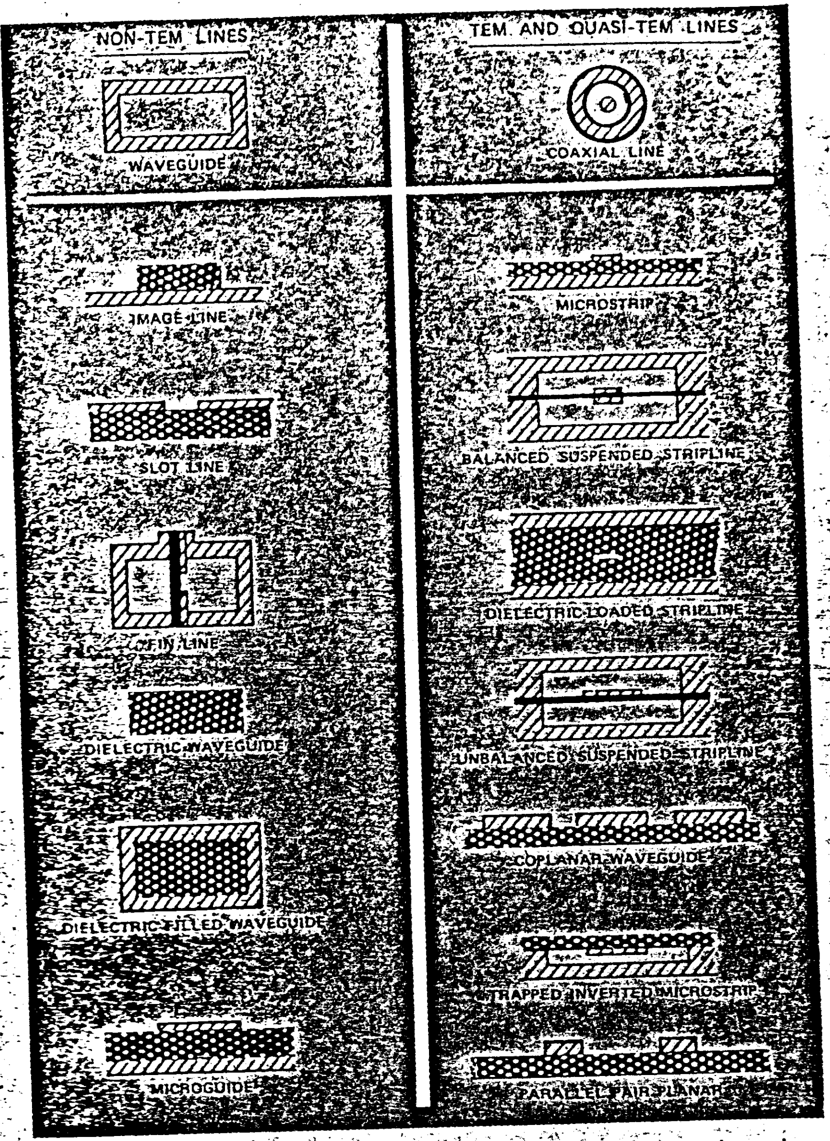
Transmission Media–What's Suitable At MM Wavelengths?

At microwave frequencies, MIC technology is widely used for low-cost, compact modules. In particular, stripline and microstrip have been found quite successful. Figure 1 shows some of the more common transmission media for microwave and millimeter wave-lengths as shown divided in non-TEM and TEM and quasi-TEM lines. There are several other types of transmission lines still in R&D, such as microguide,[5] which looks like microstrip, but is wider and propagates a waveguide mode.

The lowest-loss transmission lines are dielectric wavguide, conventional metal waveguide and dielectric-filled waveguide. Unfortunately, none of them can be considered planar, a distinct disadvantage over those that may be processed in volume using photolithographic techniques. Conductor loss of more convenient microstrip is about 0.2 dB/wavelength.[3,4]

For ease of fabrication and compatibility with semiconductor devices, those transmission lines that are particularly promising at millimeter wavelengths are:

- Coplanar waveguide
- Slotline
- Fin line
- Image line
- Microstrip
- Suspended stripline



A. Various microwave transmission media are listed by mode and according to their proficiency to operate at millimeter wavelengths.

Coplanar line eases shunt conections

A coplanar transmission line consists of a strip of thin-metallic film deposited on the surface of a dielectric substrate with two ground electrodes running adjacent and parallel to it on the same surface.[6] The rf energy is confined to a closed area and the conducting elements permit easy connection of active devices in hybrid integrated circuits. It is ideal for shunt connection elements in monolithic MIC systems. Coplanar line has the advantage of having all the conducting elements on the same side of a dielectric substrate; standard MIC photolithographic and etching techniques are applicable. Coplanar line, enclosed in a channel, has been successfully used at frequencies to 60 GHz.

Slotline allows easy coupling

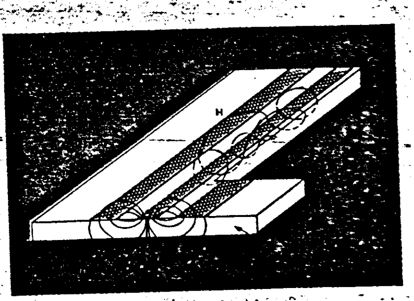
Slot transmission line was introduced by S. D. Cohn in 1968 as an alternative transmission line for microminiature componets.[7] It is particularly useful for applications requiring regions of circularly polarized magnetic field and/or shunt-mounted elements. Slotline consists of two conductors separated by a gap on one side of a dielectric substrate. Combined microstrip and slotline circuitry seem to offer possibilities with the advantage of easy coupling through the substrate from one medium to the other.

Slotline is well understood and can be fabricated using standard MIC photolithographic and etching techniques. Such transmission line techniques, enclosed in a channel, have been successfully used for the design of tapered transformers to 60 GHz.

Fin line broadens bandwidth

When slotline is used in a channel—that is, when the slotline substrate bridges the broad walls of a rectangular waveguide—it is sometimes called fin line.[8] In effect, the line is a printed ridged waveguide and can be designed to have a wider useful bandwidth than conventional line can provide bandwidths in excess of an octave with less attenuation than microstrip.[10,11] This adaptation of ridged-loaded waveguide permits circuit elements to be fabricated at low cost and is compatible with thin-film hybrid techniques.

