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GAIN AND DISTORTION MONITOR FOR GROUND-AIR-GROUND COMMUNICATION--ETC(U)
JAN 77 J PERINI, R BANTEL F30602-75-C-0121

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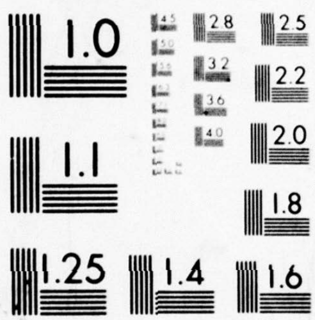

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RADC-TR-77-21
Technical Report
January 1977

GAIN AND DISTORTION MONITOR FOR GROUND-AIR-GROUND COMMUNICATION PERFORMANCE MONITORING

Syracuse University

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Ground-Air-Ground Communications
Communications Systems
Electromagnetic Compatibility

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Ground-air-ground communications are used world wide to control aircraft traffic and require the interconnections of multiple transmitters, receivers, recorders, microphones, antennae, etc. In such complex systems it is highly desirable to have some means of measuring the overall system performance with one simple test so that performance degradation can be constantly monitored. After some experimentation, it was decided that a measurement of the system distortion to a 500 Hz tone was a suitable parameter. It is also important to measure the cont.

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system overall gain so that the operators can be alerted to any drastic change in levels throughout the system. The equipment described in this report was designed specifically to perform both of these measurements.

PREFACE

This effort was conducted by Syracuse University under the sponsorship of the Rome Air Development Center Post-Doctoral Program for Air Force Communications Service (AFCS). Mr. Robert Bigelow was the task project engineer and provided overall technical direction and guidance. The authors of this report are Dr. Jose Perini and Richard Bantel.

The RADC Post-Doctoral Program is a cooperative venture between RADC and some sixty-five universities eligible to participate in the program. Syracuse University (Department of Electrical and Computer Engineering), Purdue University (School of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering), and State University of New York at Buffalo (Department of Electrical Engineering) act as prime contractor schools with other schools participating via sub-contracts with the prime schools. The U.S. Air Force Academy (Department of Electrical Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the Naval Post Graduate School (Department of Electrical Engineering) also participate in the program.

The Post-Doctoral Program provides an opportunity for faculty at participating universities to spend up to one year full time on exploratory development and problem-solving efforts with the post-doctorals splitting their time between the customer location and their educational institutions. The program is totally customer-funded with current projects being undertaken for Rome Air Development Center (RADC), Space and Missile Systems Organization (SAMSO), Aeronautical Systems Division (ASD), Electronic Systems Division (ESD), Air Force Avionics Laboratory (AFAL), Foreign Technology Division (FTD), Air Force Weapons Laboratory (AFWL), Armament Development and Test Center (ADTC), Air Force Communications Service (AFCS), Aerospace Defense Command (ADC), Hq USAF, Defense Communications Agency (DCA), Navy, Army, Aerospace Medical Division (AMD), and Federal Aviation Administration (FAA).

Further information about the RADC Post-Doctoral Program can be obtained from Jacob Scherer, RADC/RBC, Griffiss AFB, NY, 13441, telephone AV 587-2543, COMM (315) 330-2543.

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LIST OF FIGURES

1. INTRODUCTION

A communication system distortion monitor must be capable of detecting any appreciable noise or distortion which might occur in the transmitter, amplifier, receiver, etc. This distortion might arise from overmodulation, intermodulation and loop component nonlinearities; in general, harmonic distortion of the intelligence component of the signal.

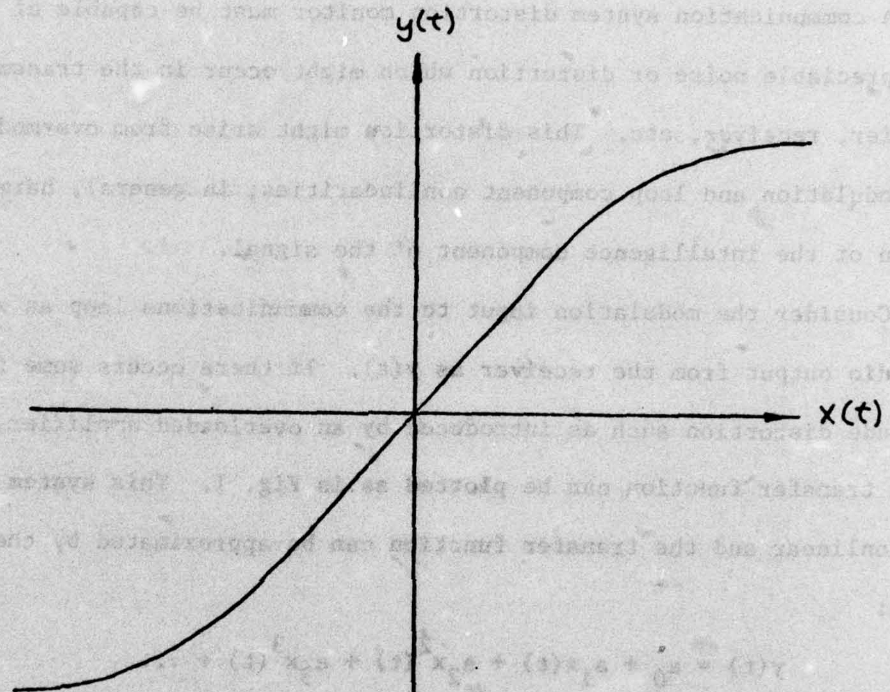
Consider the modulation input to the communications loop as $x(t)$ and the audio output from the receiver as $y(t)$. If there occurs some form of amplitude distortion such as introduced by an overloaded amplifier, the system transfer function can be plotted as in Fig. 1. This system is therefore nonlinear and the transfer function can be approximated by the polynomial:

$$y(t) = a_0 + a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \dots \qquad (1)$$

