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EXPERIMENTAL DEMONSTRATION OF AN OPTOELECTRONIC SWITCH MATRIX FOR SATELLITE-SWITCHED TDMA SIGNALS IN THE 0.3 – 4.0 GHz BAND

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(Radar and Communications Technology Branch)

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ABSTRACT

An optoelectronic switch matrix has been built and tested to explore the potential of this technology for signal routing in TDMA satellites. GaAs photoconductive detector arrays, an optical fibre signal distribution network, and current-modulated injection laser optical sources were employed to construct the 3x3 matrix. Crosspoint isolation greater than 45 dB was achieved at signal frequencies up to 4 GHz, while path-to-path crosstalk was too small to be detected. These results support the concept of optoelectronic switching for on-board TDMA in communications satellites. The experiment has pointed out areas, notably in optical distribution and detector fabrication technology, where further work can be expected to improve significantly the performance of such a switching matrix.

1. INTRODUCTION

The use of optoelectronic switch matrices for TDMA satellite on-board switching was proposed in 1979[1] and has attracted a certain amount of interest since then [2-4]. In 1981 a Joint Programme on Optoelectronic Switching was established by the Directorates General of Space Technology and Applications (DGSTA) and of Radar and Communications Technology R&D (DGRCT) at CRC. Under this programme the potential of GaAs photoconductor detectors to serve as optoelectronic crosspoint switches was established[5-7] and, at the end of the first year the fabrication of various high-isolation photoconductive optoelectronic switches had been achieved. Experimental study of these GaAs photoconductor optoelectronic switches has led to sufficient understanding of their performance to permit the construction of a 3x3 array intended to demonstrate the switching of high frequency signals over the band from 300 MHz to 4 GHz. The construction and performance of this switching matrix is described in this Technical Note.

The technical requirements for an optical switch for on-board TDMA are set out in a Request for Proposal issued by INTELSAT in 1981[4]. One express purpose of the undertaking to construct a 3x3 matrix was to explore the feasibility of an optoelectronic switch for this requirement. A discussion of the significance of the experimental results presented here in the context of SS/TDMA is given in the conclusions of this report. In general, it seems that optoelectronic switching is somewhat superior to purely optical switching and is competitive with electronic switching elements, especially for high frequency/high isolation applications.

2. OVERVIEW OF OPTOELECTRONIC SWITCHING

A functional diagram of an optoelectronic switching array is shown in Figure 2-1. Incoming signals (at the right of the diagram) are converted to optical signals by means of a suitable transducer. At present, current-modulated laser diodes are the most convenient devices for this purpose at frequencies up to a few GHz. The generation of higher frequencies may require the use of constant optical light sources with external modulators that act directly on the output light. Such devices are at present in a very early stage of development, though 18 GHz modulation of an optical carrier has in fact been achieved by a travelling-wave technique[8].

The modulated light constituting each optical signal is coupled from the light source into an optical distribution network, shown as hatched lines in the diagram. This network divides the power in the optical signal and delivers a portion to each of a number of photodetectors, shown as circles in the diagram. The optical distribution network can be constructed of optical waveguide, such as optical fibre or integrated optics waveguide, or by a suitable arrangement of optical elements acting on a freely propagating wave. One important feature of the optical distribution of the signals is that the crosstalk between channels that can occur by electromagnetic coupling between lines is negligibly small. The only source of crosstalk that can occur in the distribution side of the switch array is by light leakage, which is negligible between optical waveguides and properly designed free optical paths. A second advantage of optical signal distribution is that the optical impedance of the waveguide terminations is independent of the states of the optoelectronic switches, and therefore any reflections that may occur in the distribution network are also independent of the states of the switches in the array.

The crosspoint elements are photodetectors that convert the light signal back into an electrical signal. The electrical output lines are summed into the output ports as shown in the diagram, to arrange that the optical signal from any source can be detected and presented at any specified output. The signal collection side of the optoelectronic switching matrix thus uses electrical, rather than optical signals. In principle, the high isolation between lines tht optical distribution affords is not compromised by electrical collection. The electrical lines that lead into a summer and then to an output port can, as a group, be isolated to an arbitrary degree consistent with practicality from all the other such groups because the groups are interconnected only by optical signal paths. Thus, conceptually, the conductive walls shown dotted in the diagram can provide any required degree of isolation between output groups.

There remain two possible sources of crosstalk in the array: leakage through the switches and crosscoupling among the lines of a single group. These degradations are held at low levels by the properties of the optoelectronic crosspoint switches themselves. The optoelectronic crosspoint switching function is achieved by rendering the crosspoint photodetectors sensitive or insensitive to light. This can be easily accomplished in different ways in various optical detectors. Photodiodes are rendered insensitive by forward bias, photoconductors, and certain avalanche photodiodes by zero bias, for example. Excellent isolation can be achieved through the crosspoint switches in that a 70-to-90 dB reduction in the electrical response to an optical signal upon switching from the on-state to the off-state bias is easily obtained in several types of photodetectors. This isolation can be made completely independent of the signal frequency because it is dependent on response to the optical carrier. The problem of crosstalk occurring through the crosspoint switches is thus eliminated, and, since the only electrical output lines within a single group that carry signals are those connected to on-state crosspoints, crosstalk between the electrical output lines of a single group is not a problem.

The broadband performance of an optoelectronic switch array is not determined by the crosstalk properties of the signal distribution array or the crosspoints themselves. Rather it is determined by the high frequency performance of the optical sources and of the crosspoint photodetectors when in the 'on' states. Injection laser diodes are at present limited to modulation frequencies of a few GHz. The frequency response of a typical high performance commercial device is shown in Figure 2-2. The resonance at a frequency of about 2.5 GHz is a common feature of injection lasers and arises from an internal mechanism. Modulation efficiency is usually observed to drop off rapidly at higher frequencies.

There is considerable interest in extending the frequency response of injection lasers to achieve higher frequency analogue modulation and higher rate digital modulation on optical communication links. A system operating at 6 Gb/s has recently been demonstrated[9], and operation up to 8 Gb/s has been achieved experimentally[10]. The construction of optoelectronic switch arrays with high isolation is therefore likely to be possible to at least these digital rates. New laser structures that give small volume active regions show promise of permitting higher frequency operation. Full-depth modulation of milliwatt optical signals at 10 GHz can be anticipated with confidence for the future*. One unknown aspect of high frequency optical

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* A diode laser permitting full depth modulation at 10 GHz has been announced as a commercial product (September 1983).

signalling is the analogue modulation performance of semiconductor lasers. Further work is needed to determine linearity or differential gain and phase in the optical output, since analogue switching is likely to be an application of importance for optoelectronic switches. It is known that sufficient linearity is exhibited by available laser diodes to permit transmission of high-quality analogue optical intensity modulated television at carrier frequencies in the VHF.

The response of optical detectors can also be a limiting factor in optical transmission at very high digital rates or RF carrier frequencies. Furthermore, detectors for use in optoelectronic switches must be switchable. The type chosen for this exploration of SS/TDMA switching was a short-channel GaAs photoconductor. Such detectors have been shown in work performed previously at CRC[5] to have good photoresponse under bias of the order of 5-10 V, and reduction in photoresponse of 45 dB or more if the bias is removed. These devices have very fast response both to optical and to switching signals and can be fabricated by relatively simple technology in monolithically integrated arrays, permitting the study of integrated wideband switch matrices[11]. The optoelectronic switch matrix reported here is partially integrated.

An important design parameter for an optoelectronic switch matrix is the optical power that must be delivered to each crosspoint to achieve the desired signal-to-noise ratio in the received signal. Numerous trade-offs among switching speed, sensitivity, cost, and ease of fabrication centre on this parameter. For example, the use of avalanche photodiode crosspoints gives excellent sensitivity to the optical signal, and hence many crosspoints can be associated with each optical source by means of a high degree of power division, thus reducing source costs, which are high, on a per-crosspoint basis. On the other hand, avalanche photodiodes are relatively expensive themselves, are difficult to integrate, and require high bias voltages, which must be generated by additional circuits to control the switching function. GaAs photoconductors, as used in this demonstration, require only low-voltage (TTL-level) drive, are cheap and easy to integrate, but are relatively insensitive, so that only a few crosspoints can be associated with each optical source. In space applications, where optical source cost is not likely to be the dominant factor in evaluating an optical switch, the high switching speed, fast response, and zero off-state power consumption associated with the photoconductor have also been important factors in the choice of this type of optoelectronic crosspoint switch for the demonstration 3x3 array.

3. CONSTRUCTION OF THE DEMONSTRATION ARRAY

3.1 General Description of the Array

The experimental 3x3 switch array is shown in Figure 3-1. The entire assembly is mounted on a 2' square steel plate. At the left of the figure are the three laser diode optical sources, and the bias supply for these lasers. The signal inputs are via semi-rigid coaxial cables that connect directly to microstrip biassing circuits in the laser mounts. The optical signals are coupled from each laser into a pigtail held in a vise on the laser mount, and into an optical fibre distribution network that occupies the main area of the mounting plate. The fibres are relatively long for ease of working, and excess lengths are coiled into Petrie dishes for neatness. the three, 3-way optical fibre biconical taper power splitters are mounted on the glass slides at the centre of the mounting plate. One output fiber from each of the three splitters is led to each of the three crosspoint switch arrays at the front of the plate. Each of these arrays consists of three photoconductors connected to a single, common output line and load. The arrays are single-chip integrated devices mounted on alumina MIC substrates and connected by way of semi rigid cables to the three bias inputs and the output port.

