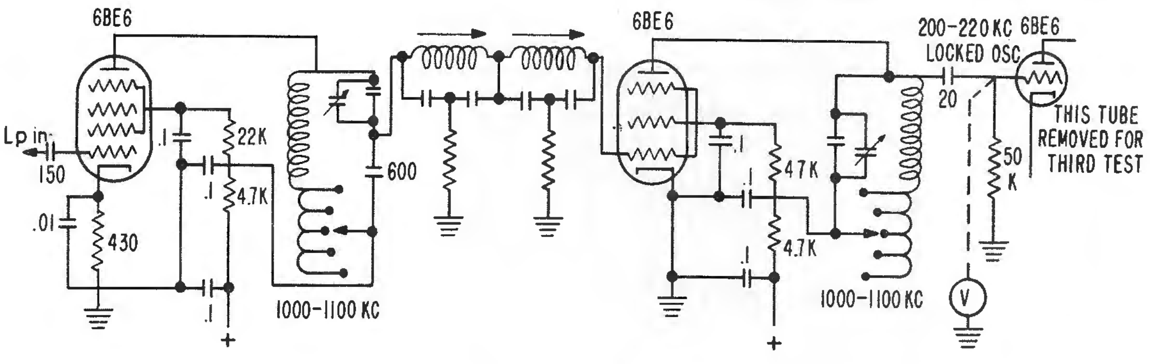

Figure 10 - Circuit of the 900-kc mixer and filter used in the first four decade sections

The mixer is a converter-type tube with the 900 kc + Δf on the first grid and the selected 10-kc harmonic on the signal grid. By keeping the level on the signal grid quite low, 0.1 volt or less, the generation of harmonics of this input is reduced to a negligible value. It can be seen that if harmonics of this signal exist in the vicinity of 900 kc, unfilterable sidebands would be produced by mixing with the 900 + Δf input. For example, if, when the harmonic selector is presenting 100 kc to the grid of the mixer, the ninth harmonic is present at 900 kc and if 900 kc + Δf is set at 900 kc + 1 cycle, a one-cycle sideband will be produced in addition to the desired output of 1 Mc + 1 cycle.

The inductance in the tuned circuits which follow the mixer and the amplifier of Figure 10 are identically constructed of two toroidal dust cores. One is wound with the bulk of the winding and the other with the tuned section of the winding. When the bulk and the tapped section are wound on the same core it becomes difficult to adjust the taps due to the interaction between the bulk and the unused turns on the tapped section. Also the distance between the taps is only one turn and it is extremely difficult on a toroidal coil to adjust to parts of a single turn. When the tapped section is wound on a separate core the turns vary more directly with frequency, therefore, if 100 turns are used to tune to 1100 kc, approximately 110 turns will be needed at 1000 kc, and each turn will represent a 10-kc change.

Due to the fact that the 900 kc + Δf input is large, an appreciable amount appears on the plate of the mixer and if allowed to pass through the following amplifier would appear on the locking grid of the divider oscillator. If this were to happen some interaction is possible when locking the oscillator from frequencies close to 1 Mc since a 1/9 lock from the 900 kc would fall at 100 kc. Also the presence of both 1 Mc + Δf and 900 kc + Δf on the oscillator may result in a mixed signal at 100 kc which would attempt to lock the oscillators. In order to prevent this occurance, two bridged T rejection filters were added between the mixer and the amplifier. These circuits are tuned one above the other and slightly above 900 kc.

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* The term Δf equals the added increments from the lower digit control sections.

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The output of this section is 10N + 900 + Δf kc and lies between 1000 kc and 1100 + Δf kc. The tuned circuits are switched at each 10-kc interval in tandem with the switching of the 10-kc selector. Since no variation in tuning follows the change of Δf the selectivity of the circuit, as shown in Figure 11, must be broad enough at each 10-kc point to cause a negligible drop in voltage over this range.