Now, for a modulating waveform such as a simple cosine wave, $x(t) = \cos \omega_o t$, the above equation can be expanded to:

$$\begin{aligned} y(t) &= \left(a_0 + \frac{a_2}{2} + \frac{3a_4}{8} + \dots\right) + \left(a_1 + \frac{3a_3}{4} + \dots\right) \cos \omega_o t \\ &\quad + \left(\frac{a_2}{2} + \frac{a_4}{4} + \dots\right) \cos 2\omega_o t + \dots \qquad (2) \\ &= A_{DC} + A_0 \cos \omega_o t + A_1 \cos 2\omega_o t + A_2 \cos 3\omega_o t \quad \dots \end{aligned}$$

Therefore, the output of a nonlinear system contains harmonics of the input. Hence, one way of evaluating the amount of distortion is to introduce a tone



TRANSFER CHARACTERISTIC OF A NONLINEAR SYSTEM FIGURE 1 x(t) into the system, and then observe the amplitudes of the harmonics of y(t). The percent distortion is then defined as

$$\% \text{ Distortion} = \sqrt{\frac{A_1^2 + A_2^2 + \ldots}{A_0^2}} \times 100 \qquad (3)$$

where A_0 is the amplitude of the fundamental frequency.

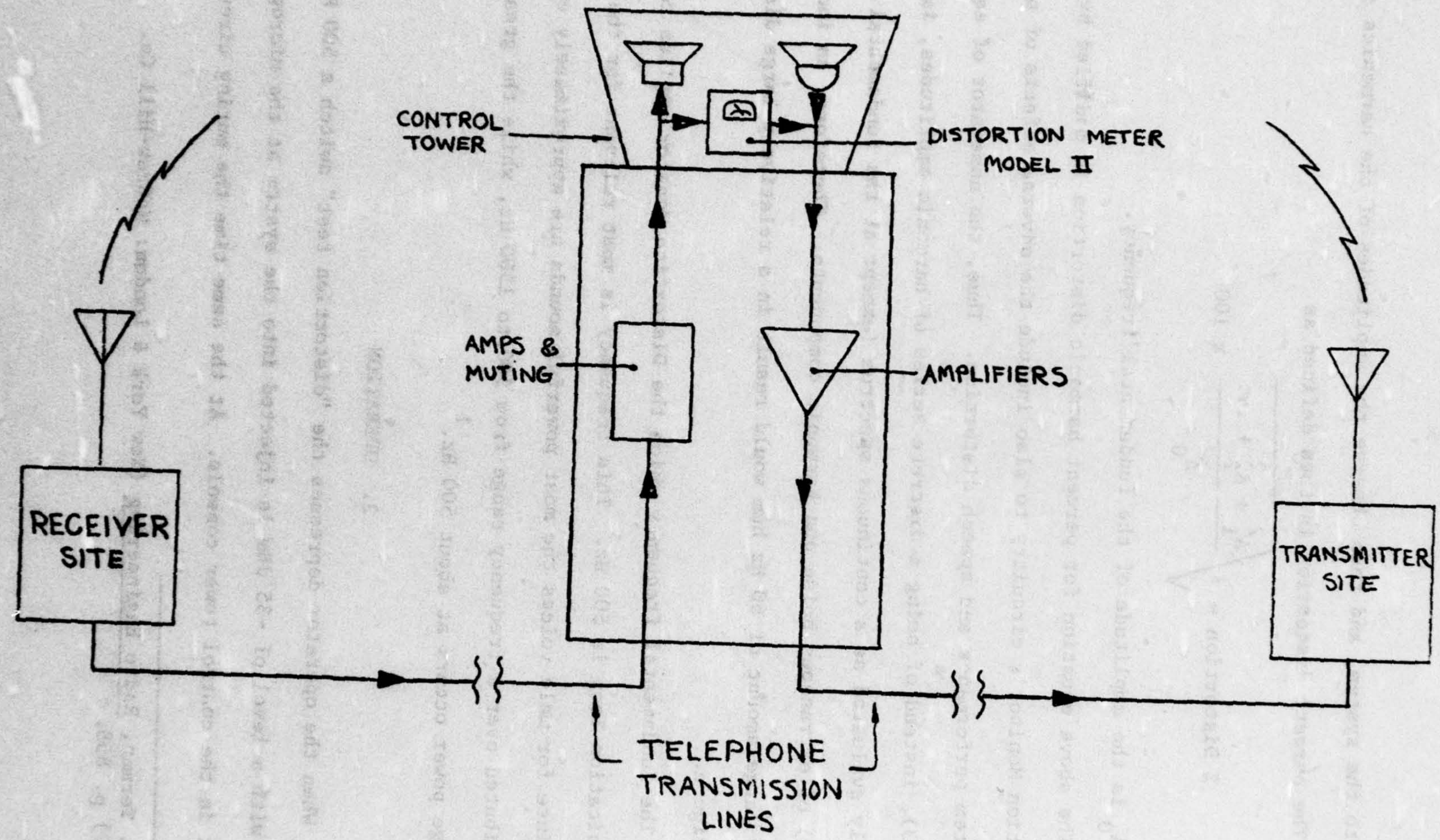
The above equation for percent harmonic distortion is modified by the Distortion Monitor's circuitry to also include the adverse effects of noise on system performance and speech distortion. Thus, the numerator of equation (3), instead of being a discrete series of harmonic amplitudes, is actually evaluated as a continuous spectrum (except at the fundamental frequency) of extraneous noise and harmonic components. Therefore, an inordinately large amount of 60 Hz hum would result in a relatively large distortion figure.

