MEASUREMENT / TECHNICAL REPORT B60423

Hewlett-Packard M2601A
Bio-Medical telemetry transmitter
FCC id: B948JAM2600

Test purpose: FCC Type acceptance
Test Facility: Test Site services, Birch street, Milford, MA

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1. INTRODUCTION

The following data have been taken in support of an Application for Type Acceptance for the Hewlett-Packard Model M2601A Biomedical transmitter (FCC ID: B948JAM2600), in accordance with Part 2 and Part 90 of the Federal Communications Commission's Rules and Regulations.

The Equipment Under Test (EUT) is a biomedical telemetry transmitter which is used for transmission of patient electrocardiograms (ECG's) within hospital buildings. It is powered by a small battery and operates in the 457 - 470 MHz frequency range. The transmitter output is 2 milliwatts. The patient leads are used for the antenna.

This application intends to use the exemption of Paragraph 90.217, which requires that the sum of the frequency tolerance and the occupied bandwidth be such that all emissions removed from the carrier by more than 40 kHz be attenuated by at least 30 dB.

2. INFORMATION REQUIRED FOR THE TYPE ACCEPTANCE UNDER PART 2.

Paragraphs	
2.983	A completed FCC Form 731 is inlcuded with the application. The full manufacturers name and address is listed on this form
2.983(b)	The equipment is identified as Hewlett-Packard Model M2601A
2.983(c)	Quantity production is planned
2.983(d)(1)	Emission designator: 16KOF1D
2.983(d)(2)	The frequency range is 460 - 470 MHz
2.983(d)(3)	The rated power of the transmitter is 4.0 mW +1, -1.5 mW
2.983(d)(4)	The final amplifier stage of the M2601A produces a maximum output power of 4 mW.
2.983(d)(5)	Quiescent current is 7.5 milliamps with a peak voltage of 1.4 Volts available at the output device for a linear power of 5.25 milliwatts.
2.983(d)(6)	The function of each active device is described in section 5 of this report.
2.983(d)(7)	Schematics are included as appendix 1 of this report.
2.983(d)(8)	The user's manual containing the operating instructions are provided as appendix 2 of this report.
2.983(d)(9)	The tune-up procedure is given in section 4.2 of this report
2.983(d)(10)	A description of the circuits for determining and stabilizing the frequency is given in section 5.3 of this report.
2.983(d)(11)	A description of of the circuits employed for suppression of spurious emissions, limiting modulation and limiting power is given in section 4 of this report.
2.983(d)(12)	A detailed description of the modulation system is given in section 4.4 of this report.
2.983(d)(13)	The data required by Paragraphs 2.985 thorugh 2.995 are included with this report.

3. MEASUREMENT REQUIREMENTS

3.1. RF power output.

The transmitter was installed in a test fixture which provides impedance matching and balancing between the transmitter's RF output and the input of the measuring equipment. This test fixture had a measured insertion loss of 10.8 dB. The output was terminated into a HP 437B with a HP 8482A sensor. Output power was measured with 3 different batteries and the results showed no significant variation in output power and is well within the power range as specified by the manufacturer.

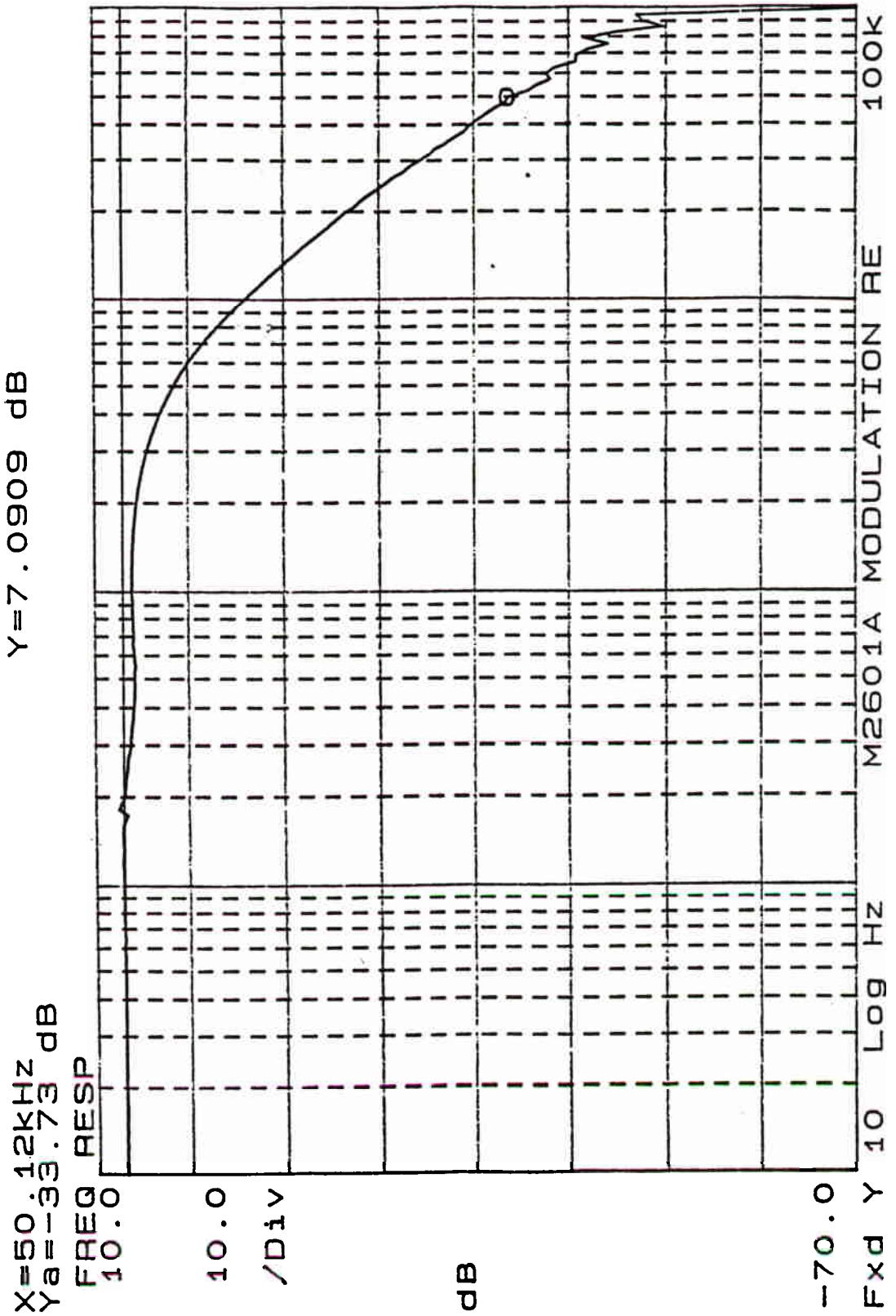
Test #	Measured output Power after 10.8 dB coupler (dBmW)	Battery type
1	- 4.05	Ultralife Lithium # 12570
2	- 4.09	Ultralife Lithium # 13410
3	- 4.01	Energizer Alkaline

3.2. Modulation Characteristics.

3.3. Digital Modulation Filter Response.

The model M2601A transmitter employs digital modulation techniques. As discussed in section ?? of the technical manual, the modulation system uses Gaussian minimum shift keying.
The analog electrocardiogram signal is converted to digital signal to produce a data rate of 9600 BPS. The means the maximum transition rate is 4800 Hz. The coded digital signal is passed through a Gaussian-shaped filter corresponding to a low-pass bandwidth of 4800Hz.
In accordance with the requirements of Paragraph 2.983(d)(12), the response of the filter has been measured using a HP3563A System analyzer and is shown in Figure 1.

