AN IMPROVED DRONE TRACKING CONTROL SYSTEM TRANSPONDER

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ABSTRACT

Improved performance has been achieved in the new Herley design of the Model MD700C-1 Drone Tracking and Control System, C-band Command and Control Transponder. The approach for obtaining better radio frequency rejection, automatic gain control, local oscillator stability, and power supply efficiency is described. New hybrid microwave integrated circuit application techniques were used to design a small local oscillator, tunable over the 5400 to 5900 MHz range with a frequency drift of less than ± 1 MHz. This low frequency drift allowed the use of a 4 pole immediate amplifier filter, 60 dB down, at 40 MHz bandwidth, which, when coupled with the three cavity radio frequency preselector filter, provides 7 pole out of band rejection for unwanted radar signals operating at close frequencies. To augment the out of band rejection, a new form of 75 dB dynamic range automatic gain control was used, which combines signal attenuation with a circuit that reduces immediate frequency noise with increasing signal. This allows rejection of the radars own in-band multipath signals by reducing the gain and threshold sensitivity. To reduce power consumption and heat while operating over a wide voltage range, a switching mode regulator and a non-saturating core power supply was designed to operate at 80% efficiency.

Compared to units in field use over the past 10 years, the new design shows improvements of 400 percent in local oscillator frequency stability, 30 percent in out of band frequency rejection, 66 percent in the automatic gain

control dynamic range, and 60 percent in power supply efficiency.

The MD700C-1 was developed by Herley Industries for the USAF SMALC, and is currently in production.

I. INTRODUCTION

The Drone Tracking Control System (DTCS) Transponder is the receiver and transmitter module of the Target Group Set (TGS) located on board, and used to command, unmanned air and/or surface vehicles (targets). The TGS is used in conjunction with Range Instrumentation Radars, operating in the 5400 to 5900 MHz frequency range, and which provide the command and control information signals from the ground to the unmanned vehicle in the form of a series of groups of 4 pulses, whose position in time provides date to the Target. Within the Target a number of sensors are multiplexed and data transmitted to the ground through a similar pulse train. Often, several radars are used for tracking one Target Group Set, while other radars on the same range are tracking other objects. For example, on the White Sands Missile Range (WSMR), up to ten (10) Range Instrumentation Radars can be operating simultaneously, all within a 250 MHz frequency band. During normal operations, radars that have their Pulse Repetition Frequency (PRF) phased, and radars that do not have their PRF synchronized, can cause signals to arrive at the Target Group Set at the same time. This can cause unwanted extraneous pulses to overlap and interfere with the desired command pulse train, and cause command loss. This is known, on the operating ranges, as friendly jamming. The DTCS Transponder currently in service was not specifically designed to operate in such a harsh radio frequency (RF) environment, and therefore does not provide adequate RF rejection in this scenario. This has resulted in uplink commands being inadvertently jammed, causing the loss of expensive unmanned targets.

The goal of the development program conducted by Herley Industries, Inc. was aimed at designing a new DTCS transponder with improved RF rejection characteristics, and other performance improvements, without increasing production cost. The MD700C-1 is the result of that successful program.

The design improvements were made in the receiver and power supply of the new MD700C-1 transponder. Figure 1 is the block diagram of this unit, exhibiting the major subsections. The receiver is a superheterodyne design. The video output, the detected 4-pulse groups, are fed to an external decoder, where they are interfaced to the flight control system of the target. Sensor data, to be sent to the ground, is formatted in the external encoder, and fed back to the transponder. Along with the transponders tracking reply pulse, this information is modulated, as a reply pulse train, onto the transmitter for transmission back to the C-band ground range instrumentation radar.

The three major contributors to the operational interference problem with the existing DTCS Transponder are:

a. The local oscillator (LO) frequency drift over the temperature range of -55°C to +75°C is about ± 7 MHz.
b. To accommodate this wide LO frequency drift, the intermediate frequency (IF) amplifier has a 40 MHz, 3 dB bandwidth with broad skirts, which gives poor out of band rejection.
c. The automatic gain control (AGC) has only a 45 dB dynamic range, giving poor multipath rejection. This situation usually occurs during the critical take off and landing maneuvers, when the radars reflected interfering signal can be the strongest, and when the danger of mishap is the highest.

Another major concern in the existing DTCS Transponder is potential reduced reliability due to self-generated heating due to low power supply efficiency. The power supply in the older unit uses a series pass transistor to regulate the incoming voltage, which can vary from 22 to 32 volts DC, down to a lower fixed voltage level for operation of the chopper power supplies. At the normal input voltage of 28 Vdc the supply is only 50 percent efficient, causing internal heat rise, thereby reducing the reliability of the transponder.

