Microwave Components THRIP Project for COE

Project Leader: Prof Petrie Meyer

Title: Microwave Components for Radar and Broadband Satellite and Terrestrial Communications

Objectives and Rationale

'Telecommunications networks have experienced an explosive growth in traffic over the last several decades, largely due to a rapid increase in global demand for voice, video, and data services. Developments in satellite-based fixed and mobile services, the advent of optical fiber networks, growth of cellular networks, the emergence of new standards for wireless mobile and personal communications, and new spectrum allocations have all contributed to this ongoing information and telecommunications revolution. Significant growth has occurred in the cellular industry, with cumulative annual growth rates in excess of 30 percent. Today there are more than 100 million cellular phone subscribers worldwide, compared to approximately 4 million users in 1988, and the number is expected to more than triple by the turn of the century. However, during the same time period, between 50 and 60 percent of the world's population is estimated to live in areas with no land-based cellular coverage. The proposed satellite-based personal communications systems (PCS) seek to extend telecommunications access to these areas. By the year 2002, the global mobile satellite services market is expected to serve more than 40 million subscribers'.

Quoted from the plenary session at the 1998 IEEE International Microwave Symposium, the foregoing passage states the views of BJ Pontano, president of COMSAT Laboratories. From this and numerous other references, it is clear that the future of communications is in broad-band, high speed digital communications via satellite. Pontano continues to list as key technologies, the following: '... innovations in lightweight filter technology for contiguous transponder channelization, frequency reuse through polarization and spatial isolation, and advances in beam-forming networks (BFNs) and shaped reflectors for narrow beams with increased gains'[1].

The importance of filters, dividers etc. is well known in the satellite communications arena, and can be viewed as a mature research field with relative little new activity. However, the new frequency band designations of 20/30 GHz (Ka-band) and 40/50 GHz (V-band) for broadband digital communications, have renewed interest in this field on a worldwide basis. The increasingly stringent specifications on channel definitions, out-band attenuation and in-band loss, coupled to requirements for weight and size reductions, have led to major advances in dual-mode waveguide filters, and dielectric loaded cavity filters.

In addition to the telecommunications aspects, there have also been significant advances in the development of RADAR in South Africa during the past few years. This has developed to such an extent, that RADAR companies are willing to invest large amounts of research funds, in order to obtain a competitive edge in the world market.

As both of these technologies use essentially the same microwave components, the purpose of the program proposed here, is to establish a center of knowledge and capability in the field of microwave components at these high frequencies, at the University of Stellenbosch. The microwave group at Stellenbosch has a long history of component design, starting in the late 70's, and is the only research group in the country which pursues this as an active research direction. The group is therefore very well positioned to extend the knowledge into the higher frequency areas.

The program focuses on the design of several prototypes - each complementing the other as to the exchange of design algorithms and analysis methods - which form part of one whole and make use of the same resources. These tasks are supported by the development of analysis software. The main thrust is in

the L-band and X-band, in order to test and evaluate the design algorithms, followed by extensions to the 30GHz.

The following prototypes are included in the program:

a] Multi-mode Waveguide Filters and Diplexers

Multi-mode filters make use of cavities supporting more than one resonating modes each. The signal is fed in one direction through the filter, rotated spatially and fed back. In this way, the size and weight of the filter is halved. These filters are widely used in satellites, but recently renewed interest has flared up worldwide in designing smaller and lighter filters with improved attenuation characteristics. At present, there is no substitute for these filters which will yield the same performance. The task is in the form of two Ph.D. programs, one on synthesis and one on analysis, both of which 2000 constitutes the second year, and one M. Eng. Sc. program, of which 2000 is to be the first year.

b] Waveguide Beam-Forming Networks

The importance of beam forming networks for high-frequency antennas cannot be over-emphasized. By forming narrow, variable antenna beams, it is possible to illuminate only chosen spots, to eliminate interfering signals and to track satellites without mechanical means. Beams can also be shaped to illuminate non-circular spots to conform to a country=s borders, for instance. Beam forming networks divide a signal into a number of components of predetermined amplitude and phase, each signal feeding one radiator of an antenna array. The beam-forming network has to exhibit very low loss, combined with high phase and amplitude stability. As these structures are quite large in electrical terms, it is very difficult to analyze them using numerical software, and impossible to optimize a design numerically. An optimization phase is, however, normally necessary, as the different sections are close together and can influence each other. In the past two years, several research groups have turned to the use of neural network models to overcome this type of problem, as these models can be optimized very quickly after being trained. This move towards neural models is very new and constitutes the leading edge in the field of microwave network research. The task is in the form of a two year Masters program, of which 2000 is the second year.

c] Overmoded Waveguide Filters

Due to the electrical nature of waveguides, it is very difficult to design filters with wide stopbands. This can lead to problems when these filters are to be used to suppress second and third harmonics generated by a transmitter, as the waveguide becomes overmoded at these frequencies (more than one mode can propagate). The design of filters in overmoded waveguides is very complex and requires close attention to the distribution of fields and the structure of the filter. The task is in the form of a two year Masters program, of which 2000 is the second year.

d] Multimode Feed for Tracking Antennas

The use of LEO satellites for communication purposes will require the use of tracking antennas, which, at high frequencies, are very difficult to design and manufacture. This project will investigate design algorithms for multimode feeds for tracking antennas, where one multimode feed is used to create a sum, azimuth and elevation beam. These antenna feeds are compact, low loss structures, but no design algorithms exist at present. The task is in the form of a two year Masters program, of which 2000 is the first year.

