

XI. TRANSISTORS

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A. I-F AMPLIFIER DESIGN STUDY

A theoretical design procedure for multistage bandpass point-contact transistor amplifiers having, within broad limits, both prescribed frequency response and gain is now under investigation. The transistors are regarded as purely resistive devices (that is, operated below the α cut-off frequency), and the dissipative interstage networks are designed with their unloaded Q 's as parameters. Attention has been given to the simplicity of the interstage networks, and coupled coils are avoided in the design except in those places where they are both practical (loose-coupled) and simpler than the network which would otherwise replace them. For well-known practical reasons only the grounded-base connection of the point-contact transistors is considered.

A simple dissipative impedance in series with the emitter occurs automatically in the design. Since there is some freedom in the choice of this impedance, a measure of compromise can be made between isolation, stability, gain per stage, and freedom from the effects of transistor parameter variations. The design proceeds by realizing the pole configuration of the prescribed response, one pair per stage. More than one pair per stage may be realized if additional complication of the interstage networks is acceptable. It is believed that within the practical range of coil Q 's available, a very much wider range of over-all Q 's can be obtained along with great freedom in the over-all gain. The precise limits between which over-all Q and over-all gain may be varied independently in this design procedure, with a given coil Q , is currently the subject of the theoretical study.

Experimental design of a three-stage amplifier to realize a Butterworth characteristic with an over-all Q of 20 is now in progress. It is expected that other amplifiers with much lower Q (approximately 4) and much higher Q (approximately 200) will be designed and tested in the future.

M. Boisvert, S. P. Kurtzman

B. BROAD-BAND I-F AMPLIFIERS*

The practical design of a six-stage, broad-band i-f amplifier with point-contact transistors is still under study. A bandwidth of approximately 2 Mc/sec, at a center frequency of approximately 3 Mc/sec, is specified. The design is based upon three

* An asterisk denotes work that has been undertaken in cooperation with members of Lincoln Laboratory under Contract AF19(122)-458. This report is therefore duplicated in the Lincoln Laboratory Quarterly Progress Report.

synchronously tuned pairs, one pair tuned at band center and the others near the band edges. The synchronously tuned pairs have up to now been close-coupled, but loss is added for isolation between the pairs. In the design of each pair, the output impedance of the first transistor and the input impedance of the second may become inductive because of the frequency dependence of α . To maximize the gain, a conjugate match would be desirable. This proves to be difficult over a wide band, but if accomplished at one frequency the gain is improved. The skirt behavior is still not satisfactory, however, and such close-coupling in each pair may have to be discarded eventually.

In the course of these investigations an oscilloscopic method of measuring complex input impedance has been devised. Accuracy of measurement is approximately 5 percent. The results check well with a theory in which the current gain of the transistor is taken in the form

$$\alpha_e = \frac{\alpha_o}{1 + \tau s}; \quad \tau = \frac{1}{2\pi f_{co}}$$

but for $f \gg f_{co}$, where f_{co} is the cut-off frequency, the effect of stray capacitance must be included. It is found that emitter bias current controls the input impedance much more than does the collector-current bias.

Six transistors were chosen for the amplifier by selecting units for which $f_{co} > 4$ Mc/sec. The pair used at midband are Western Electric 1725 transistors; those used at the band edges are General Electric G11A transistors. Unfortunately, the passbands are all near enough to the α cutoff's so that considerable dissymmetry in the response results from the frequency dependence of α .

J. W. Vorndran

C. RECEIVER STUDY*

A receiver-circuit study has been undertaken to determine the technical feasibility of employing transistor circuits in reasonably light-weight mobile communication receivers. The emphasis is on maintaining the same operational specifications as are available in an existing vacuum-tube receiver, but with a maximum reduction in the power drain from the mobile-unit battery supply. A developmental Signal Corps receiver has been selected as the foundation for this study.