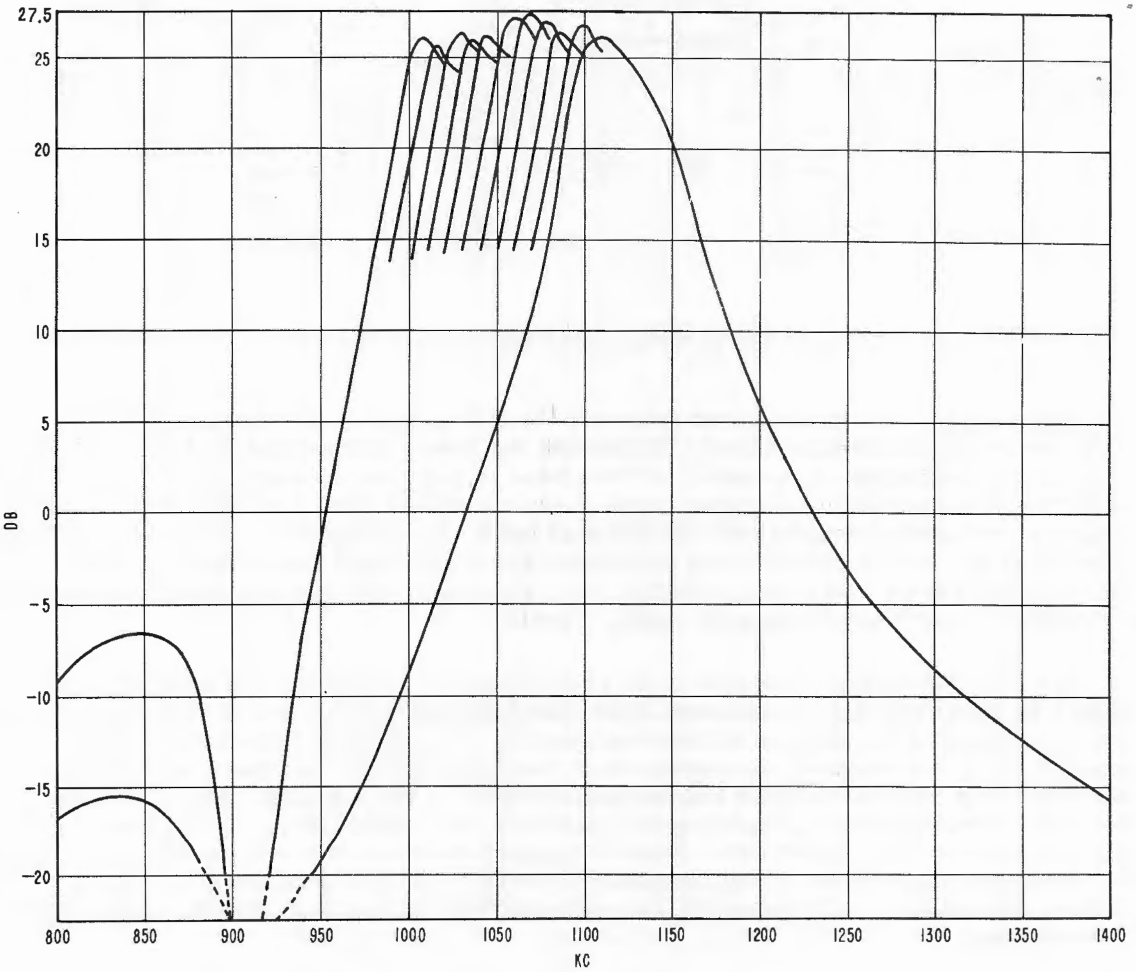

Figure 11 - Selectivity of the filter used in the first four digit control sections

The divider which follows, consists of two tuned-plate locked oscillators; the first divides the signal by two and the second divides the output of the first by five making a total division of ten. The tuned-plate locked oscillator (Figure 12) is ideally suited in this usage. The oscillator tubes are of the converter type having a separate grid for the injection of the locking voltage. This arrangement allows a wider locking range with less effect on the output voltage. The effective gain by injecting the locking voltage on the first grid permits the use of a smaller voltage. By impedance stabilization and by the use of very tight coupling between the plate and feedback coils, the effects of variation in supply voltage are reduced to a negligible amount. Tuning of the plate coil is effected by tapping the inductance. Taps