The laser power supply is a group of three precision wire-wound voltage dividing potentiometers and a switch-selectable ammeter permitting each of the three laser bias voltages to be set independently from a single power supply. Bias is applied to the photoconductive detectors by means of external manual switches (not shown) for testing purposes. Bias can also be applied by means of a circuit that demonstrates the control of the optoelectronic switch with logical elements. Both laser bias and optoelectronic switch bias are 5V positive, and therefore could be supplied by a single well regulated supply.

3.2 Optical Transmitters

The three optical transmitters employ Mitsubishi ML-4307 TJS laser diodes. These emit about 2 mW of optical power at a wavelength of 783 nm with bias current approximately 30 mA. They are very simply mounted on a brass tab permitting them to be easily interfaced with a microstrip biassing circuit. Figure 3-2 shows a laser mounted in the microstrip bias circuit. The laser and bias circuits are completely contained in brass mounts on which a fibre attachment vise is also mounted. The optical fibres are mechanically secured in the vise, then aligned with the lasers by means of micromanipulators, and epoxied in place. The complete laser mount with fibre attached is shown in Figure 3-3.

The frequency response curve shown in Figure 2-2 was taken from one of these optical transmitters. The shape of the curve is characteristic of diode lasers in general and demonstrates that the bias and signal insertion circuits can modulate the laser to the limits of its performance. The power in the optical output signal drops sharply at a modulation frequency of about 2.8 GHz and is down by 20 dB from its low frequency value by 4 GHz. It was found that sufficient optical signal power was produced to permit measurements to be made at frequencies up to 4 GHz with the switch matrix. In all these measurements the laser is biassed into the linear operation region and input signal power is 1 mW.

The transmitter package was found to radiate sufficiently that at a 4 GHz crosstalk in the switch due to electromagnetic coupling was noticeable by comparison with the reduced optical modulation available at this frequency. At lower frequencies, up to 1.3 GHz, the radiation was sufficiently contained that it did not provide the dominant source of crosstalk in the optoelectronic switch. These measurements are described more fully in Section 4.

Because no attempt was made to match the laser diode itself to the 50 Ω microstrip biassing circuit, it is possible that e/m radiation could result from this unmatched condition. Since the diode, when biassed for emission, has a low input impedance, much of the RF power reflects back to the 50 Ω driving source. Matching the diode load to a 50 ohm microstrip and source may improve the depth of modulation at 4 GHz, and should also eliminate much of the radiation. The physical configuration of the laser mount, which grounds the anode, makes it difficult to match the laser to the stripline. One approach would be to use unmounted laser chips bonded in series to gaps in the stripline.

3.3 Optical Distribution of Network

The optical distribution network serves to collect the signals from the three lasers, divide the power in each optical signal into three portions, and deliver one portion from each laser to each of the 1x3 photoconducter arrays. The distribution network was constructed entirely from Corning graded index fibre with a cladding diameter of 125 μ m and a core diameter of 100 μ m. Such fibre is not normally used for wideband optical transmission, because it exhibits a relatively large modal disperson. However, since lengths are short in the optoelectronic switching application dispersion is not an impediment, and the good efficiency with which light can be coupled into the large core gives a significant advantage.

The fibre pigtail from each mounted laser was led into a three-way biconical taper[12] optical power divider that was fabricated directly (i.e. without being spliced) in the fibre. These power dividers were mounted on glass slides and sealed with epoxy for strength. The three output fibres were led one to each detector array. To maintain order, excess lengths of optical fibre were coiled into Petrie dishes.

A check of the time-average optical power delivered to the individual detectors after the power dividing networks had been secured to the lasers showed values between about 400 μ W and 600 μ W under the operating laser bias condition.

At the detector arrays the fibres were both coupled directly to the detectors. Because the fibre core diameter is larger than the diameter of some of the detectors, the fibre ends were tapered to a core diameter of about 50 μ m before the connection was made. The physical connection of the fibres to the photodetectors was achieved by simultaneously aligning all three fibres at each chip to their respective detectors, using three, 3-axis micropositioners, and securing them in position with ultra-violet (uv) curing epoxy. The received power in each detector was measured by biassing each detector in turn and holding the photocurrent at its maximum by adjusting the micropositioners as necessary to compensate for shrinkage during the curing stage. When the uv curing epoxy had set, 5-minute air-curing epoxy was used to secure the fibres to the chip, and also to a brass crosspiece mounted above the microstrip circuit to provide strain relief on the fibres. The mounted and pigtailed chips are shown in Figure 3-4.

The experience gained in making this optical power distribution network indicates that a major bottleneck of the technology used is the need to make numerous difficult connections of fibres to very small photodetectors. The practical limit on the number of fibres which can be simultaneously aligned and epoxied by means of individual micropositioners is probably about four. Ideally, many more photodetectors than four would be required on a single chip of the array. Methods of integrating the optical waveguide distribvution network with the switch array, or of pre-aligning fibres in a matrix which could itself be aligned with the detector array will be required for the fabrication of large-scale monolithic arrays of optoelectronic crosspoint switches. Such methods are currently under investigation.

3.4 Optoelectronic Switch Array Chips

The 3x3 matrix of optoelectronic crosspoint switches was constructed using three independent monolithically integrated arrays of GaAs photoconductive detectors, one associated with each output port. Each array consisted of three photodetectors of which each had one terminal connected in common and, via a bias network, to the corresponding output port. The other three terminals were connected to the bias supplies that controlled the switching matrix. The fibres of the distribution network were connected directly to the detectors with uv curing epoxy. The three detectors of each array were not identical with each other, since the monolithic array was fabricated initially as a photoconductor test chip. The full layout of the test chip is shown in Figure 3-5, with the devices used in this work indicated. Each was an interdigitated photoconductor fabricated on a low conductivity GaAs mesa. The larger photoconductors had a diameter of 100 μ m, the smaller 50 μ m. The interdigitated metallic fingers were 3 μ m wide, with spacings of 5 μ m and 10 μ m. With the light coupled to the central portion of the active area of each device by the tapered fibres, no device-size related variations were evident in the response. The differences in interdigital gap were similarly not noticeable in the response because in all cases the photoconductors were operated at bias voltages above carrier velocity saturation value.

3.4.1 Detector Fabrication

The starting material for detector fabrication was VPE epitaxial GaAs (on semi insulating substrate) purchased from Sumitomo Electric Industries Ltd. This material was supplied with the following data:

Layer	Epi	Buffer	Substrate
Dopant	Sulphur	Non-doped	Cr - 0
Carrier concentration (cm^{-3})	$5x10^{15}$ - $1x10^{17}$	$1x10^{14}$	ρ $1x10^{7}$ Ω•cm
Thickness (μm	.3 - 1.0	3-4	390
Mobility (300°K)	≈4500 cm^2/V sec	---	---

After cleaning, mesas were formed using a proprietary isotropic GaAs etch. These mesas were approximately 1.5 microns in height, and thus extended well into the buffer to ensure isolation. The wafers were then prepared for contact formation using a chlorobenzene-aided photoresist lift-off process. The chlorobenzene treatment ensures a lip or overlay is produced in the photoresist, and results in a clean metallization lift-off. The wafers were metallized with Au/Ge (88/12) followed by Ni in a Balzers vacuum system using a multi-source electron beam gun. Approximately 1800 of Au/Ge and 300 of Ni were deposited. After removal from the vacuum system, the metallization was 'lifted-off' by placing in ultrasonic heated acetone for approximately 1 minute, and then cleaning in IPA.

The wafers were then annealed for 3 minutes at 450°C in a 4% H_2 forming gas mixture. This was followed by scribing into individual chips, epoxy die bonding on substrate, and themo-compression wire bonding to microstrip line.

The quality of the ohmic contacts between the metallizations and the GaAs epitaxial layer that formed the active region of the photoconductor was variable and this effect tended to mask systematic variations of device performance due to other device parameters. A number of techniques exist to improve the quality of ohmic contracts to low-doped GaAs. These are currently under investigation.

3.4.2 Photoconductive Array Mounts

The three 1x3 monolithic arrays of GaAs photoconductors were mounted on three physically separated independent biassing circuits. This strategy aided in preserving the output-port isolation, since each chip is associated with only one output port. The biassing circuits were made on alumina microstrip substrates. Each circuit was laid out on three separate sections of substrate: the first corresponded to the common connections at the output end, the central section carried the bonding pad for the GaAs photoconductor chip, and through the third section the bias voltages were applied. The three sections were mounted side by side on a brass jig, which also provided SMA connectors to permit external connections to be made to the microstrip, and a support structure to hold firm the optical fibres after they had been epoxied to the chip. Connection between the substrate sections was by gold-wire stitch-bonds. The final configuration is shown in Figure 3-6.

A schematic of the bias circuit is shown in Figure 3-7. The rf circuits are 50 microstrip and are connected via chip coupling capacitors to the output-port SMA connector on the output side, and to rf ground on the bias side of the photoconductor. DC bias is applied through a 400 $\frac{1}{4}$ at 4 GHz. The output side of the bias circuit is connected directly to ground and the input sides are connected directly to the three SMA connectors by which bias was applied to the photoconductors.