In passive circuits, such as filters, the fins may be directly grounded to the waveguide, and lumped elements, such as beam-lead capacitors, may be added. The gap between the fins can be varied along the longitudina



B. In coplanar line, axial and transverse H-field components exist.

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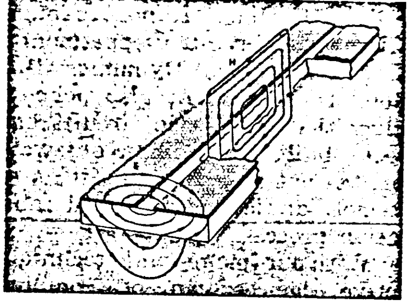

C. A slotline supports a dominant TE mode which resembles the dominant mode of rectangular waveguide and provides natural regions of circularly polarized magnetic fields.

axis to provide low-cost circuit elements. When semiconductor devices are to be added, at least one of the fins must be dc isolated from ground to permit the application of bias.[33] In both approaches, the waveguide is parted along a plane where the current flow is parallel to the break, as in a common slotted line.

During the past few years, fin line components have been fabricated successfully up to 40 GHz, and existing beam-lead devices in a simple fin-line mount may be useful beyond 80 GHz.[8] However, it is expected that mechanical tolerance of the assembly may become important much above 60 GHz.

Image-line, active IC construction

Low-loss propagation at millimeter-wave, submillimeter wave and even optical frequencies is theoretically realizable using refractive dielectric guides and image guides.[12-16] In theory, image guide is suitable for active integrated-circuit construction because the image plane can provide mechanical support to the dielectric material and also serve as heat sink and electrical ground to the integrated active devices. However, there are many practical fabrication and process problems that some researchers are trying to resolve at this point. In addition, metallic shielding around the image-guide is often necessary to reduce any radiation losses and eliminate any external electromagnetic interference.

Although rectangular dielectric guide has been applied at optical frequencies using low-dielectric constant materials,[17-26] only recently has this type of guide been used at millimeter-wave frequencies using high-dielectric constant materials.[27,28,29]* The potential of rectangular dielectric guide millimeter-wave integrated circuits has been greatly enhanced with the recent demonstration by Chrepta and Jacobs[27,29] using high-resistivity semiconductors such as silicon and GaAs as dielectric material.

Microstrip line the popular media

Standard microstrip is one media where considerable effort had been directed towards exploiting the advantages of MIC technology to higher frequencies. Impatt oscillators have been developed at 30 GHz, 60 GHz and 100 GHz using quartz substrates at Bell Laboratories.[1] Similarly, microstrip techniques have been applied to design 18-26 GHz balanced and image-rejection mixers and 18-26 GHz and 26-40 GHz polar discriminators using 0.010-inch thick sapphire substrates.[30,31] Also, several researchers have used MIC techniques to fabricate broadband components up to 60 GHz using low dielectric substrates with dielectric constant of $\epsilon \approx 2.5$.[32]

There are several difficulties that arise in extending microstrip over 60 GHz for low-loss circuits. These include critical tolerances, fragile substrates and radiation losses. The radiation losses can be eliminated by properly spacing the microstrip circuit in a channel. Some researchers have demonstrated the use of microstrip techniques up to a frequency of 100 GHz using fused silicon as the base substrate.[1] The mechanical problems can be overcome with careful design techniques.

Suspended stripline, useful to 60 GHz

Suspended stripline is essentially the same as conventional stripline. However, the transmission line is inhomogeneous because of the presence of the dielectric. As a result, high-order modes can propagate. Also, the presence of any discontinuity can cause radiation losses and higher-order modes. These can be suppressed if the suspended stripline is enclosed in a rectangular guide. The dimension tolerances and surface finish on the metallic surroundings are not critical, as compared to a standard waveguide transmission line. Such transmission line techniques enclosed in a channel have successfully been used up to 60 GHz.

Shielding important for all

Regardless of the type of planar transmission media chosen, it appears that all the millimeter circuits require metallic shielding in order to control higher-order modes, reduce radiation losses and eliminate external electromagnetic radiation interference. Generally, mode control becomes critical at higher frequencies and for broad bandwidth circuits.

In the selection of a particular transmission line, the following characteristics should be considered:

- Maximum achievable bandwidth
- Low loss or high unloaded Q
- Low-cost processing and fabrication techniques
- Ease in bonding or attaching active componets
- Radiation losses
- Susceptibility to external electromagnetic interference. ●●

package. It was also to occupy a space of 44 cu. in (723 cm^3)

"The required specifications proved too tough for this new technology and the program did not meets its goals. Only a single mixer/filter channel was finally developed," says Spielman. "Program dollars got chewed up developing standard waveguide parts not related to the dielectric waveguide technology. As a result of this program, the Navy is taking a more cautious wait-and-see attitude regarding dielectric waveguide technology.

That isn't to say that there have not been problems associated with the printed circuit designs. Stripline and microstrip designs are also struggling as they get into higher millimeter bands. This is to be expected, however, since both technologies are still in fairly early stages of development.

In a recent project for ECOM, for example, an 18-40 GHz six-channel receiver was developed by Microwave Associates in Burlington, MA, using air and teflon dielectric stripline and teflon-fiberglass microstrip in the millimeter-wave circuitry.[2] According to Dr. Charles Buntschuh, senior scientist in MA's R&D Group, "There were problems in the Wilkinson power splitters so that interactions between the following diplexing filters were troublesome." Also, mixer insertion loss tended to be quite high. "This wasn't a serious problem, just a tedious nuisance," explained Buntschuh.

Army pursues dielectric approach

At the present time, one of the strongest supporters for dielectric waveguide is Dr. Harold Jacobs, head of ECOM's Electronics Technology and Device Laboratories at Fort Monmouth, NJ. According to Jacobs, "dielectric waveguides potentially offer great cost reductions for millimeter-wave components and circuitry due to the simplicity of machining waveguide from the outside and batch-fabrication techniques.

"We still have an open mind over the various approaches to millimeter-wave integrated circuits. But we have had some of our most successful results in the dielectric waveguide area."

Comparing the three approaches, waveguide, stripline and dielectric waveguide, Jacobs sees waveguide technology as offering certain advantages such as being almost immediately available and having high

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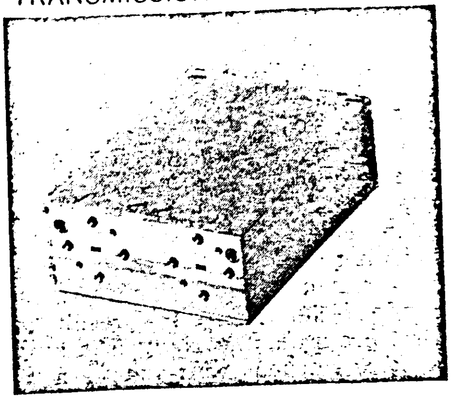
*Additional information and references on image-line are found on p. 42.