[redacted]

are made in the 500- to 550-kc oscillator at each 5 kc and in the 100- to 110-kc oscillator at each 1 kc. Each oscillator therefore is required to "pull" over the range between the taps as required by the variation of Δf. To insure that the oscillator will pull over this range (approximately 1 percent) a minimum total locking range of 2 percent is needed. A total locking range of approximately 7 percent was achieved in the final oscillator design. This allows a large margin of safety to absorb variation which may occur due to misadjustment of the tuning taps or aging of the circuit. Wide locking range is acquired by keeping the Q of the tuned circuit low, the L/C ratio high, the grid to the plate turns ratio nearly unity, and the coupling between the grid and plate as high as possible.

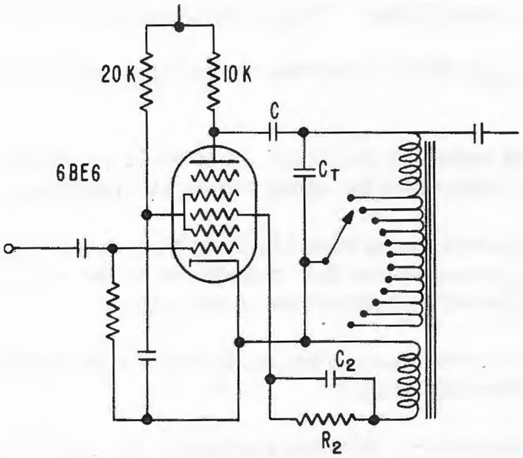

Figure 12 - Circuit of tuned-plate locked oscillator

When a locked oscillator is operated as a divider, good locking will not occur unless the harmonic content is high in the vicinity of the locking frequency. To achieve this two things are done. First, the iron used in the dust cores of the oscillator transformers is of a much higher μ than that which gives a maximum Q at the operating frequency of the oscillator. This not only reduces the Q of the circuit but also causes distortion in the feedback voltage, thereby producing harmonics. Secondly, the RC circuit in the feedback loop passes the higher frequency harmonics while attenuating the fundamental. The locking range of the 2 to 1 divider is adjusted to approximately 10 percent and the locking range of the 5 to 1 oscillator to approximately 7 percent. In addition to the division, the locked oscillators perform another important duty. The effects of any sidebands which existed on the locking voltage are greatly reduced if not entirely wiped out at the oscillator output. This is due to three facts: first, only one frequency can be divided at a time; second, because division has occurred, the frequency of the oscillator output is far removed from most of the sideband frequencies; and third, those frequencies which lie extremely close to the locking or output frequency of the oscillator so as to produce modulation of the output frequency are reduced because the amplitude of the locking voltage, and therefore the sidebands, is much lower than the output voltage of the oscillator.

A standard 800-kc signal is added to the output of the divider section to convert the signal back to the vicinity of 900 kc. At this point, Δf represents a maximum change of 11,110 cycles or approximately 12 percent of the 900 kc + Δf. Since the change is so small it is not necessary to switch the tuning of the mixer and output circuits. However, it is important that the 800-kc mixing voltage be rejected since in the following decade section

[redacted]

several interfering sidebands could be produced:

$$900 + \Delta f - 800 = 100 + \Delta f$$

$$1000 + \Delta f - 800 = 200 + \Delta f$$

$$10N + 800 = 900 \text{ to } 1000.$$

Several arrangements were tried including M-derived bandpass filters and bridged T rejection filters at 800 kc. The arrangement finally adopted (Figure 13) contains four critically coupled tuned circuits following the mixer which, together with the output tuned circuit, forms a stagger-tuned filter. This arrangement afforded several advantages:

1. Because of the large skirt rejection of this type of circuit, sufficient rejection is obtained at 800 kc.

2. Since the coupling between the tuned circuits is at critical coupling or less, and since variable slug coil forms may be used, tuning is simplified.