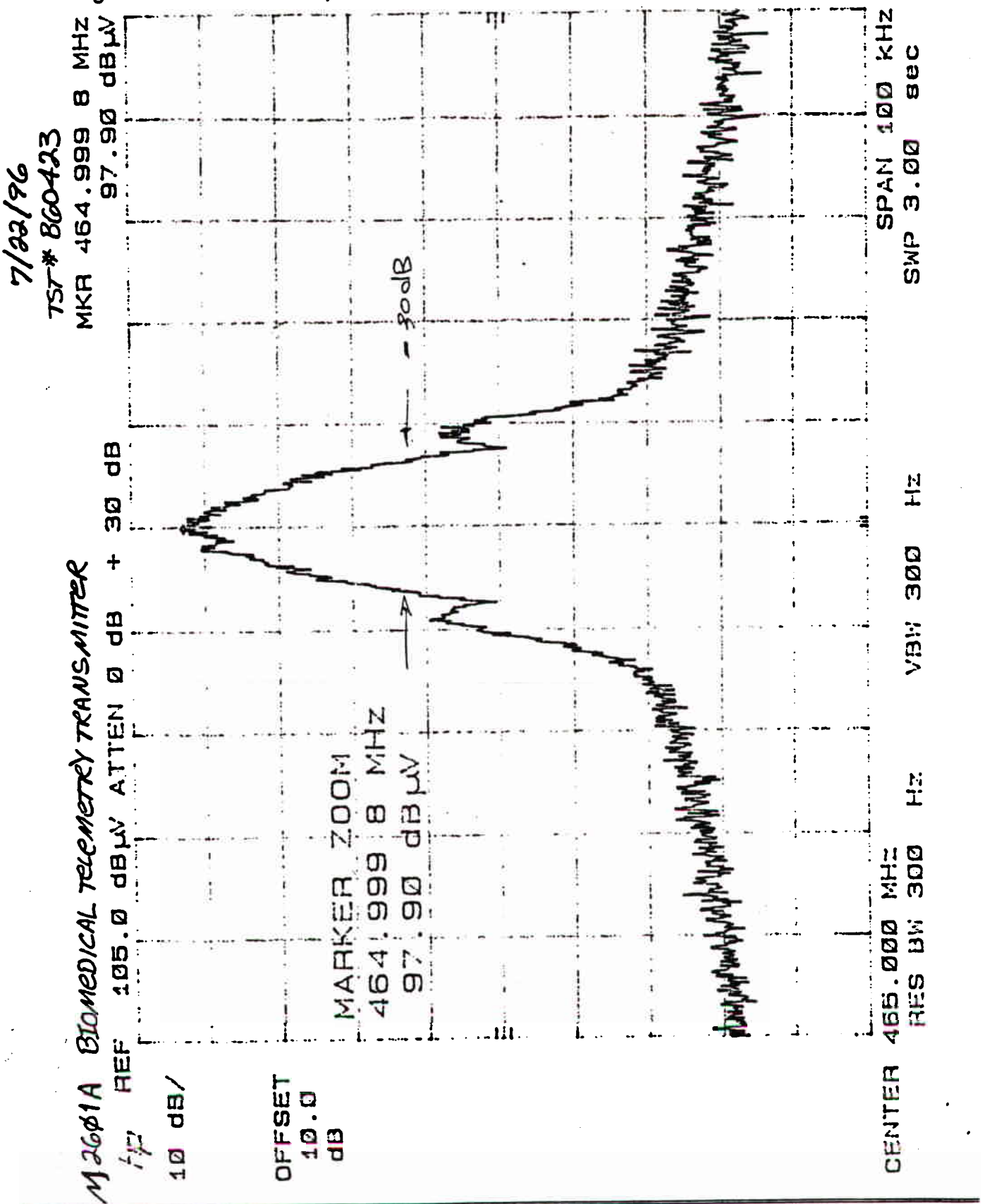
Figure 1. Modulation filter response.



3.4. Occupied bandwidth.

The occupied bandwidth of the transmitter's emission spectrum was measured using the test fixture. Spectral plots were taken of the display of the analyzer's response to a 100 Hz sinewave input applied to the EUT. Since the actual E.C.G. signal level goes through a digital signal processing stage, the resultant modulation is not influenced in terms of occupied bandwidth and spurious response by the E.C.G. signals. Therefore these measurements were conducted without imposing a (artificial) E.C.G. signal. Figure 2 shows the resultant measurements.

Figure 2. Transmitter output.



3.5. Conducted spurious emissions.

Spurious emissions at the antenna terminals were measured using the test configuration illustrated below. The output of the transmitter was connected via a HP impedance matching network with a insertion loss of 10.8 dB to a HP Spectrum Analyzer. The emission spectrum was examined up to the tenth harmonic of the fundamental (carrier) frequency. Every emission not recorded was more than 20 dB below the limit. The emissions limitation as described on 90.209 is expressed as 43+ 10log(mean output power in Watts). For 4.0 mW this amounts to 19 dB below the carrier. All the data recorded in Table 1 meets this requirement.

Table 1: Spurious emissions

Harmonic order	Frequency (MHz)	RCVR reading dBμV	Coupling network (dB)	Output power dBμV over 50Ω	relative level to carrier
.5	232.5	9.1	10.8	19.9	-86.9
1	465	96	10.8	106.8	0
1.5	697.5	27	10.8	27.8	-79
2	930	14.7	10.8	25.5	-81.3
2.5	1162	8.8	10.8	19.6	-97.2
3	1395	10.6	10.8	21.4	-85.4
4	1860	19.2	10.8	30	-76.8

Tester Signature C.R. Date: 7/22/96
Name: C.Richards

3.6. Radiated Spurious Emissions

Field strength measurements of radiated spurious emissions were made on the 3 meter Birch street test site from Test Site Services. A test site description is on file with the Commission, and this test site is accredited under the NVLAP program for FCC test methods.