3.4.3 Detector Performance

The characteristics of GaAs photoconductors were measured using both frequency and time domain techniques. In the first case, different swept frequency generators covering ranges of 0.0005-1.3 GHz, 1.3-2.4 GHz and 2.4-4.5 GHz were used to intensity modulate a semiconductor laser operating at 0.8 μm. The modulated light was then coupled using either microscope objectives or optical fibres to the detector whose bias was set nominally at 8 V. The detected signal was displayed and compared with the reference signal on a network analyzer from which the transfer function, responsivity and noise level can be deduced. The experimental result shows a 3 dB bandwidth of about 1 GHz beyond which accurate measurement can not be made due to modulation drop off and resonance in semiconductor lasers. Responsivity and Noise-Equivalent-Power of the order of $\frac{1}{2}$ A/W and 10^{-10} W/$\sqrt{\text{Hz}}$ respectively were observed.

In the time domain technique, the problem of resonance in semiconductor lasers is eliminated, extending the equivalent frequency range to the 1-10 GHz region. The experimental set up consists of an ultra fast electronic circuit capable of delivering sub-nanosecond high current pulses at a reasonable repetition rate to drive a semiconductor laser. The optical pulses achieved were as short as 80 ps. These were coupled via optical fiber to the detector which was linked to a sampling head with rise time less than 25 ps. From the detected pulse displayed on the sampling oscilloscope and knowledge of the laser impulse response, the true impulse response of the detector can be deconvolved and the value of full-width-half-maximum can be obtained. The transfer function is related to the impulse response through Fourier Transforms and from it the 3 dB bandwidth can be obtained. Alternatively, fitting a Gaussian shape to the impulse response gives a simple relationship between the full-width-half-maximum ($\Delta\tau$) and 3 dB bandwidth (BW) as $BW\,\Delta\tau = 1.38/\pi$. The results obtained from the time domain analysis indicate rise time and full-width-half-maximum as short as 50 and 150 ps respectively. The latter corresponds to a 3 dB bandwidth of 3 GHz. The high frequency limitation of these GaAs photoconductors is related to a long decay tail possibly due to trapping phenomena[13].

4. PERFORMANCE OF THE DEMONSTRATION SWITCH MATRIX

The 3x3 optoelectronic crosspoint switch array was tested for isolation, insertion loss, noise and inter-port crosstalk over the range 0-1.3 GHz by means of a network analyser and at 3.8 GHz by means of a microwave signal generator and spectrum analyser. The performance of the array up to 1.3 GHz is shown in Figure 4-1. This figure consists of 9 network analyser photographs located in a 3x3 array so that each represents the performance of the optoelectronic crosspoint switch at the corresponding position in the switch array. The horizontal axis of each photograph represents frequency, from 300 MHz, where the bias network for the laser commences to pass the modulating signal and 1.3 GHz which is the frequency limit of the network analyser used. The vertical axis represents received power in dBm measured as the power generated across the 50 Ω load in the photodetector circuit. The top line on the graticle corresponds to -30 dBm. (The laser diodes were biassed to obtain linear modulation and modulated with a zero dBm input signal.) The upper trace in each photograph represents the frequency response of the optoelectronic broadband switching matrix when the input signal passes through the corresponding crosspoint. The middle trace represents the output at the same output port if the same crosspoint is unbiassed (i.e. in the off-state). The lowest trace is the noise detected at the corresponding output port with no modulation applied at the input port but with bias on the crosspoint (the on state). The noise window is 10 kHz. It is apparent from the figure that the insertion loss between all input and output ports is between 40 and 50 dB measured at the ratio of output port power to the power used to modulate the laser. The isolation between the input ports is 45 to 50 dB and is established by the ratio between the on and off-state responses of the photoconductor. At frequencies up to 1.3 GHz, the isolation of the switches establishes the crosstalk levels of the matrix. The noise level in the 10 kHz window is over 70 dB below the signal in all cases. In a television channel the carrier to noise ratio limit of the device would then be about 55 dB unweighted which would permit switching of studio quality television on AM carriers throughout the VHF and UHF broadcast bands for TV.

The performance of the array at 3.8 GHz is shown in Figure 4-2 which is similarly arranged. In this figure each of the crosspoints is represented by a frequency spectrum showing the response at the corresponding output port to a 3.8 GHz, 0 dBm signal applied to the input port in both the on-state and the off-state. Since the frequency response of the laser in its biassing network falls off significantly for frequencies higher than about 2 GHz, this loss of signal is compensated in these results by a single stage FET amplifier at the output port under test. The frequency response of the amplifier is shown in Figure 4-3. In the frequency response traces of Figure 4-1, the upper trace shows the on-state and the lower the off-state of the corresponding crosspoint. The isolation is lower than at 1 GHz, due primarily to electromagnetic leakage around the optical paths. This arises because the optical modulation is weaker at 3.8 GHz than at the lower frequencies, so that by comparison the electromagnetic leakage is more visible. The highest isolation was 40 dB, the lowest 20 dB. There is no doubt that improvements can be made to raise the isolation to at least 40 dB at 4 GHz for all crosspoints, and, if 10 dB stronger optical modulation can be attained, the target figure of 50 dB seems not unreasonable. Significant improvements in diode laser high-frequency modulation efficiency are presently foreseen.

In summary, this demonstration switch matrix exhibits performance adequate to switch television with studio quality on carriers at frequencies up to 1.3 GHz and has demonstrated potential to extend this frequency range to 4 GHz with more advanced sources and detectors. The use of optoelectronic switches at satellite IF frequencies and the potential even for use at uplink/downlink frequencies in the 4 GHz region is thus indicated.

5. CONCLUSIONS

A 3x3 optoelectronic switching matrix with photoconductive crosspoints has been constructed and demonstrated to have good performance over the frequency band 300 MHz - 1300 MHz, permitting the switching of studio quality television on carriers in this entire band. Promising results were also obtained at a spot frequency of 3.8 GHz pointing out the potential of achieving similar performance over the range 0-4 GHz.

One goal of this experiment was to examine the potential of optoelectronic switching techniques to meet the requirements of on-board satellite-switched TDMA. The prime requirement is the ability to switch signals at frequencies around 4 GHz. It is apparent from this and other related studies that the optical sources and detectors available for this experiment do not permit the generation and reception of signals at such a high frequency without unacceptable loss and degradation. The isolation of the switch array at 3.8 GHz is about 10 dB worse than is required, and the signal-to-noise ratio in a 5 MHz bandwidth is about 20 dB worse than would be required for studio quality television. The possibility for improvement, however, seems very good indeed. The lasers used in this experiment had relaxation resonances at about 2 GHz, and the commonly observed drop in modulation efficiency at higher frequencies. Recent results in direct modulation of short-cavity semiconductor lasers have shown relaxation oscillations at 8 GHz, and full modulation of the output power at any frequency up to that value[14-15]. The average output power of these lasers under frequency modulation was about the same as that for the lasers used in the present experiment. The generation of optical signals in the required frequency range, about 4 GHz, is therefore an established possibility, though some unknowns, such as the linearity of the optical modulation still need to be determined. The detectors of the present switch array have signal bandwidths up to about 3 GHz. The limitation in this case is set by the long decay time for optically excited carriers, which may indicate the presence of trapping centres in the gallium arsenide that release stored photogenerated charge relatively slowly. Improved material may thus have reduced the numbers of such traps, and permit a closer approach to the basic transit-time limitation of the device, which is at about 10 GHz for the photoconductor used in the experiment.

Other requirements for SS/TDMA can be well met by the optoelectronic switch. A comparison of the requirements set out by INTELSAT in INTEL-209 and the measured performance of the experimental switch is given in Table 5-1

TABLE 5-1

Comparison of Measured Performance with INTEL-209

	Intel 209	Experimentally Observed
Switch Size	2x2 minimum 4x4 desirable 12x12 in principle	3x3
Transition Time	5ns	<1 ns
Power Consumption: on off	5 to 50 mW 0	10 mW 0
Uniformity of Output Power	± 1 dB	± 7 dB
Frequency Band	3.7 to 3.9 GHz	0.3 to 1.3 GHz, 3.8 Ghz
Crosstalk (all paths)	50 dB	>45 dB 20 to 40 dB

One such requirement is the possibility of expansion to large array sizes, up to 12x12 in principle. The construction of a 12x12 array using the same components as the experimental array would have been possible with an extra 8 dB loss in detected signal power at the output ports because of the additional optical power division. The isolation values would not be affected, up to 1.3 GHz, because the crosstalk in all the crosspoints is determined by residual optical sensitivity due to photovoltaic effects[5]. The signal to noise ratios would, however, be reduced by the same amount. Thus, for a 12x12 matrix, the carrier to noise ratio in any television channel up to 1.3 GHz would be reduced to 48 dB unweighted, which is still adequate for high quality television. At 3.8 GHz the optically transmitted and detected signals are much weaker, so that electromagnetic leakage determines the isolation of the switches. At this frequency the isolation of a 12x12 switch would be reduced to a alue between 12 and 32 dB. As noted above, the performance of the array at 4 GHz would be radically improved with lasers designed for high frequency operation and somewhat improved detector properties. With these foreseeable improvements, the performance at 4 GHz would resemble the experimentally demonstrated performance at 1 GHz, thus making a 12x12 matrix with adequate performance for SS/TDMA a possibility in principle.