3. Not only may the circuits be tuned to pass the proper band of frequencies, but the tuning may be adjusted to compensate for variations in the signal input level, thereby producing frequencies of more equal amplitude in the output.

4. High impedance is presented to the plates of the mixer and output amplifier, thereby increasing the over-all gain.

A representative selectivity curve for this section is shown in Figure 14.

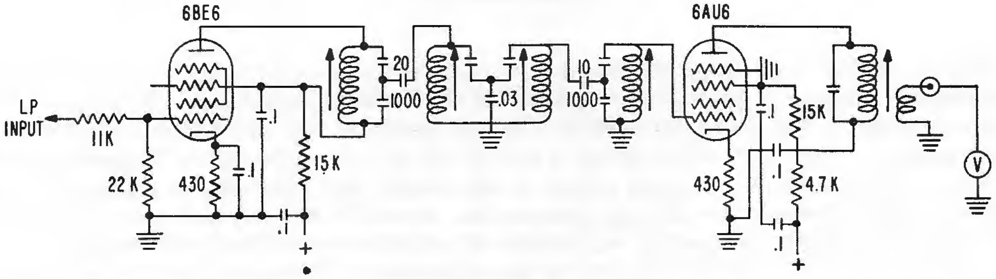

Figure 13 - Circuit of output filter of first four digit control sections

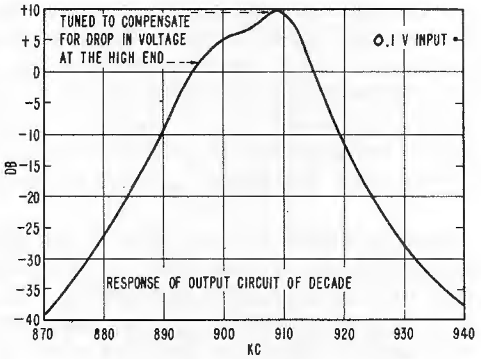

Figure 14 - Response of output of first four digit control sections

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Fifth Digit Control Section

The main function of the fifth digit control section is to introduce 10-kc increments in the output frequency by means of the 10-kc selector, the 900-kc + Δf mixer and filter, and the 1000 kc + Δf + 8 Mc mixer and filter.

The function of the first two parts is identical to that of the first two parts of the lower order decade section, as previously described. However, since this unit has no divider sections, other means must be used to gain sufficient filtering. The 10-kc selector, instead of having an amplifier and a triple-tuned circuit, consists of two amplifiers with double-tuned filters in their plates.

The 900 kc + Δf mixer and filter section is also identical to that of the lower decade sections except that an additional tuned circuit is introduced between the mixer and the amplifier.

Except for the difference in tuning, the 8-Mc mixer, filter, and output are identical in construction and operation to the 800-kc mixer, filter, and output of the first four decade sections (Figure 13).

0- to 300-kc Output Converter

In order to prove the feasibility of the lower order decade system and to provide an interim equipment, an alternate fifth decade section (Figure 3) was designed and constructed to produce an output of 0 to 300 kc variable in steps of 1 cycle to 10 kc.

The 10-kc selector and the 900 + Δf mixer and filter are identical to those of the regular fifth section. In place of the 8-Mc mixer a converter system was substituted as shown in Figure 15. This circuit in this application has several advantages over other types of converters which have higher conversion gains. Very little distortion is produced in the mixing, thereby allowing the output to approximate a sine wave more closely. The output impedance is quite low, thereby facilitating the design of the output filter. The frequency response (Figure 16) is exceptional, extending as low in frequency as desired. In testing the unit, additional low frequency decade units were inserted in the system so that increments of 0.01 cycle were available. When this was applied to the converter to produce a 0.01 cycle output it was found that not only did the output level remain constant but, as displayed on a recording ammeter, contained very little distortion. Because of the presence of the input mixing signals and the plus mixed signal, a low-pass filter is necessary at the output.