The fundamental frequency which the Distortion Monitor applies to the communication loop is 500 Hz. This frequency is most relevant for the testing since for male voices the most powerful sounds are approximately evenly distributed over a frequency range from 500 to 1500 Hz, while the greatest average power occurs at about 500 Hz.[1]

2. OPERATION

When the operator depresses the "distortion test" switch a 500 Hz sine wave with a level of -35 dBm is injected into the system at the microphone input in the control tower console. At the same time the muting circuits are

[1] F.E. Terman, Radio Engineering (New York & London: McGraw-Hill Co. 1947) p. 858.



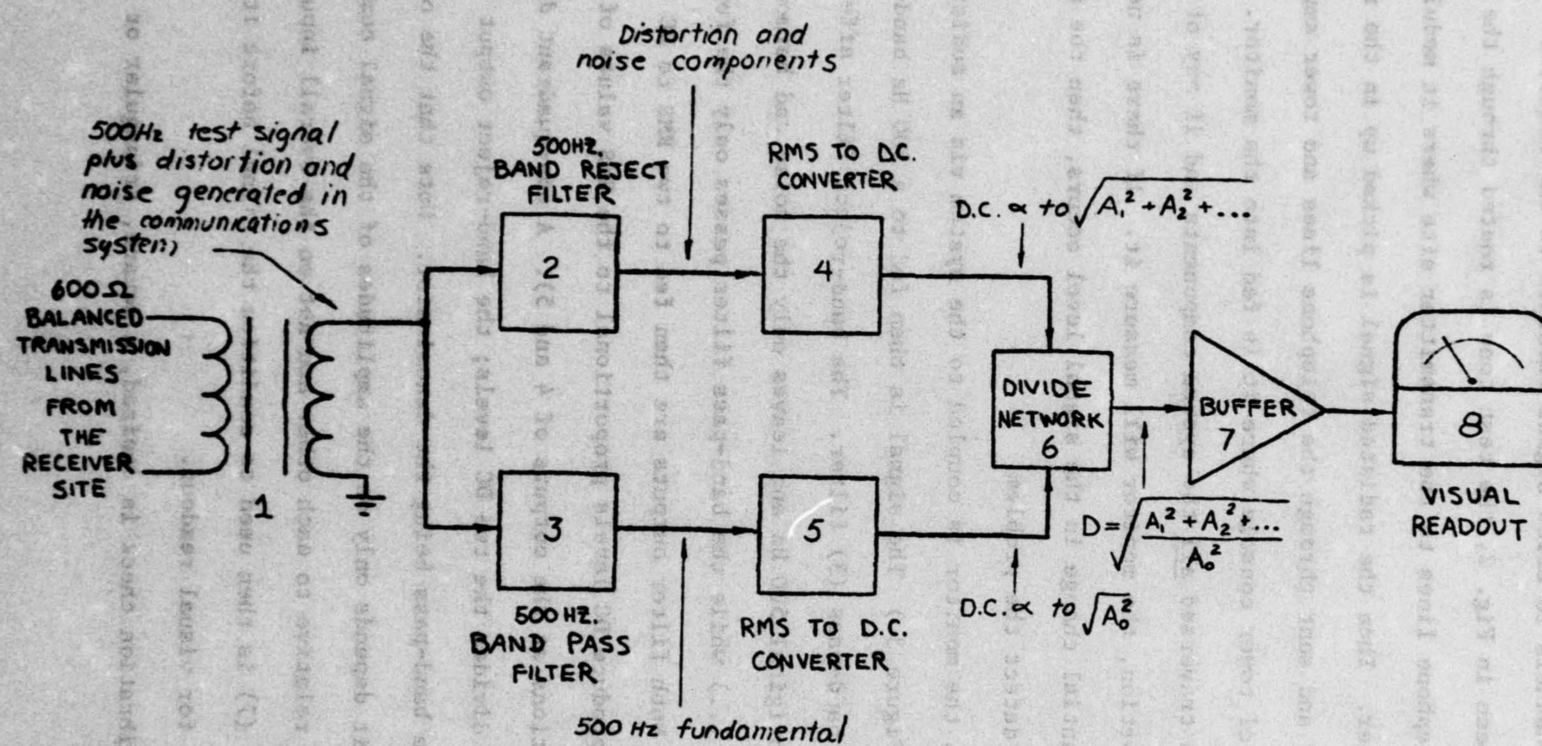
COMMUNICATIONS - SYSTEM - FIG. 2

disabled on all channels to allow signal feedback to the monitor.

As can be seen in Fig. 2, the test tone is routed through the tower amplifier and telephone lines to the transmitter site where it modulates the desired transmitter. Then the radiated signal is picked up in the receiver site, demodulated and sent through the telephone lines and tower amplifiers back to the control tower console where it is fed into the monitor. Note that the tone has traversed all the system components and if any of them are producing a distortion, the monitor will measure it. If there is no distortion but a substantial change in the signal level occurs, then the gain measurement will detect the problem.

Internally, the monitor is coupled to the system via an audiotransformer (1) (See Figure 3.) The signal is then fed to a 500 Hz band-reject (2) and a 500 Hz band-pass (3) filter. The band-reject filter effectively filters out the original 500 Hz and leaves only the noise and harmonic components (A_1, A_2. ...) while the band-pass filter passes only the fundamental frequency (A_0). Both filter outputs are then fed to two RMS to DC converters (4 and 5) which produce DC levels proportional to the RMS values of the AC inputs (See equations at the outputs of 4 and 5). A one-quadrant divider circuit (6) then divides the two DC levels; the band-reject output being the numerator and the band-pass being the denominator. Note that the output of the divide circuit depends only on the amplitudes of the signal components from the filters relative to each other and not on the overall input amplitudes. A buffer (7) is then used to condition the signal before it is sent to the meter (8) for visual readout.