The transition time of photoconductive switches has been established to be considerably less than the required minimum of 5 ns in previous work[16]. The power consumption of the photoconductors in their biassed state is well within the required maximum. The uniformity of the output power for different paths through the switch needs to be improved by about 6 dB. It should be noted, however, that the power dividers were simple taper couplers without loops. Reflection star couplers[17] have been shown to have better uniformity. Perhaps more important, the detectors themselves were not all identical, as they were part of a test mask and were made by fabrication processes still being perfected. In particular, improved ohmic contacts are expected to improve both the performance and the uniformity of the photoconductors.

In summary it can be concluded that the performance of the experimental 3x3 photoconductive optoelectronic switching array in combination with recent advances in semiconductor diode lasers indicates that the requirements of the SS/TDMA application could be met by an advanced optoelectronic switching array. It has been noted previously that such an array also offers size and weight savings by comparison with microwave technology, in that some RF shielding could be eliminated. There are also several performance advantages such as the controlled RF match that is always possible at both input and output because of the optical decoupling, and simplified assembly. Very wideband switching arrays may also be of use in terrestrial applications such as signal processing, phased antenna control, and high speed digital operations.

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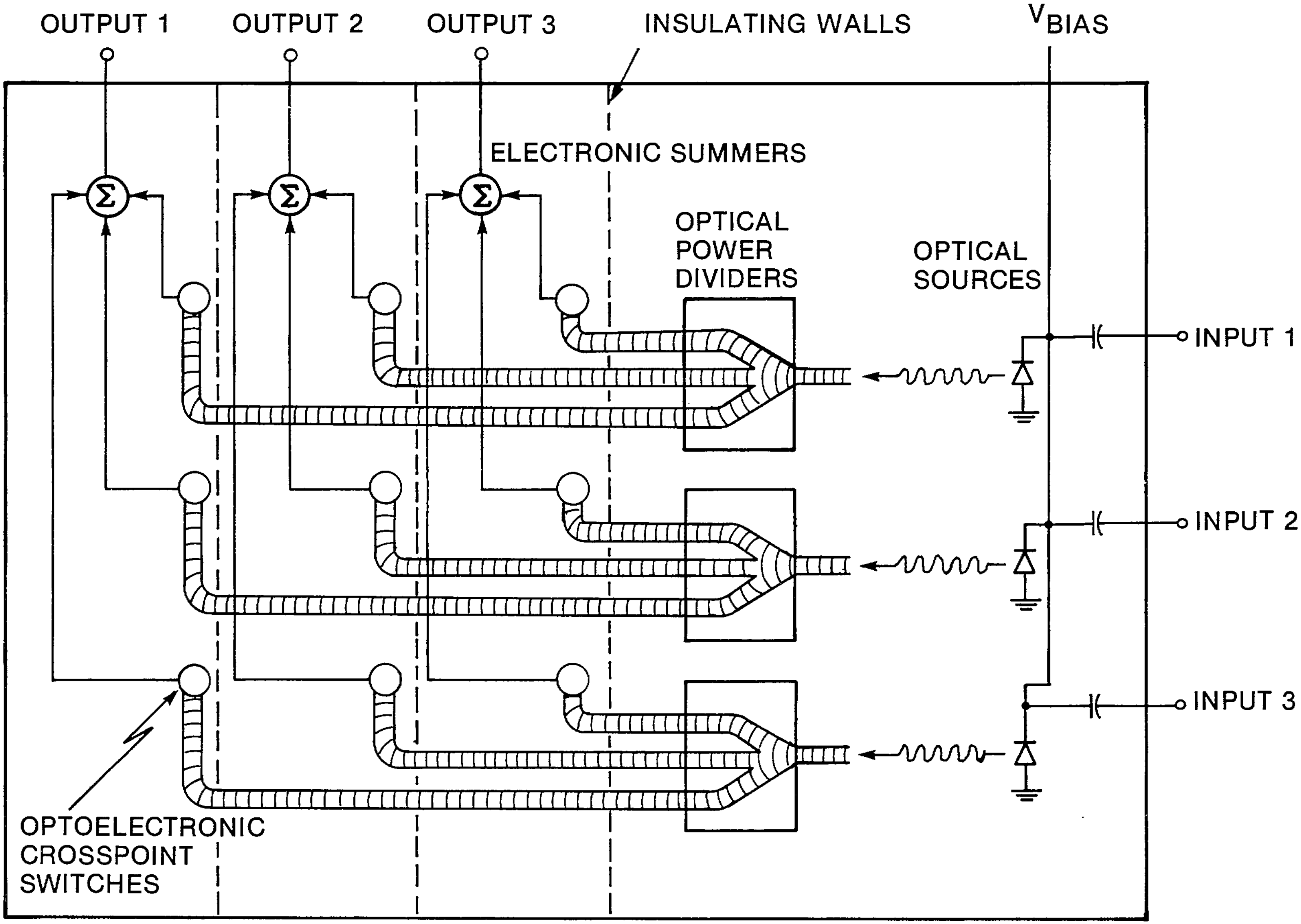

Figure 2-1 Schematic diagram of an optoelectronic switching matrix

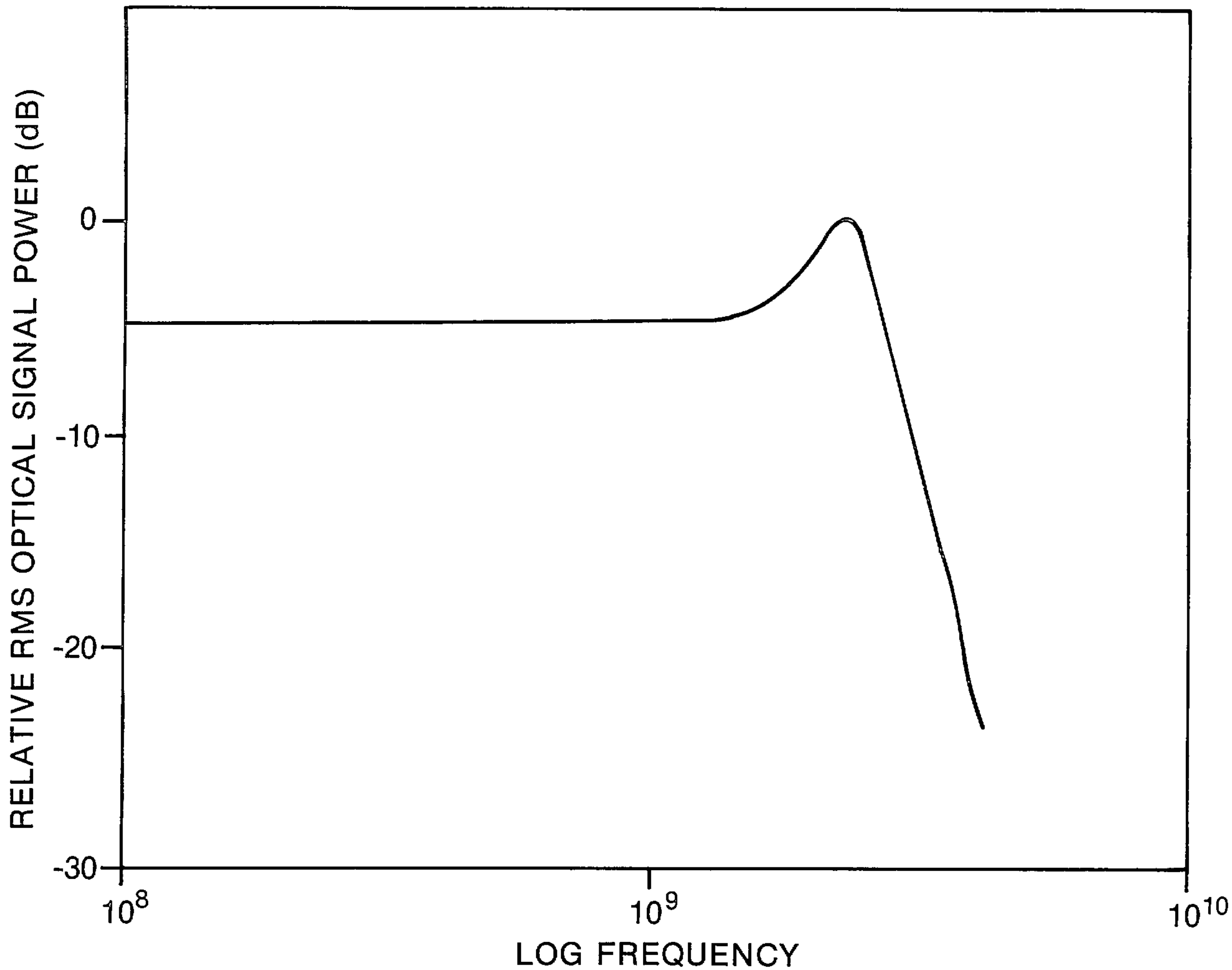

Figure 2-2 Frequency response of a typical diode laser as mounted for the 3x3 optoelectronic switching matrix (Mitsubishi TJS laser mod. ML4307 emission wavelength λ = 783 nm, threshold current I_{TH} = 25 mA).