1. **Model 4394, dielectric waveguide double balanced mixer operates at 94 GHz. The two waveguide parts are for the rf and LO. It is built by Epsilon Lambda and price is $5800.**

Q and low-loss properties. However, its cost in the past has been prohibitively high.

Suspended stripline appears attractive in the future and is being investigated for use as millimeter-wave ICs because of its wide bandwidth and potentially low cost. "However, as frequencies go higher, say above 30 GHz, the conductor losses in stripline or the other planar technologies may become excessively high," cautions Jacobs.

"Dielectric waveguides," he claims, "offer very great potential in obtaining low loss as well as meeting simpler, and lower-cost construction goals. The approach, however, is still in a research and development phase and considerable expenditures will be required before each circuitry becomes more generally available for use."

Dielectric waveguide mixers for sale

According to Robert Knox, President of Epsilon-Lambda, the concept of planar integrated circuits using high permitivity dielectric waveguide was originally developed at IIT Research Institute (IITRI) in 1969, simulated by related activities in integrated optics and in surface acoustic-wave technology. "I realize dielectric waveguide is a controversial subject," explains Knox. "Some claim it doesn't work and only looks good on paper. The fact is, however, it does work. The particular approach we're taking, that of insular-line-integrated-circuits, using inexpensive alumina dielectric as the waveguide medium, lends itself to low cost from both a materials and fabrication point of view."

Epsilon-Lambda sells the only dielectric waveguide component available today, a 94 GHz balanced mixer/preamp, Fig. 1. Its price is $5,800 in unit quantities.

"The price is comparable to metal waveguide devices for this frequency," notes Knox. "But I see the potential for lower costs and think that in quantities of about 300, a price of $1,875 is realistic. The mixer diodes are at present a principal cost factor, however. Fabrication of the ceramic parts while not trivial, allows cost reductions for large volume production."

"We're planning to go into production with this mixer in the next few months and to sell 'insular-line' balanced mixers/preamps at 35 and 60 GHz as well. Unit prices should be around $3,900 and $5,100, respectively."

"I don't know of any integrated circuit components that are presently being sold commercially above 18 GHz," observes Knox, "although I do expect to eventually see certain components offered for operation to 40 GHz."

"Many people tend to draw a line at 18 GHz, where microstrip or stripline techniques work," he continues. "Since there are no fundamental frequency limits, efforts continue to extend printed circuit designs higher into the millimeter region. While they work in a fashion, they require specialized techniques, which make them less cost effective."

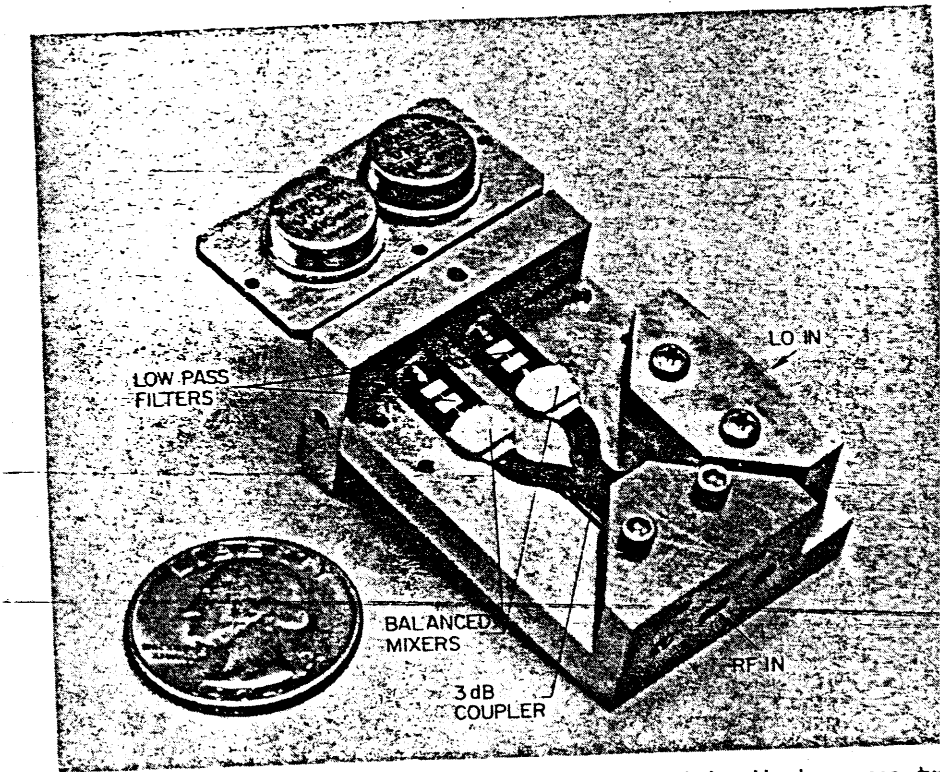
Dr. H. John Kuno, manager, Microwave Circuits Department at Hughes Electron Dynamics Division, Torrance, CA, also acknowledges that microstrip circuits have been built at millimeter wavelengths but also considers it an extremely difficult design and fabrication process.

"With our image-guide technique, active devices can be combined right into the dielectric guide, (Fig. 2.). The image plane serves as a heat sink and mechanical support as well as a ground plane," Kuno notes. Biasing is achieved by connecting a printed circuit lead, like microstrip, on top of the dielectric without affecting the fields in the waveguide.

According to Kuno, Hughes is using single crystal silicon for their dielectric waveguide because "it is a well known semiconductor material, can be chemically processed easily, and by selecting the proper crystal orientation one can make use of preferential etching techniques."

"It will eventually allow us to go to monolithic integrated circuits," claims Kuno, "but this is still several years away. We are not working on monolithic designs right now, because there are some tremendously complex processing steps involved, and we don't feel this is the right time or place to spend R&D money."

(continued on p. 40)



2. **Balanced mixer in silicon image-guide** developed by Hughes uses tw Schottky barrier mixer diodes imbedded in silicon dielectic. Transitions a for the LO and rf inputs. The Avantek thin-film amps are used as i-f amp

DESIGN AND PERFORMANCE OF A BROADBAND MIC LOW NOISE K-BAND BALANCED MIXER, POLAR DISCRIMINATOR AND RELATED COMPONENTS

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Abstract

The design and experimental performance of a broadband (18-26.5 GHz) single balanced mixer, polar discriminator and related components fabricated in microstrip on 0.010-inch thick gold plated sapphire is described. Typical conversion loss of 7.5 dB with a maximum of 8.5 dB at the top of the band was achieved in the mixer. The output polar angle of the discriminator is linear within ±15° with an input signal level of -14 dBm. Full utilization of planar techniques is made that could also be applicable for frequencies up to and above 60 GHz.