When a calibration check is desired, a square, triangular or sine



DISTORTION MONITOR MODEL II

FIGURE 3

wave is internally generated and processed through the monitor. These waveforms are calculated to give 46, 12 and 0 percent distortions. The accuracy can be double checked by switching from the 100 to 25 percent scales and noting any difference.

With all switches in the normal positions, the monitor reads the overall gain taken from the headphones output. Its reference is 0 dBm (1 mW at 600 ohms). When in the "gain test" position, however, the 500 Hz tone is introduced into the system and the received signal is then measured to give the system overall gain. Due to the fact that the test should include all the system equipment, it is necessary to disable the muting circuits in the receiver portion of the control tower so that the 500 Hz tone can reach the control tower console. For simplicity this is done by disabling all muting circuits at the same time. Therefore, to avoid microphonics, tests should not be performed when another channel is being used in the transmit mode.

3. CONSTRUCTION

One important distinction of the Gain & Distortion Monitor is that it features plug-in-module construction. This does away with much point-to-point wiring which in some cases may lead to intermittent operation and eventual failure. Also, these printed circuit boards can easily be removed and modified or fixed if necessary, without returning the entire unit to Syracuse University. Minor future changes can simply be accomplished by plugging in a new board.

Another important feature is the electrical diagnosis system of test jacks located on the rear panel. With the aid of an oscilloscope, each test jack will show a voltage waveform from an appropriately located point within the electronic circuitry. These voltage readings can then be used to diagnose most problems within the monitor without even removing the cover. (For further explanations and a chart of voltages, see Appendix B.)

Whenever possible, large scale integrated circuits have been employed. These circuits, like the true RMS-to-DC converter modules, effectively reduce the component count thus increasing the reliability. Also, a large scale integrated circuit is inherently more stable than its individual discrete components.

4. EVALUATION AND RECOMMENDATIONS

Initial testing by actual in-the-field operation was performed at Richards-Gebaur Air Force Base. At this installation, the flight controllers recorded the distortion readings obtained for four different frequencies, three times a day. A letter on "Report on Field Testing of G/A/G Communication Performance Monitor" is in Appendix A, and a synopsis of the data follows.

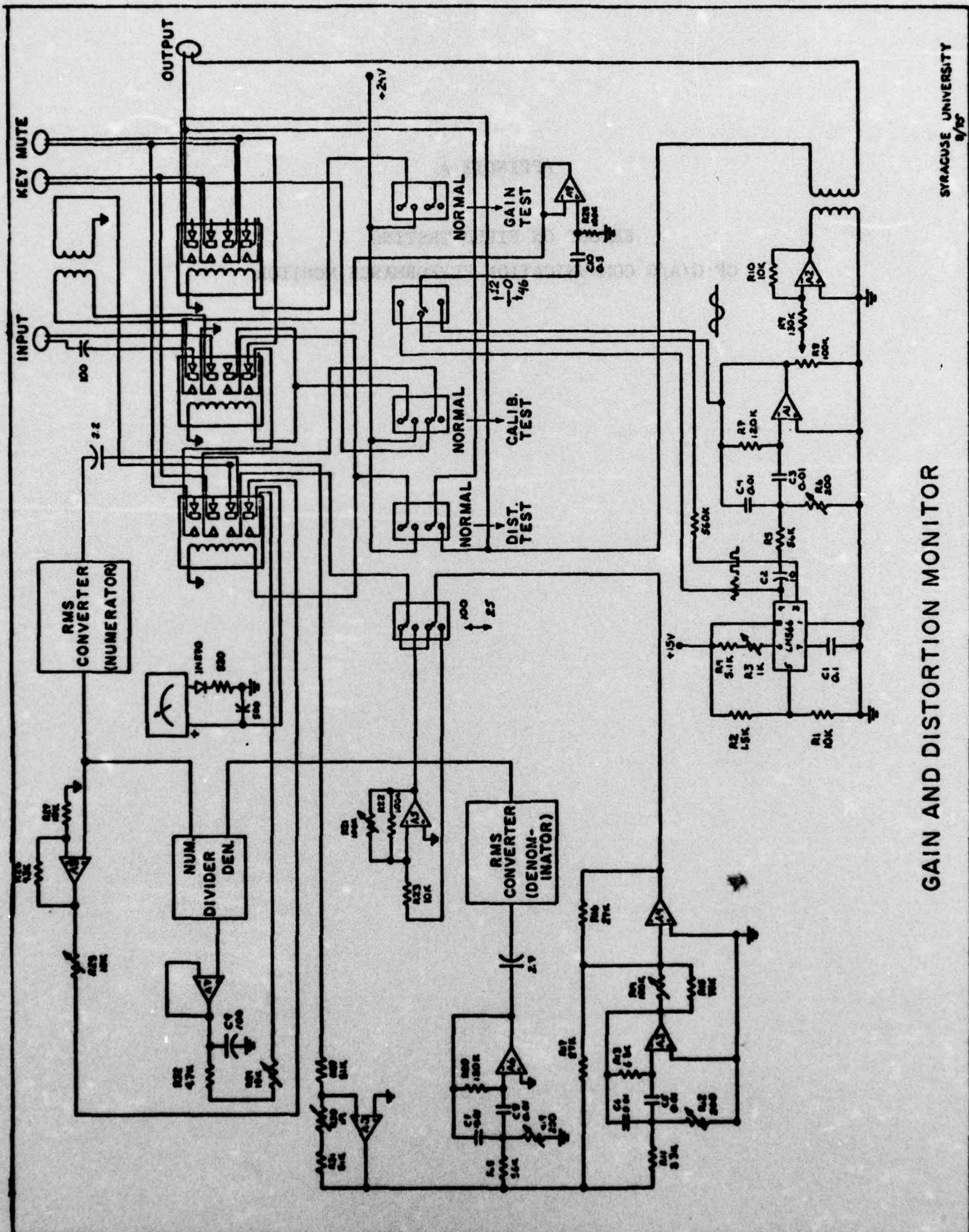
Freq (MHz)	High	Low	Mean	Std. Deviations	*Readings
124.2	60.	2.	21.00	4.33	68
236.6	25.	18.	21.90	1.71	71
289.4	40.	5.	16.50	11.81	70
324.3	22.	2.	10.76	2.93	70

