LB - 812

AN AUTOMATIC NONLINEAR DISTORTION ANALYZER

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
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Approved

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Introduction

This bulletin describes a system for automatically recording the nonlinear distortion frequency chasacteristic of a loudspeaker. The system consists of the standard automatic recorder for obtaining the response frequency characteristic, coupled with a system of electronically switched high-pass filters which suppress the fundamental, and pass the harmonics for obtaining the distortion frequency characteristic. Two characteristics are obtained on the same graph sheet, namely, the response frequency characteristic and the distortion frequency characteristic. The vertical displacement between the two characteristics thus obtained gives the amount of distortion at any frequency.

General Discussion

The nonlinear distortion characteristic of a loudspeaker is a plot of the total distortion, in per cent of or in decibels below the fundamental, versus the frequency at a specified power input. Although there are several good instruments commercially available for a "point-by-point" distortion analysis, the length of time required for such an analysis coupled with the possibility of overlooking narrow frequency bands of high distortion makes this type of equipment impractical for distortion analysis of loudspeakers. If the nonlinear distortion characteristic of loudspeakers is to be examined on a basis comparable to that with which the frequency response of a loudspeaker is obtained today, some sort of automatic equipment is required for obtaining the nonlinear distortion characteristic.

In general, loudspeakers exhibit unsymmetrical even harmonic and symmetrical odd harmonic distortions. However, the higher order components above the second and third are of such small magnitude as to be of secondary importance. Although, it may be useful to know whether the principle contribution to the overall distortion is due to second or third harmonic distortion, it appears that for most loudspeaker research and development work, an automatic recording system which depicts the total distortion produced by a loudspeaker would be very useful. It is to this end that a reliable system has been developed, designed and built by means of which the total rms distortion is automatically traced on the same graph sheet with the response, but vertically displaced on the logarithmic ordinate scale with respect to a conventional response frequency characteristic. This bulletin describes this system for obtaining the nonlinear distortion frequency characteristic of a loudspeaker or any other transducer.

Theory

The automatic nonlinear distortion analyzer consists of the conventional system for obtaining a response frequency characteristic of a loudspeaker coupled with an automatic means for suppressing the fundamental frequency (Fig. 1). The loudspeaker is supplied by a pure tone from a low-distortion oscillator and power-amplifier combination. The sound output of the loudspeaker is picked up by a calibrated microphone, both located in a free field room. The

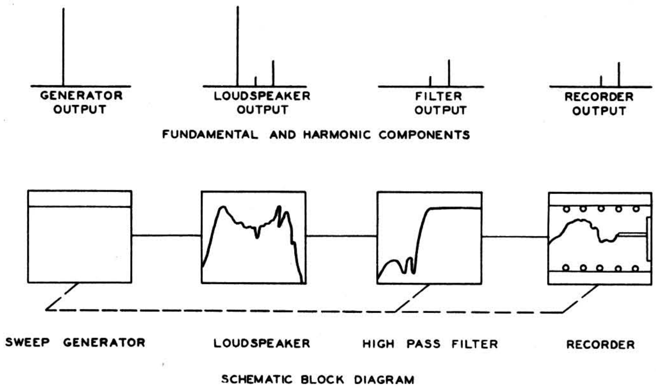

Fig. 1 - Functional diagram of a nonlinear distortion analyzer.

output of the microphone is amplified and fed to a recorder and a response frequency characteristic of the loudspeaker is obtained with this system in the conventional manner. To obtain the distortion frequency characteristic which depicts the distortion generated by the loudspeaker as a function of the frequency, the system for automatically suppressing the fundamental is connected between the microphone, amplifier and the recorder. Under these conditions, the voltage applied to the recorder is the root-mean-square total of the harmonic frequencies generated by the loudspeaker.

In the system described above, the major problem becomes one of attenuating the fundamental frequency in a dependable and fairly rapid manner. Of the several methods available for eliminating the fundamental, a reliable and straightforward one is shown in Fig. 2.

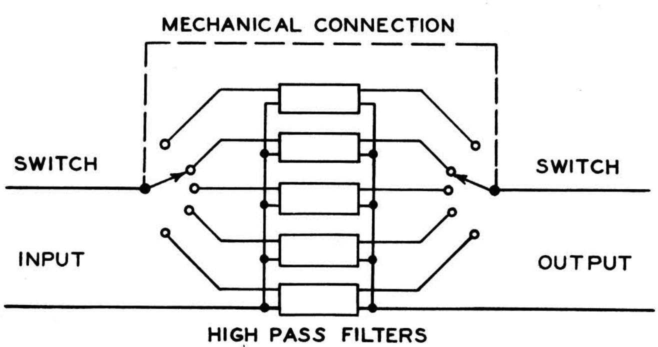

Fig. 2 - A nonlinear distortion analyzer consisting of a series of high pass filters which can be switched to suppress the fundamental and pass the harmonics.