Introduction

There is an increasing need for broadband millimeter wave superhet and instantaneous frequency measuring (IFM) receivers for surveillance, electronic countermeasure (ECM), and electronic support measure (ESM) applications. This paper describes the design and performance of a 18-26.5 GHz single balanced mixer, polar discriminator and 3 dB quadrature hybrid for a future surveillance or ESM receiver front end. The components were fabricated using microstrip techniques to reduce the effects of parasitics thereby obtaining the desired broadband performance. In addition, the design in MIC leads to compact size, performance repeatability in duplicate models and the potential for low manufacturing costs.

MIC Balanced Mixer

The basic assembly of the single balanced mixer fabricated is shown in Fig. 1. It consists of a 3-dB quadrature coupler, two mixer diodes, and low pass filters to isolate the IF frequencies from the LO and RF frequencies. The IF frequency is 60 MHz but by appropriate design of the low pass filters has a pass band up to 10 GHz. The circuit was fabricated on a 0.010-inch thick gold plated sapphire substrate ($\epsilon_r \approx$ 9.6). Sapphire is used because smoother surfaces and constant dielectric with frequency can be obtained thereby reducing the circuit losses and optimum performance in 3 dB quadrature hybrids with frequency.

The substrate was mounted on a test fixture specially designed for readily testing microstrip circuits on various sized substrates. The fixture has transitions from semirigid coaxial lines to microstrip. These transitions use a two section stepped transmission line to provide a low VSWR up to 40 GHz.

Measured performance of the mixer is given in Figs. 2 and 3. Figure 2 shows the conversion loss as a function of frequency for an LO power of 1 mW and diode current of 1.0 mA. The double side-band noise figure at 26 GHz is shown in Fig. 3 as a function of diode bias current for various LO powers. The IF amplifier noise figure is assumed to be 1.5 dB. These results show that for a diode bias current of 1.3 mA the noise figure does not change appreciably with a 9 dB variation in the LO power.

The return loss for both the RF and LO ports was measured to be less than 10 dB across the frequency band. The minimum LO and RF isolation measured at the optimum noise figure current setting is 6 dB. An isolation of 10 dB can be achieved if bias currents are set to equal 2 mA.

Hewlett Packard Schottky barrier beam lead diodes (HP 5082-2769) were used with $C_{tot} \leq 0.1$ pF. These diodes were connected electrically in shunt by mounting them between the microstrip line and a grounding post through the substrate to the ground plane. A broadband RF match (return loss typically 12.5 dB) to the diodes was obtained by including the package parasitics as part of a lumped element matching network.

MIC Polar Discriminator

A polar discriminator consists of two in-phase power splitters, three quadrature 3-dB hybrids, a delay line, and four detector diodes arranged in the configuration shown in Fig. 4. The delay line is used to introduce a phase shift proportional to the frequency of the incoming signal. The rest of the configuration is used to obtain the dc voltages proportional to the sine and cosine of this phase angle.

In realizing the polar discriminator two previously designed MIC single balanced mixers were used. The bias current of each Schottky barrier diode was adjusted for optimum performance as a detector rather than as a mixer diode.

The entire polar discriminator was fabricated in microstrip using 0.01-inch thick gold plated sapphire except for the delay line. Semirigid coaxial line was used for the delay line merely as a matter of convenience and final versions of the circuit would be fabricated entirely in microstrip. Much of the circuit had been fabricated previously on a sapphire substrate for use in an image reject mixer. The experimental model of the polar discriminator was assembled by adding a microstrip in-phase power splitter and a coaxial delay line to the microstrip image-reject circuit as shown in the assembly in Fig. 5.

Both swept frequency and single frequency measurements of the polar discriminator were made over the 18-26.5 GHz frequency range. The cosine and sine output voltages were used to drive the horizontal and vertical axis respectively of a Textronix 502 oscilloscope and an x-y recorder. Single frequency measurements of the phase angle of the polar display were made as a function of frequency. The polar angle of the discriminator is linear within ± 15°. The amplitude variation over the band was ±2 dB after taking into consideration the variation due to the test sweeper. These results were obtained at a signal level of -14 dBm. Similar results were obtained at -23 dBm.

MIC 3-dB Quadrature Hybrid

The 3-dB quadrature hybrid was realized by connecting two 8.34-dB edge-coupled microstrip couplers in tandem. Cross overs were placed at the center of each 8.34-dB coupler in order to preserve the overall symmetry of the 3-dB hybrid and assure that the quadrature phase relationship between the outputs was maintained over the entire band. Because the coupler is physically very short, the crossovers represent a significant portion of its length and have a significant effect on the performance by introducing discontinuities that increase the ripple response. The effects of the crossovers and also of the discontinuities presented to the coupler at its ports during testing are evident in the performance characteristics of Fig. 6.

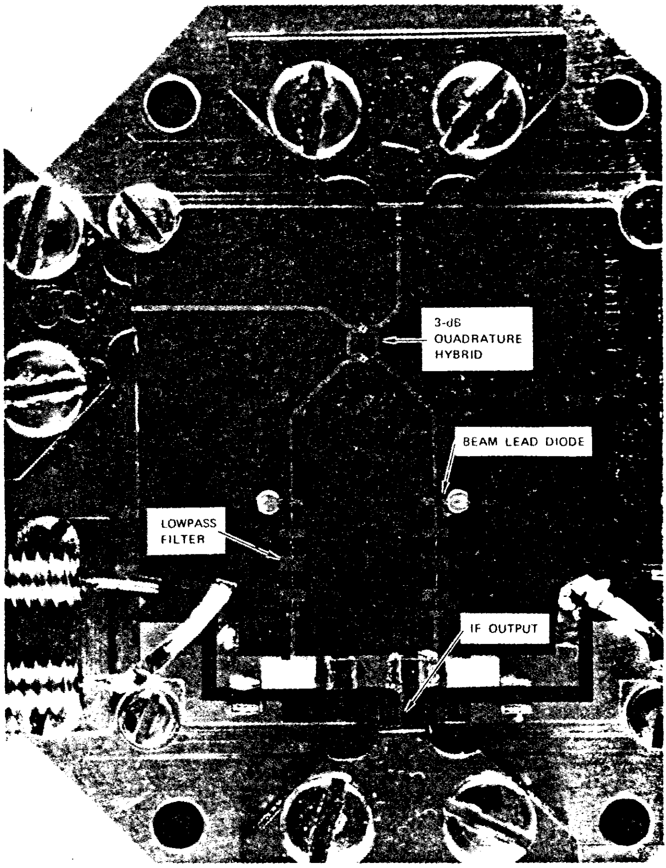


FIGURE 1 PHOTOGRAPH OF MICROSTRIP SINGLE BALANCED MIXER ASSEMBLY

Over the 18.0-26.5 GHz band, the coupling imbalance is ±0.7 dB maximum. The dissipation loss through the coupler is about 0.8 dB for each path. This loss also includes losses introduced by connectors and transitions used to test the hybrid and would be somewhat less for the hybrid imbedded in the balanced mixer or the polar discriminator circuitry.