*Reading in % distortion; calibration checks were adequate and within tolerance.

In a subjective evaluation of the voice quality by the various controllers who used the monitor during the testing period, no problems with voice quality were evident even though the average distortion reading was about 20% with a high of 40%. This indicates that an experienced listener can tolerate a relatively large amount of distortion and that an acceptable range of channel distortion might be less than 50% for voice quality to remain tolerable. This suggests that a correlation study between distortion and intelligibility should be carried out, perhaps with the use of the Articulation Index Measuring equipment located at RADC. Once this is established, then ranges of distortion for satisfactory (green), marginal (yellow) or bad (red) conditions can be easily set and a three light display used to warn the operator.

This 3 condition system of evaluating voice quality is a highly desirable feature which should be included in any future monitors since it enables the controllers to tell at a glance the condition of the communications channel. However, to circumvent the problem of the correlation between voice quality and percent distortion, as mentioned above, the monitor should have an internal adjustment which would set the threshold of the yellow and red conditions with respect to the distortion reading. Actual operation with the monitor permanently installed at Richards-Gebaur AFB, along with Articulation Index testing at RADC, could then be used to establish the subjective limits of voice quality.

Other plans for the Gain and Distortion Monitor include using a sample and hold technique which would allow measurements to be made during an inaudiable amount of time <u>each time</u> the microphone is keyed. The results would then be displayed for the flight controllers as one of three colored lights. Also, a digital display could be included for use by technicians in order to maintain the channel condition at maximum quality. Therefore, this monitor would provide a constant, non-bothersome check on the entire communications system in order to immediately ascertain if the system parameters are within a certain tolerance.



GAIN AND DISTORTION MONITOR

APPENDIX A

REPORT ON FIELD TESTING
OF G/A/G COMMUNICATION PERFORMANCE MONITOR

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 1842 ELECTRONICS ENGINEERING GROUP (AFCS)
RICHARDS-GEBAUR AIR FORCE BASE, MISSOURI 64030

09 JUN 1976

REPLY TO ATTN OF: EPELC

SUBJECT: Report On Field Testing Of G/A/G Communication Performance Monitor

TO: AFCS/OA/Dr Y.S. Fu

1. After a great deal of difficulty in keeping the Performance Monitor on the air, it is felt that sufficient initial data has been gathered to analyze if the concept, as currently conceived, should be pursued. Recognizing the O&M problem of voice quality recognition on the G/A/G system and the need for a performance monitor above the purely subjective interpretation of the controller or A/C pilot, I feel that this performance monitor, although it has merit, does not resolve the problem.

2. Testing difficulties, although causing extended delays, were minor, i.e. a faulty relay in the monitor, burnt out power on light. Interfacing the monitor into the operational system caused the greatest difficulty. The relay (and 24 volt source) required to defeat the mute relay in the 4-channel was somehow always being mysteriously disconnected, thereby nullifying the test procedure with erroneously high distortion figures. A local modification to utilize the monitor's internal 24 volt supply, only succeeded in burning out the power supply. In any case, these problems could be resolved by permanent installation. If the monitor were modified so that the testing was automatically completed when the channel in use was keyed, the major complaint of the user would be solved.

3. Discussions with various controllers who used the monitor during testing indicates that no problems with the voice quality were evident. A reading of 60% on 26 Apr 76, frequency 124.2 MHz, correlated with maintenance actions then in progress (PMI). The following summarizes the data gathered:

Freq(MHz)	High	Low	Mean	Std Deviations	* Readings
124.2	60.	2.	21.00	4.33	68
236.6	25.	18.	21.90	1.71	71
289.4	40.	5.	16.50	11.81	70
324.3	22.	2.	10.76	2.93	70

*Reading in % Distortion; Calibration checks were adequate and within tolerance.

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4. Observation is that the monitor is stable on channel measurements (re: 124.2, 236.6, 324.3) and it is highly suspect that difficulty (radio or more probability land lines) on 289.4 could be found if investigated. This action has not been requested. The important point remains that the basic problem has not been resolved since a Green, Red, Amber condition cannot be identified from that data and a particular reading by the controller, identified as a problem channel.

5. Recommend Dr. Perini analyze the limited data and the OPR re-evaluate the requirement before proceeding with development of the ATC G/A/G monitor "per se".