II. DESIGN IMPROVEMENT PHILOSOPHY

The use of modern microwave chip transistors, monolithic amplifiers, and beam lead and chip diodes, in combination with thin film passive circuits, makes it possible to reduce the size of all active circuits to approximately 1/5 that of previously produced circuits using packaged devices. Since the Q of elements needed for oscillator frequency control and filtering is proportional to their volume, the use of hybrid thin film active circuits allows for large (high Q) network elements to achieve good frequency stability and signal filtering. Analysis of overall system performance requirements led to providing 75 dB of AGC attenuation in the IF amplifier, and dividing the bandwidth limiting functions between a 3 pole microwave filter and a 4 pole IF filter. A graph of the IF amplifier AGC curve is shown in Figure 2. Since the allowed narrowness of the IF filter is limited by the LO frequency stability, considerable emphasis was applied to reduce LO frequency drift to under ±1 MHz. The combination of these design concepts has led to a unit with 88 dB rejection of RF signals ±20 MHz from the center frequency. The improvement of power supply efficiency to reduce internally generated heat and improve reliability was based upon the use of modern monolithic pulse width modulation control chips in combination with efficient magnetic circuit designs.

III. LO/MIXER AND IF AMPLIFIER DESIGN

The LO and mixer used in the MD700C-1 design is a microwave integrated circuit (MIC) consisting of a mixer and part of the oscillator circuitry printed onto an Alumina substrate. The mixer consists of a rectangular implementation of the classical rat race hybrid. A beam lead diode pair in a tee configuration was used to provide nonlinearity for the mixing to occur.

A schematic diagram of the LO and mixer is shown in Figure 3 and topographical view in Figure 4.

The three critical elements of the oscillator which impact on the potential frequency drift are: the proper selection and application of the bipolar transistor chip; use of circuitry printed directly on the Alumina substrate; and inclusion of a coaxial cavity resonator. All three of these items can improve the thermal stability of the oscillator in the Herley design.

First, the transistor chip is eutectically bonded to the chassis floor. This provides an extremely good mechanical, electrical, and thermal connection between the transistor and chassis. This connection is critical to the stability of the oscillator.

The second item is the Alumina substrate which has a dielectric constant temperature coefficient of 113 PPM/deg C. Although there are more exotic materials with better temperature coefficients, this material provides good electrical stability as well as good mechanical stability.

The third and most important item is the coaxial resonator. The frequency controlling element of the resonator is made of INVAR which has a near zero temperature coefficient. Silver plating of the entire cavity structure provides an unloaded Q of greater then 600, a factor of six better than microstrip resonators.

Oscillation in the circuit takes place at a frequency where the sum of the reactances is zero. By employing a cavity with a high loaded Q in the circuit, a small change in frequency creates a large reactance change of the cavity around its resonant frequency, and compensates for changes in transistor and circuit reactances with time and/or temperature. As a result, changes in the transistor and its associated circuit have a small effect on the oscillator frequency; and, the coaxial cavity with its stable resonant frequency over temperature, leads to an oscillator with less than ±1 MHz frequency drift over the full temperature range.

The IF amplifier consist of three silicon bipolar monolithic microwave integrated circuit (MMIC) amplifier gain stages, having 20 - 22 dB gain each, and a 1 dB compression point of 4 dBm. A measured noise figure of better than 2.8 dB is in good agreement with the manufacturer’s specifications. Each device requires only two support components for bias, which reduces parts count dramatically over prior designs, thus leading inherently to higher reliability. The three stage amplifiers in the MD700C produce 60 to 64 dB gain with less than 2.8 dB noise figures. A schematic diagram of the IF amplifier and filter is shown in Figure 5 and a topographical view in Figure 6. Because these are broad band 50 ohm gain blocks, no alignment is needed, total parts count is reduced, and manufacturing is simplified. Following this amplifier, but in the same package, is the four pole filter which provides 12 MHz, 3 dB bandwidth, and rejection at ± 20 MHz of 60 dB. Thin filter reduces the total noise power presented to the video detector, providing a better signal-to-noise ratio to the detector, and better sensitivity. A graph of the existing IF amplifier bandpass is shown in Figure 7 and the new IF amplifier bandpass, in Figure 8.