The following portions of the receiver will be studied for operation with transistors of both the point-contact and junction types:

- | | |
|------------------------------|------------------------------|
| 1. Audio amplifier | 4. Beat-frequency oscillator |
| 2. 455 kc/sec i-f amplifier | 5. Noise limiter |
| 3. Detector and AGC circuits | 6. Crystal calibrator. |

It is expected that a redesign of the above portions of the receiver from vacuum-tube to

(XI. TRANSISTORS)

transistor circuits will save 40 watts of supply power (out of a total of 70 watts required by the present complete vacuum-tube receiver).

At first, point-contact transistors alone will be considered for all six portions, in order to become familiar with the problems rapidly despite the present insufficient supply of junction units. It is expected that this supply problem will be relieved by the time the point-contact study is completed.

The audio-amplifier specification requires a bandwidth suitable for voice transmission, and an output of 200 mw into a 600-ohm load. An audio amplifier employing Western Electric 1698 transistors has been completed. The output stage comprises two transistors in class A push-pull, driven by a single-ended driving stage transformer coupled to its input. All transistors are connected in grounded-base configuration. The characteristics are:

1. Output power into 600 ohms (with approximately 5 percent distortion) - 100 mw
2. Audio signal input power - $10 \mu\text{w}$
3. Total audio power gain - 10,000
4. Total dc supply power - 550 mw
5. Frequency response (between 3-db points) - 40 cps to 7 kc/sec.

These results indicate that a push-pull parallel combination of junction transistors could provide the 200-mw specification.

A simple crystal-diode detector circuit at the input of the audio amplifier worked very satisfactorily. Approximately $25 \mu\text{w}$ of 50 percent modulated rf power was required to produce 100 mw at the load.

The 455 kc/sec i-f amplifier specifications require three bandwidths:

1. 2 kc/sec between 6-db points; 10 kc/sec between 80-db points
2. 4 kc/sec between 6-db points; 14 kc/sec between 80-db points
3. 8 kc/sec between 6-db points; 26 kc/sec between 80-db points.

Previous experience with other transistor receivers suggests that it may be very difficult to achieve the required selectivity and variability with conventional components in the interstage coupling networks. While such a design will, nevertheless, probably be attempted later, attention has first been focused on the possibility of using electromechanical filters to provide the selectivity at some low-level section of the amplifier. This selective section will be followed by additional gain stages using broad-band coupling networks of high power-efficiency. The electro-mechanical filters developed by Collins Radio Company, Incorporated, appear from their specifications to be satisfactory for this service, and one of these units is on order.

W. E. Morrow, Jr., S. Schwartz

D. DISCRIMINATOR*

A preliminary study of discriminators has been carried out using n-p-n junction transistors. At a center frequency of approximately 2 kc/sec, linear response over a range of ± 25 cps has been achieved. The sensitivity is approximately 0.1 volt/cps. Fluctuations in sensitivity have been correlated with the "channel effect."

In conjunction with the discriminator study, some limiter circuits tuned at corresponding frequencies have also been considered. A single n-p-n junction stage in the grounded-emitter connection has performed acceptably. Limiting action occurs principally at the collector diode. The output varies by ± 10 percent for input variations of 10 to 1. Choice of bias influences greatly the actual input-signal level at which the "knee" of the limiter characteristic occurs. Differential phase shift between input and output is small in the working neighborhood of 2 kc/sec. Approximately 10-20 mw of supply power is required to obtain 1 mw across a 100 K load.

C. R. Hurtig

E. CIRCUIT NOISE PROBLEMS*

The general aim of this investigation is to discover circuit and system principles or techniques, if any, which will minimize the contribution made by transistors to the noise figures of circuits in which they may be involved. There is, of course, a very wide variety of possible specific systems which could be considered: amplifiers in various frequency ranges, mixers, detectors, limiters, and the like. Before any of these can be discussed, however, any special characteristics of transistor noise must first be appreciated. Moreover, valid equivalent circuits which place these special characteristics in evidence would be of great benefit in handling any particular problem.