FOR THE COMMANDER

ROBERT W. NEILL, P.E.
Chief, Elect Engr Division

APPENDIX B

Electrical Diagonsis System

On the back panel of the Distortion Monitor are nine test jacks which give easy access to eight test points within the monitor. The voltages and waveforms at each point can be used to diagnose most problems which may arise. A brief description of each test point follows:

Brown	- output of divider module
White	- output of denominator RMS converter module; denominator input of divider module
Yellow	- input to denominator RMS converter module
Blue	- input to numerator RMS converter module
Black	- common
Orange	- output of numerator RMS converter module
Green	- input to band-pass and band-reject filters
Grey	- output test waveforms from the buffer circuit
Red	- input to the distortion circuit amplifier

On the following page is a chart which shows typical voltages produced with the monitor in the calibration test mode. If a problem does arise, a chart can be filled out by a technician and with a description of the problem, mailed to:

Dr. J. Perini/Bantel
Rm. 111 Link Hall
Syracuse University
Syracuse, N.Y. 13210 (315) 423-4388

If the problem is simple, we can correct the ailment by letter or phone.

BLACK IS COMMON CONNECTION	46% TEST	0% TEST	12% TEST	12% ON 25% SCALE (x4)
BROWN	4.9 VDC (slight ripple)	≈ 50mVDC	1.2 VDC	5.2 VDC
WHITE	2.4 VDC	3.3 VDC	4.1 VDC	← same
YELLOW	7.0 VPP SINE WAVE	9.6 VPP SINE WAVE	11.4 VPP SINE WAVE	← same
BLUE	7 V	≈ 75 mVPP NOISE	13 V	← same
ORANGE	1.16 VDC (slight ripple)	≈ 4 mVPP NOISE	0.5 VDC	2.1 VDC
GREEN	6 VPP	9.6 VPP SINE WAVE	14.6 VPP TRIANGULAR WAVE	← same
GREY	1.1 VPP SQUARE WAVE	2 VPP - 500 Hz. SINE WAVE	3 VPP TRIANGULAR WAVE	← same
RED	1.5 V	2 VPP SINE WAVE	3 VPP TRIANGULAR WAVE	← same

APPENDIX C

Printed Circuit Boards

On the following pages are top view diagrams of the printed circuit boards used in the Gain and Distortion Monitor. Note that each element has a unique reference number which refers it to the schematic (at the end of this report).

Below is a brief description of the function of each board.

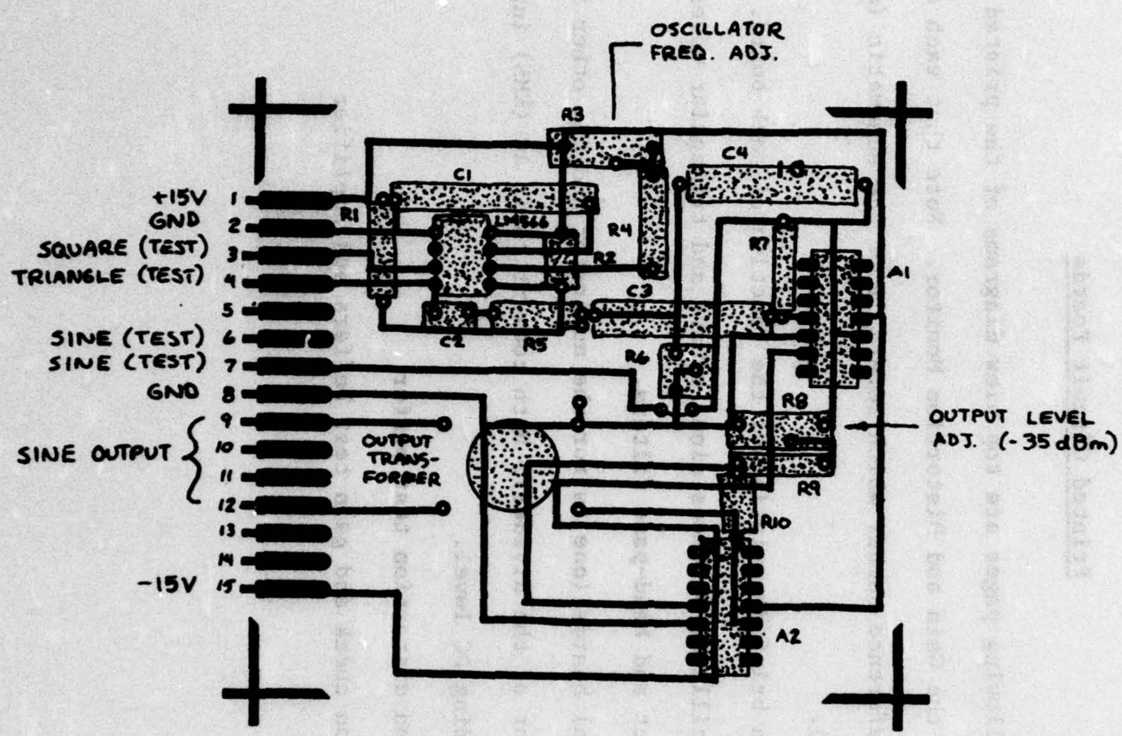
D1 - 500 Hz oscillator produces sine, square and triangular waves.

D2 - band-reject and band-pass filters.