IV. AUTOMATIC GAIN CONTROL DESIGN

Past system designs used a pin diode limiter/attenuator in front of the low noise amplifier to achieve 45 dB of receiver gain control. Located in front of the RF amplifier. the AGC circuit did not reduce receiver noise with increased signal. This results in the receiver threshold circuit always operating at 10 dB above noise, causing the transmitter pulse to have jitter. The 45 dB AGC dynamic range is insufficient when the unmanned vehicle is close to the controlling radar, and the signal levels exceed the AGC by 35 dB. This permits multipath signals up to 35 dB below the main radar’s signal level to be detected by the receiver, and passed on to the decoder along with the desired pulse train. The presence of these extraneous pulses, can cause command lose of the vehicle. Therefore, two improvements were made in the new Herley designed transponder AGC circuit, to improve the dynamic range, and to reduce receiver noise.

The AGC dynamic range was raised to better than 75 dB, while reducing the receiver noise with input signal level. To achieve this, the AGC circuit was designed to control the gain of the IF amplifier by reducing the Vcc supply to the three MMIC amplifiers. The full 75 dB gain is obtained by reducing the IF amplifier Vcc from 9 volts to 5 volts while holding a constant amplitude video output pulse. The new AGC design will eliminate multipath signals over a full 75 dB range, permitting more reliable take off and landing of the unmanned vehicles. By reducing the IF amplifier gain, the noise level is reduced to zero after 10 dB of AGC signal, allowing the transponder receiver to operate virtually noise free. This permits the receiver threshold detector to operate jitter free from noise, and produces better overall system performance.

V. POWER SUPPLY DESIGN

From an overall design evaluation of the transponder, Herley concluded that considerable improvement in the operating efficiency and reliability could be obtained by redesigning the power supply. A block diagram of the existing power supply is shown in Figure 9. The series regulator is effective for removing ripple and small changes in supply voltages, but becomes inefficient over the wide required operating range of 22 to 32 volts DC. The regulated DC voltage, of approximately 20 volts, feeds a saturating core DC to DC converter operating at 10 KHz. Additional circuitry is required around this to prevent the sudden saturation of the core from damaging the switching transistors. The design chosen by Herley for a new, high efficiency power supply uses a switching mode regulator. The switching mode regulator replaces the series regulator and the DC to DC converter is driven by, and synchronized to, the switching regulator. The block diagram of the high efficiency power supply is shown in Figure 10. The pulse width modulation control uses a simple integrated circuit operating at 100 KHz to drive a switching power Field-Effect Transistor (FET). The pulse width is varied, depending on the load requirements and the supply voltage variations, to provide a constant input voltage to the DC to DC converter. The DC to DC converter is synchronized to the oscillator of the pulse width regulator controller. The driver converter results in better controlled switching characteristics without the high current transient of the saturating core type design. In addition, the higher operating frequency of 50 KHz provides lower ripple on the output for the same storage capacitance when compared to the earlier 10 KHz design.

The improvement in efficiency for the regulator part of the circuit is shown in Figure 11. The plot for the switching mode regulator is the measured results for an output of 20 volts DC at 1.3 ampere with an input supply voltage of 22 to 32 volts DC. A power conversion efficiency of better than 90% is obtained throughout the 22 to 32 voltage range. The second plot depicts the maximum efficiency of a series regulator operating over the same supply voltage range. For a 22 volt supply the efficiency is above 90%, however the efficiency then drops with increasing supply voltage to 62% at 32 volts input. At this point the series pass transistor is dissipating over 15 watts, whereas the switching mode transistor is dissipating less than 2 watts over all supply voltages. In addition to the efficiency improvement, the pulse width modulation control circuit also provides for a slow startup, to limit the inrush current, and provides protection against overload.

The DC to DC converter uses n-channel power MOSFET devices driven directly from a second, control integrated circuit (IC). The transformer is a low parasitic, high frequency design, using a ferrite core. The output DC voltages were reduced from three to two separate rails to provide for a simpler secondary circuit. The total power supply, including EMI filter, polarity protection, regulation and DC to DC Converter, provides 75% efficiency over the input supply voltage of 22 to 32 volts DC. This results in a considerable reduction in transponder dissipation as shown in Figure 12. The dissipation is plotted as a function of PRF for both the new and earlier designs of DTCS transponders. The lower dissipation in the new power supply will reduce the operating temperatures of the overall transponder circuitry, and thereby contribute to improved reliability.