Conclusions

The utility and advantages of planar MIC techniques applied at millimeter wavelengths have been demonstrated successfully by the above development. The above design techniques are applicable for frequencies greater than 80 GHz by proper selection of the substrate and active devices. Also the above planar techniques can be used for larger integration of components in millimeter wave subsystems.

Acknowledgments

This work was partially supported by the Naval Electronics Laboratory Center, San Diego, CA, under Contract N00123-74-C-1957 under the technical guidance of Mr. John Reindel, Technical Program Manager, and Mr. John Griffin, Program Manager.

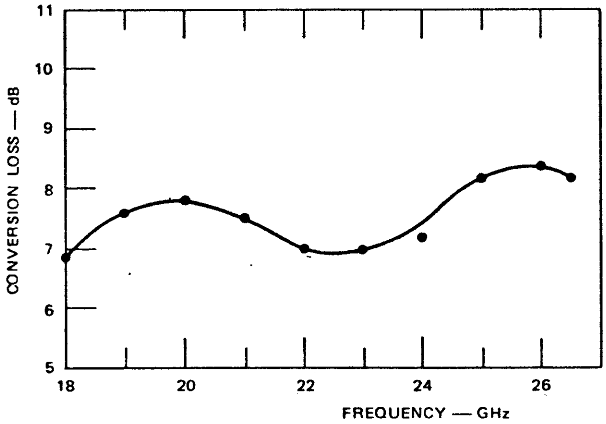
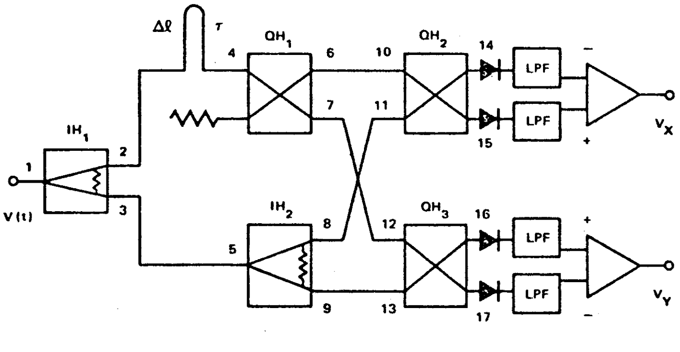


FIGURE 2 CONVERSION LOSS AS A FUNCTION OF FREQUENCY FOR THE SINGLE BALANCED MIXER. LO Input power = 0 dBm, diode bias currents = 1 mA.



IH = In-phase Hybrid
QH = Quadrature Hybrid
τ = Delay Line of Length $\Delta\ell$
LPF = Lowpass Filter

Figure 4 BLOCK DIAGRAM OF POLAR DISCRIMINATOR

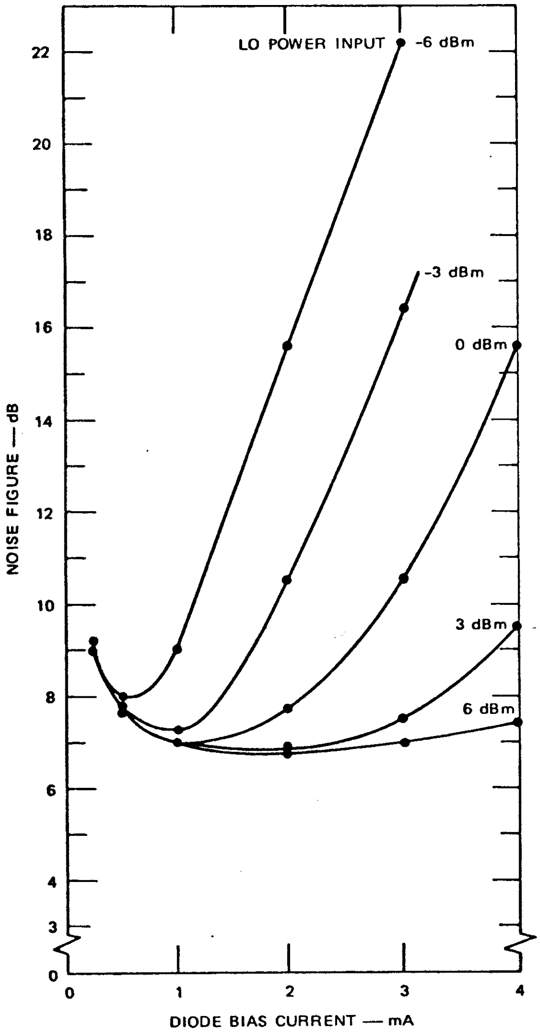


FIGURE 3 DOUBLE SIDEBAND NOISE FIGURE OF THE SINGLE BALANCED MIXER AS A FUNCTION OF DIODE BIAS CURRENT FOR VARIOUS LO DRIVE POWERS