To date, therefore, the first effort has been directed toward collecting and studying the available material on transistor noise characteristics, and making some preliminary confirmatory measurements of their noise spectra and the dependence of rms noise on the operating point. Further experimental work will be done on noise characteristics if the available data taken by others are insufficient or incomplete in any important respect. Since the "available" information on transistor noise is widely scattered, and not all published in the open journals, the collection of data and the planning of further experiments is a lengthy process.

On the basis of preliminary information a rather simple new equivalent circuit of the transistor has been proposed which places in evidence at least one special feature of the noise. The circuit contains one "noisy" resistor, along with other "noiseless" resistors. The fact that only one noise source appears, however, means that the circuit is not a general representation for an arbitrary noisy two terminal-pair network. On

(XI. TRANSISTORS)

the other hand, this is just the point; with but a single noisy element, the circuit can nevertheless be made to give the right order of magnitude for both the emitter and collector rms noise voltages from an "average" point-contact transistor. Moreover, it is also suggestive of one physical model for the origin of noise. Whether or not it can yield the other special characteristics of transistor noise cannot be determined until all these characteristics are known. The circuit itself suggests some further experiments, so future work will be aimed at a simultaneous determination of special noise characteristics and the validity of this convenient but very tentative equivalent circuit.

M. Strieby

F. DIRECTLY COUPLED AMPLIFIERS*

In previous reports, a method of balancing the I_{CO} (collector current with zero-emitter current) drift in junction transistors has been described. An unsatisfactory dynamic range of approximately 27 db was reported for the system when Bell Laboratory n-p-n transistors were employed. It was believed that the dynamic range was limited by the "channel effect" in these units.

Inasmuch as the structure of p-n-p alloy (or "fused") junction units appears less susceptible to "channel effect," the balancing circuit was again constructed and studied with two such transistors. The dynamic range obtained, over a range of ambient temperatures, was exceedingly low. To explain this surprising result, the variation of I_{CO} with temperature was checked for each of the four junctions on the two transistors. Except for one junction (which was actually used as emitter in transistor operation), the temperature dependence was close to that expected from theoretical considerations. The thermal properties of the local packaging around the junctions was, however, radically different for each one. This fact was determined from measurements of the manner in which the reverse current for each diode built up with time after the sudden application of reverse voltage. These differences have been shown to account for the failure of the balancing circuit to provide large dynamic range, although the reasons for the differences between junctions are not yet understood.

C. R. Hurtig

G. PHASE MODULATOR*

The crystal-controlled oscillator, in which the amplitude of oscillation was originally very sensitive to a change of transistors, has been improved considerably. After several circuit configurations were studied, the grounded-base connection, with crystal from emitter to ground, was finally adopted. Output is taken from the collector through an impedance-matching tuned circuit, which also provides sinusoidal waveform.

(XI. TRANSISTORS)

Amplitude control is provided by a variable resistance from emitter to ground. Output power is approximately 1 mw, with an over-all efficiency of 10 percent. Interchangeability of transistors is good; only small changes of amplitude occur with any 1698 transistor for which $\alpha > 2.3$ and $r_c > 15$ K. Frequency stability is that of the crystal.

J. C. Pinson

H. LOW-FREQUENCY OSCILLATORS*

Using n-p-n junction transistors, several audio oscillators have been designed at frequencies of approximately 2000 cps. These are not crystal-controlled, because it is desired that they should be capable of controlled frequency deviation. Two transistors are used in the oscillator design, with amplitude control incorporated by using diodes. Except for a warm-up drift of approximately 5 cps, the final oscillator is stable to within approximately 0.02 percent in frequency for a period of an hour at room temperature. The frequency drift has been correlated with "channel effect."

The oscillator requires approximately 200-mw power, and delivers approximately 20 volts (rms) across 33 K. The proper choice of an appropriate output transformer is important if the oscillator is to work near its maximum dissipation rating.

C. R. Hurtig