The reference level for spurious emissions was taken at an ideal dipole exited by the rated nominal radiated output power according to the following relationship:

$$E = \frac{(49.2 \times P)^{1/2}}{R}$$

were
E = Electric Field intensity in V/m
P = Transmitter power in Watts
R = Distance in meters

At the rated output power of 4 mW (according to the specification sheet), this calculates out to 0.148 V/m or 103.4 dBuV/m

Paragraph 90.209 requires that the spurious radiated emissions be attenuated at least 43 + 10 log (mean output power in Watts) below the unmodulated carrier. In this case the equipment's rated power of 4.0 mW requires a minimum attenuation of 43 + 10 log (.004) = 19 dB below the reference level of 103.4 dB(μV/m), or 84.4 dB(μV/m). The data , as reported in Table 2 clearly meets this requirement.

Table 2: Spurious radiated emissions

Freq MHz	Signal level B(uV/m	Amp. dB	Ant. Factor dB	Ant. pol. H/V	Cable loss dB	Product level dB(uV/m)	Margin to carrier dB	Comments
58.17	23.1	0.0	8.4	H	1.6	33.1	-61.9	
465.00	72.2	0.0	18.1	V	4.7	95.0	0.0	carrier
1395.00	45.8	34.4	25.9	V	1.3	38.6	-56.4	
1860.00	44.4	34.0	27.0	V	1.5	38.9	-56.1	
2325.00	41.5	33.9	29.0	V	1.7	38.3	-56.7	
2557.00	34.8	34.0	30.3	V	1.8	32.9	-62.1	
2790.00	43.9	34.1	31.0	V	1.9	42.7	-52.3	

Tester Signature C.R. Date: 7/22/96
Name: C.Richards

3.7. Frequency Stability

The model M2601A transmitter was placed in a Thermotron Model S-1.2 Temperature chamber. The 9.0 Volt supply voltage was provided by an external DC power supply to allow precise control of the voltage for the tests. The temperature was set at 10°C intervals between -20°C and +60°C. At each setting, the device was allowed to stabilize for 30 minutes before the measurement was made. The output frequency was measured directly with a HP8902A measuring receiver. The data is reported in table 3 below.

Paragraph 90.213 of the Commission's rules specify that a tolerance of +/-0.005% of the carrier frequency for mobile stations. For a transmitter operating at 463.537750 MHz, the tolerance translates into an allowed frequency error of +/- 2317 Hz. The data in table 3 meets this requirement.

Using the same configuration discussed above, the supply voltage of 9.0VDC was varied +22% to -33% while the temperature was maintained at 25°C. The carrier frequency was measured directly with a HP8902A measuring receiver. The data is reported in table 4 below. The transmitter continuously maintained the rated frequency tolerance.

Table 3: Frequency versus temperature

Supply voltage = 9.0V DC
Reference Frequency = 463.53750 MHz

Temperature (°C)	Measured Frequency (MHz)	Error (Hz)	FCC Limit per 90.213 (Hz)
-20	463.53776	260	+/- 2317
-10	463.53785	350	+/- 2317
0	463.53785	350	+/- 2317
10	463.53778	280	+/- 2317
20	463.53762	120	+/- 2317
30	463.53741	-90	+/- 2317
40	463.53721	-290	+/- 2317
50	463.53716	-340	+/- 2317
60	463.53720	-300	+/- 2317

Table 4: Frequency versus Supply voltage

Temperature = 25 °C
Reference Frequency = 463.53750 MHz

Supply Voltage (V DC)	Voltage (%)	Measured Frequency (MHz)	Error (Hz)	FCC limit per 90.213 (Hz)
11.0	122	463.53740	-100	+/- 2317
10.0	111	463.53740	-100	+/- 2317
9.0	100	463.53740	-100	+/- 2317
8.0	89	463.53740	-100	+/- 2317
7.5	83	463.53740	-100	+/- 2317
7.0	78	463.53740	-100	+/- 2317
6.5	72	463.53740	-100	+/- 2317
6.3	70	463.53740	-100	+/- 2317
6.0	67	463.53739	-110	+/- 2317
5.8	cutoff			+/- 2317

4. GENERAL INFORMATION.

4.1. General product description.

This is a milliwatt narrow band FM transmitter operating under license in the UHF Land Mobile Radio Business Band. It is to be operated by a 9 volt battery for up to 6 days, and be worn by a cardiac patient in a health care facility for the purpose of monitoring the patient's electrocardiogram (ECG) and other physiological data. The data is encoded into a digital format which modulates a carrier in a FSK mode. This signal is received at a central monitoring station and displayed for analysis by the clinical staff and by computerized monitoring. The RF carrier is generated by a digitally controlled PLL synthesizer. The frequency is internally set by the digital controller and is not accessible to the patient. The unit may be operated in a mode that connects it to a stationary platform and is fed other measurements.

4.2.Tune up procedure

The reference oscillator frequency is adjusted for 12.80000MHz +/- 100 Hz. There are two potentiometers which are used to set the modulation deviation. These are set in production and are inaccessible to the user. There are no other adjustments.

4.3.Circuits that limit spurious outputs

There are two sources of potential spurious outputs, the VCO and the reference oscillator. The VCO spurious are filtered by two double-tuned filters as well as by series resonant traps formed by combination of these components and circuit board trace inductances. This combines to reduce the level of VCO harmonics to less than -45 dBm without adjustment. The accuracy of the alignment is assured by tolerance of the capacitors of +/- 5%, or +/- .25 pF for capacitors less than 10 pF. All capacitors are COG temperature coefficient and the inductors are thin-film fixed parts with 0 to +125 PPM tempco.

The TCXO reference oscillator operates at 12.8 MHz and is also the system clock for the digital system. This ensures that all frequencies are stable and fixed in their relationship. The PLL system and the digital system generate many subharmonics of the reference oscillator and can be difficult to keep out of the RF output.

This design ensures that these spurious signals are suppressed by several commonly used methods. The PC board layout and layer arrangement carefully separate the physical structure of the RF and digital section, and the RF section critical components are under a metal shield soldered to the PCB. The RF section has separate voltage regulators to isolate the supplies from the digital noise, and many resistors, chokes, and capacitors further filter the noise between sections. The RF signal is carried to the leadset connection by a coaxial cable.

The PLL IC incorporates a loop lock signal output which is monitored by the digital controller, U101. On start up, shut down, and for any other reason the loop is not locked, the RF output is suppressed. In the event that the battery is removed and the digital section is no longer active, there is a direct path for the RF to be shut down via U407, which senses that the regulator is not in regulation. Q404, Q407, R483, R484, R481, R482, R486, and R485 form this circuit.

There is additional circuitry to ensure that at low battery conditions, U407 remains in regulation albeit at a slightly lower voltage. This ensures that the output remains properly modulated and on frequency, while the power output is approximately 2 dB lower than nominal. This condition will exist for up to 10 minutes at the end of the battery's normal discharge cycle.

4.4.Circuits that limit modulation.

The transmitter modulation is obtained by superimposing the GMSK shaped waveform on the modulation ports. It is processed to ensure that the DC component is stable to minimize carrier frequency offset. The modulation is derived from a duty cycle modulated signal that is generated by U100, a ASIC, which controls the information bit rate and waveshape in hardwired logic. The clock is the 12.8 MHz reference oscillator.