This consists of a series of high-pass filters sequentially interposed between the microphone pickup and the recording equipment to attenuate the 40 to 15,000 cycle sweep fundamental. The primary advantage of using this method for harmonic distortion measurements is its dependability. The filters themselves may be made very rugged. Furthermore, should the filter switching circuit fail to function properly, the distortion readings will immediately go to 100 per cent, thus reading fundamental rather than harmonics and thereby providing a positive check against a possible switching error.

Design

The design of the system described in the preceding section is not difficult. However, several practical problems are involved. The useful frequency range of each filter is determined by two frequencies, namely, f_c and f_∞. The frequency at which the response is down one db is f_c. This frequency sets the lower limit of the useful pass band of each high-pass filter when recording distortion to an accuracy of 10 per cent. The frequency at which the response is down 60 db is f_∞. This frequency sets the upper limit of the useful rejection band of each filter when recording distortion to an accuracy of 10 per cent for a 0.3 per cent second harmonic distortion value. The f_c and f_∞ overlap characteristic of the adjacent filters are very close at the lower frequencies, and it therefore becomes very important that the frequency at which a filter is switched be held to a close frequency tolerance, if the full possible accuracy of the distortion analysis is to be realized. For this reason, an electronic rather than a mechanical system for the detection of the switch frequency is used. A typical bridged-T network employed for switch frequency detection is shown in Fig. 3. The response frequency characteristic of the network is also shown in Fig. 3. The inductors, capacitors and resistors of the network are sufficiently stable so that frequency adjustments are infrequent. In order to make up for the difference in amplitude between the fundamental and the harmonic levels normally encountered, a microphone preamplifier is necessary. It is important that this amplifier generate a very low level of harmonics, and be essentially noise-free due to its position in the system. The network of the preamplifier, the high pass filters, and the automatic switch

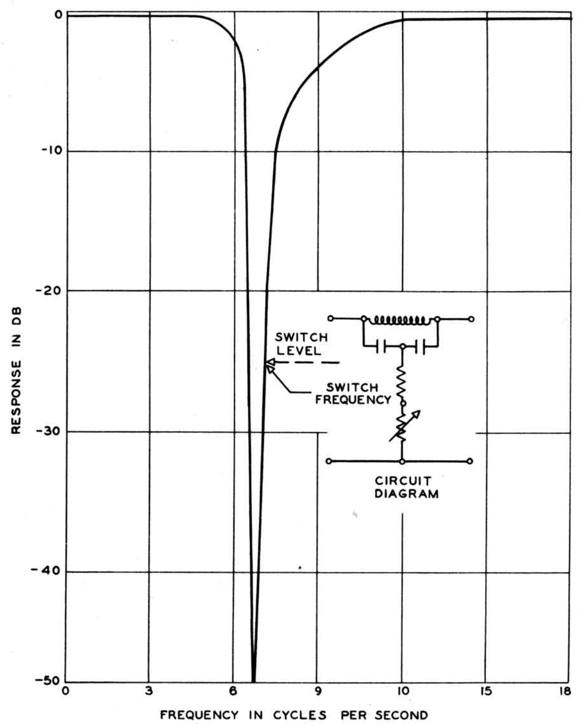

Fig. 3 - Bridged T network used for initiating the switching of the filters. The graph depicts the response characteristic of the network.

Frequency detection and the switching together make up a system which, when used with any conventional automatic oscillator-recorder system, provides a recording instrument for total rms distortion analysis.

A functional block diagram of the complete analyzer recorder system is shown in Fig. 4.

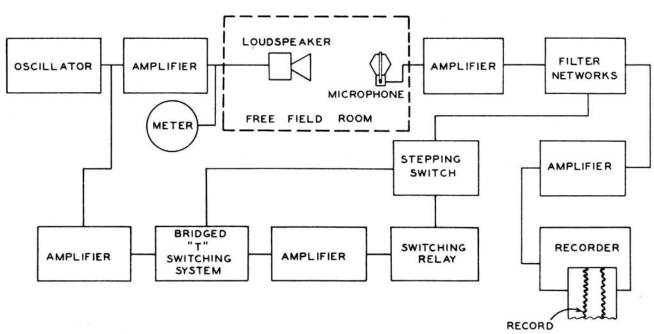

Fig. 4 - A complete block diagram of the complete automatic nonlinear distortion recording system.