VII. CONCLUSIONS

The application of modern technology to some very old circuit and system concepts has been shown to produce benefits in performance, reliability, and manufacturing cost. Stabilization of the LO, use of a narrow pass band IF amplifier, and amplifier AGC control, date back to World War II and are covered in detail in many text books. The approach presented in this paper has realized a small, compact, and inexpensive method of achieving frequency stability of a solid state LO to ± 1 MHz. A simple IF amplifier design using three MMIC amplifier devices with a narrow pass band output filter, provides better system interference rejection, performance, and AGC dynamic range. By using devices that have been developed in the last ten years, a more efficient and reliable power supply and regulator have been developed. The result is that the new MD700C-1 Transponder provides superior performance and reliability over the previous units.

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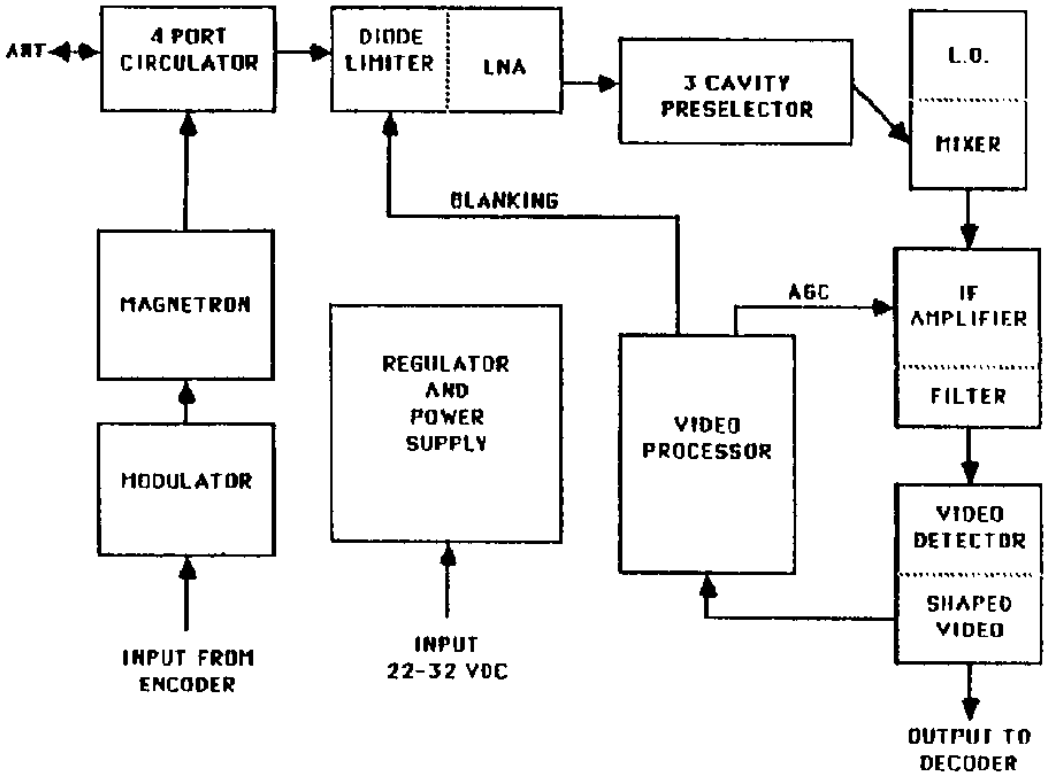