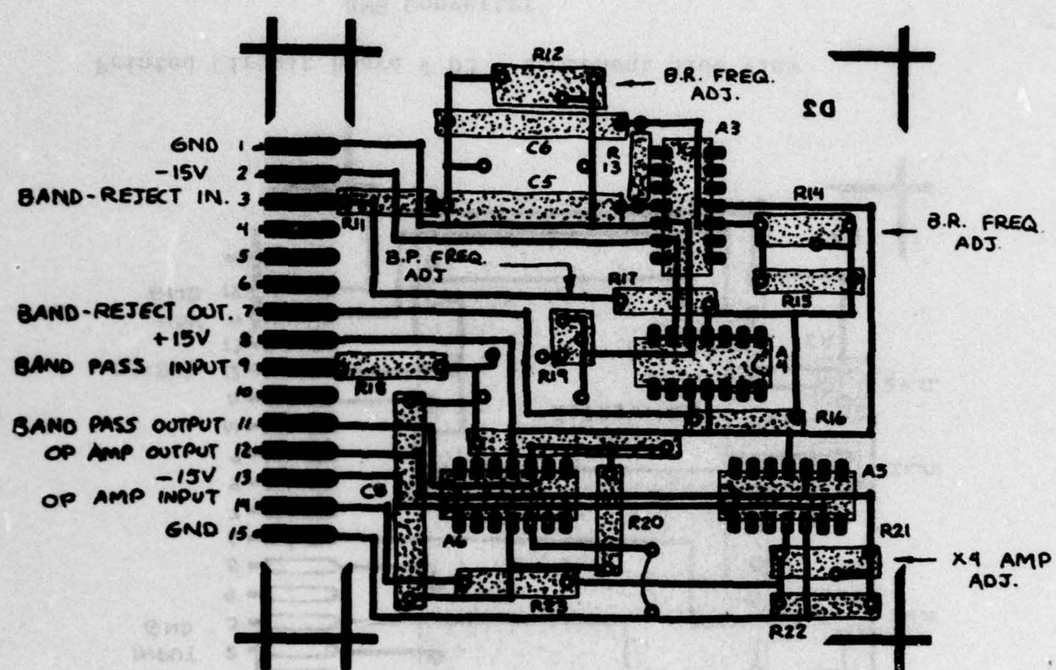
D3 - 2 identical boards (one is for the numerator and the other is for the denominator of the divider); both convert their AC (RMS) inputs to a corresponding DC level.

D4 - divider and distortion test buffer

D5 - calibration check and gain test buffers and amplifier

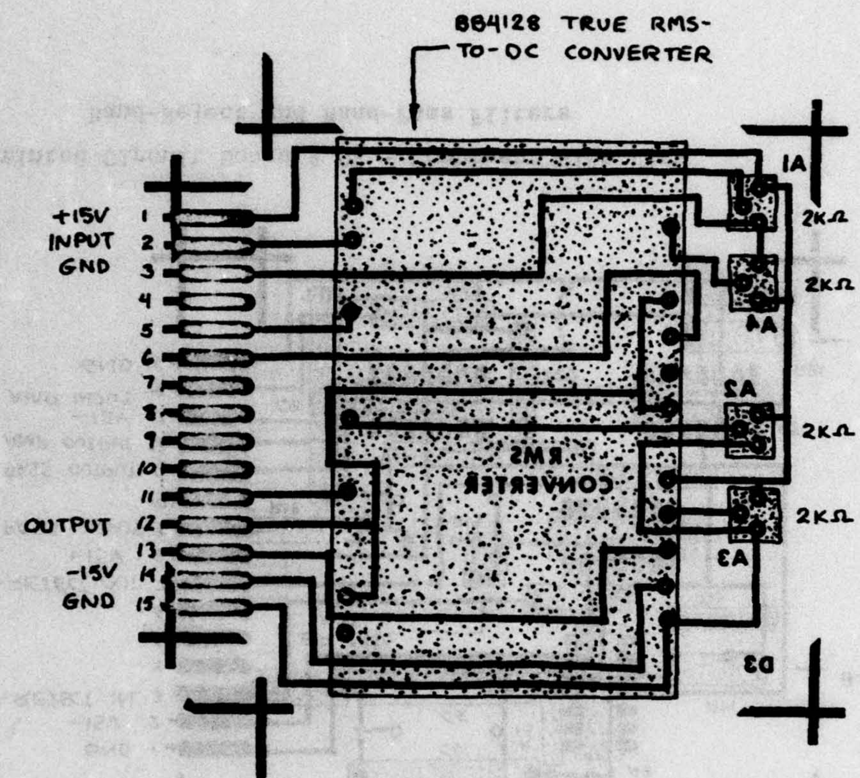


Printed Circuit Board # D1 - Component Side View
Generates sine, square and triangular waveforms