The oscillator, power amplifier, microphone amplifier and recorder are located in permanent racks. A photograph of the recording equipment is shown in Fig. 5. The distortion analyzer is

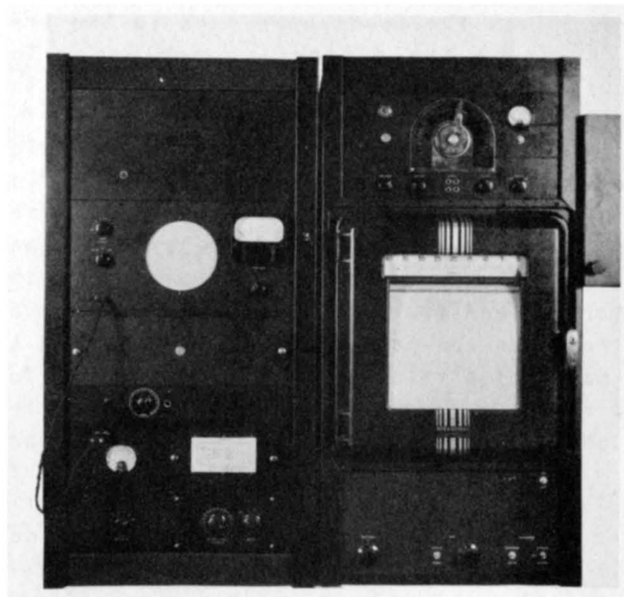

Fig. 5 - An automatic response frequency recorder.

located in a portable cabinet. A photograph of the distortion analyzer is shown in Fig. 6.

The sweep oscillator, an RCA Type 68-B beat frequency oscillator of exceptionally low harmonic content, is rotated, through a mechanical linkage, by a Leeds and Northrup Speedomax recorder at a sweep speed of $2\frac{1}{2}$ minutes for 30 to 17,000 cycles. The output of the oscillator is fed to both the amplifier

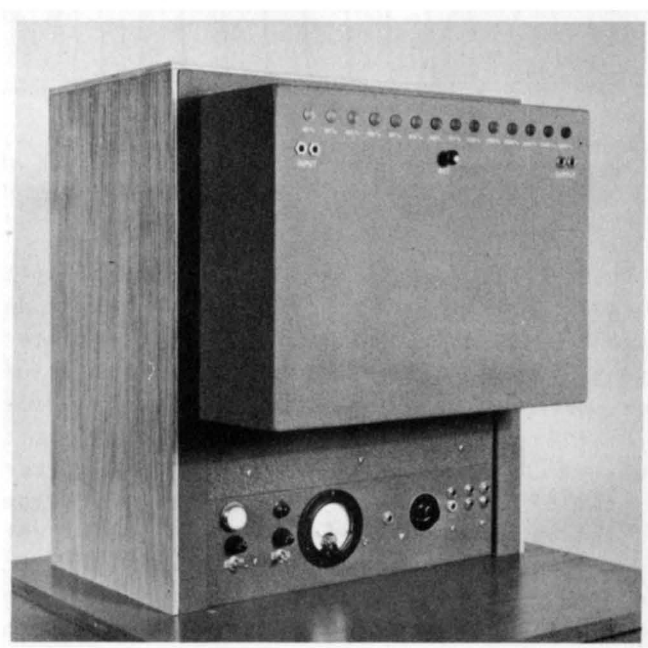

Fig. 6 - The nonlinear distortion analyzer.

which drives the loudspeaker and to the preamplifier of the distortion analyzer. The output level of the amplifier which drives the loudspeaker is shown on the output meter. The output of the preamplifier of the distortion analyzer is fed to the bridged-T switching network. The sound output produced by the loudspeaker is picked up by a microphone and amplified and fed to the filter system of the distortion analyzer. The inputs and outputs of the fourteen low-pass filters are connected to two banks of a relay-operated step switch. The step relay is operated from the output of the bridged-T switching network. Considerable care was taken so the filters met the f_c and f_∞ requirements. The f_c/f_∞ ratio was eventually fixed at 4:3 which gives a useful frequency range of ½ octave per filter or fourteen filters for the 40 to 15,000 cycle audio range. Fig. 7 shows the response frequency characteristics of fourteen high-pass filters used in the system.