FIGURE 1 BLOCK DIAGRAM FOR MD700C-1 TRANSPONDER

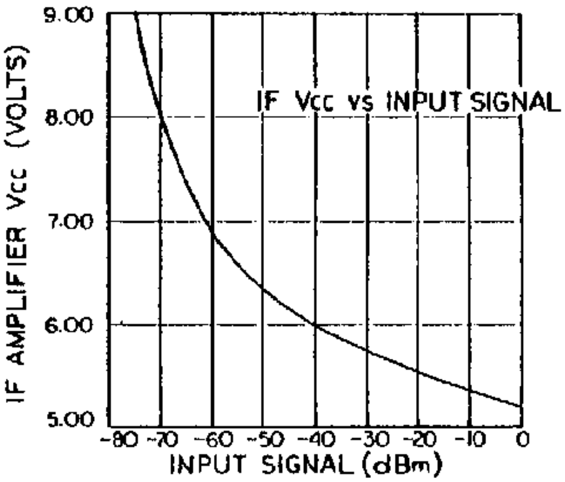

FIGURE 2 IF AMPLIFIER AGC CURVE

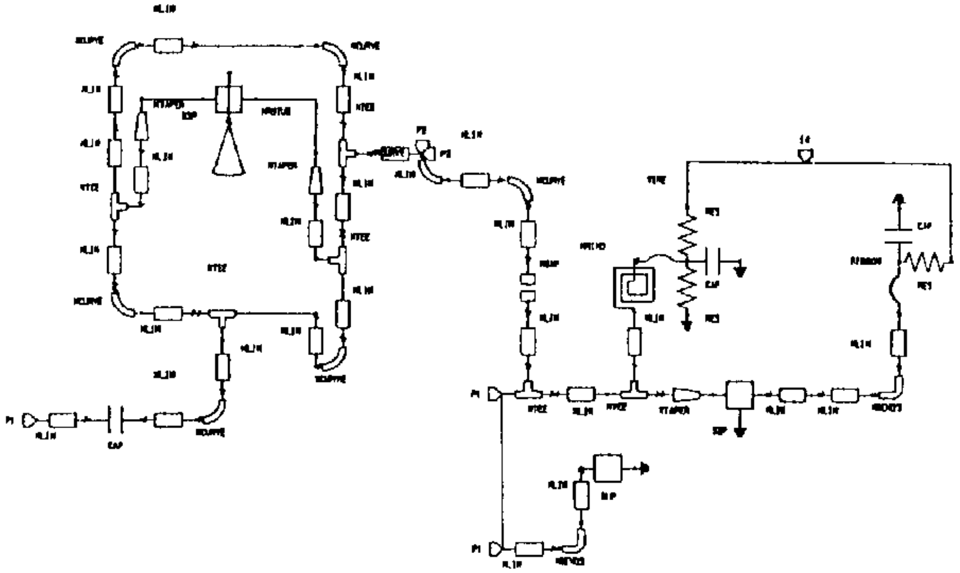

FIGURE 3 SCHEMATIC OF THE LO AND MIXER

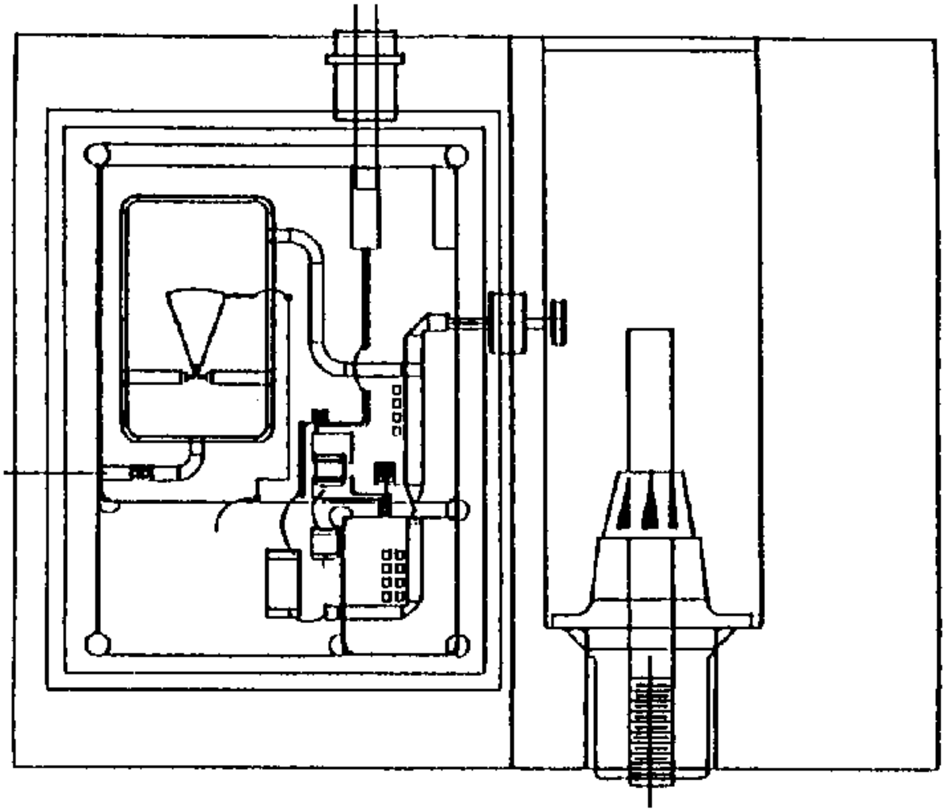