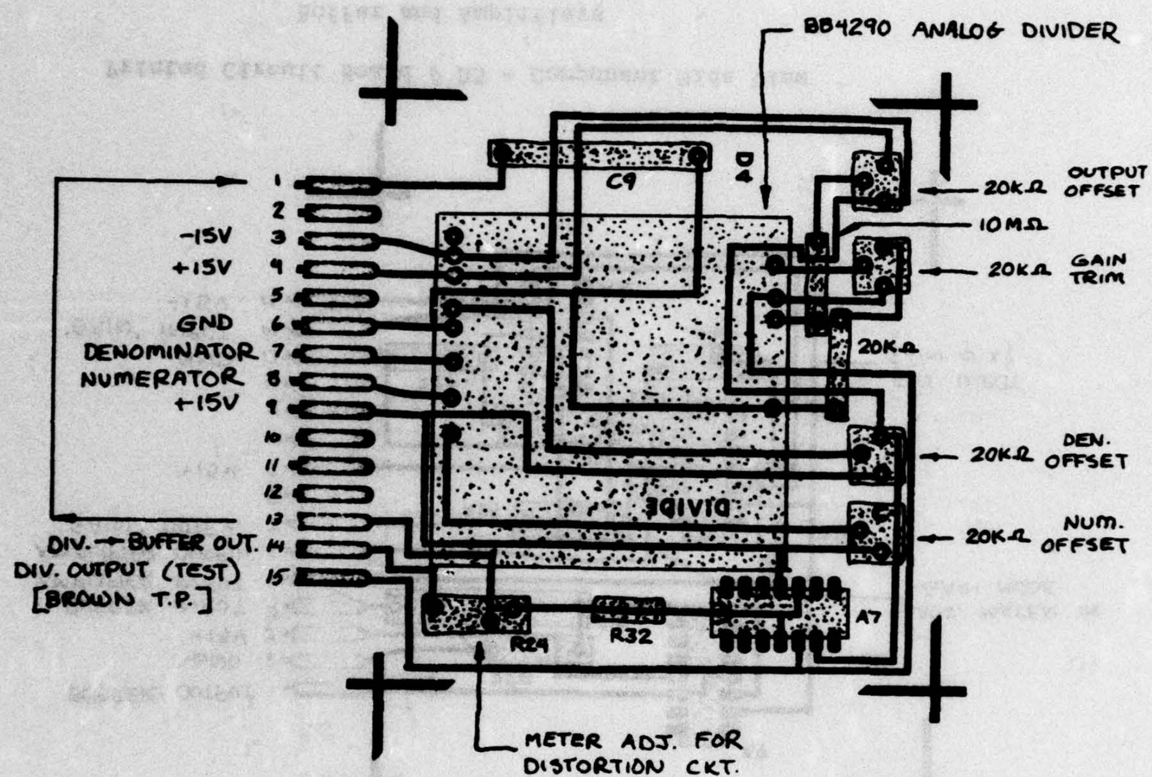
Printed Circuit Board # D2 - Component Side View

Band-Reject and Band-Pass Filters



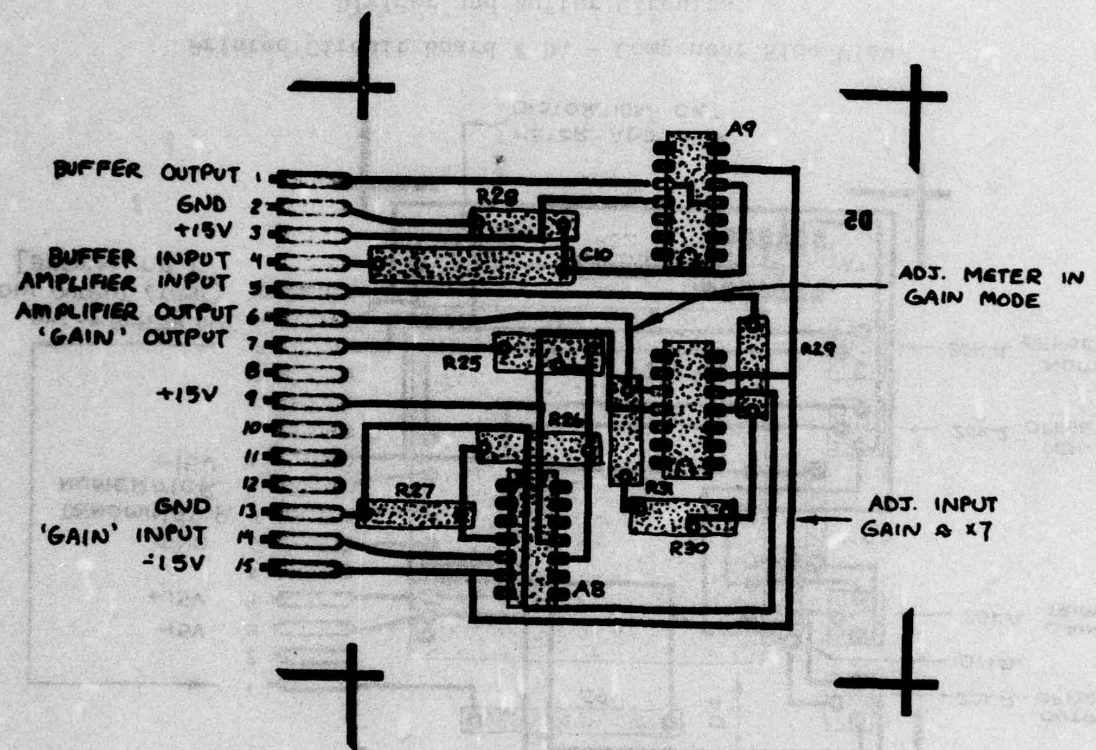
Printed Circuit Board # D3 - Component Side View

RMS Converter



Printed Circuit Board # D4 - Component Side View

Divider and Buffer Circuits



Printed Circuit Board # D5 - Component Side View

Buffer and Amplifiers

APPENDIX D

Distortion Check

1. Select the frequency to be tested on the console.
2. Depress'gain' switch and note the value on the gain scale. Adjust the headphone volume control (top right-hand side of the console) so that a gain reading of 0 $\pm$ 3 db is obtained. (This must be done for every frequency.)
3. Release the gain switch and depress the 'distortion test' switch. If the distortion (read on the 100% scale) is below 25%, further accuracy can be obtained by switching to the 25% range.
4. After the distortion test is completed, make sure the scale switch is on the 100% position so as not to damage the meter on the next test.
5. To check the accuracy of the distortion monitor, depress the calibration check switch and set the right hand switch to 46%, 12%, or 0% and read the meter. Distortions of 12% and 0% should also be checked on the 25% scale range.

Note: If the distortion is unusually high, check for 60 Hz hum.

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METRIC SYSTEM

BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

SUPPLEMENTARY UNITS:

plane angle	radian	rad	...
solid angle	steradian	sr	...

DERIVED UNITS:

Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
electric potential difference	volt	V	W/A
electric resistance	ohm	...	V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m/s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

* To be avoided where possible.

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