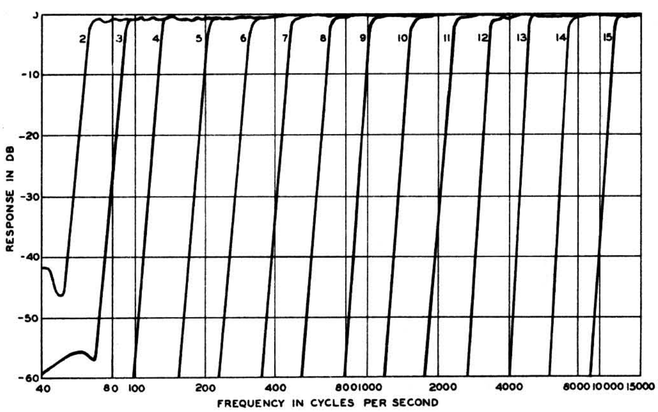

Fig. 7 - The response frequency characteristics of the fourteen high pass filters used in the nonlinear distortion analyzer.

Filters 2, 3, 4 and 5 have respectively 40, 45, 50 and 55 db attenuation for f_∞. The remainder have over 60 db attenuation for f_∞. The filters are 600-ohm, single ended, M-derived, torroidal core networks. The insertion loss, which varies from filter to filter, was equalized by suitable resistance pads across the output terminals. Filters 2 and 3 were heavily shielded to reduce hum pickup. A series of panel lights connected to the third bank of the step switch indicates the particular filter in operation at any time. Electronic frequency detection of the proper switch frequency and the switching operation occurs as follows. A constant amplitude signal supplied by the oscillator is fed to the preamplifier on the distortion analyze panel. The amplified signal is then fed to the frequency selective network as shown in Fig. 4. Fourteen of these selective networks, one for each high-pass filter, are connected in sequence to the fourth bank of the step switch. As the oscillator sweeps through the null frequency of the particular bridged-T network in the circuit, the switching relay closes, and thereby energizes the solonoid of the step relay. This solonoid action sets the step switch. As the oscillator frequency increases, the relay i deenergized, and the step switch advances thereby placing in the circuit both the next bridged-T switch network and the next high-pass filter. This process is repeated for each network until the fourteen bridged-T switch networks and the fourteen high-pass fundamental removing filters have been used. The output of each filter contains the harmonics and the highly attenuated fundamental. The output of each filter in turn is fed to an amplifier and the recorder. The recorder has a range of 0 to 40 db above a zero input level of 0.005 volt, with a zero range adjustable ±5 db. The recorder is designed to operate between 40 and 15,00 cycles to an accuracy of ½ per cent of ful scale, and has a response speed such that the pen will traverse any part of the nominal 10-inch chart and arrive at complete balance without overshooting in two seconds.

For a loudspeaker distortion analysis, a conventional amplitude vs frequency response curve is first run with the power amplifier adjusted to furnish the proper power level to the loudspeaker under test, and with the distortion analyzer step switch solonoid power turned off. The recorder preamplifier is adjusted to a level such that the recorder will not go off scale for the response curve. The response frequency characteristic is run with this gain setting. This procedure is repeated with the distortion analyzer step switch solonoid power turned on and with the gain control of the preamplifier turned some 20 to 40 db higher. The resultant curve, with due consideration for the difference in preamplifier settings, gives the relative distortion frequency characteristic of the loudspeaker under test.

A response frequency characteristic and a distortion frequency characteristic taken on 3-inch dynamic loudspeaker for an input of 0.

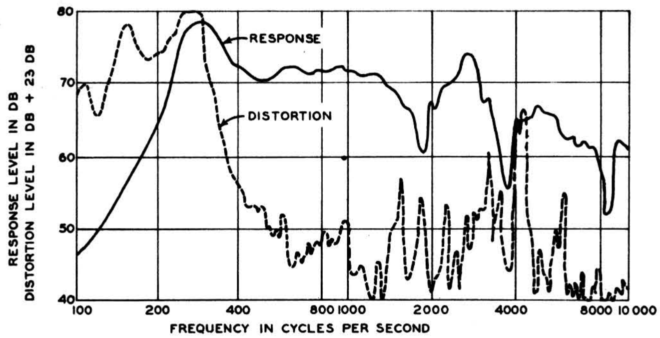

Fig. 8 - The response frequency characteristic and the distortion frequency characteristic of a three inch direct radiator loudspeaker for an input of .1 watt. Note that the level of the distortion curve has been raised 23 db.

watt is shown in Fig. 8. The gain of the preamplifier was increased 33 db for the distortion frequency characteristic. The response frequency characteristic and the distortion frequency characteristic drawn in the true relation on the same graph are shown in Fig. 9. The