FIGURE 4 TOPOGRAPHICAL VIEW OF THE LO AND MIXER

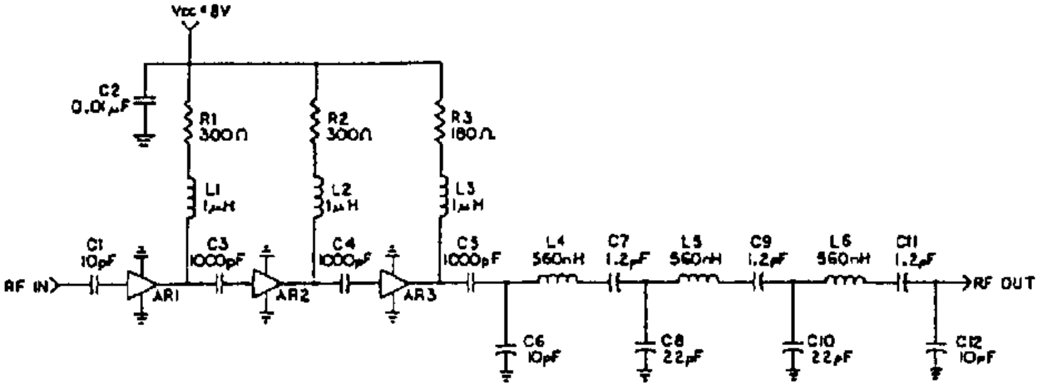

FIGURE 5 SCHEMATIC OF THE IF AMPLIFIER

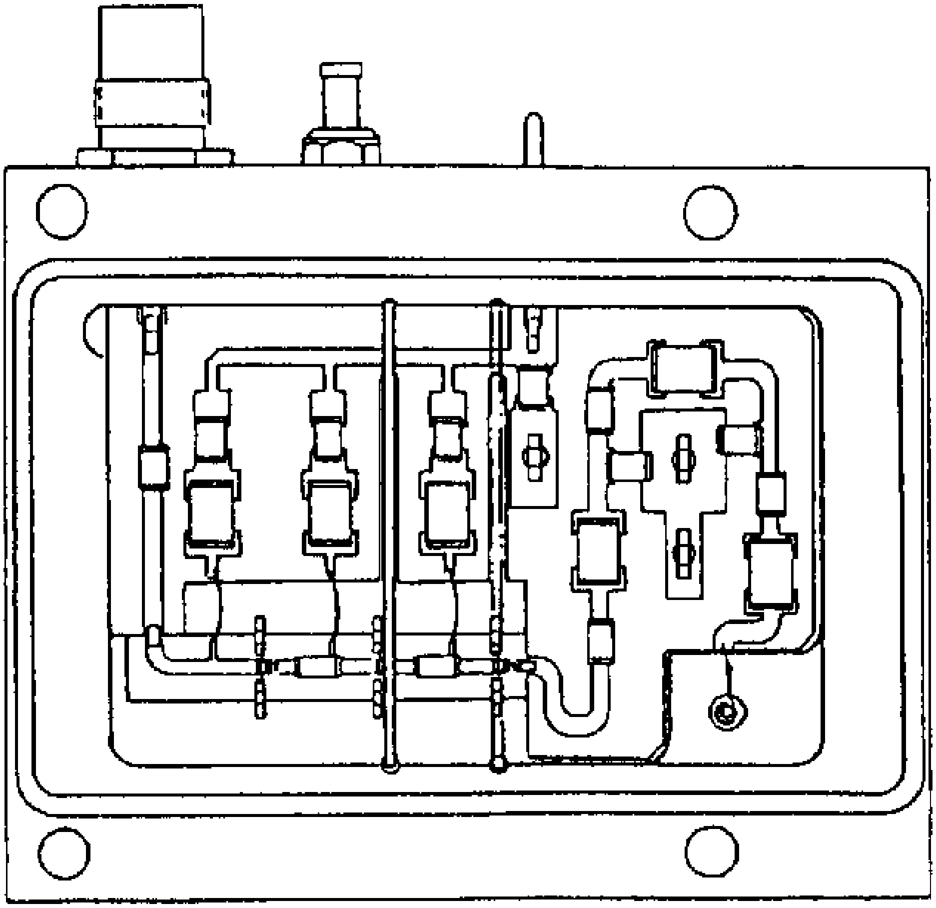

FIGURE 6 TOPOGRAPHICAL VIEW OF THE IF AMPLIFIER

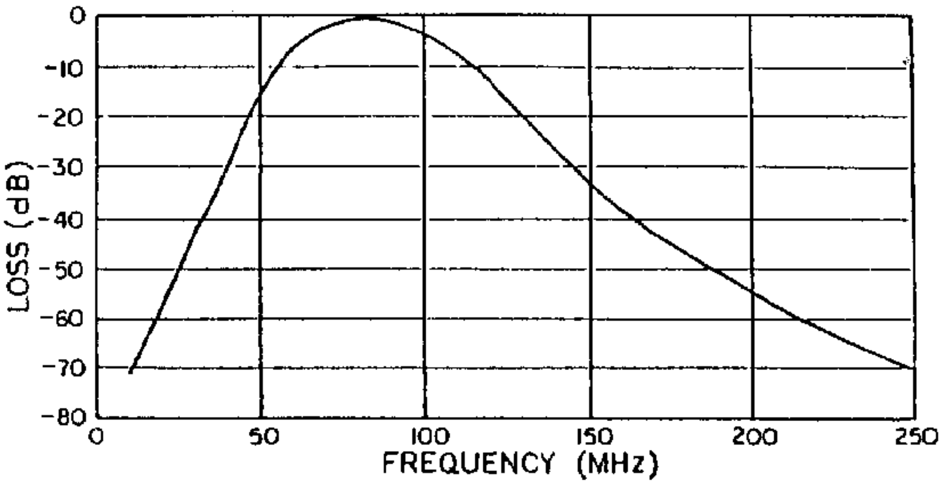