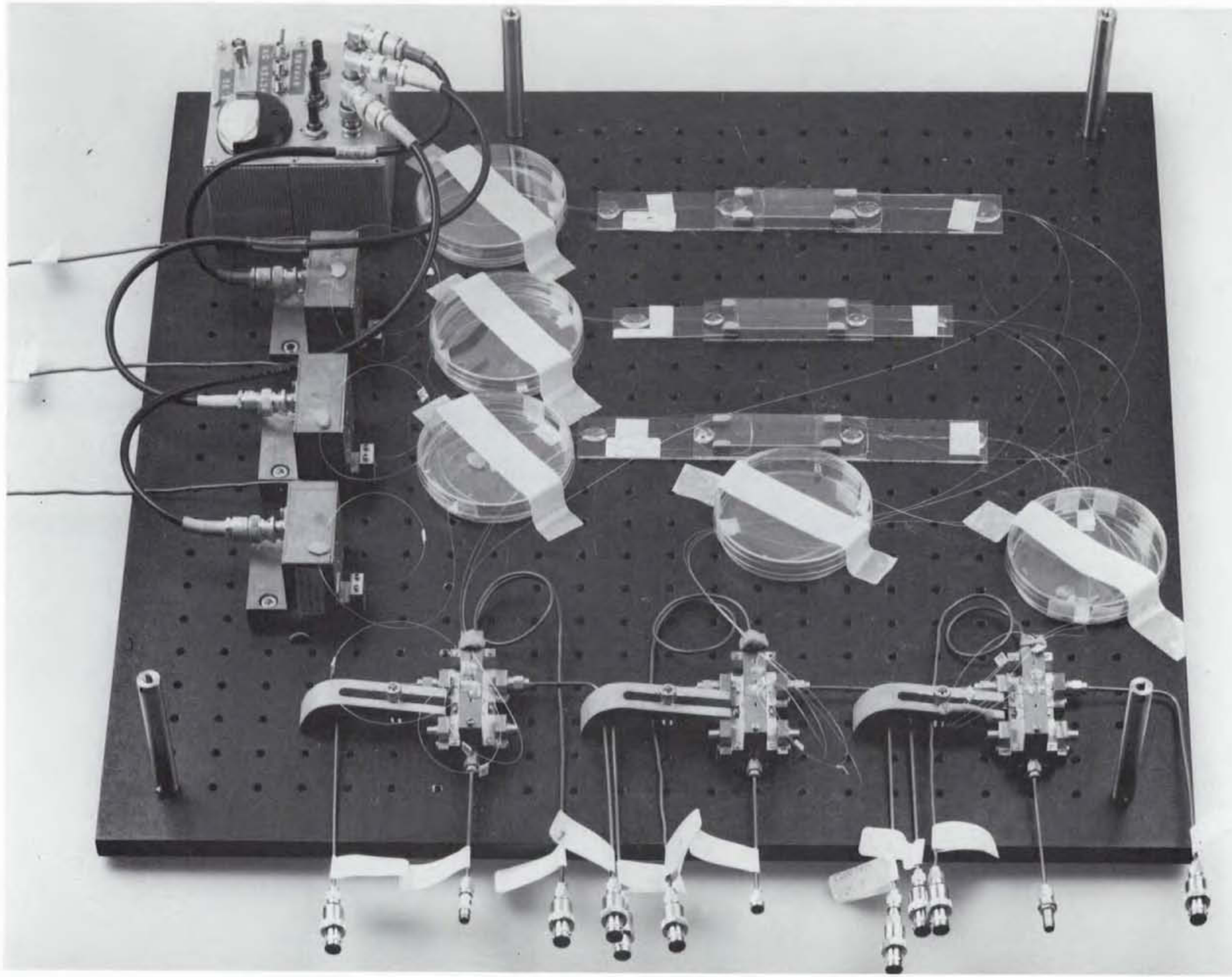

Figure 3-1 Photograph of the experimental 3x3 optoelectronic broadband switching matrix