The output of the encoder is filtered by U105 and R124, R125, R127, R126, C115, C116, and C117. This forms 3 poles of a Gaussian filter. R143 provides a bias for U105. The other half of U105 supplies the DC reference voltage of 1.5 volts by buffering a voltage divider, R139, R140, and C126, which filters any noise on the VCC supply. The 1% resistors and 5% COG capacitors ensure that the filter's characteristics are stable and as designed. The main shape of the waveform is determined by the shaping coefficients stored in the ASIC, U100, so that the waveform is stable and accurate by design.

4.5.Circuits that limit power

The transmitter output power is constrained by the voltage and current available to the output transistor, Q406. The current is set by the current drain of the PLL IC, 6 mA, and the reference oscillator, 1.1 mA. There is an additional .7 mA drawn thru Q405 by R468. Also, the bias thru Q402 reduces the current drain by .3 mA. The total current available at Q406 is therefore 7.5 mA. The voltage is set by U407 at 6.4 volts, while the bias at the base of Q406 is 5 volts, so that the peak voltage at the collector is1.4 volts. Therefore the power available at the collector of Q406 is 5.3 mW, and there is approximately 1.5 dB loss in the output filter. This gives the output power as 3.7 mW. 4 mW is obtained by driving the output stage slightly into saturation. Stable currents and voltages in the various stages ensure that the signal levels and gains are consistent over all part variation and tolerance.

is set by R431 for the VCO and R432 for the TCXO. As the RF frequency shifts across the band, there is a slight mismatch in deviation caused by the change in divide ratio in the PLL. I.e., the deviation of the TCXO is effectively multiplied by the total divide ratio of output frequency to reference frequency. In this case, the limitation of 10 MHz bands imposes a limit which is well within the tolerance of the system, or .1%. The modulation varactor, CR401, provides a constant deviation gain in the VCO despite changes in frequency since it is a very small proportion of the total circuit capacitance.

This scheme ensures a well controlled deviation, waveform, data rate, and therefore a stable and consistent spectrum.

4.7. Product Label

FCC ID: B948JAM2600

5. CIRCUIT DESCRIPTION

Please refer to Fig. 1, "TUHFMAN Digital Synthesizer" for the schematic and to Fig. 3: "M2601 RF Block Diagram".

5.1. General

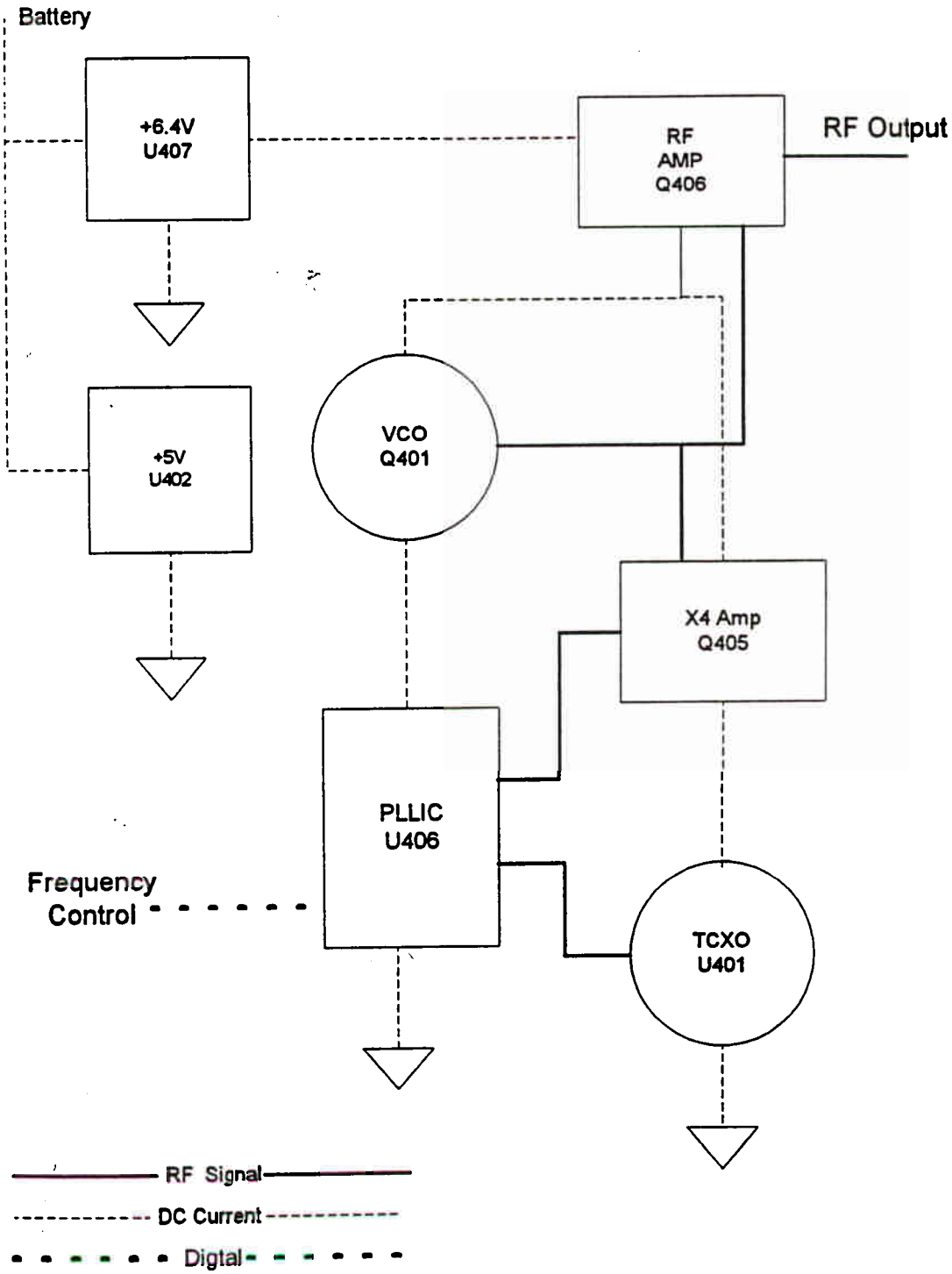
The synthesizer is a digital Phase Lock Loop. The blocks are arranged so as to minimize current consumption. Also, the VCO operates at 1/2 the desired carrier frequency, and the PLL operates at 2x the carrier frequency. Additional circuitry is provided to control start up and unlocked operation so as to prevent uncontrolled RF signals. Supply voltages are actively regulated and temperature compensated. There are no RF adjustments; frequency is controlled by a precision, low temperature drift TCXO reference via a PLL, and amplitude is controlled by high tolerance part selection and precise current and voltage control.

A unit is designed to operate over a 10MHz wide band with the frequency information retained by non-volatile memory in the digital section. Construction is all surface mount, high tolerance parts, and the RF output is radiated by the patient leadset.