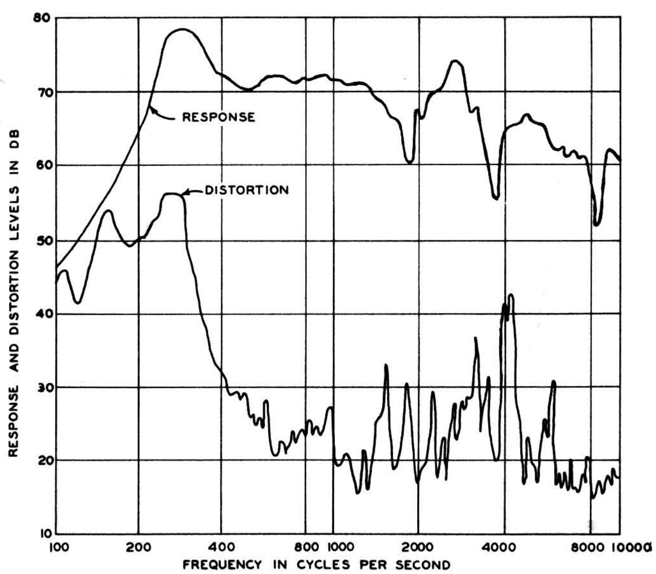

Fig. 9 - The response frequency characteristic and the distortion frequency characteristic of a three inch direct radiator loudspeaker for an input of .1 watt. Data obtained from Fig. 8.

distortion in per cent of the fundamental as a function of the frequency obtained from the data of Figs. 8 and 9 is shown in Fig. 10. It will be seen that the distortion is relatively large. This is due to the small light-weight diaphragm used in this loudspeaker to obtain high sensitivity.

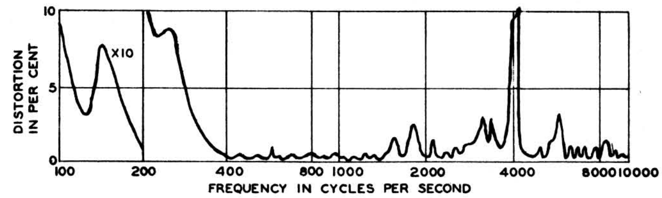

Fig. 10- Distortion frequency characteristic of a three inch direct radiator loudspeaker in per cent of the fundamental. Data obtained from Fig. 8.

A response frequency characteristic and distortion frequency characteristic taken on a 12-inch loudspeaker for 1 watt input is shown in Fig. 11. The distortion in per cent of the fundamental is shown in Fig. 12. It will be seen that the distortion produced by this loudspeaker is very low. This loudspeaker will deliver a sound level of 80 db in the average living room for an input of 0.1. Thus it will be seen that for reproduction in the home, a loudspeaker of this type exhibits less distortion than some of the other elements in the reproducing system.

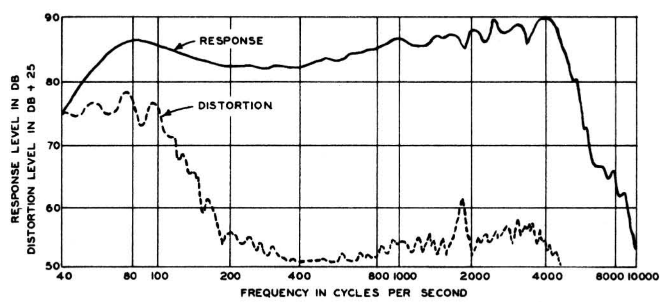

Fig. 11- The response frequency characteristic and the distortion frequency characteristic of a twelve inch dynamic loudspeaker for an input of one watt. Note that the level of the distortion curve has been raised 25 db.

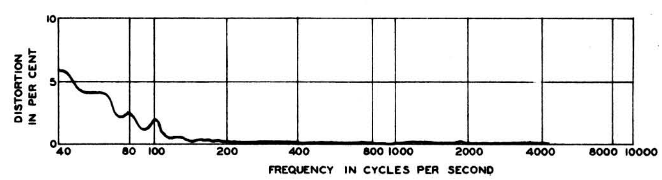

Fig. 12- Distortion frequency characteristic of a twelve inch direct radiator loudspeaker in per cent of the fundamental. Data obtained from Fig. 11.

From the characteristics depicted herein, it will be seen that the distortion frequency characteristic of a loudspeaker exhibits larger variations than the response frequency characteristic. To obtain an accurate characteristic under these conditions in a reasonable length of time, some sort of automatic or semiautomatic recording means is required. For example, in the case of the distortion frequency characteristic of Fig. 8, it would be practically impossible to obtain this curve by a point-by point method. Typical distortion characteristics illustrate the usefulness of an automatic curve tracing distortion analyzer for obtaining the distortion characteristics of loudspeakers.

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