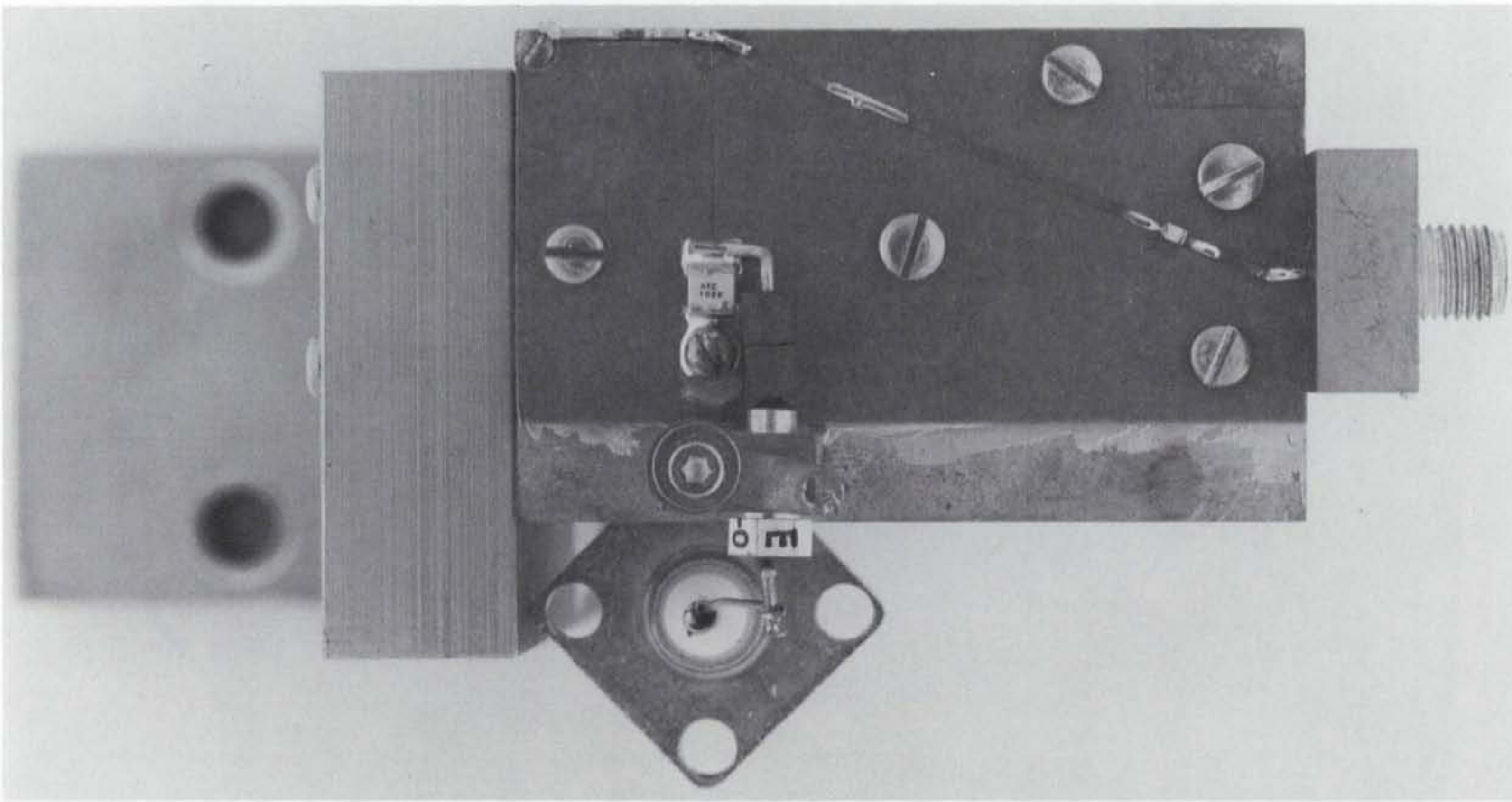

Figure 3-2 Photograph of the microstrip laser biassing circuit

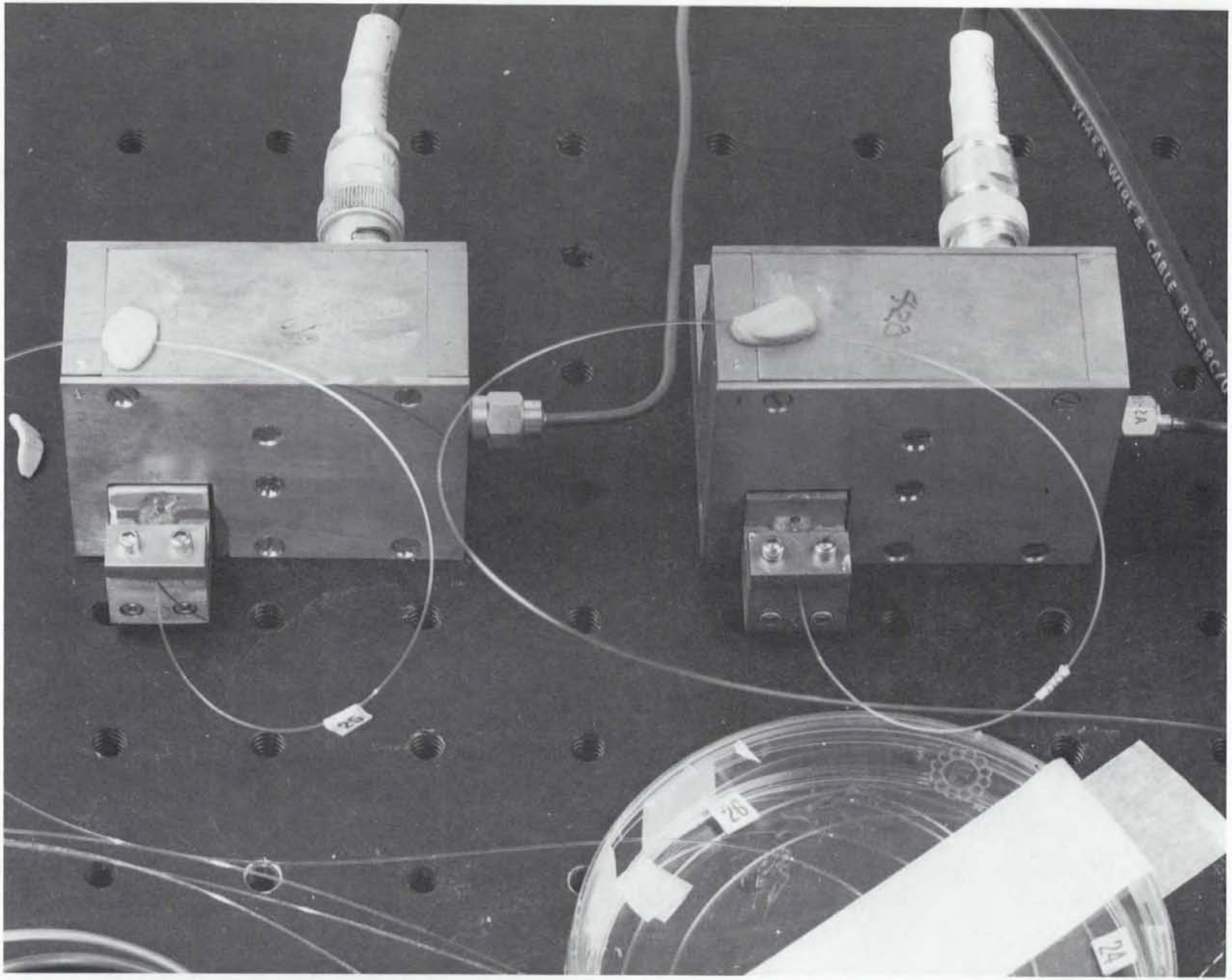

Figure 3-3 Photograph of two of the mounted and pigtailed laser transmitters

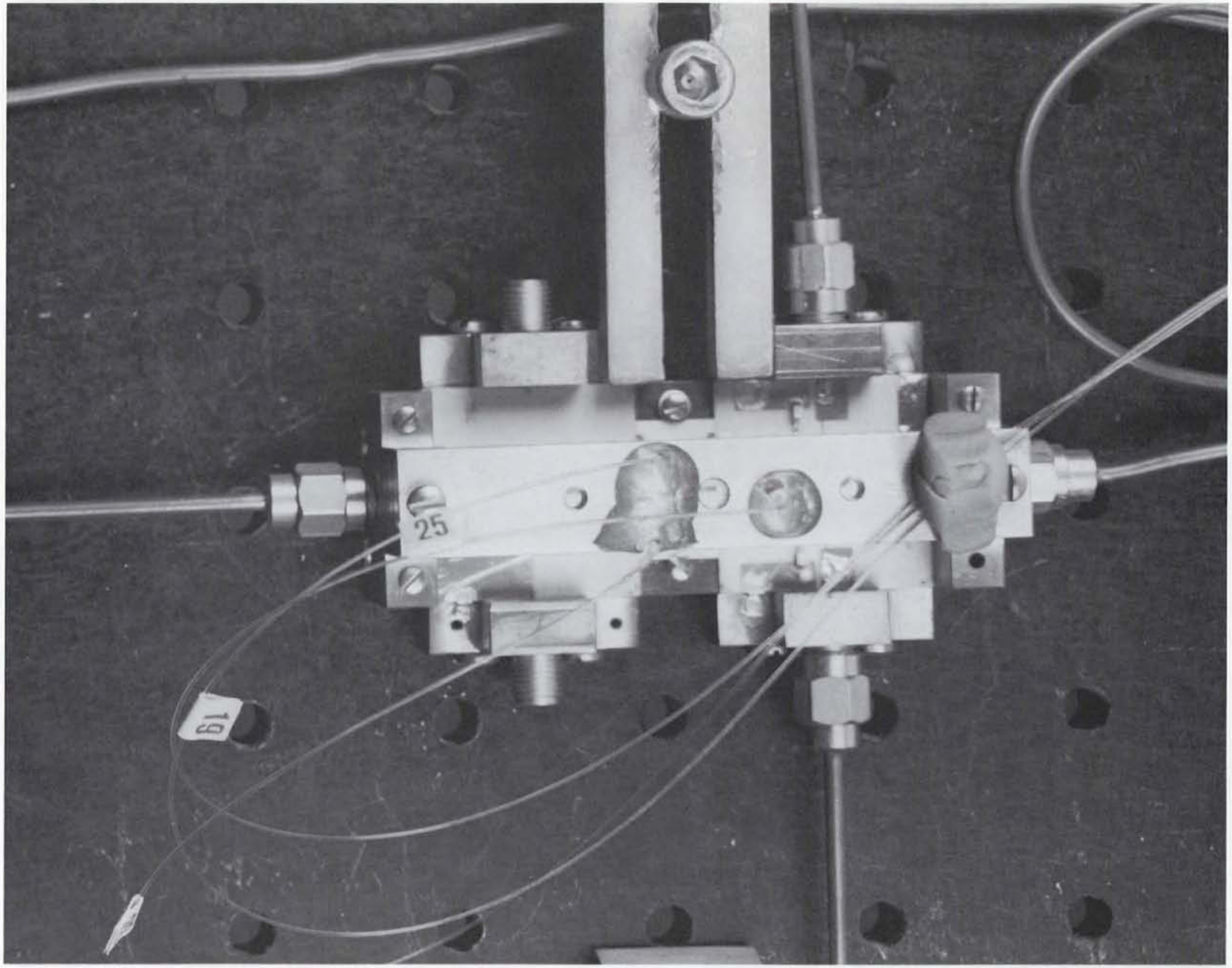

Figure 3-4 Photograph of a single detector array chip as amounted with fibres bonded to it

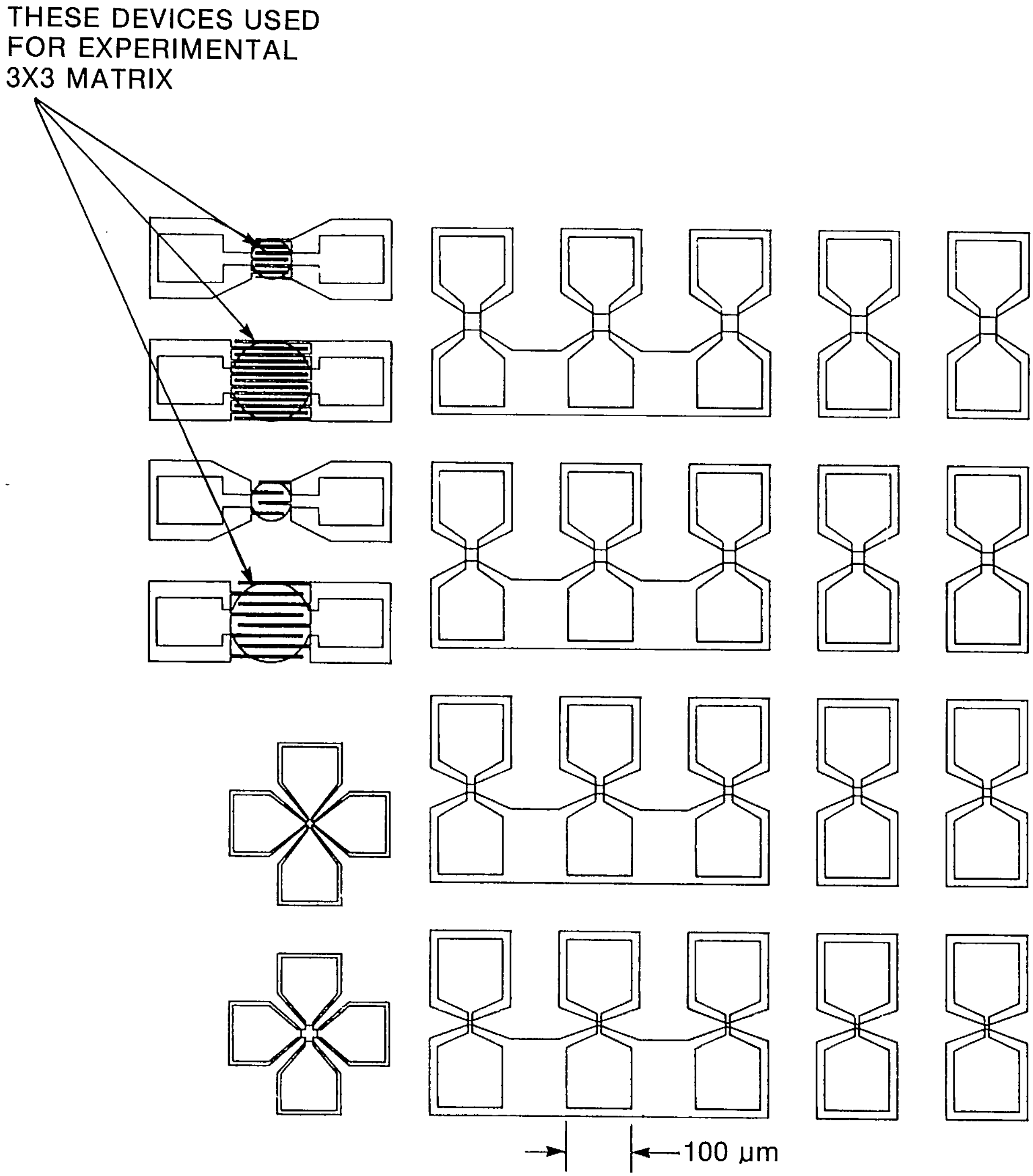

Figure 3-5 Layout of the photoconductive test chip indicating the three interdigitated photoconductors used for each detector array in the experiment