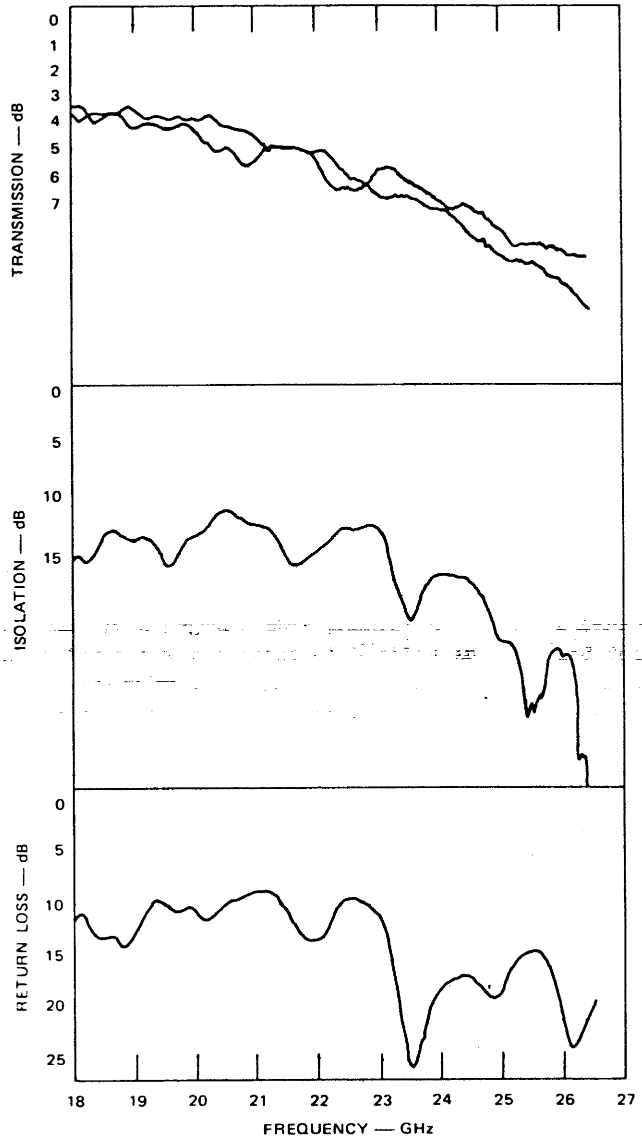


FIGURE 6
PERFORMANCE CHARACTERISTICS FOR THE K-BAND, MIC, 3-dB, QUADRATURE HYBRID

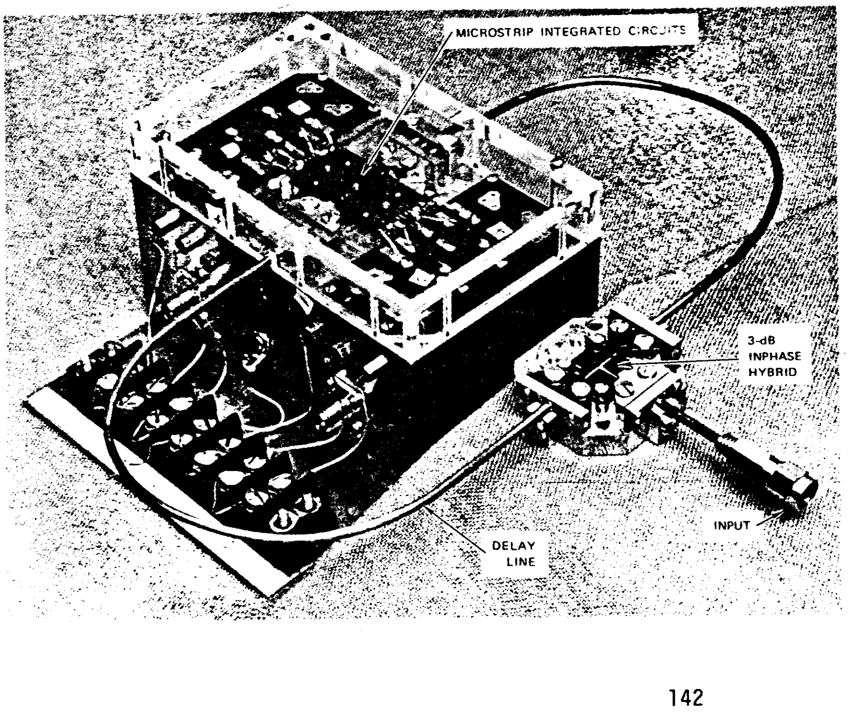


FIGURE 5
PHOTOGRAPH OF THE EXPLORATORY MODEL OF MIC K-BAND POLAR DISCRIMINATOR

COOPERATIVE SIGNAL PROCESSING BEACON TRANSPONDER FOR AIRPORT TRAFFIC CONTROL

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Abstract

In recent years there has been an interest in physically small, low-cost, low-energy consuming electronic markers for air traffic control on the ground. In this paper a solid state 14.5 GHz low-cost beacon transponder is investigated that provides a target-like signal for a maximum range of 5 miles in various weather conditions when illuminated by an existing 14.5 GHz surface detection radar developed by Texas Instruments (TI), Dallas, Texas.[1]

Introduction

In recent years, there has been a great interest in electronic markers for tagging materials and vehicles, for air traffic control on the ground, and for surveillance or tracking of personnel over a limited area. In this paper state of the art in low-cost beacon components are investigated that provide a target-like signal for a maximum range of 5 miles in various weather conditions when they are illuminated by airport surface-detection radars. Design details of a 14.5-GHz solid-state cooperative beacon transponder are discussed. Low-cost digital logic techniques are used instead of analog techniques for isolation of receiver and transmitter, and for signal processing. A pulsed, low-Q, coaxial IMPATT diode oscillator was used in the transmitter, and a diode detector was used in the receiver. The power output measured from the IMPATT diode oscillator was 4.8 watts peak, the duty cycle was 0.7%, the pulsewidth was 450 ns, and the dc-to-RF efficiency was 7%. Output power measured from the beacon transponder was 2.4 watts and the minimum detectable signal at the receiver was -42 dBm.

Transponder Design

A block diagram of a solid-state cooperative beacon transponder is shown in Figure 1. The design of the various components in the system allows the use of microwave integrated circuits and hybrid integrated-circuit techniques. Such techniques are useful for large production at low cost. The important features of the design are: (1) One antenna system is utilized. Transmitter and receiver are combined via a circulator. A circulator was selected for ease in fabrication; however, for production models a diplexer will be used. (2) A high-power IMPATT diode oscillator is used in the transmitter. (3) For low cost and limited range (2.5 miles) in clear weather, a detector with signal-to-noise-ratio (SNR) of 13.8 dB was selected for our transponder. For 5 miles range or more and 16 mm/hr of rain with SNR ratio of 13.8 dB, a mixer pumped with a Gunn diode oscillator scheme can be used in the receiver for additional sensitivity. (4) A high-gain video amplifier with limiting capability is used to amplify the detected pulses. In the limiting mode the amplifier was designed to minimize pulse envelope distortion for any false triggering of the logic gate at close and far range from the ASD radar. (5) Low-cost digital techniques are applied for processing, gating, isolation between receiver and transmitter, and pulse shaping instead of analog techniques. Digital techniques are used where size, volume, and uniformity in circuit design are necessary. (6) Input and output pulsed RF signals from the transponder are synchronized without any change in repetition rate, pulsewidth, or duty cycle in the envelope. This is important for the airport surface-detection (ASD) radars where identification of the location is obtained from the envelope and delay-time information of the various signals received at the radar. Delay through the transponder is constant and can be taken into consideration in the radar processing and memory unit. (7) An RF switch is operated in time sequence after the IMPATT diode oscillator is operating in a steady-state condition. This control is maintained by the memory logic. This design adaptation is useful because rise and fall times of the output pulsed RF signal from the transponder are strictly dependent on the RF switch operation. To obtain fast rise times in an IMPATT diode oscillator, complicated voltage- and current-shaping networks are necessary in the pulse drivers because the matching network of the IMPATT diode oscillator depends on the pulse duration and repetition rate that cause thermal heating of the diode junction. The only disadvantage of the RF switch is in the extra insertion loss, which decreases the overall efficiency of the system. In production-type models, the switch can be eliminated and IMPATT diode oscillators with current shaping networks can be used. To conserve the dc power consumption, the IMPATT diode oscillator is also pulsed at the same repetition rate but with a much larger pulsewidth.