FIGURE 7 EXISTING IF AMPLIFIER BANDPASS

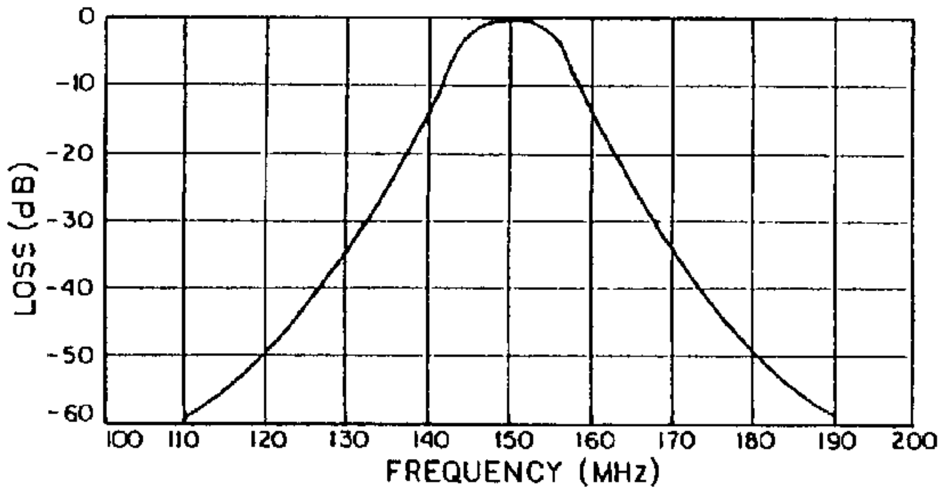

FIGURE 8 NEW IF AMPLIFIER BANDPASS

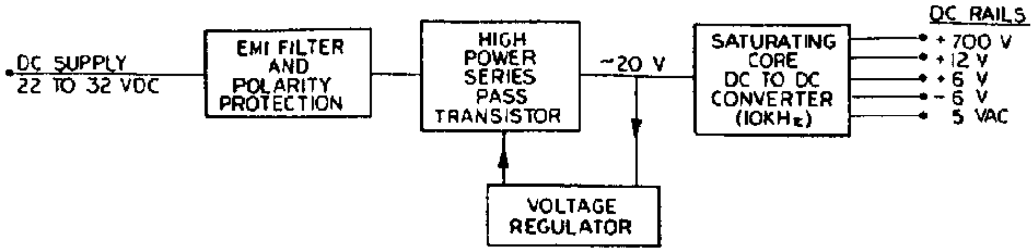

FIGURE 9 BLOCK DIAGRAM OF
EXISTING POWER SUPPLY

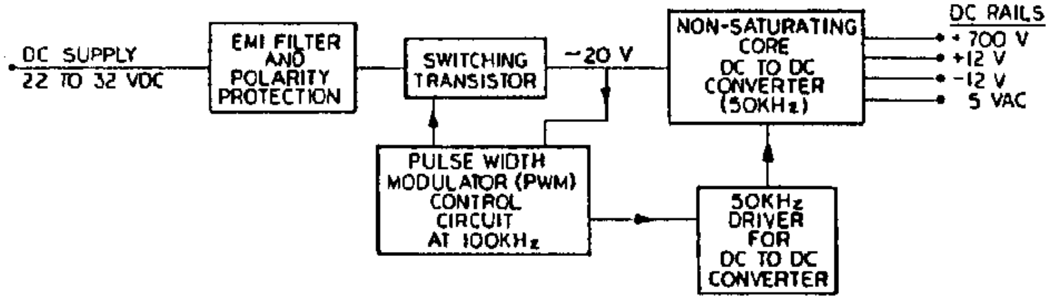