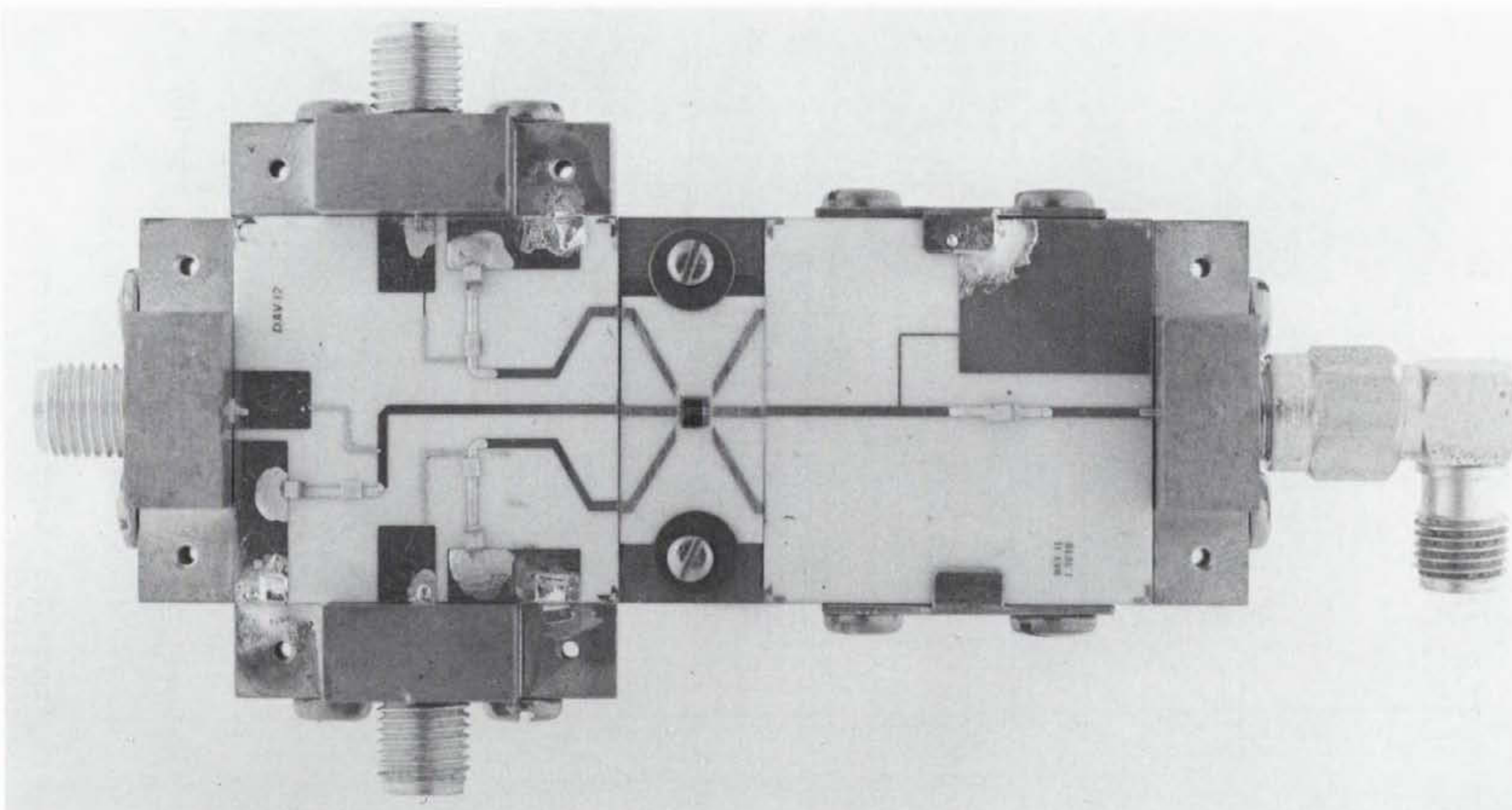

Figure 3-6 Photograph of the microstrip detector bias circuits

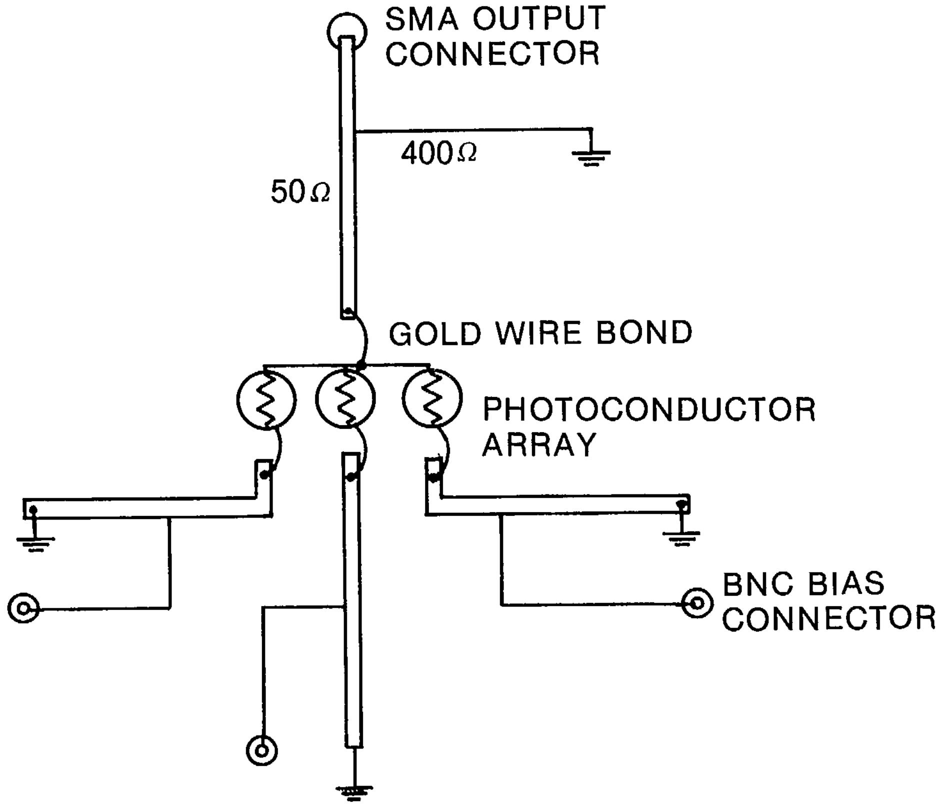

Figure 3-7 Schematic of the detector bias circuits

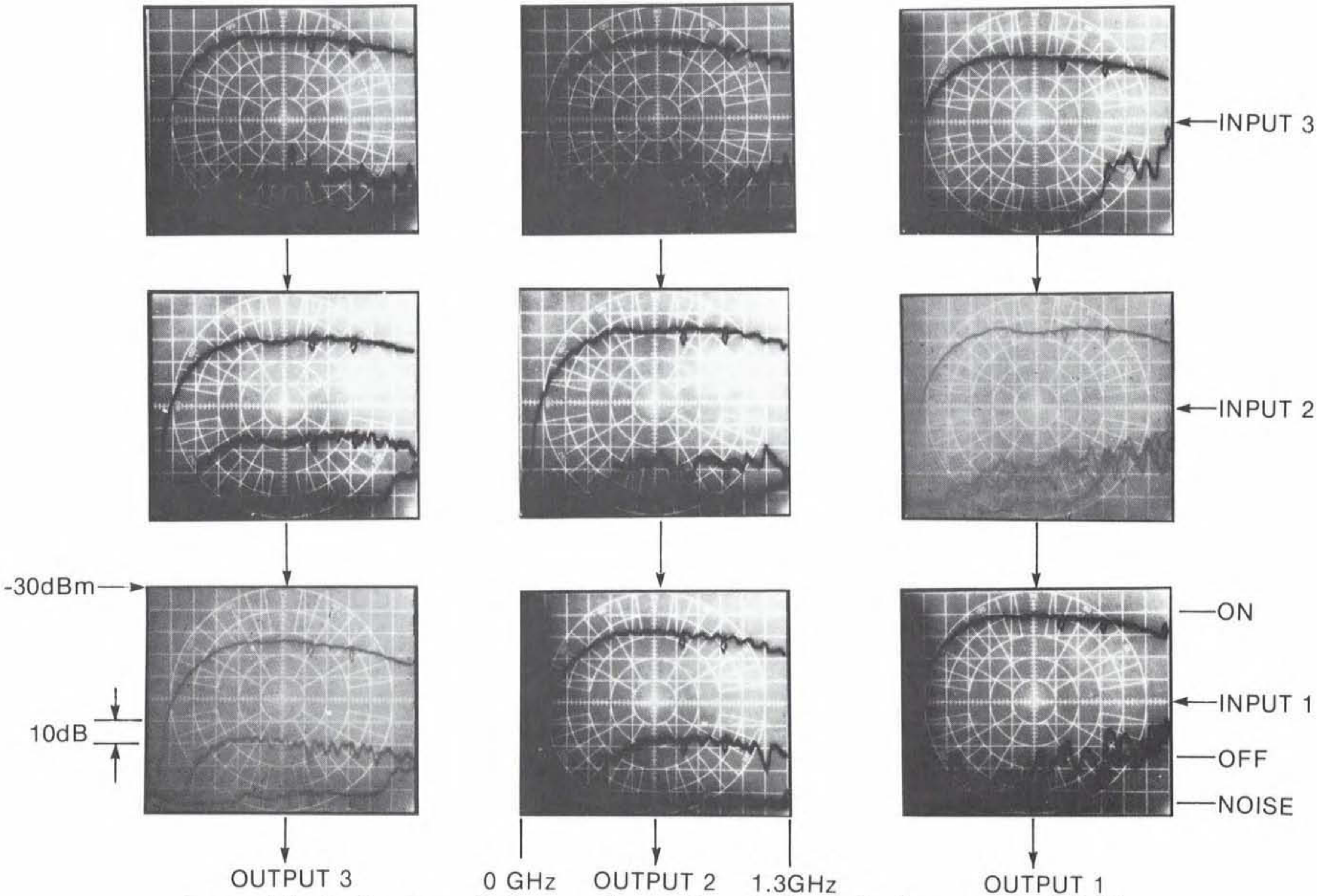

Figure 4-1 Performance of the optoelectronic switch matrix from zero to 1.3 GHz