The key features of the breadboard beacon transponder and details of the individual components are shown in Figure 2. The disassembled IMPATT diode oscillator showing all the key mechanical details of the design is shown in Figure 3.

Test Results and Data

A semiautomatic test setup was assembled to allow simultaneous observation of all the critical test parameters of the RF components and logic circuits in the breadboard beacon transponder. Figure 4 shows a frequency spectrum of the pulsed RF output from the beacon transponder. This response was observed on the HP spectrum analyzer. The nulls shown in the figure are sharp and the envelope is very close to the (sin x/x) representation. Figure 5 shows a fixed delay, through the transponder, of 300 ns between the input and output signals from the beacon transponder. The delay is dependent strictly on the logic gate and delay mechanism built into the processor. With minor adjustments, delay can be reduced to 40 to 60 ns.

Conclusions

The characteristics of the cooperative beacon transponder are tabulated in Table 1. In this table the designed and measured results are compared. All the design goals were achieved except the power output. The power output was slightly low (2.4 watts instead of 3.3 watts) because of excessive losses in the output isolator and switch (3.2 dB instead of 2.8 dB) and lower efficiency of the IMPATT diode oscillator (7% instead of 10%). If this transponder is used with a simple dipole antenna (gain 3.2 dB) in the field tests, then the effective radiated peak power available will be measured greater than 3.3 watts. The receiver sensitivity was slightly better than the theoretical because the noise figure of the video amplifier used was lower. Based on a transmitted peak power of 2.4 watts from the beacon transponder, the maximum range to the TI ASD radar achievable should be 3.5 miles in 16 mm/hr of rainfall and greater than 5 miles in clear weather. By reduction of losses in the RF switch and isolator, more power can be achieved at the output of the transponder. Based on the beacon-transponder receiver sensitivity of -30 dBm and SNR of 13.8 dB, the maximum range from the TI ASD radar achievable should be 1.60 miles in 16 mm/hr of rainfall and 2.5 miles in clear weather.

Table 1. Characteristics of the Cooperative Beacon Transponder

Parameters	Designed	Measured	Comments
Transmitter			
frequency	14.5	14.7 GHz	Can be set to any frequency, depending on the design of cavity in the oscillator.
Pulsewidth	50 ns	50 ns	35 ns minimum. Maximum value depends on IMPATT diode circuit.
Peak power	3.3 W	2.4 W	Higher power levels can be obtained depending on IMPATT diode circuit using multiple diodes.
PRF	15 ±0.5 kHz	15 ±0.5 kHz	15 ±0.5 kHz. Variable; thus parameter is not critical.
Delay	300 ns	300 ns	40 ns minimum. Maximum value variable.
Receiver			
frequency	14.3 GHz	12-18 GHz	12-18 GHz, can be set to any frequency.
Minimum detectable power level	-42.5 dBm	-42 dBm	Intermittent output signal from the transponder.
Sensitivity with SNR = 13.8 dB, and probability of detection 0.95	-28 dBm	-30 dBm	-30 dBm. For higher selectivity, use mixer receiver.
Video bandwidth	50 MHz	50 MHz	50 MHz maximum (limited by logic circuit bandwidth). Selectable for larger bandwidths by using high-speed circuits.
Antenna			
Gain	None	None	2.2 dB for simple dipole
Power consumption,			
dc	Not specified	6 watts maximum	No attempts were made to reduce dc power consumption or design a power supply. IMPATT diode oscillator draws power only during the pulse period.

Acknowledgment

The author wishes to acknowledge the valuable suggestions by Dr. Don Parker. Valuable direction in steering the research program toward the more immediately useful objectives were received from the technical monitor, Mr. Ralph Arenz. This work was part of a U.S. Air Force program.

Reference

1. A Fang, "Comparative Performance of Three Airport Surface Detection Radars," Technical Report TR71-037, Texas Instruments, Dallas, Texas (1971).