FIGURE 10 BLOCK DIAGRAM OF
HIGH EFFICIENCY POWER SUPPLY

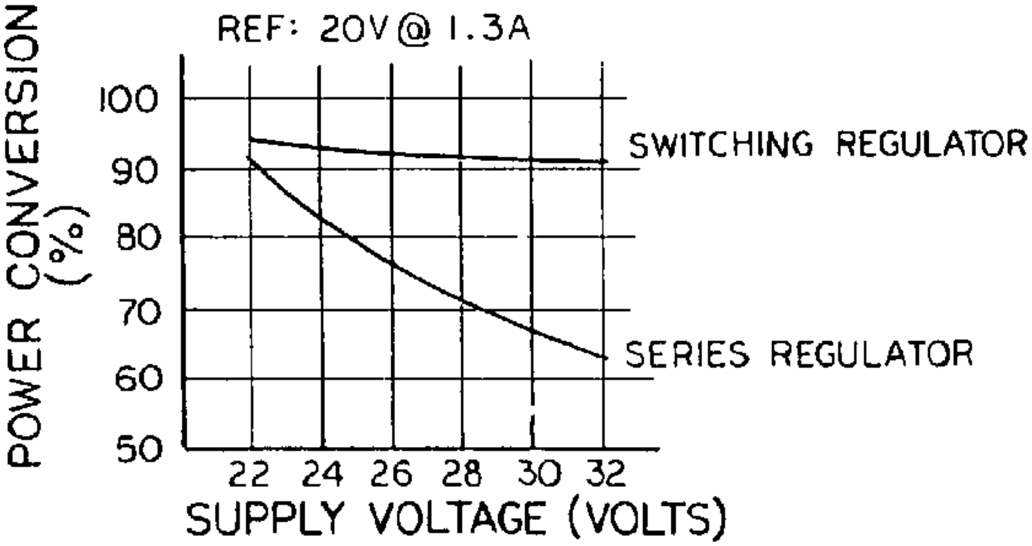

FIGURE 11 MEASURED EFFICIENCY
OF DC REGULATORS

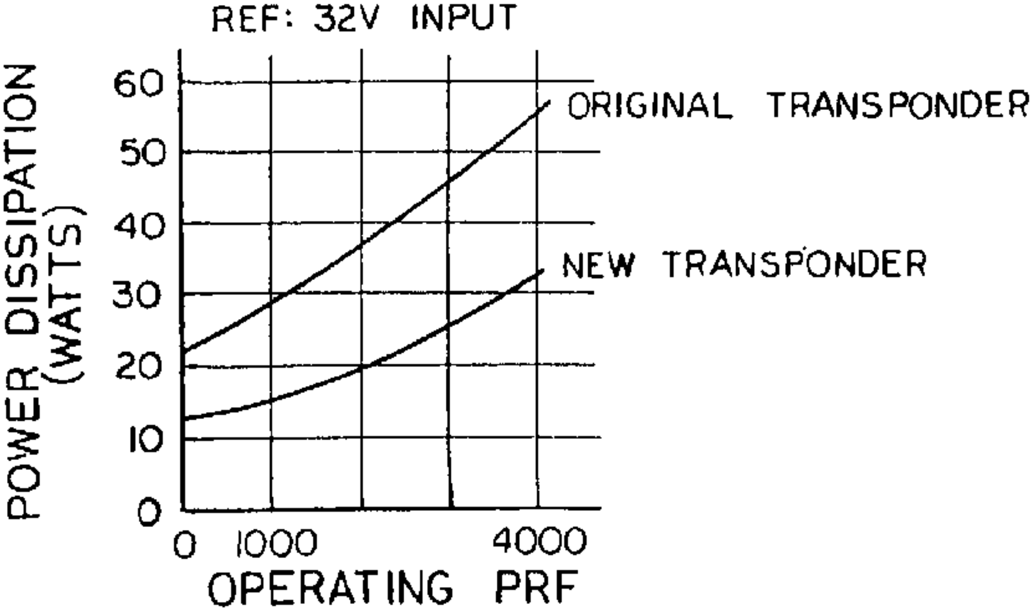

FIGURE 12 TRANSPONDER DISSIPATION
WITH PRF