5.2. Active elements.

U401 is the Temperature Compensated Crystal Oscillator (TCXO) for the reference signal
U402 Regulates bias voltages
U406 is the PLL control IC
U407 Regulates the battery voltage and supplies current to the RF section.
Q401 is the gain element for the Voltage Controlled Oscillator (VCO)
Q402 temperature compensates the bias voltages
Q403 provides attenuation of the RF output when active
Q404 and Q407 shut off the RF section when the supply voltage is low
Q405 is an RF amplifier and buffer for the signal feeding the PLL IC
Q406 is the RF output transistor
CR401 frequency modulates the VCO
CR402 tunes the VCO frequency

Figure 3: M2601A RF Block diagram



5.3. VCO

The VCO (Q401) is a common collector Colpitts circuit with frequency control provided by CR402. Bias is provided by R407 from Q402. The current thru the VCO is 5.6 mA, which is the current supplied to the PLL IC, U406, minus the bias current thru R406 and Q402. C435 and C436 provide feedback, C434 raises the "Q" of the oscillator tank which is formed by inductor L466 and the capacitance of its surrounding capacitors. C433 reduces the frequency deviation due to CR402 and blocks the varactor bias voltage. C432 and CR401 provide frequency modulation. The 2nd harmonic of the oscillator current is filtered and passed to the output via L454, C473, C463, L467, C469, C454, R472, and R466. The oscillator is run at 1/2 the output frequency to gain isolation from output load changes. The fourth harmonic is filtered and passed to Q406 via C474 in parallel with an inductor which is part of the circuit board, and C472 then R467. R434 provides an emitter load, while C442 and C443 bypass RF frequencies. Additional audio frequency filtering is provided by C441, R478, C444, and C445 to isolate the noise generated by U406, Bias is supplied by R406 and the +5RF output of U402. R404, and R405 set the bias voltage on Q402 whose emitter stabilizes the bias for the VCO as well as Q405.

The VCO control tuning voltage is 0 to 4.8 volts from the phase detector in the PLL IC. The nominal frequency range is approximately 435 to 485 MHz to allow for part tolerance and temperature drift.

5.4. X4 amplifier

Q405 amplifies the 4th harmonic of the oscillator and C471, L470, C418, C413, L469, and C412 filter and suppress the other harmonics. The bias for this transistor is provided via R465 from Q402. The current passes from Q406 and is set by the TCXO oscillator, whose nominal current is 1.1 mA. The voltage at the emitter of Q405 is 3.2 V, and R468 drains an additional .76 mA through this transistor. C416 is an RF bypass at its emitter. L453 is an RF choke to pass the DC current and block AC components from the output stage.

5.5. Output Stage

The output transistor has most of the current used by the RF circuit thru it which is 7.5 mA, supplying current to the VCO and the X4 amp. Its' output is filtered by C460, L462, L461, C462, and C417. These elements form a double tuned filter. Topology and values are designed to not only pass the desired frequencies but form notches to suppress harmonics of the VCO. The voltage available across the output transistor is 1.5 volts. L460 is an RF choke which supplies the DC power, and C404 and C405 are bypass and filter capacitors for high and low frequencies. C451 bypasses RF frequencies and also series resonates with L460 to suppress the fundamental output of the VCO.

Bias is supplied to Q406 at 5.0 volts by R466, R409, C402, C401, and R401 which filter and bypass the bias voltage.

5.6. TCXO

The TCXO is an OEM unit which consists of a crystal oscillator operating at 12.8 MHz and which has been temperature compensated to hold its frequency within +/- 2.5 PPM over the transmitter's rated operating temperature range. The aging rate is less than 1 ppm per year. The circuit is a self-biased NPN transistor in a Colpitts configuration, with temperature compensating circuitry, and modulation capability. The output is buffered with a second NPN transistor. It is designed to operate at 3 volts and 1.1 mA. The frequency is adjusted at the factory to an NBS traceable standard.

5.7. PLL Operation

U406 is a digital PLL IC incorporating RF prescaler, counters, phase detector, and logic to control its' functions. It receives control information via resistors R411 thru R413, and R419 thru R421 from the digital controller in the unit. C421, R423, R416, and C420 form the loop control filter, while R417, C419, R418, C477 and R479 provide additional suppression of reference frequencies from the phase detector. R410 and C411 provide a filtered +5 volts to run the phase detector. R414 sets the phase detector gain.

The loop operates in a novel way in that the operating frequency of the PLL is twice that of the desired output frequency. This is to allow the loop to operate at twice the normal speed so that the reference sidebands can be further suppressed and the loop can more effectively correct for load induced frequency pulling.

5.8. Modulation

The modulation is supplied via "mod" input and "+1.5" input and is set by R431 and R432. The modulation is applied both inside the loop to the TCXO and outside the loop to the VCO. This makes the frequency bandwidth of the modulation extend from DC to 16 KHz. The potentiometers allow the deviation of both paths to be set to 2.4 KHz peak and to be balanced.