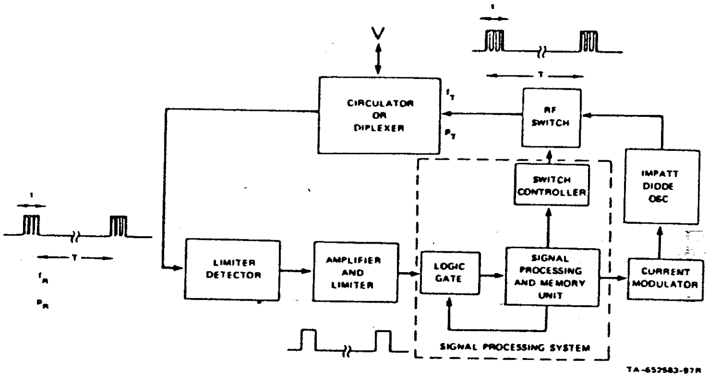


Fig. 1 Block Diagram of Cooperative Signal-Processing Beacon Transponder

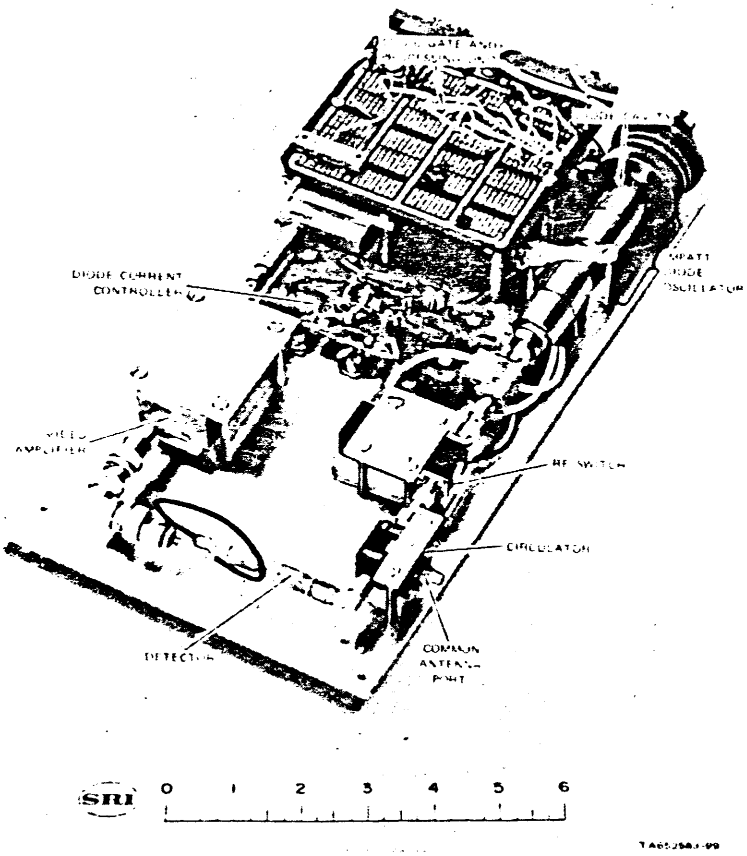


Fig. 2 14.5-GHz Solid-State Cooperative Beacon Transponder for Airport Surface Detection (ASD) Radar

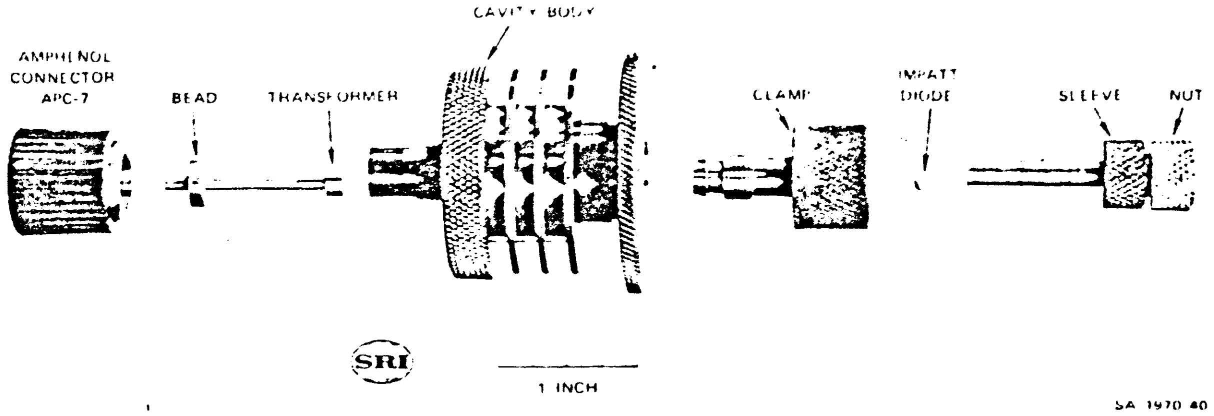
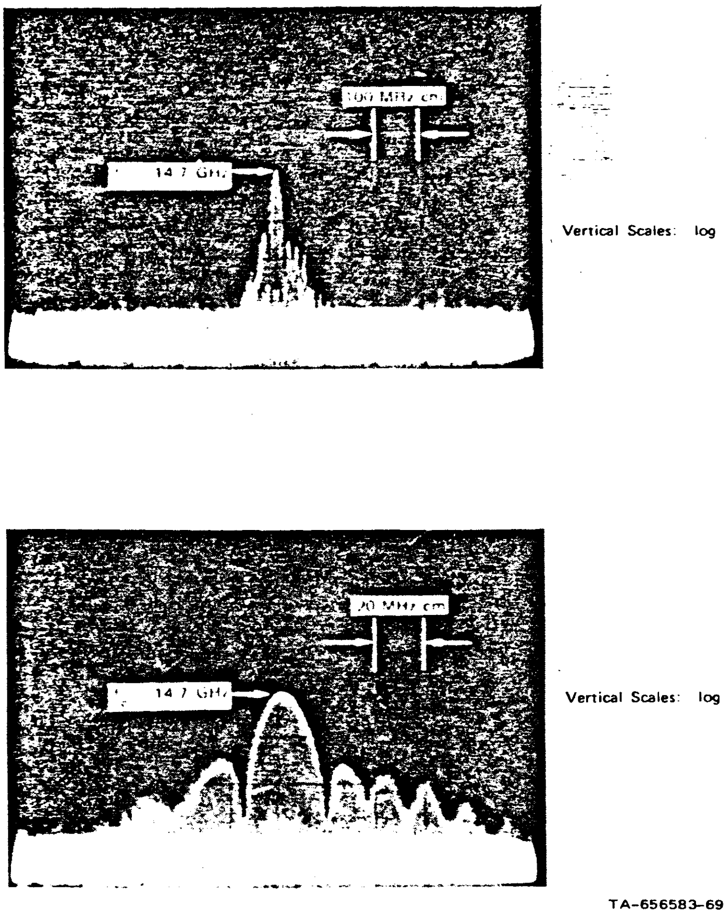


Fig. 3 Disassembled Ku-Band IMPATT Diode Oscillator



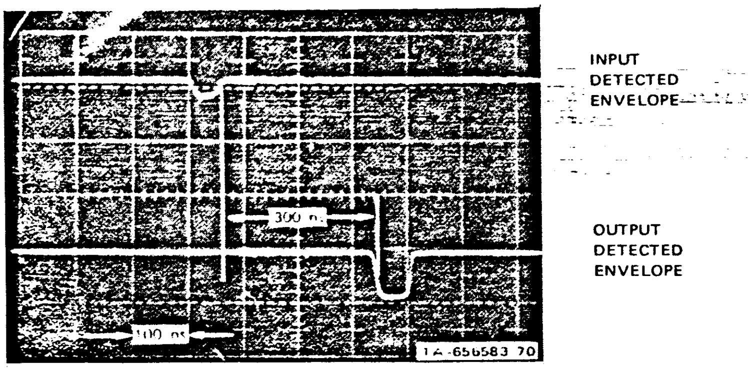


Fig. 5 Delay Between Input and Output Pulsed RF Signals to the Beacon Transponder

Fig. 4 Frequency Spectrum of Output Pulsed RF Signal from the Ku-Band Beacon Transponder (sin x/x)