This filter consists of two constant K center sections terminated by N sections. The high frequency cutoff is at 330 kc and the terminal impedance is 500 ohms. The above circuit operates satisfactorily at 300 kc and below.

CONCLUSIONS

An equipment can be built within reasonable size, weight, and power limits which will produce, from a single fixed frequency source, an output which is variable in one-cycle steps from one-cycle through 100 Mc and which retains the original accuracy of the source. The technique for obtaining the low-order increments and frequencies has been incorporated in a test model and found to operate very satisfactorily. Increments to as low an order as desired can easily be obtained with the addition of identical low-order digit control sections. Development is being continued to produce an equipment, using the complete technique, which has an output range of 1 cycle to 100 Mc.

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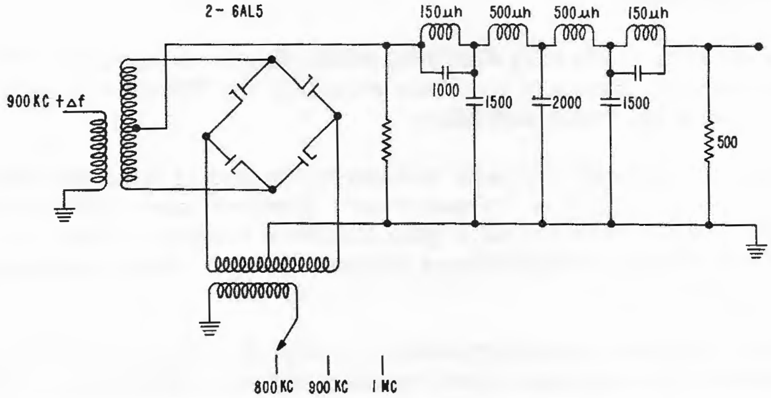

Figure 15 - Circuit of 0- to 300-kc converter replacing 8-Mc mixer in fifth digit control section

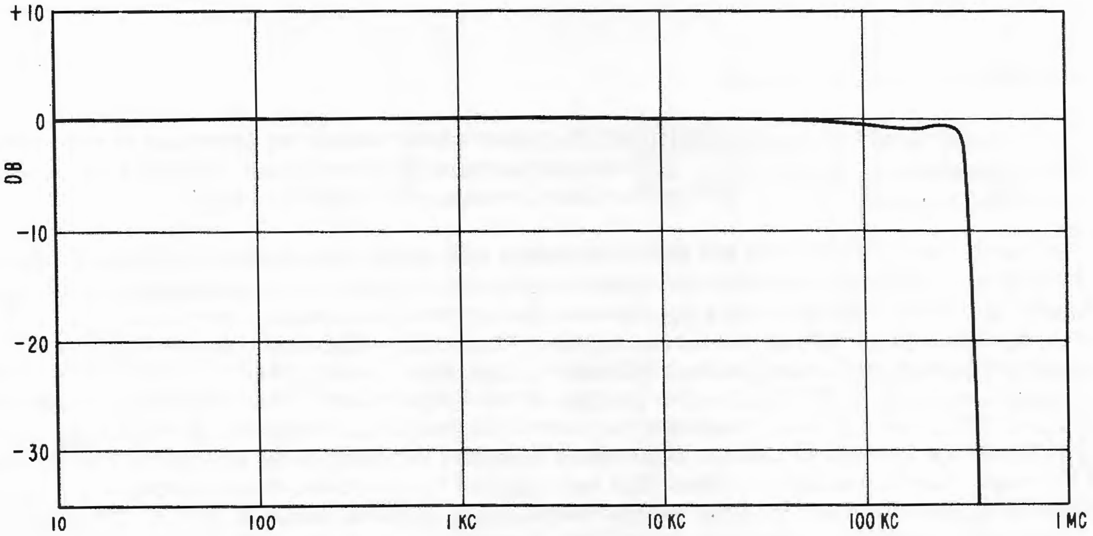

Figure 16 - Frequency response of the first five digit control section using 0- to 300-kc converter

ACKNOWLEDGMENT

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