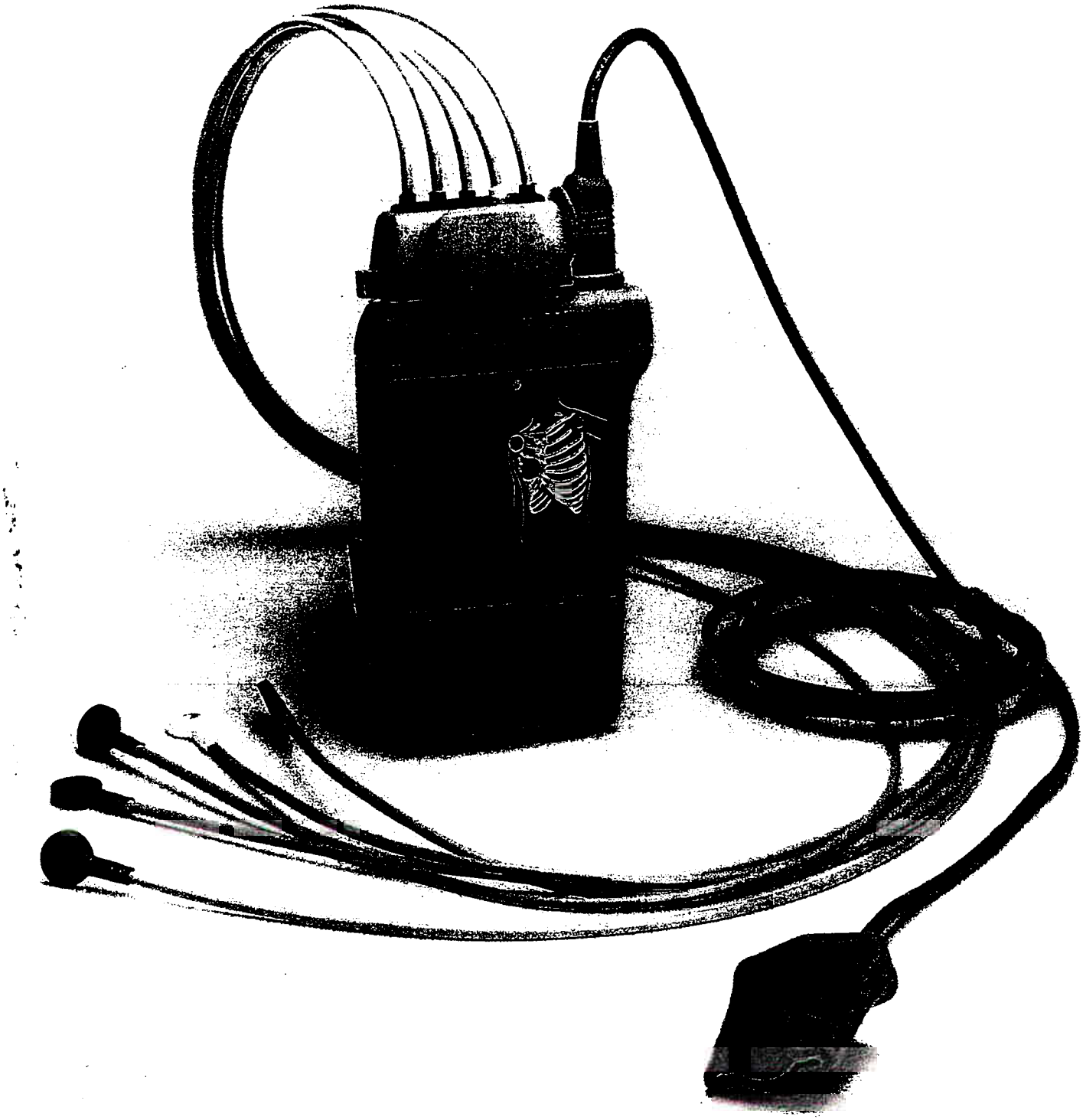
The modulation is generated by U100 and is filtered by U105 and its' associated components. The combination of shaping of the waveform in U100 and the filter's response form a Gaussian filter to produce the appropriate bandwidth limiting in the resultant RF spectrum. R430 and C430 further reduce out-of-band noise to the input of the modulation. See Section 4.0 for further details.

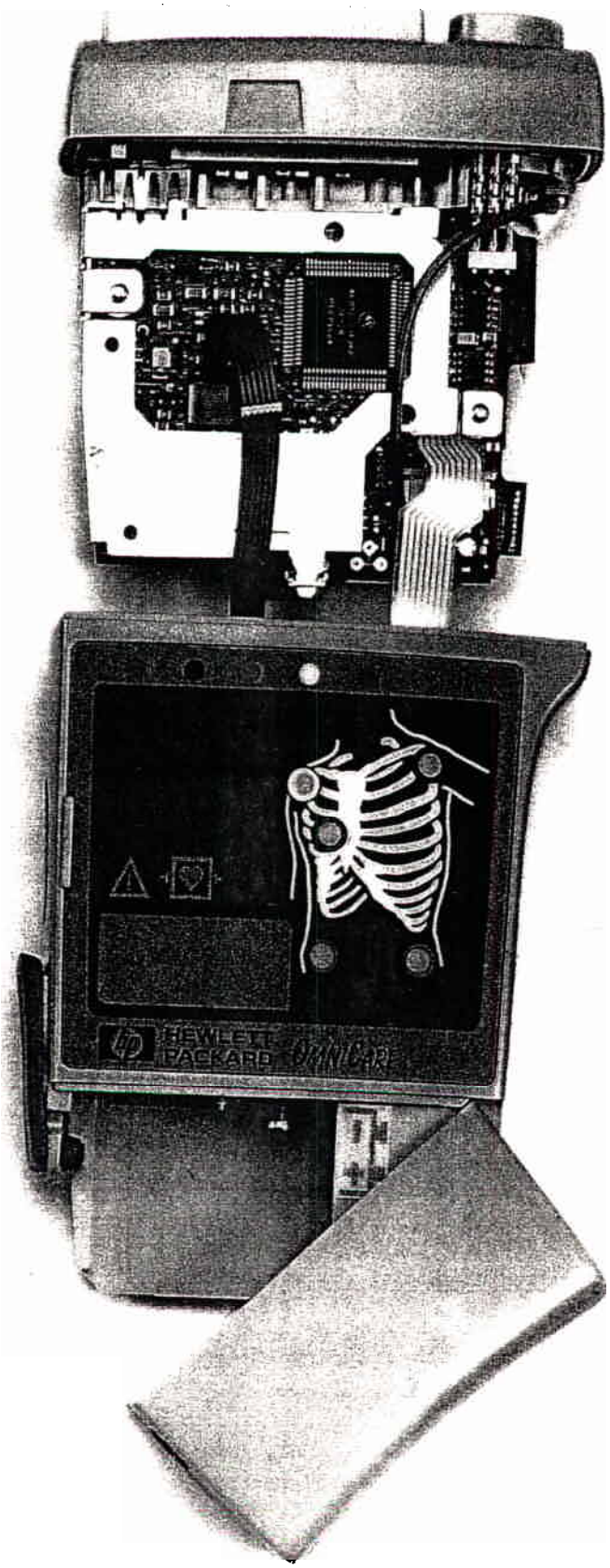
Attachments:

1: Product Schematics

2: Product Photo's

3: User manual

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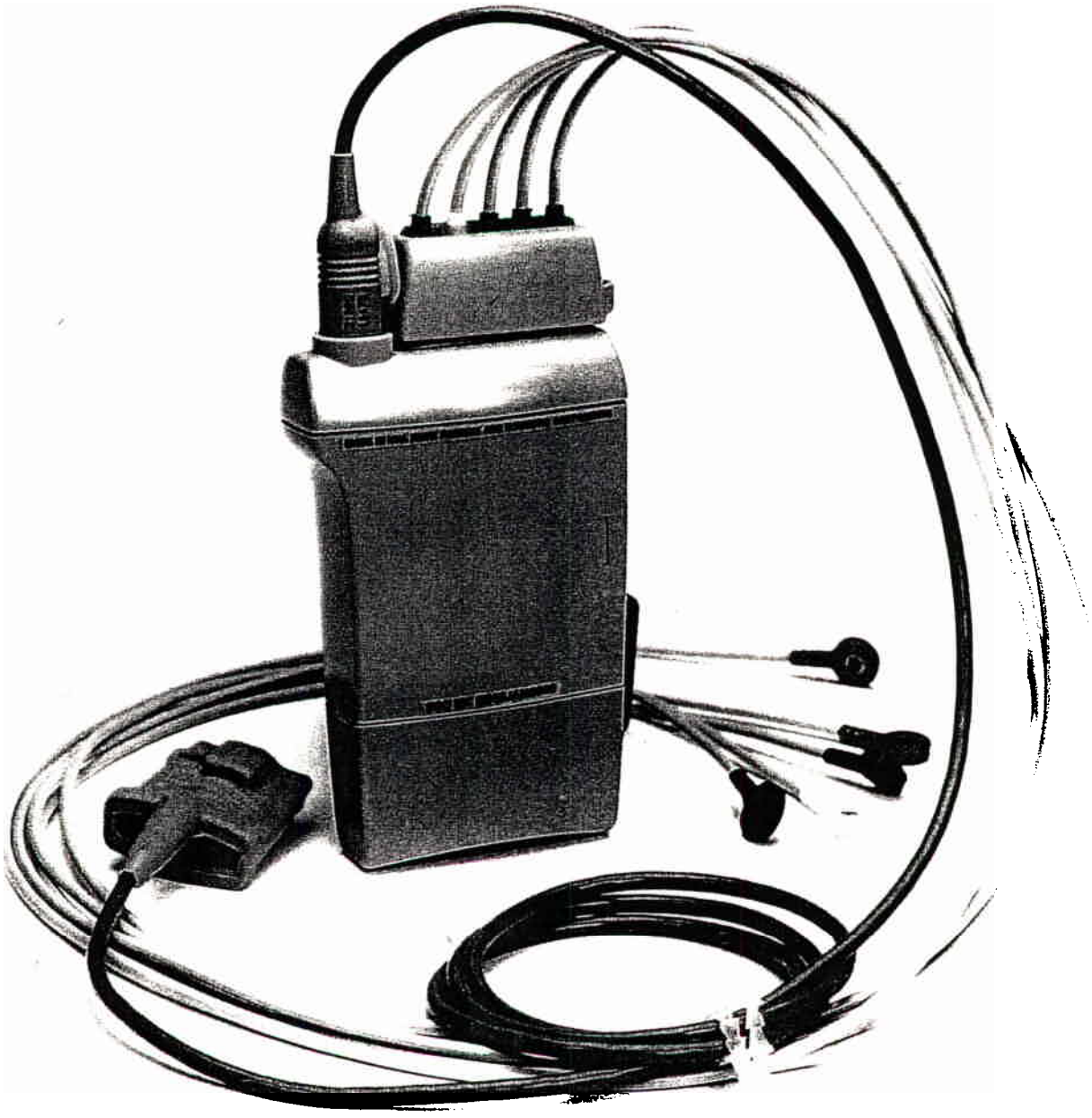