e] L-band solid-state amplifier

This project has as aim the development of a high-powered L-band solid state amplifier. The technology is applicable to both RADAR and cellular base stations. It follows the world-wide trend of moving towards solid state technology for broadcasting and radar amplifiers, due to the inherent graceful degradation. The key areas are power levels and bandwidth, which in turn are dependent on wide-band matching and combining circuits. The task is in the form of a 9 month TIPTOP 1 placement at the US, supported by one US staff member.

f] *X-band waveguide limiter*

This project has as aim the development of a limiter to secure the safe operation of sensitive receivers. The first protoytype will be at X-band, with the aim of expanding the frequency to 30GHz. The challenge is to develop a wide-band structure, capable of handling high power levels, with a quick recovery time. The task is in the form of a one-year post-doctoral appointment.

As all of the tasks will produce one or several prototypes, this program has a very high potential for commercialization. In the case of [e] and [f], the prototypes will be commercialized immediately by the company involved, following an additional development stage. All the other prototypes constitute items which cannot be mass-produced, and are very expensive to manufacture. As they are normally low-volume with high added value, they can easily be commercialized by very small companies.

It follows that development of this expertise have a high possibility of job creation for both high-skilled labour and artisans. The program is designed to investigate quick turnaround design techniques and low-cost manufacturing techniques, to give local companies a competitive edge in the international market.

The products will constitute the leading edge of technology, and will, as such, generate a high potential for international sales and investment. Again, tasks [e] and [f] are already earmarked for international investment in the associated company, once commercialized.

The program is also designed to train a number of high level engineers through the use of advanced degree programs, i.e. on a Masters and Doctorate level.

Proposed Workplan

The workplan can be broken down into the separate tasks as follows.

a] Multi-mode Waveguide Filters and Diplexers

Persons involved:

Mr. W Steyn	PhD
Mrs. R Geschke	PhD
Mr. L Sam	M. Eng. Sc.

Target dates:

- Literature study – April 1999
- Development of analysis software – December 1999
- Design and construction of simple prototypes at 10GHz – December 1999
- Proposal of new topologies – June 2000
- Improvements on analysis software – December 2000
- Design and construction of new prototype at 10GHz – December 2000
- Design and construction of simple prototype at 30GHz – June 2001
- PhD Dissertation – December 2001

Corrective action:

This task will include Mr. Sam (african male) and Mrs. Gescke (white female).

b] *Waveguide Beam-Forming Networks*

Persons involved:

Ms. M Müller	MSc. Eng.

Target dates:

- Literature study – April 99
- Creation and training of a neural net model of a crossed-guide waveguide coupler – Dec. 1999
- Design of a beam-forming network using these models – April 2000

- Design and construction of prototype at 10GHz – August 2000
- M-thesis – December 2000

Corrective action:

This task will include Ms. Müller (white female).

c] Overmoded Waveguide Filters

Persons involved:

Mr CAW Vale MSc. Eng.

Target dates:

- Literature study – April 99
- Proposal of new configuration for overmoded filters – December 1999
- Design and construction of prototype at 10GHz – August 2000
- M-thesis – December 2000

d] Multimode Feed for Tracking Antennas

Persons involved:

Mr APE van der Colff MSc. Eng.

Target dates:

- Literature study – June 2000
- New algorithms for optimisation of waveguide feed – June 2001
- Design and construction of prototype at 10GHz – August 2001
- M-thesis – December 2001

e] *L-band solid-state amplifier*

Persons involved:

Mr P Fourie	Industry researcher
Dr. C van Niekerk	US staff member

Target dates:

- Literature study – June 2000
- Design and construction of prototype – December 2000

f] *X-band waveguide limiter*

Persons involved:

Ms. B Jokanovic	Post-doctoral fellow
Prof. P Meyer	Team leader

Target dates:

- Literature study – June 2000
- Design and construction of prototype at 10GHz – December 2000

All of these tasks will be coordinated with industry on an on-going basis, with regular and ad-hoc meetings.

Outputs for 2000

- Triple-mode Waveguide Filter
- Quadruple-mode Waveguide Diplexer
- Bandstop waveguide filter for multiple propagating modes
- Design algorithms and computer software for multi-mode bandstop filters
- Numerical analysis software for waveguide couplers
- Neural network models for waveguide couplers
- Prototype waveguide coupler
- Prototype L-band amplifier
- Prototype X-band limiter
- Design reports, conference and journal papers
- Two M-theses

Outputs for further Years

- Additional prototype filters, diplexers and antenna feeds
- Three PhD dissertations
- Two M-theses
- Additional design reports, conference and journal papers

Project Summary

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Team Members

Mr. P Fourie
Dr. C van Niekerk
Dr. B Jokanovic

Students

Mr. CAW Vale (white male, ID 7609235223089, MSc.Eng. NRF prestige bursary)
Ms. M Müller (white female, ID 7607190030085, MSc. Eng.)
Mr. W Steyn (white male, ID 7212135020083, PhD. Eng.)
Mrs. R Geschke (white female, ID
Mr. APE van der Colff (white male, ID NRF grant-holders bursary)
Mr. L Sam (african male, ID)

TIPTOP candidates

Mr. P Fourie (TIPTOP 1) (white male, ID , from Reutech Radar Systems, 1/4/2000 to 31/12/2000)
Mr. W Steyn (TIPTOP 4)
Ms. M Müller (TIPTOP 4)