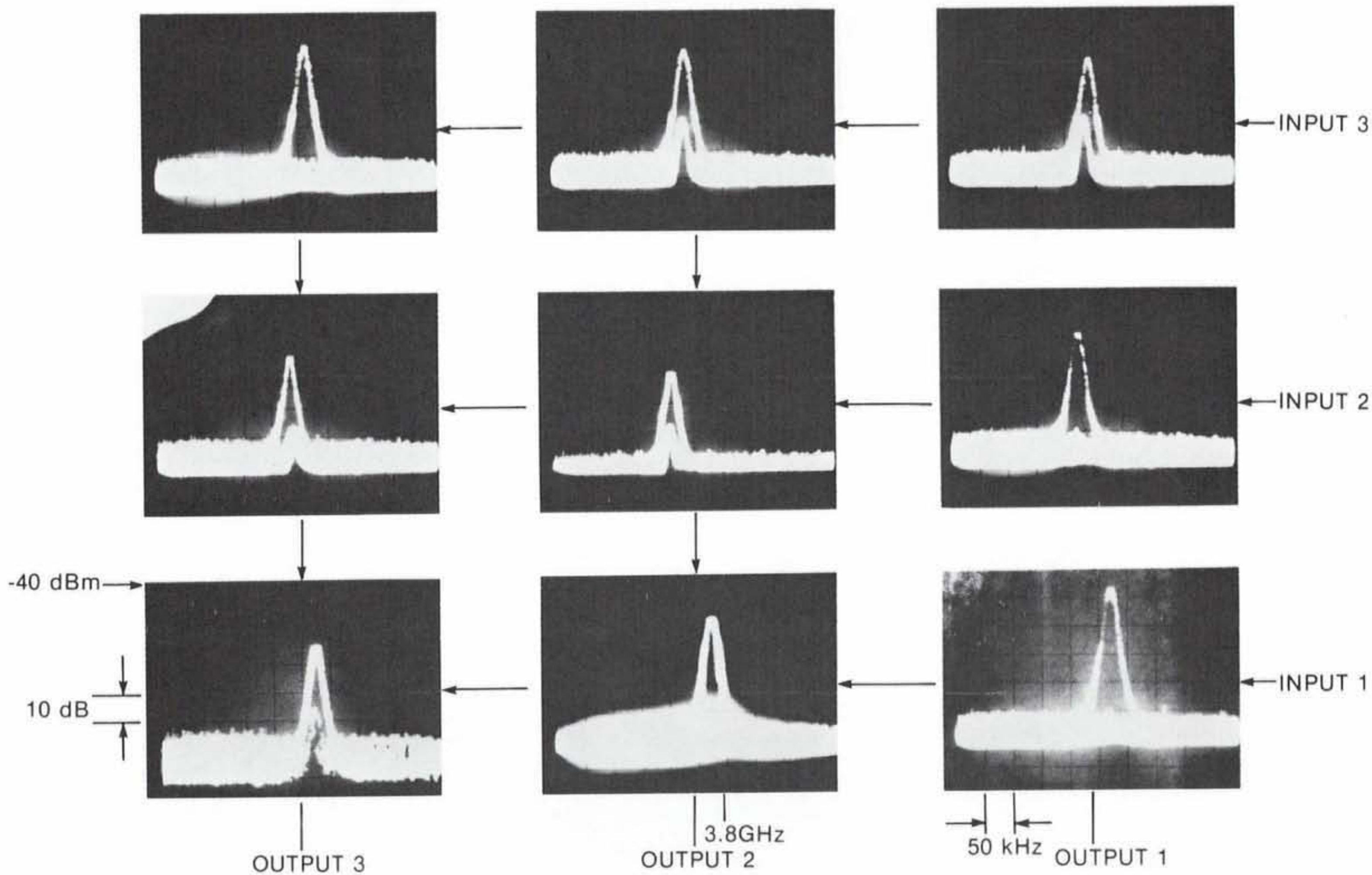

Figure 4-2 Performance of the optoelectronic switch matrix at the frequency 3.8 GHz

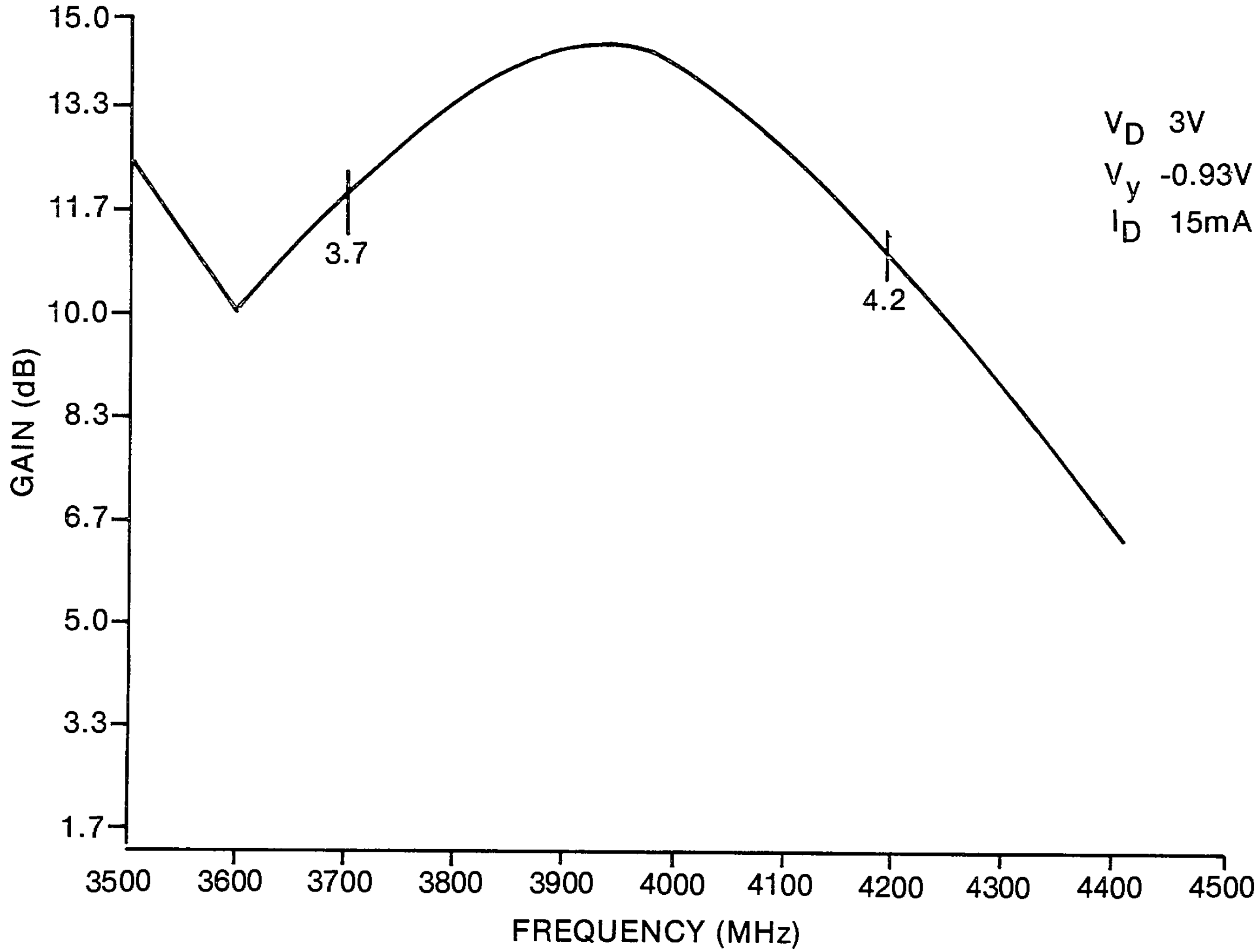

Figure 4-3 Frequency response of the FET amplifier used at 3.8 GHz

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8. **ABSTRACT:** See Page 1

9. **CITATION:**