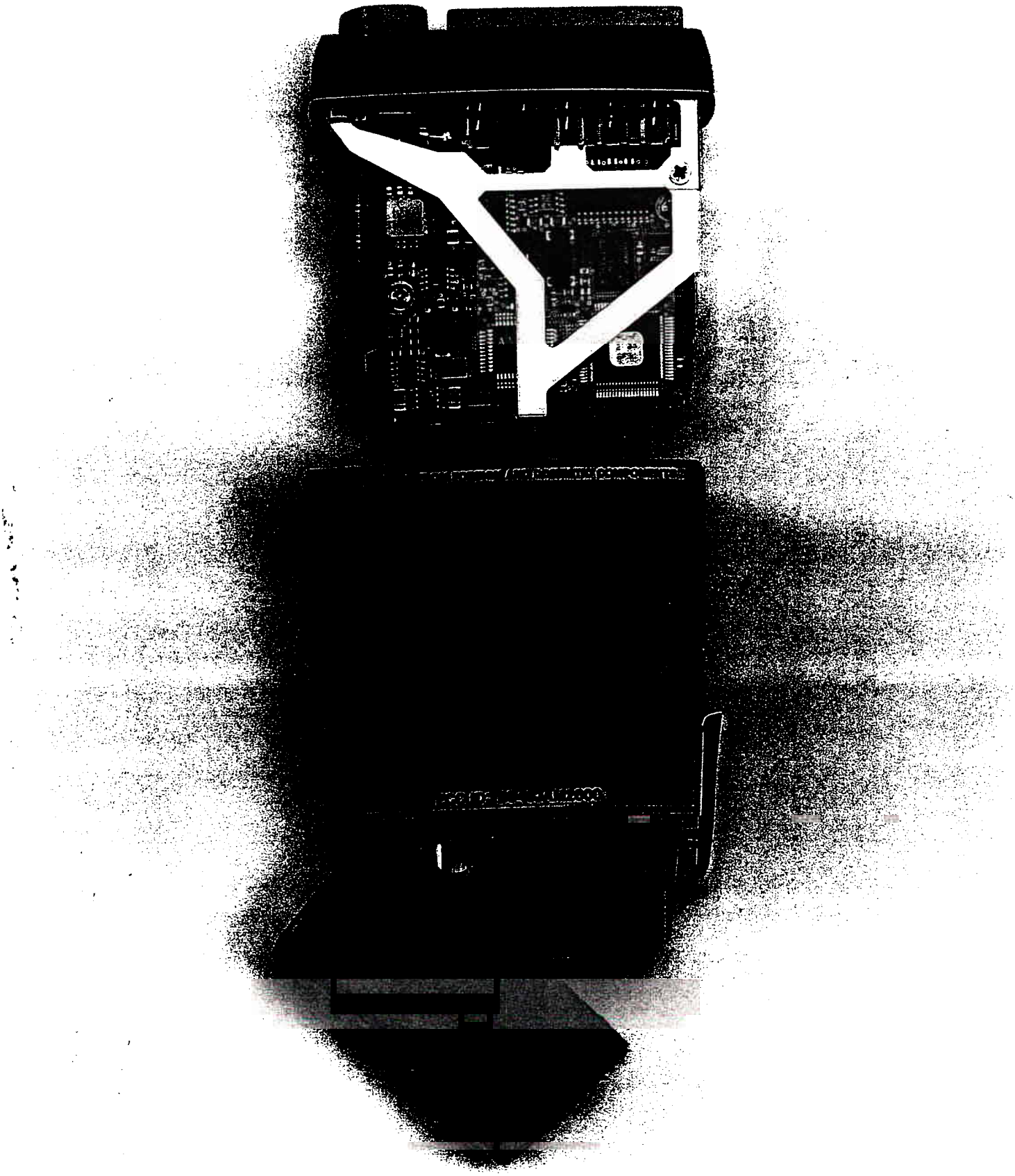

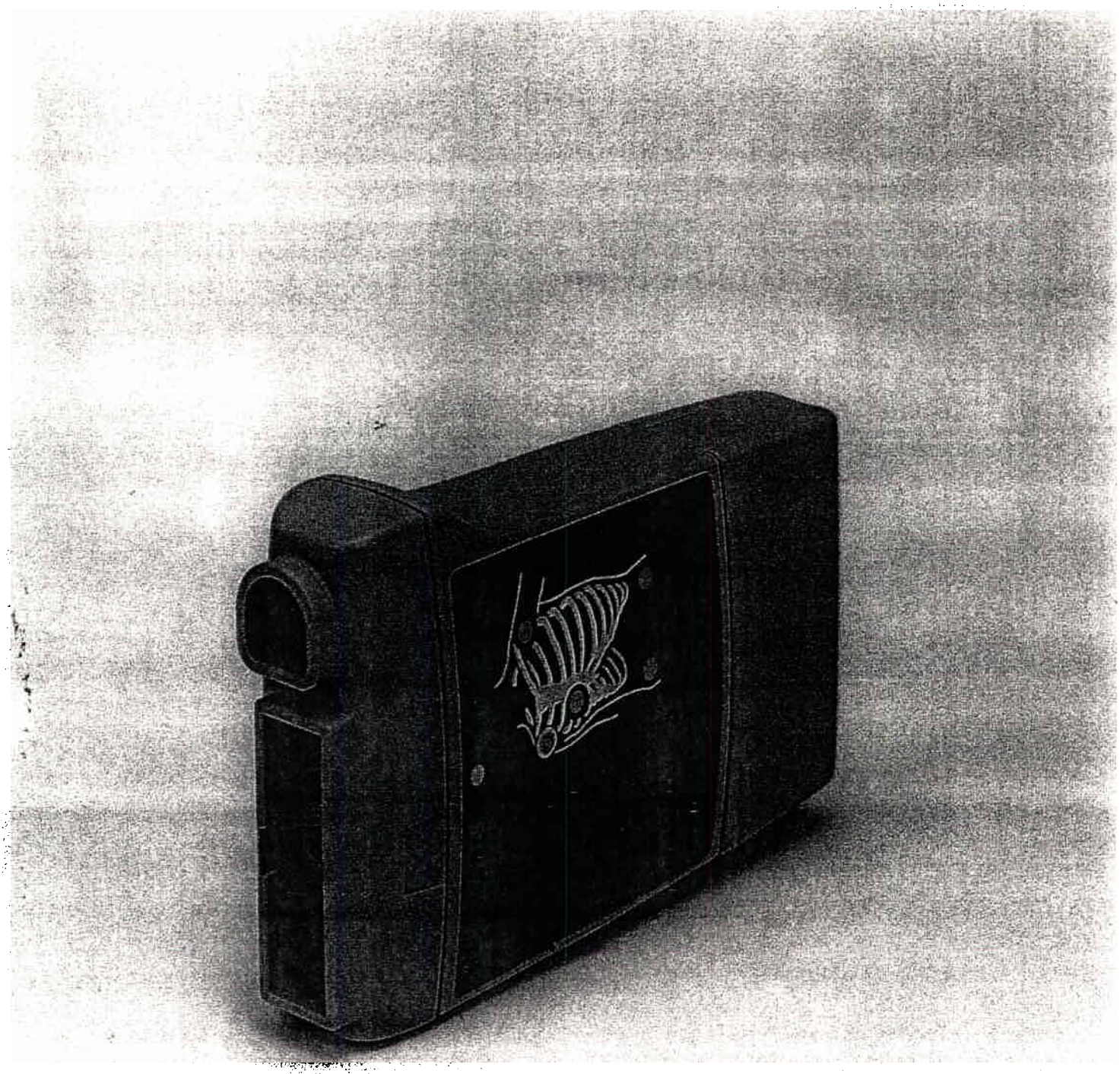

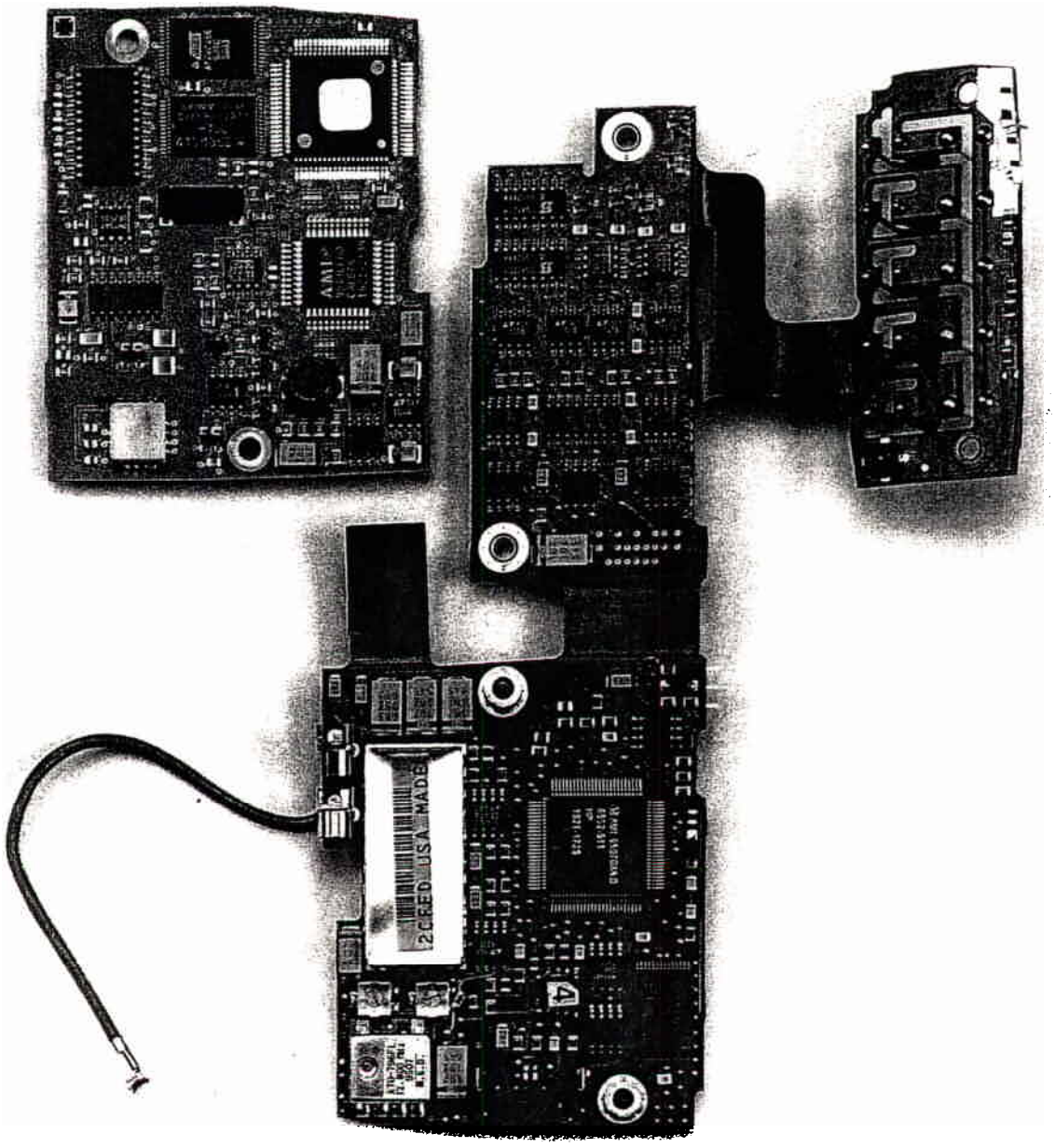
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